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Cave Closing as a Conservation Method

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Abstract

Cave closing may be necessary in certain circumstances. These include: 1. Preservation of nature. 2. Scientific purposes. 2.1. Speleological research. 2.2. Use of the cave environment. 2.3. Use of the cave situation. 3. Utilization. 3.1. Show caves. 3.2. Medicinal caves. 3.3. Economic uses. 3.3.1 Water. 3.3.2 Other economic uses. 4. Protection of human life.

Cave closing may be total or partial, and permanent or temporary. Cave closing may serve several goals at once. Cave closings must be carefully planned and designed. It is important not to disturb the natural environment, ventilation, and air flow. The closing should not interfere with animal migration, or the flow of water into or out of the cave. The entrance should remain as natural as possible. The material used to close the cave should blend with the natural surroundings. The gate should be difficult to destroy or breach. Cave closing in Hungary is briefly reviewed.

Cave closing is an intervention into the nature and natural conditions of caves. It is a necessary evil in certain situations. This paper will discuss some of the conditions under which cave closing may be useful or justified.

Preservation of nature

Well-decorated caves may be closed in order to preserve their original condition. Such cave preserves may be visited only at certain intervals for scientific purposes. In Hungary, one such cave is the Hideout Hole which was described by Dr. Attila Kosa in the September 1975 NSS News. The Hideout Hole is made up of shafts whose walls are covered with exceedingly beautiful, but very fragile pisolites. It is impossible to descend the shafts without destroying some of the formations. Hideout Hole was documented thoroughly, and then closed. The public can enjoy the cave through written and photographic accounts.

In some inhabited areas, caves may be closed in order to indirectly protect nature. Caves that are left open, especially vertical caves, may be used to dispose of dead animals or rubbish. Such disposal endangers any underlying caves, and may affect the entire karst groundwater system.

Scientific purposes

Caves may be closed for a variety of scientific purposes. In such cases, the only people who may visit the cave would be qualified scientists. Such research caves are closed to protect their natural conditions, and to protect experiments and instruments from deliberate or accidental damage. There are several categories of caves closed for scientific purposes.

Speleological research. A closed cave may be used for speleological research. This would include research on cave geology, biology, hydrology, meteorology, and paleontology.

Use of the cave environment. A cave may be closed in order to use some of its special qualities like total darkness, constant temperature, and constant humidity. The simplicity and constancy of the cave environment make caves into unique natural laboratories. In Budapest, the Hungarian Water Research Institute (VITUKI) used the St. Ivan Cave as a laboratory for many years. At the biological laboratory in Hungary's Baradla Cave, most of the research is done on plants and animals that are not cave-adapted.

Use of the cave situation. A closed cave may me used for research that is not at all cave-related. Researchers can use a cave as an isolated place to observe trace elements, or to measure the transmission of radiation through stone.

Utilization

Show caves. Show caves offer everyone an opportunity to see the wonders of the underground world. Show caves are usually well-decorated and well-known, so they must be closed to protect the formations from vandals.

Ice caves deserve a special mention. In some cases, ice caves may only be visited during certain seasons or during certains part of the day. The number of visitors may be limited, because body heat from large numbers of people could warm the air of the cave, and cause the ice to melt.

Show caves also have various technical installations and safety appliances such as lights and elevators. If these are used in an unworkmanlike manner, damage or an accident may result. Therefore, show caves must also be closed to protect man-made features.

Medicinal caves. Some caves are used for medicinal purposes. These caves have to be closed to prevent damage to the cave's curative effects. Often only a limited number of people may use the cave for some restricted period of time. Too many people may warm or otherwise affect the cave air enough to damage the curative powers of the cave. Medicinal caves must be closely monitored to maintain them in a clean condition with unvarying temperature and humidity.

Economic uses. Some closed caves are used for economic purposes. The only people who are allowed to visit these caves are people who perform work or services in the caves.

Water Supplies. Some caves are closed to protect drinking water supplies. In some cases, water is obtained at the cave entrance or at a cave stream resurgence. Water may also be obtained at a spring that is fed by cave streams and sinkholes. The caves and sinkholes that form part of the underground watershed may be closed to protect water supples.

Other Economic Uses. Caves have other economic uses that range from mushroom-growing and cheese-aging to the use of cave air for air conditioning. The microclimate of caves may be useful in storing and preserving agricultural products (vegetables, fruits, saplings). The cave may also be used for storage simply because it is enclosed and protected from the elements.

Protection of Human Life

Non-cavers may venture into caves, lose their way, extinguish their lights, and suffer accidents. Accidents are most common in larger caves and maze caves. ONe way to prevent such accidents is to close frequently-visited caves. In Hungary, cavers closed all of the caves in and around Budapest where such accidents were likely to happen. Organized cavers can request keys to the caves for tourist and training trips.

It is common for cavers to find the carcasses of animals that have fallen into potholes, sinkholes, and vertical caves. Careless adults and children may also fall into such holes, especially when the entrances are obscured by brush. In some cases, cavers have to close vertical caves by building a cover or fence.

Some caves contain poisonous gas, most commonly carbon dioxide. Visitors who do not expect such gas may get a headache, giddiness, or retching that can result in an accident or death. Such caves may have to be closed to prevent such accidents.

Cave closing may be total or partial. A partially closed cave is a cave that remains open to qualified, competent visitors. Show caves are partially closed at or near their entrances at all times. If the closing is for scientific or conservation purposes, it may be adequate to close only parts of the cave. If the cave is situated on an internationally boundary, with entrances in two countries, it may be necessary to have a gate on the international boundary in the cave. The Baradla-Domica Cave on the boundary between Hungary and Czechoslovakia has just such a gate.

Cave closing may be permanent or temporary. If the necessary research or excavations have been completed, a closed cave may be reopened to the public. A cave may be closed so that it can be reopened easily or with great difficulty. After exploration and documentation have been completed, a cave may be closed permanently. Perhaps this cave will not be visited for decades, until cave sciences have advanced, and new research can be performed.

Cave closing may serve several goals at once. Closing a show cave can also serve a goal of preservation. The purpose of a cave closing may change with time. The Matyas Cave in Budapest was originally closed to prevent cave accidents. Later, a geophysical laboratory was established in the cave, and an area in the cave was separately closed off.

Cave closing has to be carefully thought out and designed. The closing should not badly alter the natural environment of the cave. The caving should not change the natural ventilation or air flow within the cave. This could be especially important in caves with poison gas. The closing should not restrict the movements of animals (such as bats) that live in the cave. The closing should also not interfere with the movement of water into and out of the cave.

If possible, the cave entrance should not be importantly altered. It is desirable to build any physical barriers inside the cave rather than at the entrance or surface. This is not always possible, of course. The gate should be of a design and construction that conforms as much as possible with the cave environment. Finally, the gate or barrier should be build so that it is difficult to breach or destroy.

This discussion will conclude with a brief review of cave closing in Hungary. There are about 1300 known caves in Hungary. Of these, 34 are closed to protect natural features. There are 8 caves closed for scientific reasons. The research caves include 5 used for speleological research, 2 used for the constant cave environment, and 1 used for the isolated environment. There are 10 show caves in Hungary, and four caves that are used for medicinal purposes. Three caves are closed to protect sources of drinking water. One cave (20 m long) is used for other economic purposes to store saplings. A total of 12 caves have been closed to protect casual visitors from accidents. The total number of closed caves in Hungary is 53 out of 1300 or about 4%.

Origin and Composition of Underground Fauna in Poland

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Abstract

About 80 troglobites, stygobites and endogeous species have been recorded in Poland to date. Nearly 75 per cent of them were found during the last ten years. Among all the underground dwelling invertebrates occuring in this country the Oligochaeta, Ostracoda, Amphipoda, Collembola, Coleoptera, Opiliones, Aranei and Hydracarina were intensively studied in recent years and are better known taxonomically. Of that, 30 per cent of different category taxa are mentioned from Poland only (endemics?).

Distribution and zoogeographical relationship of more interesting true inhabitants of the subterranean life zone of Poland are discussed. These species represent various relicts from several stages of colonization of the underground habitat during different paleographic and climatic conditions. Oldest relicts (Tertiary) are between aquatic and endogean forms. Cavernicoles represent subtroglobites, neotroglobites and troglobites in statu nascendi.

Origin of the underground fauna in Poland in relation to the Pleistocene glaciations with special emphasis to the problem of refugia under the ice is discussed.

Introduction

In the past ten years, significant progress has been made in knowledge of the fauna inhabiting so called hypogean life zone on the Polish territory. This zone is understood here in a broad sense as that occupying small spaces and large chambers or channels in rock beds (in the part accessible to people named caves) developed both in aerated and saturated zone, fissures near surface of rock massifes and microcavernes underneath deeply embedded stones or boulders (endogeous environment), as well as gravels and sands completely or permanently impregnated with ground water (interstitial medium). The majority of earlier investigations were concentrated upon cave environment, while during last years, underground waters of non-cavernous areas were intensively studied. As a result, the number of obligate underground-dwelling organisms found in Poland increased about four times in comparison with that known 15 years ago (Skalska, Skalski 1969; Skalski 1972). The purpose of this paper is to review some of the progress that has been made in recent years in knowledge of the fauna of the hypogean life zone in Poland.

The results of investigations on the underground fauna of Poland are distributed in more than 200 papers listed by Kowalski (1951-1954), Chodorowski (1959), Skalska and Skalski (1969, and Skalski (1973, 1976). The most intensive investigations took place in mountain and submountain regions of the country (caves, endogeous and interstitial medium), in the Kraków-Czestochowa Upland (caves), and recently (Skalski 1981a) in the Malopolska Gap of the Vistual (underground water). These researches are mainly concentrated upon faunistical and systematical problems. Among all the invertebrates occuring in the hypogeous life zone of Poland, the Oligochaeta, Ostracoda, Amphipoda, Collembola, Coleoptera, Opiliones, Araneae and Hydracarina were intensively studied in modern aspect and are better known taxonomically.[1]

As a result of these researches approximately 500 species of invertebrates have been recorded in subterranean domain of Poland. They are numerously represented by Insecta (40%) and Arachnida (20%). The majority of these have entered into this environment quite accidentally from the surface, and some appear more or less regularly. Limitation upon space makes it impossible to mention here all those species. Only more interesting true underground inhabitants are discussed in the paper.

Total 76 species, subspecies and forms from 32 families belonging to 8 orders and classes have been recorded in Poland only in the hypogeous life zone. They are summarized numerically by taxonomic group in table 1. A check-list of these taxa is published separately (Skalski 1981b). Of this total, 52 are aquatic and 24 are terrestrial, of which 20 terrestrial and 2 aquatic, hitherto, were found in caves only. Both aquatic species are certainly widely distributed in different habitats of stygal, particularly Troglochaetus berancki Del. in interstitial medium. On the other hand, stygobiontic amphipods Niphargellus arndti (Schell.) and Niphargus tatrensis Wrześn. living in various types of underground waters commonly occur in caves. Analogically, endegeous beetle Pseudanophthalmus pilosellus (Mill.) was noted from cave. To date, 28 taxa or about 6% of the total fauna and 36% of true underground forms, of this number, 19 aquatic and 9 terrestrial (including undescribed), have been recorded in Poland only. Approximately one-half of them are endemics. Probably some taxa are more widespread but they were described in last years and its distributional pattern is known insufficiently. Also, the systematic status of certain forms must be revised. Finally, it is possible that among species as far as known at present in Poland from cave localitites a few occur in our country also in non-cave habitats e.g. guanobiontic mites Oribella cavatica Kunst and Phaulodiaspis advena (Träg.) may be to appear in nests. The remaining 48 taxa (64%) represent widespread forms distributed as follows: Middle Europe-16%, South Europe including Corsica-16%, West Europe-12%, East Europe-9%, over all Europe excluding northern part-4% and North Europe-1%, lastly 6% are taxa insufficiently known. Distribution of underground species in Poland is given in table 1.

The present patterns of the hypogean species in Poland are the results of faunal differentation that vary in age from the Tertiary to Holocene. The number of true hypogean-dwelling species in our fauna, however, is very low in comparison with that found in regions south of the country. The majority of species highly specialized and well adapted for subterranean mode of life (paleostygobites) are the Tertiary relicts. Many authors have noted the striking relationship between the northern limits of distribution of Tertiary relicts and the limit of maximum extension of the Pleistocene glaciers. This phenomenon has generally been attributed to past glacial conditions which destroyed forms that inhabited circumboreal areas during the Tertiary. As the main destructive factors are taken into consideration a low temperature at glacial and peryglacial areas particularly during Mindel and Riss Glaciations, and isolation of subterranean domain by continental ice sheet from the surface from which nutrient material flows in this environment. The view is generally taken that the Tertiary relicts survived in refugia outside the glacial limit. As the glaciers retreated they recolonized ice-free areas.

Discussing the occurrence of Tertiary relicts in the hypogean domain of Poland it is necessary to treat the solid and liquid medium separately. In the first case, caves occupy a special place. Although some karst areas, such as the main ridge of the Krakow-Czestochowa Upland or a part of the Sudeten Mts., were probably ice-free nunatakes during the Mindel Glaciations (map 1), the inside cave temperatures were too low (mean annual below $0^{o}C$) for breeding permanent residents. Similar thermic conditions were during next glaciation (Riss). Many caves probably were also isolated from the surface by ice or fluvial deposits. As a result, any cave-limited species that might have existed there prior to the Pleistocene were subsequently exterminated by the above effects of glaciation. In contrast to earlier suppositions (Skalska, Skalski 1969) any terrestrial Tertiary relict did not survive Pleistocene glaciations in our caves. Only a few species (P. pilosellus (Mill.), Duvalius Subterraneus (Mill.), D. microphthalmus (Mill.) and probably opilionid Siro carpaticus Raf.), associated with endogeous habitat, which is characterized better trophic and thermic conditions than caves (unglaciated slopes, higher temperatures in summer), survived these glaciations in the Carpathian refugia. Congeners of

[1] Present state of knowledge of the Trubellaria, Oligochaeta, Ostracoda, Amphipoda, Isopoda, Trechinae (Coleoptera), Opiliones, Araneae, Hydracarina and Chiroptera occuring in hypogeous life zone of Poland is given in the Proceedings of the 1st Symposium on Underground Fauna of Poland in 1979 (1981).

these species occuring in Europe south of Poland and in North America (Pseudanophthalmus) are true troglobites or paleotroglobites understood as forms well morphologically and biologically adapted for a cave environment. The problem of the Carpathian refugia in detail is discussed by Pawlowski (1975).

As regard the liquid medium a new look on the problem of Tertiary relicts in glaciated areas is presented. Some groundwater species, undoubtly belonging to forms of the Tertiary age, in Central Poland extend north of the southern limit of glaciation (map 1). This phenomenon has been explained by its post glacial dispersal, and the Carpathian and Sudeten Mts. were mentioned as nearest refugia in which these ancient forms might have persisted.

On the basis of the recent observations in arctic and subarctic regions, it has been stated that: groundwaters of karst massifes are unfrozen (Pulina (1968), isolation of the groundwaters by ice sheet is not quite close. Inside of glaciers are well developed drainage systems opening free flow of water from the ice surface to the geological deposits under the ice cap (Drozdowski 1979, Klysz 1980, Ruszkowski 1980, Zygmunt 1980). These observations are up-to-date not only for the present day glacial regions, but, it seems that similar phenomena occurred also at the time of the Pleistocene glaciations. It must be taken into account, moreover, the fact that the margin of glaciers during the Mindel and Riss Glaciations reached 50-51° of latitude where climatic conditions favored desintegration of the ice mass much more than that recently in arctic regions. Direct passages are noteworthy as important way for supply of subglacial refugia with food.

Among stygobites representing in our fauna marine Tertiary relicts (paleostygobites per analogia to paleotroglobites), 4 species from the genus Niphargus occur north of the southern limit of the Pleistocene glaciations. From those, 3 species (Niphargus aquilex Schiödte, N. tatrensis, N. leopoliensis Jaw.) have wider ranges and are distributed both north and south of the maximal glacier limit. Remaining, N. casimiriensis Skalski, is a local endemic species associated with petrostygocenose of the Cretaceous limestones in the Malopolska Gap of the Vistual (Skalski 1981a). Crangonyctid Synurella coeca rafalskii Skalski is other endemic amphipod occurring at the same petrostygocenose. The hypothesis that the area of the Malopolska Gap of the Vistula was s subglacial refugium might explain the presence of the some pre-Pleistocene relicts in the Malopolska Upland. Northern limit of the most paleostygobites occurring in our country, e.g. T. Beranecki, N. arndti, four Niphargus species, probably Crangonyx paxi Schell., oscilates near the line of the maximal extension of glaciation (map 1). Of these isolated localities of N. aquilex and N. tatrensis farther north of that are most probably a result of its post glacial or present day dispersal. Also, the majority of stygobiontic Ostracoda and Hydracarina were recently distributed by interstitial route along main rivers. Remarkable is locality of water mite Balcanohydracarus corsicus E. Ang. on glaciated area of the country. This species is yet known from Corsica and Poland only.

All terrestrial cave-limited species living in Poland can be recognized as neotroglobites and subtroglobites. Likewise, in our stygofauna the majority of species must be included correspondingly with neostygobites and substygobites. The first category comprises forms a little modified morphologically and biologically in adaptive process to the subterranean life which are restricted to this environment only. They have rather a small range or are limited to a single cave system, e.g. endemic beetles Catops tristis infernus Szymcz. and Choleva lederiana gracilenta (Szymcz. Skalski, Wójcik 1968). The subtroglobites and substygobites are species limited to the subterranean environment only in one of periphery part of the area occupated, in opposite part of that, under changed climatic conditions, they occur also in non-cave habitats, e.g. springtails Mesachorutes ojcoviensis Stach, Onychiurus schoëdti (Lie Pett.), Arrhopalites pygmaeus (Wank.), spider Porrhomma egeria Sim. or ostracod Nannocandona faba Ekman. Several members of mentioned categories represent various geographical elements and relicts from different climatic conditions of the late Quaternary. More characteristic examples of that are given in table 2.

Recent climatic warming-drying has caused the limitation of certain mountain species (e.g. Ischyropsalis hellwigi (Panz.) or Lephtyphantes monticola Kulcz.) to cold habitats in lowland of which caves and groundwaters are particularly important. These relict troglophiles and stygophiles are the first step to previous categories.

Finally, in underground populations of some species inhabiting both surface and subterranean environment (no isolated each other) on the same area, in a part of specimens were observed modifications to hypogean mode of life such as depigmentation of the body, reduction of the eyes, prolongation of appendages etc. (e.g. Onychiurus armatus var. multituberculatus Stach, Gammarus pulex polonensis G. Kar. et Pinkster, Asellus aquaticus F.?. Neobisium Muscorum (Leach)).

Thus, above discussed successive levels in the process of subterranean evolution in speleofauna can be schematically presented as follows:

	ecological category		cave environment
	trogloxenes	→	penetration
	troglophiles	→	population
	relict troglophiles	→	adaptation
troglobites (s.l.)	subtroglobites	→	isolation
	neotroglobites	→	speciation
	paleotroglobites	→	specialization

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Table 1

Group	a*	b*	c*	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	Remarks
Tricladida	1	1								1				syst. stat. unc.
Archiannelida	1	1			1									
Oligochaeta	4	5	4 sp.		1	2						2		
Ostracoda	8	11	3 sp. 1 ssp.		5			9	2	4			3	
Copepoda	2	3	1 form			1							1	
Amphipoda	10	13	2 sp. 2 ssp. 1 f.		3	3	1	1	2	3		2	2	
Collembola	11	15	1 sp. 1 ssp. ?	1	6	3						4		
Coleoptera	5	7	2 ssp.			2	1	1	2			2		3 sp. endogeous
Opiliones	1	1	1 sp.						1					endogeous
Aranei	1	1		1		?					1	1		
Acari	3	4	1 sp. ?		1							2		distr. uncert.
Hydracarina	29	38	6 sp.	1	1	12	10	15	8				1	
Total	76	100	18 sp. 6 ssp. 2 forms	3	18	23	12	26	15	8	1	13	7	
Water	52	68	17 taxa	1	11	16	11	25	12	8	-	2	7	
Terrestrial	24	32	9 taxa	2	7	7	1	1	3	-	1	11	-	

*
a. Total number of taxa
b. % of total underground taxa
c. Number of taxa known from Poland only

1. Lower Silesia 1/
2. Sudeten Mts.
3. Tatra Mts.
4. Pieniny Mts.
5. Western Beskid Mts.
6. Eastern Beskid Mts.
7. Lubelska Upland
8. Świetokrzyskie Mts.
9. Kraków-Czestochowa Upland
10. Wielkipolsko-Kujawska Lowland

1/ zoogeographical regionalization see map 1

Composition and distribution of true underground fauna in Poland

Table 2

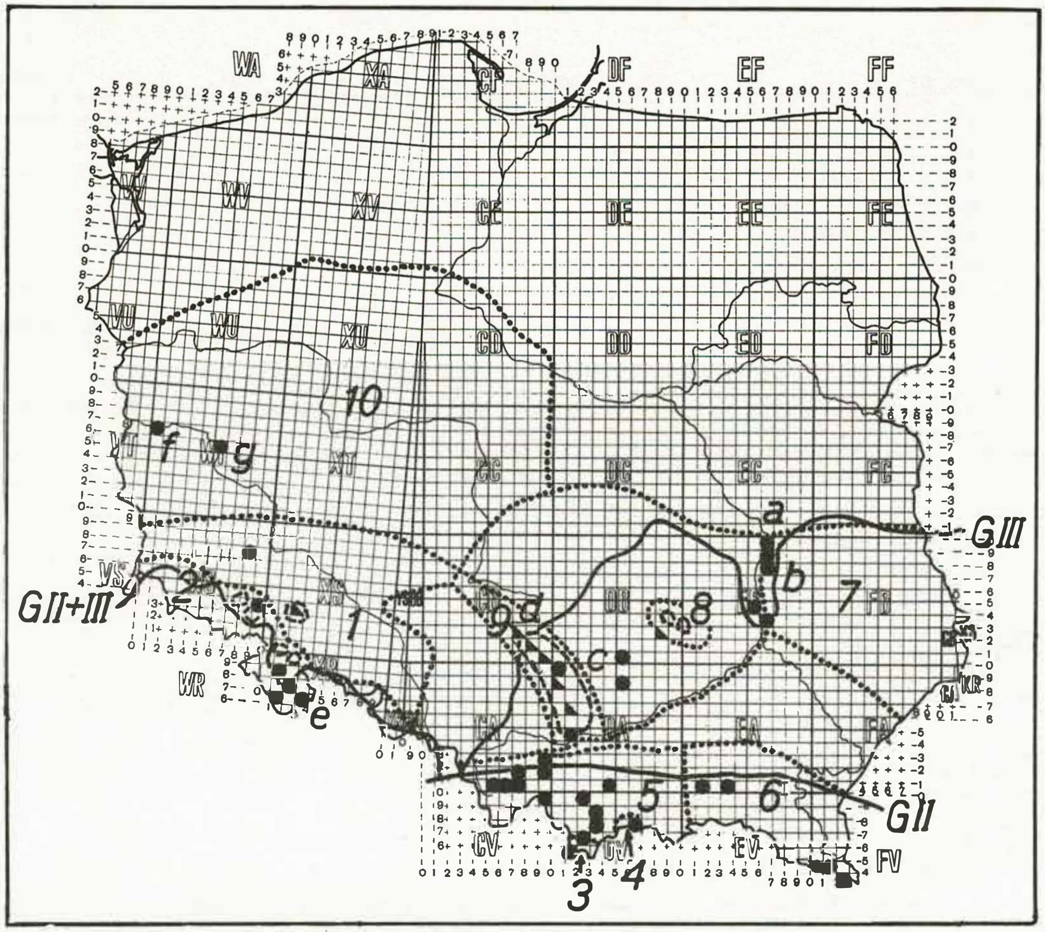
Climatic changes causing isolation of selected species in caves in Poland during late Quaternary

Species	a*	Climate favoring occurrence on the surface in Poland	Climatic changes causing isolation in cave environment	Occurrence in non-cave environment also (on tje surface)
S. emucronata	stb	warm	turn colder	M-S Europe
M. ojcoviensis	stb	warm	turn colder	S Europe
O. schoetti	stb	cold	grow warm	N Europe
O. cf. alborufescens	?	cold	grow warm	Alps nom. ssp.
A. pygmaeus	stb	temperate-humid	dry	W Europe, N America
C. tristis infernus	ntb	temperate	grow warm	N Europe nom. ssp.
Ch. lederiana gracilenta	ntb	cold	grow warm	N Europe nom. ssp
P. egeria	stb	temperate-humid	dry	N-W Europe

*
a. ecological classification

Abbreviations:

stb-subtroglobite
ntb-neotroglobite



Map 1: Distribution of selected troglobites and stygobites in relation to maximal extension of Pleistocene glaciations.

Abbreviations:

- -maximal extension of Minde (G II) and Riss (G III) glaciations
- -nunatakes
- -zoogeographical regionalisation (1 - Lower Silesia, 2 - Sudeten Mts., 3 - Tatra Mts., 4 - Pieniny Mts., 5 - Western Beskiden Mts., 6 - Eastern Beskiden Mts., 7 - Lubelska Upland, 8 - Świetokrzyskie Mts., 9 - Kraków-Czestochawa Upland, 10 - Wielkopolsko-Kujawska Lowland; cave regions - 2, 3, 4, 5, 6, 9)
- -distribution of Niphargus species (paleostygobites)
- -distribution of P. egera (subtroglobite)

a -isolated locality of N. tatrensis (recent dispersal)
b -locality of N. casimiriensis and S. coeca rafalskii (endemics)
c -isolated locality of N. leopoliensis (relictous ?)
d -locality of C. tristis infernus, Ch. lederiana gracilenta (neotroglobites, endemics) and Onychiurus ch. alborufescens (glacial relict)
e -area of occurrence of N. arndti and localities of Crangonyz paxi, Onychiurus paxi (endemics), Schaefferia emucronata, Oncopodura reyersdorfensis, Arrhopalites bifidus (neostygobites and substygobites, interglacial relicts) and O. schoetti (substygobite, glacial relict)
f -locality of N. aquilex (recent dispersal)
g -locality of B. corsicus

Simulation of Rock Pendants - Small Scale Experiements on Plaster Models

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Abstract

The classical theory of Bretz (1942) on the development of roof or rock pendants is widely accepted, appearing in many textbooks in karst geomorphology. However, this genetic theory has never been checked by experiments or direct process observations. This problem arose during the course of a study of some karst caves in Norway and experiments were conducted. It was found that sub-watertable channels between a sand fill and the roof of an inclined tube can produce a sinuos or even a braided pattern of flow. It was further observed that, without sediment fill, only a scalloped surface was formed on the roof and walls of plaster models. However, in contact with granular material, an uneven surface was formed, having indentations of the same order of magnitude as the grains. Anastomosing channels, "true" pendants and trunk half tubes were produced in this way. These results indicate that: 1. A corrosion mechanism controlled by the rate of flow is necessary. 2. A granular material in contact with the limestone surface seems necessary to produce half tubes and pendants. Except for the problems of scaling-up, these results are in agreement with the theories of Bretz (1942) and Renault (1967/68).

Zusammenfassung

Die klassische Theorie von Bretz über die Entwicklung von Deckenzapfen oder "rock pendants" ist weit verbreitet, akzeptiert und erscheint in vielen Lehrbüchern über Karstgeomorphologie. Diese genetische Theorie aber ist noch nie durch Experimente oder durch direkte Observierung des Prozesses geprüft worden. Dieses Problem entstand im Laufe von Untersuchungen einiger Karsthöhlen in Norwegen und Experimente wurden deshalbs ausgeführt. Wir fanden, das Kanäle unter dem Wasserspiegel zwischen Sandablagerungen und der Decke eines schräggestellten Rohrs sinusförmige oder sogar verzweigte Ströhmungsmuster bilden können. Es wurde weiterhin observiert, dass ohne Sedimentablagerung nur eine "scalloped" Oberfläche an der Decke und dem Wänden des Gipsmodelles gebildet wurde. Im Kontakt mit körnigem Material dagegen wurde eine rohe Oberfläche geformt, die Vertiefungen der gleichen Grössenordnung wie die Körner hatte. Anastomosierende Kanäle, wahre "Pendante" und "Sammelhalbröhren" entstanden auf diese Art. Die Resultate zeigen, dass 1) ein Korrosionsmechanismus, kontrolliert durch die Ströhmungsgeschwindigkeit, nötig ist und 2) ein körniges Matrial im Kontakt mit der Kalkgesteinsoberfläche nötig zu sein scheint, um Halbröhre und Pendante zu bilden. Abgesehen von gewissen Schwierigkeiten beim Ueberführen zu grösseren Masstab stimmen diese Resultate mit den Theorien von Bretz und Renault überein.

Introduction

Rock pendants are bedrock bodies of moderate and equal dimensions that protrude in a regular pattern from the enveloping surfaces of cave passages. In textbooks, they are often described as "stalactite-like forms in bedrock" (Sweeting 1972, Warwick 1962, 1976). Bögli (1978) classifies them as related to bedding or joint plane anastomoses. The genetic theory of Bretz (1942) requires a sediment fill contemporary or subsequent to the formation of the main passage (paragenesis, Renault 1968), making ceiling half tubes to a closely related feature. In this context, pendants should rather be defined by their intermediate spaces than by the rock protrusions themselves. From experience and literature, the term "pendant" seems to cover different and polygenetic forms. To cover all these forms, the following classification is suggested:

I. Inherited Structures
   a). "Pendants" formed by differential corrosion (petromorphs, stylolites, fossils, schist clast inclusions (St. Pierre 1966)).
   b). Joint-determined mazes, sometimes exposed by breakdown or vadose erosion.

II. Structures Formed Directly by Hydraulic Processes
   a). Bedding and joint plane anastomoses exposed by breakdown.
   b). Upwards corrosion above a sediment fill, i.e. Classical "Bretzian" or paragenetic pendants.
   c). Possible stream "scour" forms (Jacuks 1977).

Field Observations

The caves of Glomdalen near the Svartisen ice cap, North Norway are excavated in a very pure, homogeneous and coarsely crystalline calcite marble, Fig. 1. Pendants and half-tubes are abundantly developed, with all signs pointing towards a paragenetic origin (type IIb above). A general tendency found, was that larger "trunk" half-tubes branched into anastomoses (pendants) and coalesced into trunk tubes again, Fig. 2. In some cases the larger half-tubes showed internal scalloping, which could be proved to have an up hill direction of flow (Lauritzen 1981). Laminated and sometimes cross-bedded sediments from phi -4 to +6, most probably of glaciofluvial origin, was in some places wedged in between pendants, leaving a tubular space along the ceiling, Fig. 3.

The pendants and half-tubes can be described as "rejuvenated" anastomoses, developed along surfaces of higher hydraulic conductivity, i.e. the interface between the passage wall and a sediment fill. Half-tubes, which on this scale must be regarded as master conduits, occur either along the shrinking or settling void along the ceiling, or along sediment beds of higher hydraulic conductivity (grain size) where they intersect the walls, or in some cases, even the floor. Pendants occur often where hydraulic gradients between previously unconnected master (half-tube) conduits occur, Fig. 4. According to the direction of flow, these trunk half-tubes are manifolds and collectors respectively, an analog to the concept of arterioles, capillary bed and venules in chordate anatomy (Romer 1970).

As experimental verification of the paragenetic theory of pendant formation is not known, some pilot experiments were done.

Experimental

Subaquatic meandering

A simple phreatic loop was constructed from plexiglass tubing, 10 cm diameter, Fig. 5. Water and suspended sand were led through it. A delta-type sedimentation was easily obtained which subsequently filled up the passage completely. After a short period of increased rate of flow, which opened up a straight channel along the ceiling, the discharge was slowed down and kept constant, while a small support of sand was added. An undulating channel soon developed which was stable for at least one night before it straightened up along the ceiling. Further experiments in tubes with flat ceiling indicate a greater stability, Fig. 7. The "sinuosity" of the thalweg in these channels changed with discharge, Fig. 6. Low discharge gave largest sinuosity, and also braided channels (anastomoses). If the ceiling consists of a soluble material, incised channels should be expected to be formed.

Plaster Models

Plaster blocks, either buried in the sand or cast onto the ceiling of the tube developed a rough surface, usually on their underside. Substitution of the sand with 2 mm glass beads gave a similar result. The rough surfaces resemble the branched half-tubes and pendants, Fig. 7. It should be noted that limestone boulders supported in sandy streambeds often show pendants on their underside, but not elsewhere. Without the sediment fill, only a smooth surface was found. A plaster block that was protruding from the sand fill into the waterfilled space above, developed a distinct border between a smooth surface and "pendants".

Plaster tubes filled with various grades of sediment gave the same type of pattern. When silt was used, 1-2 mm wide half-tubes formed in some places, while the internal pores of the plaster was widened as well, indicating the limitation of using palster. A set-up with flat ceiling gave excellent results, Fig. 8.

Another experiment where a plaster block was placed in sand with an inlet tube below it, developed a nicely radial pattern, similar to the ceiling of a cave passage.

Discussion

Although carried out in a scale of 1/10 or less of the natural, the experiments indicate that formation of sinuous channels along the ceiling of sediment-filled tubes may take place in sub-watertable conditions. This is consistent with the requirements of Bretz (1942) who associated sinuous half-tubes with the aggradation of a subwatertable stream bed. The observation of half-tubes and pendants with uphill scalloping in steeply dipping passages also account for a phreatic development. The metastability of the sinuos channel seems related to the small dimensions used, and further experiments are needed with larger tubes.

Plaster simulations are carried out by assuming a similarity in the dissolution kinetics of plaster and limestone. The formation of pendants seems to require a mechanism where the local dissolution rate increases with the rate of flow. Another problem is the scale in hydrodynamic experiments, where the viscosity of water is exaggerated in small scales. The "pendants' formed in the experiments are about 1/100 to 1/10 of the corresponding forms in nature, and this is the strongest objection to the results. Further experiments on grain size dependence and a larger scale of the models are in progress.

Acknowledgements

Financial support was provided by Fridtjof Nansen's and affiliated funds for the advancement of science and the humanities; the Department of Zoology, University of Oslo provided the aquarium facilities necessary for the experiments.

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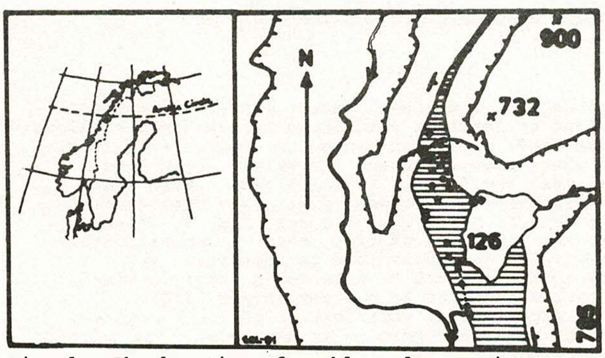

Fig. 1. The location of marble and caves in Glomdalen, North Norway.

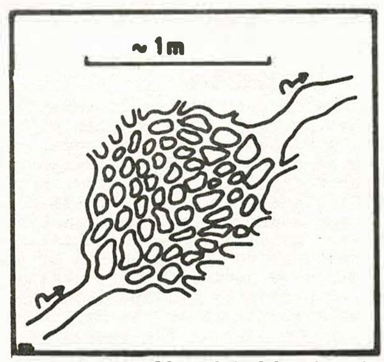

Fig. 2. Scalloped half tubes branching into pendant zones and coalescing into half tube.

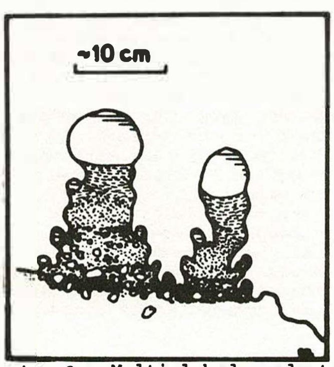

Fig. 3. Multi-lobed pendants with sediment in situ. Laminated sediment and tubular spaces at different levels.

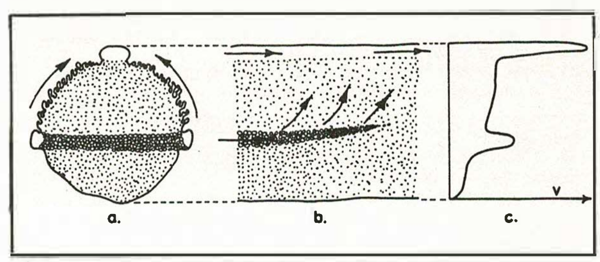

Fig. 4. a) Completely filled phreatic tube, half tube developed in zones of increased hydraulic conductivity. b) Longitudinal section. c) Vertical distribution of flow velocity.

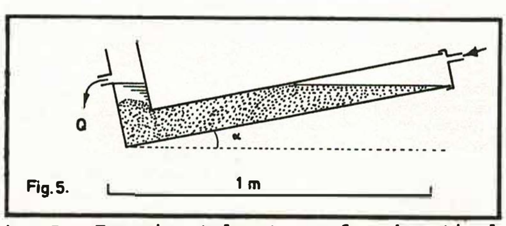

Fig. 5. Experimental set-up of a phreatic loop made of Plexiglass tubing.

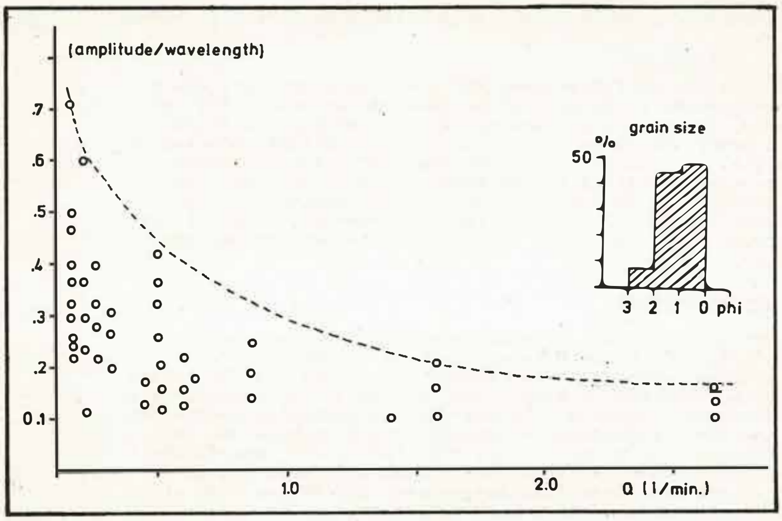

Fig. 6. Plot of "sinuosity" (amplitude/wavelength) of sinuous channel against discharge. Slope of tube (α) 22°. The grain size of the sand is shown.

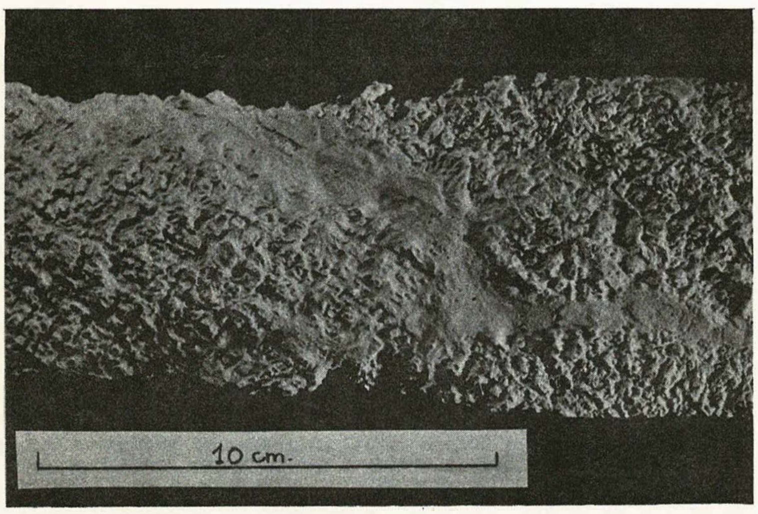

Fig. 7. Plaster model experiment. Winding and branching half-tube and pendants incised into the flat roof of a tube.

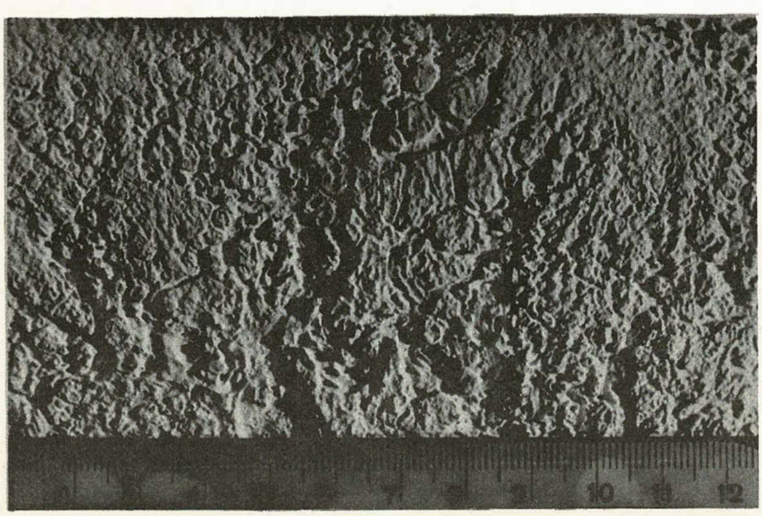

Fig. 8. Flat plaster block immerced in sand. Braided channels and pendants.

Glaciated Karst in Norway

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Abstract

About 1% of Norway's surface (3,000 km^2) consists of limestones, and karst landforms are abundantly developed in the purer limestones. Cave systems in dolomites are observed as well, Most of the karst landforms in Norway are known as caves, as surface morphology has been widely neglected. More than 600 caves are known at present. The caves are in most cases complex in outline, consisting of multilevel galleries of phreatic/vadose origin. As glacial landforms are dominating the large-scale landscapes in the cave areas, the topographical position of the caves is important when considering their mode of formation and age. A pre-glacial or "galeic" surface, multi-stage glacial valley profiles and river canyons can be distinguished as elements, often in decreasing order of age. To complement other genetic classification systems for caves (Ford 1977), a system considering the cave's situation in these landforms is suggested.

Zusammenfassung

Ungefähr 1% der Oberfläche Norwegens (3,000 km^2) besteht aus Kalkgesteinen und Karstformen sind in der reineren Kalkgesteinen reichlich entwickelt. Die meisten Karstformen in Norwegen sind als Höhlen bekannt, deren Oberflächenmorphologie meistens vernachlässigt worden ist. mehr als 600 Höhlen sind bis heute bekannt. Die Hählen sind in der meisten Fällen kompliziert aufgebaut und bestehen als Galerien in mehreren Stockwerken phreatischenßvadosen Ursprungs. Da die glazial geformten Landformen die Landschaft der Höhlengebiete dominieren, ist die topographische Lage der Höhle wichtig zum Verständnis der Entstehungsart und zur Altersbestimmung. Eine preglaziale oder "paleische" Oberfläche, Talprofile in mehren Stadien und Flusschluchten können als Elemente unterschieden werden, oft in abnehmender Altersreihenfolge. Als Ergänzung zu anderen Klassifikationsystemen für Höhlen wird ein System vorgeschlagen, das die Lage der Höhlen in diesen Landformen berücksichtigt.

Introduction

The distribution of the 600 karst caves at present known in Norway is shown in Fig. 1. The karstic rocks are methamorphized marble of the Caledonides (North and Central Norway) and contact-methamorphized or slightly modified Ordovicio-Silurian limestone in the Oslo graben. The most important karst regions are the Saltfjellet - Svartisen and bordering areas, situated approximately around the Arctic Circle.

Surface forms

As most of the previous work on Norwegian karst has been carried out by people mainly interested in caves, surface morphology is not much known. A few areas above the tree-line in the Svartisen region have been measured for morphometrical use. Doline densities exceeded 800 depressions/km^2 with joint dolines (Helldén 1974) as the most abundant forms (up to 75%) in areas of little soil cover. In an area of deep karst (holokarst) about 7% of the surface area was occupied by depressions. When considering all the measured dolines known, they vary in size from about 0.5 m to 1 km in diameter, and there are many small forms (0.5 - 2.5 m) and few large types. The large group of small forms has possibly been developed postglacially (10,000 years), while the largest forms probably have survived glaciation.

Glacial landforms are abundant; schichtrippenkarst, schichttreppenkarst, true pavements and roche moutonnées are common, depending on the dip of the limestones. The glacial karst forms can be classified by the system suggested by Ford (1977).

Caves

The longest cave system in Norway is 12 km, while the deepest is 675 m. Most of the caves of more than about 1 km length are complex (branched) in outline, consisting of multi-level galleries having both phreatic and vadose characteristics. Previous workers have suggested a post-glacial (Corbel 1957), sub-glacial (Horn 1947) and inter/preglacial (Horn 1947, Jenkins 1959) development of caves, indicating a polygenetic origin.

Recent speleothem datings (Lauritzen and Gascoyne 1980) have revealed some cave passages to be older than the last glacial. In some caves where topography and lithology are favorable, former uphill phreatic flow paths have been detected by scallop studies (Lauritzen 1981). This direction of flow is consistent with ice flow under glacial maxima, and is often associated with paragenetic alteration of the roof. This phenomenon is taken as an indication of sub-glacial speleogenesis, Fig. 2. (Lauritzen, in preparation).

In spite of that most workers found a depleted aggressiveness of sub-glacial waters (Ek 1964, Ford 1971), the sub-glacial corrosion found must be seen in relation to the allogenic character of the karst drainage in Norway. In narrow limestone bands, even a depleted aggressiveness may be important when allogenic waters come in contact with a limited outcrop of carbonate rock.

Caves and the Larger Landforms

In several cases, cave systems seem to have been truncated by glacial action, leaving cave fragments in a "hanging" position in the sides of U-shaped valleys. Norway's topography can be divided into a pre-glacial or paleic surface, defined by the summits of mountains. This surface was characterised by broad, shallow valleys corresponding to semi-arid conditions in Tertiary (Gjessing 1967). Several subsequent paleic surfaces and valley stages have been suggested as well. Upon this surface, glacial landforms are superimposed. Vertical plots of caves in valley cross-sections often show a relation to the older surfaces, Fig. 3. For instance, Bauer and Zötl (1972) refer to a concentration of large passages to certain levels in Austria. A first-stage classification of caves in such profiles may be of great help before detailed studies of sediments and speleothem datings can give a more exact chronology.

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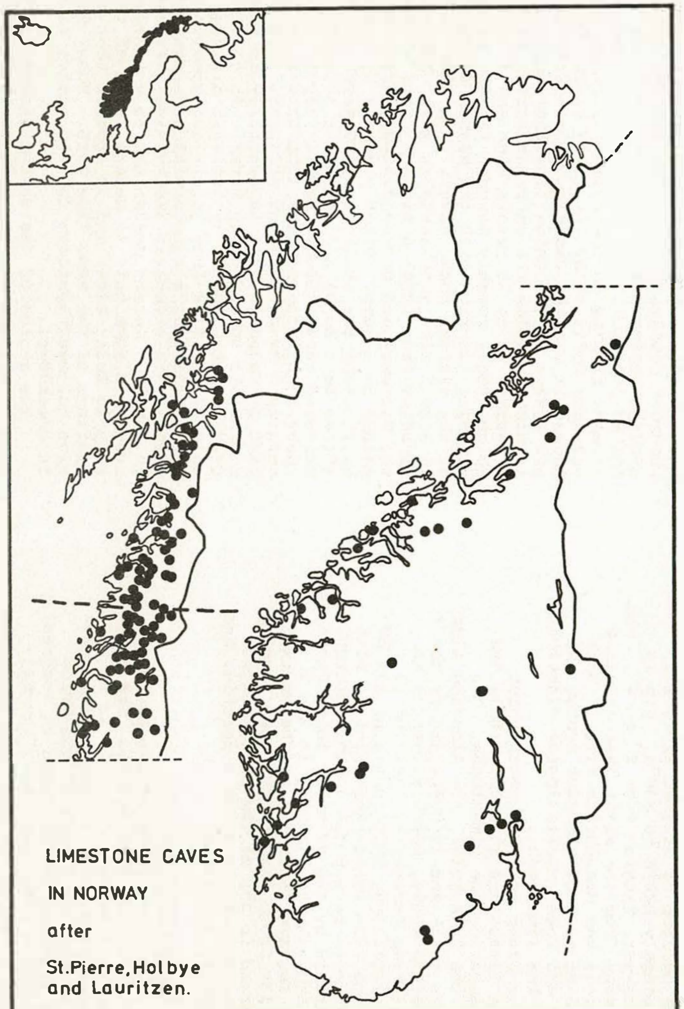

Figure 1: Limestone Caves in Norway

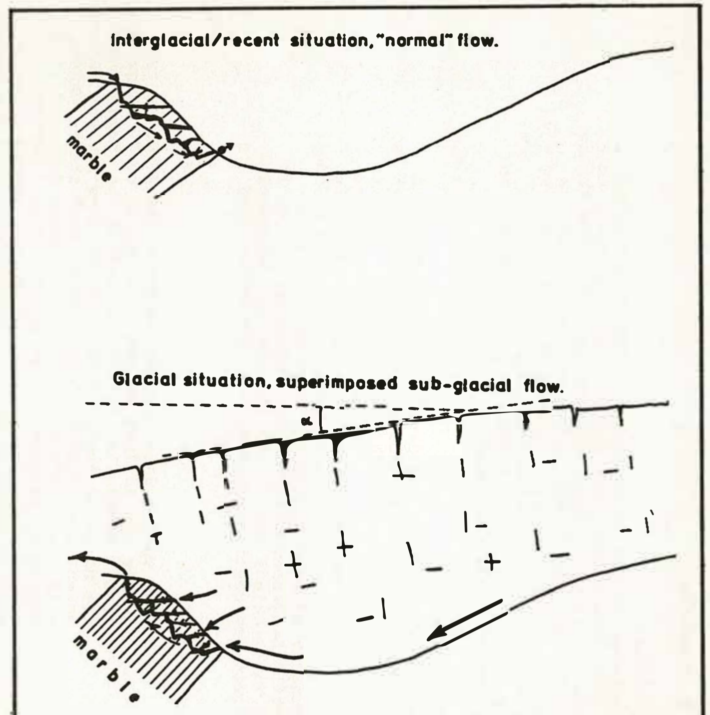

Figure 2:

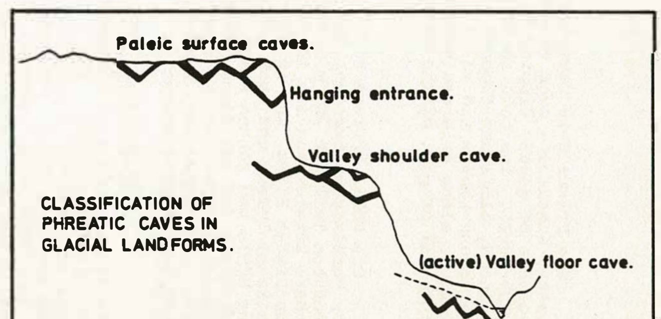

Figure 3:

Geography of the Friars Hole Cave System, U.S.A.

Douglas M. Medville

Abstract

The Friars Hole Cave system in eastern West Virginia, is the third largest cave in the United States, containing over 61 km of surveyed passage. The cave is in upper members of a 200 meter thich sequence of gently dipping Mississippian limestones with primary passage development along the strike (N20°-30°E). The cave is developed in a temperate zone fluviokarst and is beneath narrow, strike oriented, limestone floored valleys and adjacent clastic-capped ridges. Sinking streams enter the cave via vadose shafts and solutionally enlarged joints; a majority of the lateral passage development however, is along enlarged bedding plane partings. The cave has a linear extent of 6.3 kilometers and takes all or part of the drainage of a 71 km^2 area, depending on the season.

Zusammenfassung

Die Höhle "Friars Hole", im östlichen Teil des West Virginiens, ist die drittgrößte Höhle in den Vereinigten Staaten, und sie ist über 61 km in gemeßener Länge der Galerien. Die Höhle liegt im obersten Teil der 200 m dicke Schicht des Mississippien Kalksteins von schwacher Neigung, und die größte Entwicklung ist in der Streichrichtung (20°-30°) des Kalksteins. Die Höhle liegt in einem gemäßigten Klima, und in einem fluviatil Karst unter schmale, schichtstreichenparallele Täler mit Kalksteinboden, und auch unter die nächst liegende, klastisch bedeckte Gebirgskämme. Flüsse fließen zur Höhle und senken durch vadose Schachte oder lösungserweiterte Klüfte ab; aber die größte entwicklung der seitliche Galerien ist auf die Schichtflächenabsonderungen. Die Höhle ist 6,3 km in lineale Ausbreitung und nimmt einen Teil oder allen Wasserablauf von 71 km^2 je nach der Jahreszeit ein. Die Gestaltung, Hydrologie, und Verwandschaft mit dem oberflächlichen Karst der Höhle wird auch beschrieben werden.

Location and Setting

The Friars Hole Cave system is located in eastern West Virginia, U.S.A. The climate of the area is temperate and humid with mean annual precipitation of 98 mm and mean annual temperature of 11°C. Ridges and knobs of a dissected plateau lie just to the west of the cave and reach elevations of 1370 meters. These are composed of Mississippian and Pennsylvanian shales and sandstones and form the main recharge area for water draining into the cave. Immediately to the east of the cave lies Droop Mt., elevation 950 meters, a narrow ridge which is an eastern spur of the plateau to the west. Along the base of the west flank of Droop Mt. and paralleling it for 11 km is a narrow, strike oriented exposure of Mississippian limestones of the Greenbrier Group, totaling 4.5 $km.^2$ in area. It has been suggested[1] that this outcrop (elevation 720-760 meters) is coincident with the former bed of Hills Creek,[1] a major stream flowing from the northwest and now sinking in the limestone. The limestone exposure contains features typical of a humid, temperate zone karst; dolines up to 50 meters across and up to 20 meters deep, blind valleys containing sinking streams, and numerous cave entrances. The streams which sunk into the limestone drain an area of 71 km^2 with most of this water ultimately entering and flowing through the Friars Hole cave system. In Figure 1, a map of the cave and the area around it is given.

The limestone outcrop is aligned along the regional strike; roughly N20°E to N30°E. Dip is gently to the northwest, ranging from 2° to 4°. The dip direction is away from the major base leveling drainage in the area; the Greenbrier River. This river is about 6.5 km east of the cave system and flows on Devonian and lower Mississippian clastics below the base of the limestones.

The Greenbrier Group is a 200 meter thick sequence of marine limestones with thin shale and sandstone beds separating the limestones. The highest member of the Greenbrier, the Alderson limestone, is 10 meters thick and is underlain by the 8 meter thick Greenville shale, which serves as an aquiclude. Beneath the Greenville lies the 45 meter thick Union limestone, which contains all of the entrances to the cave system and which is also the lowest limestone to be exposed in the outcrop. The Union is underlain by the 40 meter thick Pickaway limestone. Beneath the Pickaway is the 8 meter thick shaly Taggard formation and below that, the lower Greenbrier Group limestones. The Taggard has not been observed in any of the cave passages entered to date and apparently forms a perching bed upon which the cave is developed.

System Configuration

As of early 1981, over 61 km of passage has been surveyed in the Friars Hole system. The major passage orientation, as shown in Fig. 1, is NE-SW, subparallel to the strike. All of the system's entrances are in the upper 10 meters of the Union limestone. While solution in the Union is frequently initiated along bedding plane partings, the majority of passage development in this unit results from vadose water moving downward along joints typically one to five meters wide and up to 20 meters high. Water also enters the system via shafts that are up to 30 meters deep. Of the cave's eight entrances, six consist of or lead to such shafts which, with the enlarged joints, carry water downward in a stairstep pattern for up to 50 vertical meters.

While surface water enters the system via the Union limestone, the great majority of passage development and almost all of the lateral streamflow in the cave takes place along solutionally enlarged beds in the Pickaway limestone just below the Union/Pickaway contact. These passages can be fairly voluminous, achieving dimensions of 15 meters in height and width for considerable distances.

The Friars Hole system is fairly complex in terms of passage development and a detailed discussion of its speleogenesis is beyond the scope of this paper. The cave however, can be described in terms of three almost-separate drainage basins within it, each containing its own master stream and infeeders. The dashed lines in Figure 1 indicate the general location of the divides between the basins. These internal basins are described below.

The Canadian Hole Drainage

The northernmost drainage in the system; Canadian Hole, contains 18.6 km of surveyed passage and has a vertical extent of 143 meters. This is by far the most complex part of the system, containing numerous infeeder complexes, long sections of strike oriented passages, some of which have been abandoned by streams flowing in lower levels, large chambers, and passages modified by low angle thrust faulting. Access is via the Canadian Hole entrance, a series of six shafts in the Union limestone totaling 43 meters in depth. Below the entrance series is First Canyon, a passage 12 to 15 meters high and 3 to 6 meters wide which trends roughly downdip for 550 meters to an ultimate junction with the master stream in this part of the system; Rocky River. The flow in this stream is 3 to 5 cfs; substantially more than would be expected from local drainage. this stream flows in the Pickaway and can be followed upstream for 650 meters to a sump. Other passages at higher levels lead north along the strike to a 70 meter diameter chamber (Crows Nest Room) and then to a 500 meter long strike oriented crawl (Almost Hell). Beyond this, the cave opens to a large complex (The Ontario Extension) containing 7 km of surveyed passages. The drainage in this part of Canadian Hole is generally to the west and southwest; toward Rocky River. At the north end of the Ontario Extension is an internal drainage divide with some of the flow from inlets going north and west, finally joining a substantial streamway trending southwest. This streamway (Rocky River II) has been followed for 1100 meters downstream to a terinus in a large breakdown room only 70 meters north of the upstream sump in Rocky River and it appears that these are two sections of the same flow path. Rocky River II has also been followed upstream for 850 meters to a terminis in breakdown.

The source of the master stream in Canadian Hole lies in streams sinking well to the north of the system.

The largest of these streams is Hills Creek having a catchment area of 37 km^2 and sinking 2.5 km to the north of the upstream end of Rocky River II. Under high flow conditions some of Hills Creek flows across the limestone and enters a cave (Hills-Bruffy Cave) on the west side of Droop Mt. This water has been traced to a spring on the east side of Droop Mt.[2]; Locust Spring, and does not enter the Friars Hole system. Prior to entering the Hills-Bruffy cave, Hills Creek is a losing stream; some of its water sinking into alluvium in its bed. Indeed, in low flow conditions, all of Hills Creek sinks in its bed and has been traced[3] to a south flowing stream in Cutlip Cave, 500 meters south of the sinking of Hills Creek. The Cutlip Cave stream has been traced in turn for 1.8 km to the south to another cave (Clyde Cochran Sinks) where the cave stream flows into a 10 meter diameter sump. The flow path is shown as the dashed line in Figure 1. This sump is only 120 meters to the north of and at the same elevation as the upstream end of Rocky River II in Canadian Hole and it is almost certain that the two streams are the same. It is concluded therefore, that much of the water flowing through Canadian Hole is derived from Hills Creek and other sinking streams to the north of the system and that these streams are being pirated from a relatively short (but complex) flow path beneath the north end of Droop Mt. to a more circuitous, strike oriented flow path which parallels the west side of the mountain.

The master stream in Canadian Hole; Rocky River, flows downstream to the southwest and terminates in rockfall along a fault. The downstream terminus lies at the lowest point in this part of the system; 143 meters below the Canadian Hole entrance and is not seen again in the system. This downstream end lies beneath the north end of the largest chamber in the cave, Monster Cavern, 100 meters in diameter and up to 60 meters high. A 30 meter waterfall enters this room from the west and sinks in breakdown in the floor, probably joining the Rocky River 30 meters below.

The Central Drainage

To the south of Canadian Hole lies the Snedegar/Crookshank/Rubber Chicken/Toothpick complex, forming the central and largest drainage basin in the system with 30 km of surveyed passage. Unlike the Canadian Hole drainage, all of the streamflow in this part of the system is derived from streams sinking in valleys directly above and entering via domes or entrances.

In the central drainage, two major flow paths exist. The longer of these begins where a stream flowing from Droop Mt. sinksand flows for over 2300 meters, generally to the southwest and west. This stream then joins another (sinking in the upper Friars Hole valley) and flows NNW along strike for 3000 meters. Streamflow for most of this distance is in the upper Pickaway limestone in passages up to 20 meters wide and 15 meters high. The second flow path is a west and north flowing stream from the Snedegar part of the system. The two streams join at a near-sump in the upper Pickaway and then flow for another 1600 meters to the west and southwest. The combined streams drop stratigraphically, finally reaching a terminal sump at the lowest point in the system; 180 meters below the system's high point. This sump appears to be in the lower part of the Pickaway limestone.

It should be noted that a clearly defined drainage divide between this central drainage and the northern drainage in Canadian Hole does not exist. The deeper Canadian Hole drainage lies directly beneath and is gradually capturing the surface stream which would otherwise flow into the Snedegar stream entrance in the central drainage. In dry weather, this stream sinks in its bed 200 meters up-valley from the cave entrance and enters Canadian Hole via the 30 meter waterfall in Monster Cavern, mentioned above. This chamber underlies the valley and flowthrough time is on the order of a few minutes. In higher flow conditions, the stream does reach the cave entrance but even then, a significant quantity of water sinks within the first 40 meters of passage, flows through choked joints in the passage floor and reappears at the Monster Cavern waterfall.

In addition to the two major flow paths in the central part of the system that are noted above, a substantial paleo-flow route exists. This route begins in the Canadian Hole (northern) drainage as a 1300 meter long, strike oriented passage just west of and at about the same elevation as the base of the Canadian Hole entrance series. The passage, called the Highway, is 2 to 4 meters high and 10 to 12 meters wide. It formerly contained a south flowing stream but has not been abandoned with current drainage crossing it and flowing more or less downdip. ultimately joining the Rocky River to the west. The southern terminus of this passage is in fill and breakdown beneath a surface sink. One hundred meters to the south and at the same elevation is a continuation of this passage in the central part of the system, also called the Highway. This passage segment continues south for 800 meters and then treands west for over 2000 meters, averaging 10 to 15 meters in height and width. While this was a major flow route, formerly carrying water into the current main drainage path in the central part of the system, it is today almost totally abandoned, only carrying a very small (less than .1 cfs) stream derived from local drainage in the valleys above.

The Friars Hole Valley Drainage

The southernmost drainage in the Friars Hole cave system lies south and west of the rest of the cave. Here, streams flowing from local clastic ridges reach the upper Union limestone which outcrops in the narrow Friars Hole valley. These streams drain an area of 4.35 km^2, sink at several major insurgences (one of which is an entrance to the cave), and drop 45 meters into a master drainage route carrying water to the southwest. This passage is in the upper Pickaway limestone and has an average width of 15 meters and height of 10 meters for a distance of over 1500 meters. The stream in it has an average flow of .50 to 1.00 cfs and is underfit. It would appear that in the past, substantially more water flowed through the Friars Hole trunk passage than at present and that some of this water; from the upper Friars Hole valley and from Brushy Mt. to the east, is now flowing north through the central part of the system. The connecting passage between the two drainages is a phreatic tube up to 4 meters wide and 10 meters high with solution scallops indicating paleo-flow to the southwest; i.e. toward the Friars Hole Cave drainage. The mechanism for capture of this flow by the central drainage as well as the development of the Friars Hole cave part of the system is the subject of a separate ongoing study(4).

While the stratigraphic horizon at which solution in Friars Hole cave is taking place is the same as in much of the central part of the system; the upper Pickaway limestone, toward the cave's downstream end this changes abruptly. There, the cave stream entrenches itslef in a narrow canyon, abandons its former flow route to the southwest, and drops rapidly, losing 30 meters in elevation over a short distance. The stream, flowing west, is then lost beneath breakdown along a fault. This sequence of streamflow for a long distance in the upper Pickaway followed by rapid downcutting to a terminus also occurs in the northern and central drainage basins of the system.

Conclusion

The Friars Hole cave system is aerially extensive, hydrologically complex, and highly dynamic. Numerous instances of abandoned passages by downcutting streams, downdip diversion of flow routes, and subsurface drainage divides have been observed. No evidence exists for there ever having been a single conduit carrying one master stream through the entire length of the system. Rather, it appears that numerous streams, sinking over the length of an 11 km long limestone outcrop have resulted in the development of several separate caves which have subsequently been integrated into a single large system.

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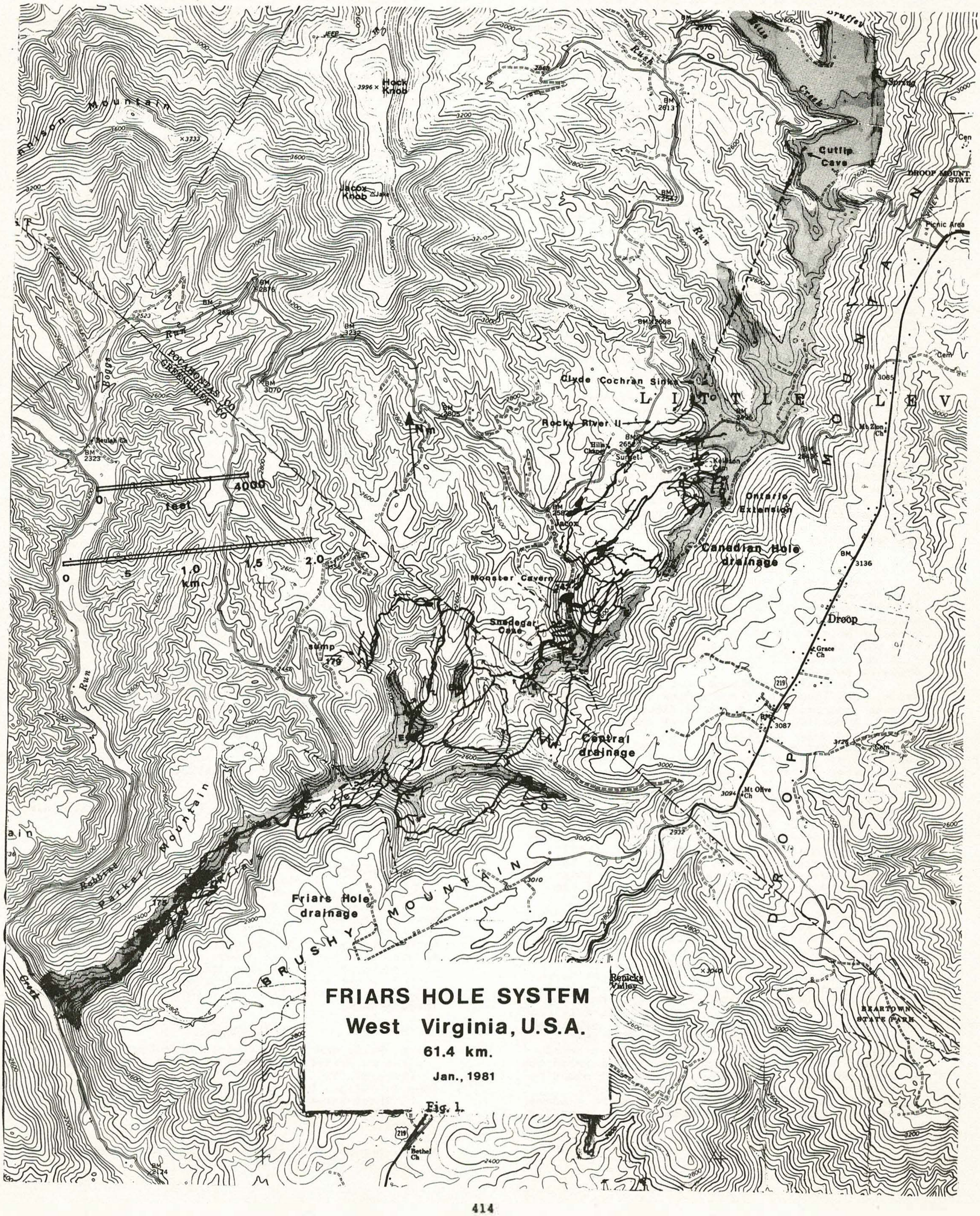
FRIARS HOLE SYSTFM
West Virginia, U.S.A.
61.4 km.
Jan., 1981
Hock Knob
Jacox Knob
Cutlip Cave
Clyde Cochran Sinks
Rocky River II
Ontario Extension
Canadian Hole drainage
Monster Cavern
Snedegar Cave
Central drainage
Friars Hole drainage
BRUSHY MOUNTAIN
LITTLE LEVEL
DROOP MOUNTAIN
Droop
Parker Mountain
POCAHONTAS CO
GREENBRIER CO
0 4000 feet
0 .5 1.0 1.5 2.0 km
BEARTOWN STATE PARK
Renicks Valley

Fig. 1.

Aggressive Behavior of the European Cave Salamander Proteus anguinus (Proteidae, Urodela)

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Abstract

The animals normally rest in groups under stones. In these communal resting places the members communal resting places the members are in contact without any aggressiveness. When a ♂ comes into sexual motivation he established a territory. Then he defends his territory against all intruders except ♀♀ in reproductive status with tail-beating, ramming and biting. The territorial ♂ is only able to identify such a ♀ after direct body contact. He seems to get a chemical information in the genital region of the ♀. All other animals avoid the territory. For this avoidance reaction the ♂ seems to give no special chemical signal: In the test situation the animals do not differentiate between water coming from an aquarium with an aggressive ♂ and water of another animal. But they can distinguish water of conspecifics from water of the relative Necturus maculosus and also water of conspecifics from control water. So there must exist only a species specific chemical information in the water.

In the choice test between bricks which have been used before by other animals as resting places the animals prefer the bricks of an other animal from their own. They do the same in case of the brick of an aggressive ♂. But they avoid this brick after an aggressive contact in the territory of the owner. So we can conclude that in addition to a species specific chemical information which is transported by the water Proteus uses a substrate specific chemical information. This substance is individual specific but it transmits no further detailed information. For the avoidance of a special territory the animals need an individual aggressive contact before.

Comparative studies with the epigean Proteidae Necturus maculosus have been studied.

Zusammenfassung

Normalerweise ruhen die einzelnen tiere in gruppen unter steinen. In diesen Ruheplätzen liegen die tiere eng aneinander ohne aggressives verhalten. Sobald ein ♂ fortpflanzungsbereit wird, errichtet es ein territorium. Dieses territorium wird gegen alle eindringlinge mit ausnahme von fortplfanzungsbereiten ♀♀ verteidigt. Dabei zeigt das ♂ Schwanzschlag, Rammen und Beißen. Vor einem Angriff prüft das ♂ den eindringling mit der Schnauzenspitze. Im falle eines fortpflanzungbereiten ♀ scheint es dabei eine chemische information in der genitalgegend zu bekommen. Alle anderen tiere meiden die territorien ohne daß man dafür ein spezielles chemisches signal findet. Die tiere unterscheiden nämlich in der testsituation nicht zwischen Wasser aus einem aquarium mit einem territorialen ♂ und Wasser von einem anderen Artgenossen. Sie bevorzugen aber das arteigene Wasser vor dem des verwandten Necturus maculosus und vor Kontrollwasser. Es existiert also im Wasser eine artspezifische chemische information.

In Wahlversuchen mit ziegelsteinen, die vorher als Verstecksteine dienten, bevorzugen die tiere steine von fremden tieren gegenüber den eigenen. Das tun sie auch mit dem stein eines aggressiven ♂. Sie meiden einen solchen stein erst, wenn sie vorher im territorium des besitzers angegriffen wurden. Wir können also feststellen, daß zusätzlich zu einer artspezifischen chemischen information im Wasser beim grottenolm auch eine substratgebundene existiert. Diese gibt zwar eine individualspezifische information, sagt aber nichts über den aggressiven Zustand eines tieres. Zum meiden der territorien scheinen die tiere jeweils eine aggressive Erfahrung zu benötigen.

Vergleichsversuche zu diesem problemkreis wurden mit dem oberirdisch lebenden Proteiden Necturus maculosus bereits begonnen.

Introduction

A morphological changement common to all animals that live permanently in completely dark cave biotopes is the reduction of eyes and pigment (Wilkens et al., 1979). The only behavioral change so far noted is reduced aggression in fish--the cave-dwelling tetra Astyanax mexicanus (Burst, 1980) and the "cave molly" Poecilia sphenops (Parzefall, 1979).

The blind cave salamander Proteus anguinus, an inhabitant of limestone caves in Yugoslavia, has been found to exhibit aggressive behavior (Briegleb, 1962). In continuing this investigation (Parzefall, 1976; Parzefall et al., 1980) we are currently interested in the ways aggresive behavior patterns are elicited and detected in the dark. Since this salamander has no recent European relatives, the representative of the salamanders living above ground chosen for comparison was the North American Necturus maculosus.

Materials and Methods

The specimens of Proteus anguinus brought from Yugoslavia in 1955 have continued to reproduce regularly in the cave at Moulis. Here they are kept under flowing water in aquaria of different sizes, the largest being concrete basins several meters in length. These conditions correspond closely to those in the natural habitat.

The animals were observed with an infra-red imaging device and infra-red lamps. The behavior was recorded with an infra-red video camera and a 1 inch recorder, the latter situated outside the cave to protect it from moisture. The video picture was transmitted by a 500 m long cable with amplification.

To test for the presence of substrate-bound chemical information, the animals were provided with tiles as hiding places. After they had been occupied for some time, the tiles were tested in choice experiments (Fig. 1) in a neutral aquarium. The possibility that chemical information is transmitted in the water was tested with a choice chamber (Fig. 2) containing water taken from occupied aquaria.

The related surface-dwelling salamander Necturus maculosus was obtained from a dealer in Wisconsin. These salamanders were kept and observed at various temperatures (11°-23°C).

The results were evaluated statistically by Wilcoxon's rank-sign test (Siegel, 1956).

Results

Proteus exhibits very little locomotor activity. Normally the individuals rest in groups under stones, where they are in close body contact. Long-term observation by video camera has shown that the animals hardly move at all for periods of hours. They have a strong preference for shelters between vertical slabs of stone, gaps just wide enough that they can squeeze in. They rarely leave these shelters, even to feed. Observations in the cave at Moulis indicate that they consume a proper meal only once a week. on the average; if food is offered at shorter intervals it is ignored.

Aggressive behavior associated with feeding was observed only in juveniles. If several young animals arrive at a food source simultaneously, the largest drives the others away with bites and strokes of its tail. Sexually mature animals were never seen to behave aggressively in this situation.

The adults exhibit aggressive behavior only when they are in mating condition. The first signs of this state are an increase in locomotor activity and a distinct swelling of the cloacal region in both sexes. In females, the eggs can be seen shimmering through the abdominal wall. A male ready to copulate establishes a territory and no longer allows all other animals into his vicinity. After testing an intruder briefly with the tip of the snout (Fig. 3a), the male defends his resting place, usually beginning with a tail stroke and proceeding to bite vigorously if the intruder does not flee (Fig. 3b, c). He may also charge toward and attempt to ram his opponent. The charges and tail strokes are always produced in the same temporal pattern. In this respect they differ from the corresponding movements made during swimming and walking. It is not yet clear to what extent the water movements generated by charging and tail-beating act at a distance as signals of aggression. When different animals are experimentally introduced into a territory, it is evident that gravid females are only rarely attacked

(Fig. 4). Because an attack is always preceded by examination with the snout tip, it appears that the females signal their readiness to copulate by a chemical substance. But when two-choice test were done in the choice chamber, female-water being paired with either control water or water from non-gravid animals, there was no discrimination. Nor were the shelters of females preferred to those of animals not in mating condition. We conclude that the chemical signal of the female is detected only by direct body contact.

The fact that most of the animals avoid the territory of a male suggested that the males emit a chemical signal. However, a number of experiments with male-water in the choice chamber gave no positive results. Similarly, no consistent avoidance was exhibited in two-choice tests with different shelters in a neutral aquarium (Fig. 5a). The shelter of a territorial male was avoided in neutral surroundings only if the test animal had previously been attacked by this male in his territory (Fig. 5b). We may infer from these results that the shelters carry individual-specific chemical information, so that animals learn to avoid a territory once they have been attacked. The presence of such an individual-specific substance is also clearly revealed when a test animal in a neutral aquarium is presented with its own shelter together with a strange one. The animals discriminate, choosing the strange shelter (Fig. 6).

The aggressive behavior patterns that have been described are also used by the females after egg-laying, to defend the spawn (Briegleb, 1962).

By contrast, when kept in our aquaria the only recent proteid, Necturus maculosus, has so far directed tail strokes and biting toward conspecifics only during feeding. Preliminary comparative experiments indicate that Necturus also releases a substrate-bound substance, and that is species-specific (Parzefall et al., 1980).

The results to date make it clear that chemical communication is an important factor in the aggressive behavior of Proteus anguinus. Our observations also suggest that the water waves produced by charging and tail strokes are recognized as an aggressive signal at distances of several centimeters. As yet, however, this interpretation has not been confirmed experimentally.

Summary

The blind cave salamander Proteus anguinus exhibits aggressive behavior in the form of tail strokes, ramming and biting. Juveniles ~~fight over prey~~ in this way, whereas males in mating condition use these patterns to defend their territories, and females to defend their spawn.

The territory is not defended against gravid females; they are evidently recognized by chemical information when the male touches them with the snout. The avoidance of a territory is based on the production of an individual-specific chemical substance, which is released continually in contact with the substrate. Not until it has been attacked does an intruding animal learn to avoid the shelter of the attacker.

The surface-dwelling proteid Necturus maculosus has so far been observed to employ tail strokes and biting only during disputes over prey.

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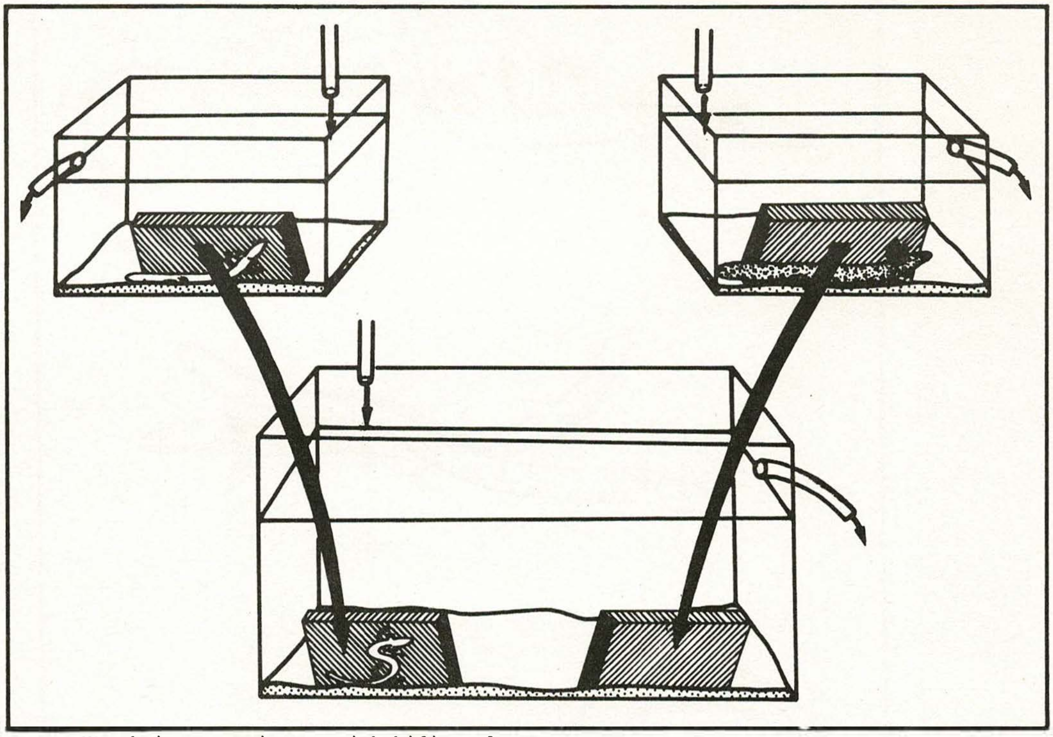

Fig. 1 : Choice experiments with hiding places. Each animal lives in an aquarium with a tile (above). The tiles were tested in a neutral aquarium (below).

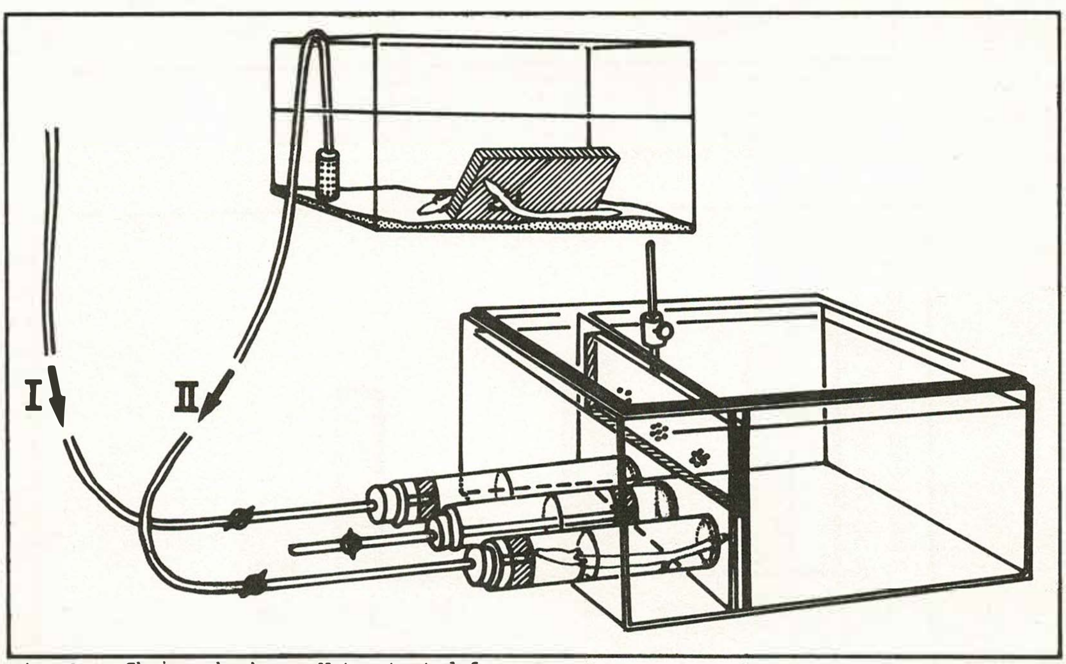

Fig. 2 : Choice chamber. Water tested from an occupied aquarium (I) and a second one (II) void of animals.

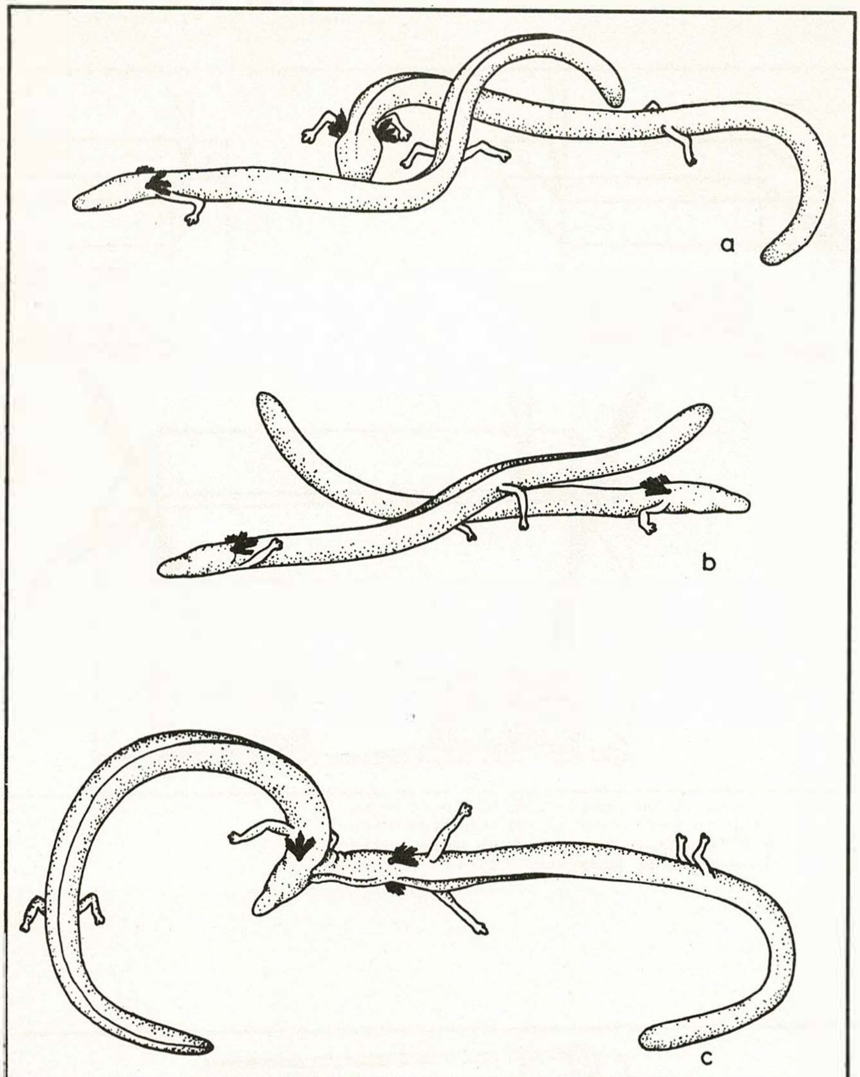

Fig. 3 : Male of Proteus testing an intruder (left) with the tip of the snout (a). Both animals show tail strokes (b). The territorial male bites the intruder (c). After photographs Parzefall (1976).

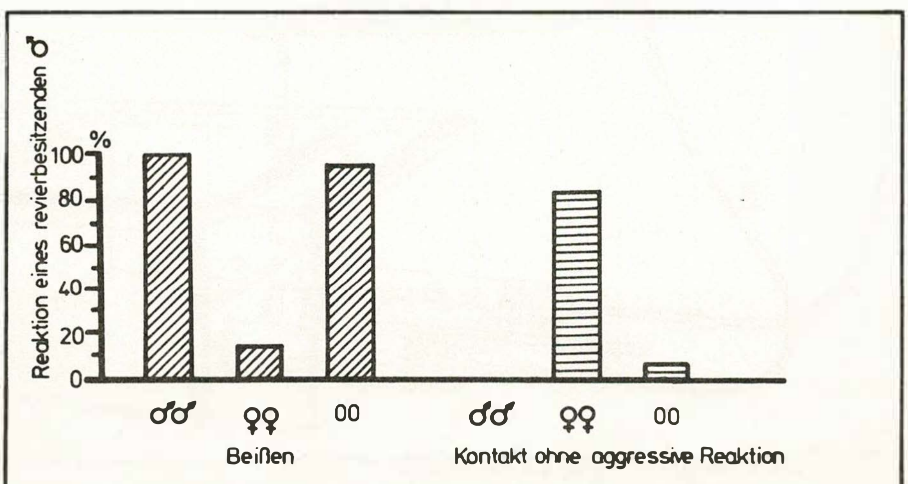

Fig. 4 : Reaction of a male of Proteus against intruders in its territory. 00 = animals besides the reproductive state. After Parzefall (1976).

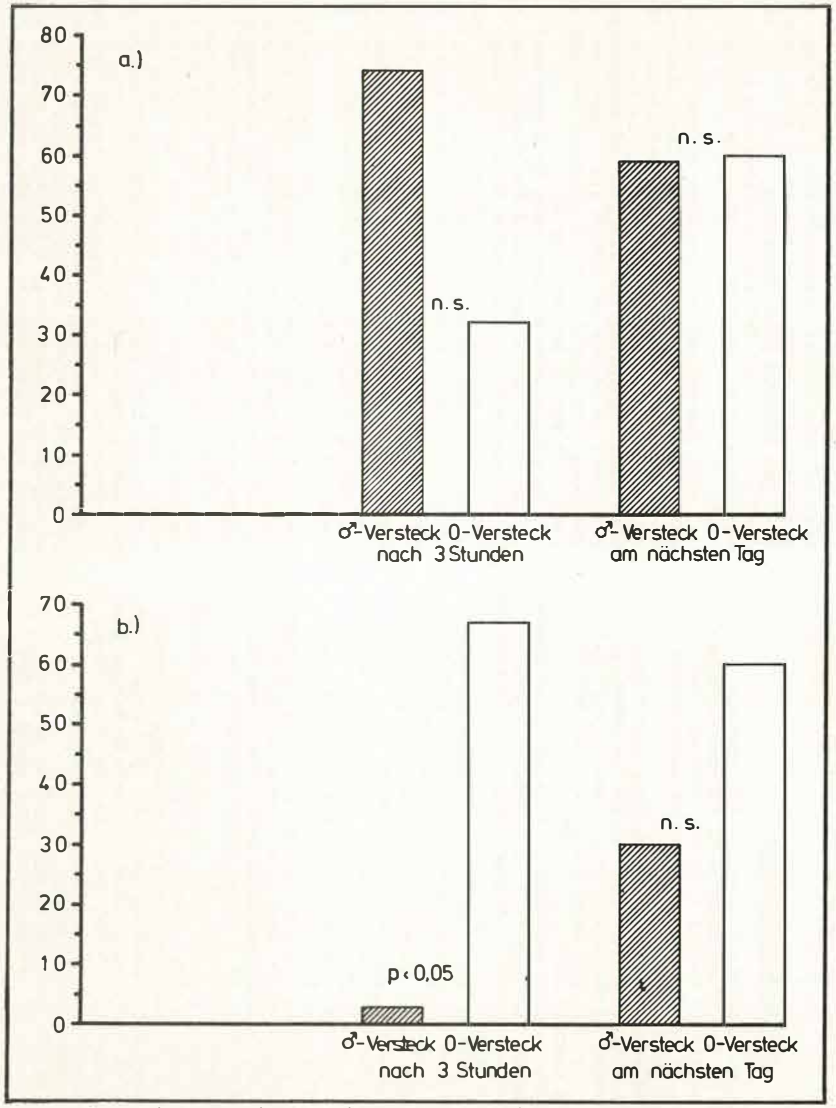

Fig. 5 : Choice experiments with Proteus, a.) the animals tested do not know the male the tile of which is presented. n = 8. b) The animals have been attacked in the territory of the male the tile of which is presented. n = 6. Parzefall (1976).

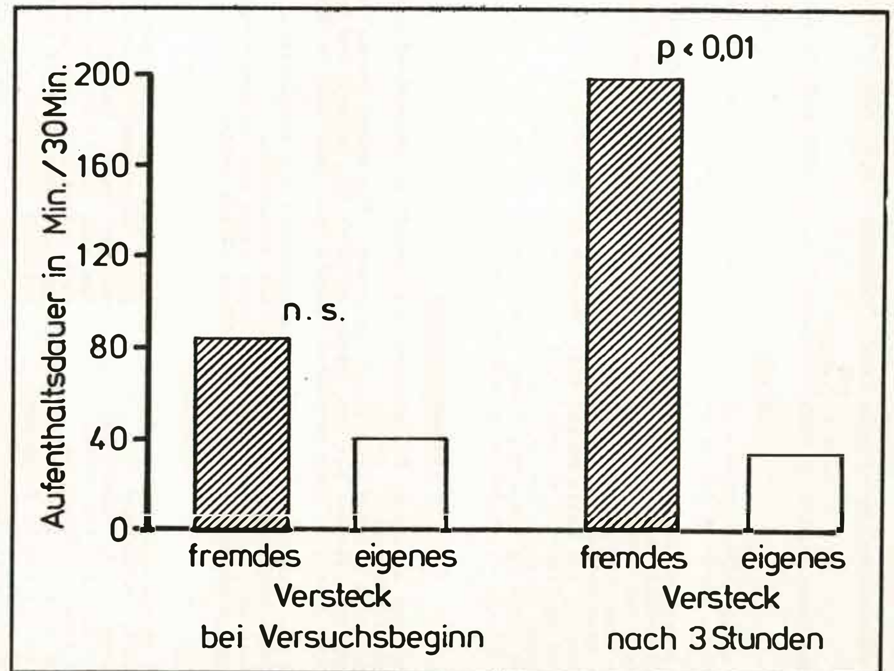

Fig. 6 : Choice experiments with Proteus. The test animal is presented with its own shelter together with a strange one in a neutral aquarium. After Parzefall (1976).

Radiation Hazards in Natural Caves

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Abstract

The major concern on the possible effects of very low doses of ionizing raditions in recent years put a speical emphasis also on exposure due to enhanced natural radioactivity. Caves may be a typical example of such an exposure.

The presence of high levels of radon and radon daughters has been found in many caves in various regions of the world. In principle such levels may present a certain degree of radiation hazards both to cave guides and visitors. The levels of radon and radon daughters concentrations found in some caves are reported together with some original data measured in the largest and most visited Italian show cave. The full set of results is used to make an approximate evaluation of the radiation hazards in caves. Such evaluation has been performed on the basis of the risk factors derived from the lung cancer rate among miners. The validity of the application of these risk assessments to the cave environment is analyzed owing to the great differences existing between the radon daghters exposure in uranium mines and caves.

The case of commercial caves is therefore taken into account due to the number of visitors, which sometimes is rather large and the existence of a critical group constituted by the people engaged in the management.

Zusammenfassung

Im Bereich der Wirkung sehr niedriger Dosisleistungen, grosse Aufmerksamkeit ist auf die Aussetzung hoher natürlicher Radioaktivität geschenkt worden.

Höhlen können einen Beispiel solcher Aussetzung vorweisen. Ein hohes Niveau von Radon und Radon-Nachfolger ist in vielen Höhlen, zusammen mit den Werten betreffs die grösste und meist besuchte ilalienische Schauhöhle, werden hier gezeigt. Alle Ergebnisse werden dazu gebraucht um die Strahlenbelastung in Höhlen abzuschätzen.

Die Abschätzung nimmt als Grundlage die Lungenkrebs-Häufikeit bie Bergleuten. Der Unterschied in der Strahlenbelastung zwischen Uranium-Gruben und Höhlen ist untersucht.

Spezielle Aufmerksamkeit wird an Schauhöhlen geschenkt, wegen der zahlreiche Besucher und der Anwensenheit der kritischen Gruppe bestimet bei der in die Höhlen tätige Leuten.

Introduction

Scope of the present paper is the evaluation of the possible hazards due to natural radiations in caves both to the personnel engaged in the commercial caves, the cavers and the public visiting the caves.

It is well known that also caves in limestone without anomalous concentrations of U 238 and Ra 226 may have an atmosphere rich in Rn 222 and Rn daughters. From this point of view the cave configuration, the micrometeorology and the airflow patters play an important role (Anonimous, 1977, Yarborough et al., 1978a). Eventually in the cave passages where the air is stagnant the concentration of Rn 222 ~~and Rn dau~~ghters will be high.

Exposure Evaluations

The radiation protection practice for uranium miners brought to the establishment of exposure limits. It is not worthwhile to recall here the problems deriving from the different percent ages of equilibrium of Rn daughters with respect to Rn 222.

To overcome these problems the Working Level (WL) is a useful concentration unit defined as "an combination of short-lived Rn daughters in a liter of air that will result in the ultimate emission of $1.3.10^5$ MeV of potential alpha energy" (I.C.R.P., 1976).

The exposure is then measured in Working Level Month (WLM). A WLM is an exposure to a Rn daughter concentration of 1 WL for one "month" (corresponding to 170 working hours or 2000 working hours per year) (I.C.R.P., 1976).

In Table 1 the values of Rn 222, Rn daughters and yearly cave personnel exposure measured in some caves (Ronaki, 1972, Trout, 1975, Wilkening and Watkins, 1976, Yarborough et al., 1976, Yarborough, 1978a, b, Miki and Ikeya, 1980, Seymore et al., 1980) are reported.

The values spread over very large ranges and, in some case, the yearly cave personnel exposure approaches the maximum limit of 4 WLM recommended by the International Commission on Radiation Protection (I.C.R.P., 1976).

It must be pointed out that people with the possibility to be exposed to more than 3/10 of such a limit (i.e. 1.2 WLM) should be considered under the rules for occupational exposure. As a consequence they must be monitored routinely (I.C.R.P., 1977).

If the personnel engaged in a commercial cave should often be considered in this category of people, the situation for cavers and visitors is completely different.

A simple evaluation made by Knutson, 1977 shows that also a very active caver will never accumulate during his lifetime an exposure of 120 WLM which is the value above which a statistically significant increase of lung cancers is detected among miners.

For visitors the problem in practice is negligible because it can be assumed that they spend a few hours per year, i.e. nearly 1/1000 of the time spent underground in caves by the personnel conducting tours. Therefore the exposure is reduced with the same ratio with respect to that delivered to the cave personnel. Furthermore, the exposure of a visitor is nearly 1/100 of that he may receive in his dwelling (Stranden, 1980).

Risk Assessment

The exposure to Rn increases the incidente of lung cancer. The average value of the observed mean annual rate of lung cancer incidence among different groups of minders corresponds to an excess of lung cancer of 5 x 10^{-6} per WLM and year (Stranden, 1980). But this risk coefficient found for miners appears to be overestimated by a factor of 4 (Stranden, 1980 to 8 (Cohen, 1980).

This assumption is supported by the results on the evaluation of the lung cancer for low-level exposures in houses. On account of better ventilation the concentration of aerosol in indoor air is smaller than in mine air. Therefore the fraction of unattached Rn daughters is higher in indoor air. For caves this phenomenon is probably still enhanced because of the very high purity in the cave air.

By taking into account this fact the over-estimation of the risk coefficient found for miners when applied to different situations seems to be justified. According to some authors there is a relationship between ciagarette smoking and lung cancer induction by exposure to Rn daughters, nevertheless the most recent finding do not seem to support this view point (Cohen, 1980).

Therefore, by assuming a more realistic coefficient ranging between 0.5 and 1 for cave personnel and general population, an excess of lung cancer of 0.5-1 case per million of persons with an annual exposure of 1 WLM seems to be reasonable.

The total annual rate of lung cancers obviously depends upon the age distribution of the group concerned and the latent period between the exposure to Rn and the cancer appearance. This estimation is rather uncertain because the exposure is not istantaneous but it is extended over a rather long time. Anyway, if the relation between RN exposure and lung cancer incidence is linear, a "doubling exposure rate" of between 2 and 3 WLM/yr may be assumed. That means one additional lung cancer on the entire lifetime every ten thousands people exposed.

Therefore, the corresponding figures for cave visitors are totally negligible. As it was reported before also the most active caver will never accumulate an exposure greater than a few WLM/yr during his career and therefore the cave personnel of a commercial cave may be considered as the critical group according to the criteria of radiation protection. As a consequence, it is suggested that a code of practice should be established for each commercial cave in order to limit the exposure of its personnel.

The procedure is rather simple and cheap because a monitoring of Rn 22 and Rn daughter levels along the cave is required for a limited period to ascertain the seasonal variation. Then the record of the time spent in the cave will permit the evaluation of the WLM accumulated by each people.

Such a procedure is already adopted for instance in Mammoth Cave (Carson, 1980) and confirms that no personnel be exposed to more than 120 WLM in a lifetime notwithstanding the rather high values of Rn daughter concentration measured in the cave (see Table 1).

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Annex I

During October 1980 a survey in the largest and most visited Italian show cave was made to measure the Rn 222 and Rn daughter concentrations.

The Grotta Grande del Vento (Ancona, Central Italy) extends over 12 km of mapped passages and nearly 1 km is now open to the public.

The classical two-filter method (Thomas, 1970) has been used for Rn 222 measurements, while the WL have been measured by the Markov method (Markov et al., 1962) (Figure 1).

Table 1
Radon, Radon Daughters and Yearly Personnel Exposure in Various Caves

Reference	Cave	Radon pCi/l	Radon Daughters WL	Yearly Cave Personnel Exposure WLM
Ronaki, 1972	Abaliget, Hungary	91 (average)		
Trout, 1975	Cottonwood and Jurnigan, N.M., USA	8-40		
Wilkening, 1976	Carlsbad,N.M., USA	13-55		1.42-6.06 (estimated)
Yarborough et al, 1976, Yarborough, 1978a	Carlsbad, N.M., USA		0.04-0.99	0.06-2.70
"	New, N.M., USA		0.27-0.35	
"	Timpanogos, Utah, USA		0.03-0.02	
"	Lehman, Nev., USA		0.10-0.37	0.01-1.36
"	Wind, S. Dak., USA		0.05-0.19	
"	Jewel, S. Dak., USA		0.13-0.28	
"	Crystal, Calif., USA		0.003-0.22	0.03-0.99
"	Marble, Calif., USA		0.01	
"	Oregon, Oreg., USA		0.02-0.35	
"	Valentine, Calif., USA		0.003-0.13	
"	Round Spring, Mo., USA		0.003-0.60	0.10-1.13
"	Great Onyx, Ky., USA		0.48-1.22	
"	Crystal, Ky., USA		0.70-1.49	
"	White, Ky., USA		0.45-0.64	
Yarborough, 1978a,b	Mammoth, Ky., USA		0.12-2.02	0.001-3.98
Miki, 1980	Akiyoshi, Japan	0.005-13		
Seymore et al, 1980	Howe, N.Y., USA	1.3 - 32	0.008-0.25	0.096-3.00
This paper	Grotta Grande del Vento, Italy	14-20	0.08-0.15	0.36-0.68

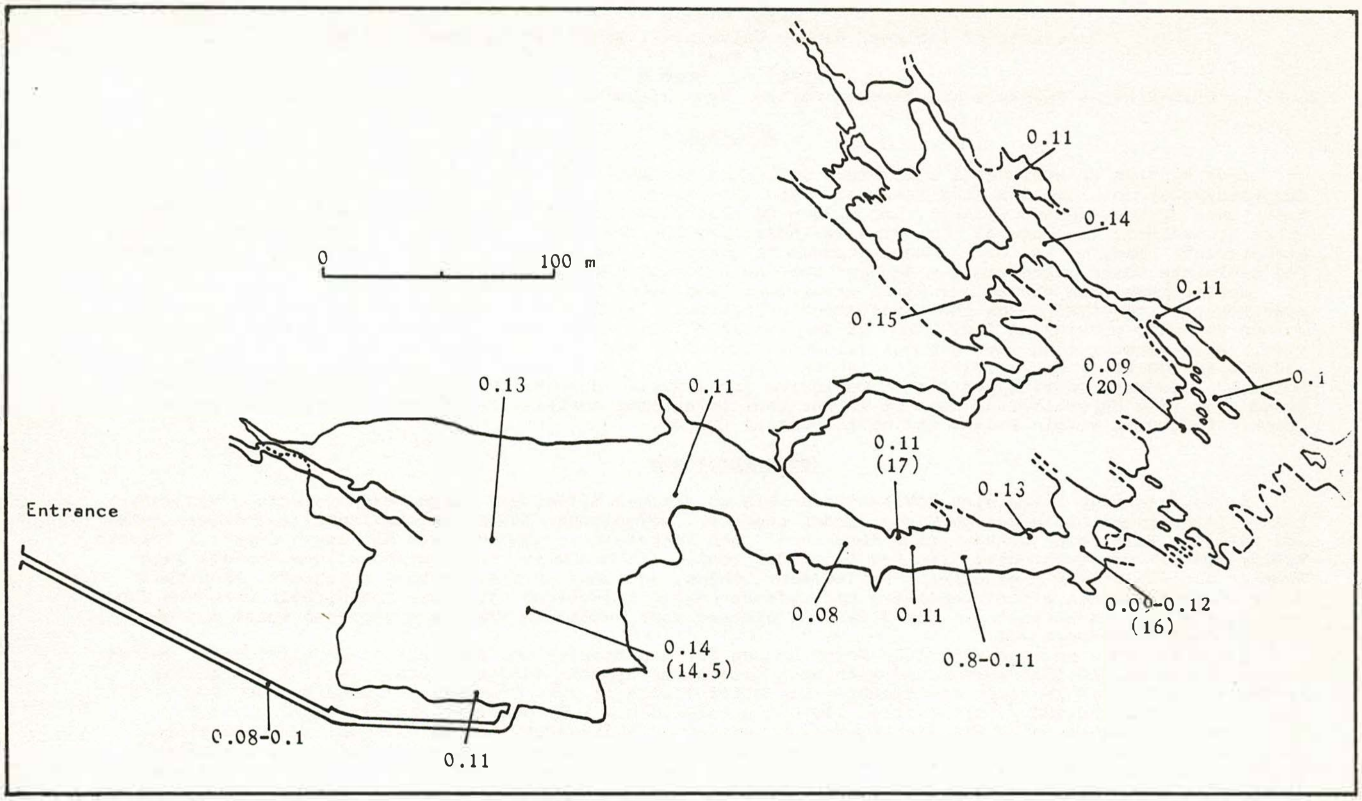

Figure 1 - WL values measured in the Grotta Grande del Vento (Ancona, Central Italy). (Rn 222 concentrations in pCi/l reported in parenthesis).

Radiometric Dating of Polish Cave Speleothems: Current Results

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Abstract

Cave systems up to several kilometers in length are known in areas of Poland underlain by Late Precambrian/Palaeozoic marbles (the Sudetes), Devonian limestons (the Holy Cross Mountains), Upper Jurassic limestones (Cracow-Weilun Upland), and Middle Triassic/Lower Cretoceous limestones and dolomites (the Tatra Mountains). The age of the caves is uncertain, but generally thought to be Late Tertiary to Early Pleistocene. Many of the caves, most exposed in quarries, are partially or totally filled by speleothems and sediments which often contain Neogene through Holocene vetebrate remains.

Speleothems from these four kàrst areas have been dated by the $^{230}Th/^{234}U$ method. These ages place some temporal constraints on the development of the karst landscape beneath which the speleothems have formed and also provide an indication of the timing of climatic events in Poland during Late Pleistocene time. Ages cluster into four groups: (i) about 300,000 y B.P., (ii) 220,000 to 180,000 y B.P., (iii) 130,000 to 100,000 y B.P., and (iv) at about 60,000 y B.P., indicating that speleothem deposition was episodic, occurring during periods of worldwide interglacial climate throughout the Late Pleistocene. Based upon this chronological date it is possibel to attempt correlation of the local glacial stratigraphic sequences within Poland and north-central Eurpoe.

Zusammenfassung

In Gebieten von Polen sind Höhlensysteme bis zu einigen Kilometern Länge bekannt, welche von Jung-Präkambrischen/pälaozoischen Marmoven (inden sudeten), devonischem Kalkstein (Heiligenkreuzberge), unter Jur asischer Kalkstein (Krakow-Weilun-Oberland), und Kalkstein und Dolomit vom Mittleven Jura zur Unteren Kreide (Tatra) unterschichtet Sind Das Alter der Höhlen ist ungewiss, aber eswird allgemeine als Jung-Tertiär bis Pleistozän angenommen. Veiledieser Höhlen, meistens in Steinbrüchen exponiert, sind teilweise oder vollkommen mit Sintermassen und sedimentengefüllt, welche oft Reste von Wirbeltieren vom Jung-Tertiar zym Holozän enthalten. Das Alter von Sintermassen ausdiesen vier Karstgebieten wurde mit der $^{230}Th/^{234}U$-methode bestimet.

Diese Alter geben eine zeitliche Beschränkung Für die Entwicklung der Karstlandschaft, unter welcher die Sintermassen gebildet wurden und enthalten auch einen Hinweis aufden zeitchen Verlauf des Klimas in Polen während des jüngeren Pleistozän. Die Alter fallen in vier Gruppen: (I) ungefähr 300,000 y. B.P., (II) 220,000 bis 180,000 y. B.P., (III) 130,000 bis 100,000 y B.P. und (IV) ungefähr 60,000 y.B.P., dies deutet devaufhin, dass die sintermassenablagerung episodischwar, und in Perioden von weltgeitem, zwischeneiszeitlichem Klima währeud des jüngeren Pleistozän stattfaud. Gestützt auf diese chronologischen Daten istsmöglich die Lokalen, eiszeitlichen, stratigraphischen Folgen Plens mit den rom nördlichen zentral Eurpoa versuchsweise zu korrelieven.

Introduction

Karst areas with specific features are widespread throughout Pland's territory, but most are covered with Genozoic loose deposits. The surface karst areas in Poland occupy the area of only about 8000 square kilometers (i.e. 2.5% of the country surface) in the southern part of the country. Cave systems up to several kilometers in lenght have been explored in areas under lain by Paleczcic or Late Precambrian (?) marbles (the Sudetes), Devonian limestones (Holy Cross Mountains), Upper Jurassic limestones (Cracow-Wielun Upland) and Middle Triassic through Lower Cretaceous limestones and dolomites (Tatra Mountains). The age of these caves has hitherto been uncertain, but they have generally been presumed to have formed during the Late Tertiary and Pleistocene. Some of them (mostly encountered in quarries) are partly or totally filled by cave formations) speleothems and detrital deposits). These sometimes contain Neogene through Holocene vertebrate remains)Glazek et al., 1972).

The deposition of speleothems within caves from regions having pronounced Pleistocene climate changes have been shown to be a climate-related process (Atkinson et. al., 1978, Harmon et. al., 1977, Thomson et al., 1974). In such areas, speleothem depostion is substantially reduced during glacial periods of low biotic activity, permanent ice cover, and/or periglacial frouzen ground.

Close relation between glacial deposits and caves in Poland provide an indication of the time-scale of climatic events during the Pleistocene in Poland and enables some further correlations.

This research was made possible by a joint exchange programme between the Universities of Warsaw and Glasgow.

Methods and Results

Previous studies (Atkinson et al., 1978, Harmon, in press, Harmon et al., 1975, 1977, Thompson et al., 1974, 1975) have shown that calcium carbonate speleothems can be confidently dated by U-series methods if they contain trace amounts of U, but are free of detrital Th or Pa. In such instances, absolute dating is possible within time range 5-400 ka b.p. provided the carbonate is dense and impermeable, and primary calcite shows no signs of diagenetic alteration or peostdepositional leaching. Analytical procedures used were similar to those described by Harmon et al. (1975) and Atkinson et al. (1978). With exception of a stalagmite from Bandzioch Cave in the Tatra Mountains (3 analyses of subsequent layers), was found to have contamined with detrital Th. This was undertaken by mean of a "pseudo-isochron" technique as described by Harmon (1980).

We have obtained 9 $^{230}Th^{234}U$ dates from 14 analyzed samples of stalactites, stalagmites and flowstones from caves and quarries (Table 1) from the four main cave regions of Poland (Fig.1).

Discussion

Our reconnaisance study has indicated that the uranium content of speleothems in cave regions of Poland is sufficient for dating purposes.

Among the speleothems, flowstones are the least favorable for uranium series dating due to frequent contamination with detrital material (three omitted samples with excess of detrital ^{232}Th).

The age data we have obtained from our study of Polish speleothems is typical of climatic control. All of the nine ages fall within periods of time considered to be interglacial or hot interstadial. This is illustrated in Fig. 2. Where the speleothem records for European (including Poland) and alpine areas of western North America are compared with the marine foraminiferal oxygen isotope record (Shackleton and Opdyke, 1973) and the coral-reef sea level record (Harmon et al., 1978, Neuman and Moore, 1975, Mesolella et al., 1969, Bender et al., 1973, Ku et al., 1974, Bloom et al., 1974) for the past 4000,000 years. Five ages fall within isotope stage 5, two within stage 7, one within stage 9 and one within stage 9, as well as one within stage 3.

Based upon this correlation with the continuous marine paleoclimate record, it is tempting to carry the procedure a step further and attempt to correlate the speleothem record with the discontinuous glacial stratigraphic sequence of Poland (Rozycki, 1978). Such a correlation would place the five ages of the last interglacial (stage 5) as correlative with the "Eemian" interglacial and the two ages of the penultimate interglacial (stage 7) as correlative with the Lublin intergalcial which has been independently dated at 245±45 ka by thermoluminescence techniques (Lindner and Proszynski, 1979). This would require the Warta glaciation to correlate with stage 6 (130-190 ka), the Odra glaciation to correlate with stage 8 (290-250 ka) but the San glaciation must not be younger than stage 10, and is likely to be older, perhaps of stage 12 age.

On the basis of the distribution of age determination we correlate the 60 ka depositional events in Tatra Mountains with Chelford interstadial in Britain (Atkinson et al., 1978) and "Chapin Soil" onterstadial within Wisconsinian in North America (Harmon et al., 1977). The 100-130 ka period represents the Last ("Eemian") Interglacial in north Central Europe and may be correlated with Ipswichian interglacial in Britain (Atkinson et al., 1978) and Sangamonian interglacial in North America (Harmon et al., 1977). We correlate the 160-220 ka period with the Penultimate interglacial in north Central Europe ("Rugen-Warmzeit"- Harmon et al., 1980, Lublin interglacial - Lindner and Proszynski, 1979), Odintsovo interglacial in the western USSR (Zubakov, 1978), penultimate interglacial in the North American and European speleothem records (Hoxnian - Waltham and Harmon, 1977, Grotte Valerie interglacial II - Ford, 1976). The earliest data about 300 ka may be correlated with the antepenultimate interglacial period in the North American and British speleothem records (Grotte Valerie interglacial I - Ford, 1976, "?Cromerian" - Waltham and Harmon, 1977). It must be stressed, that such an indirect correlation is most tentative and is to be regarded with some degree of caution. But this caution is rather low with relation to commonly applied interregional correlations of schemes obtained by a "count from top method"(cf. Kukla, 1978).

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Table 1   U concentrations, istotope activity ratios, and calculated ages for the Polish speleothems analyzes

Lab. no. of sample	Locality /cf. letters In Fig. 1/	U conc. /ppm/	$\frac{230}{234}Th$	$\frac{234}{238}U$	$\frac{230}{232}Th$	Age /years B.P./	Comments
	Holy Cross Mountains						
360	Kozi Grzbiet Quarry - f	4.1	.83±.03	.97±.03	60	$195,000^{+24,000}_{-19,000}$	flowstone
	Cracow-Wielun Upland						
349	Pietrowa Szczelina Cave - g	.37	.95±.03	1.04±.03	100	$300,000^{+80,000}_{-40,000}$	flowstone
353	Mala Cave - b	.70	.65±.03	.92±.02	28	112,000±8,000	flowstone
355	Mckra Quarry - c	.41	.68±.03	1.46±.02	86	117,000±.9,000	flowstone
362	Wierzchowska Gorna Cave - d	1.2	.68±.03	1.22±.02	25	120,000±9,000	stalagmite
363	Wierzchowska Gorna Cave - d	.70	.72±.03	1.50±.02	23	124,000±9,000	stalagmite
	Sudetes						
356	Niedzwiedzia Cave - e	.19	.86±.03	1.45±.02	100	$180,000^{+21,000}_{-17,000}$	stalactite
	Tatra Mountains						
414	Mietusia Cave - a	9.1	.41±.03	1.04±.01	200	60,000±5,000	flowstone
359	Bandzioch Cave	.74	2.15±.03	1.52±.03	.98±.03	124,000 +66,000 -14,000	stalagmite layer: upper
354	Bandzioch Cave	.45	2.86±.03	1.53±.02	.97±.02		middle
358	Bandzioch Cave	.80	7.17±.05	1.51±.02	.75±.04		bottom

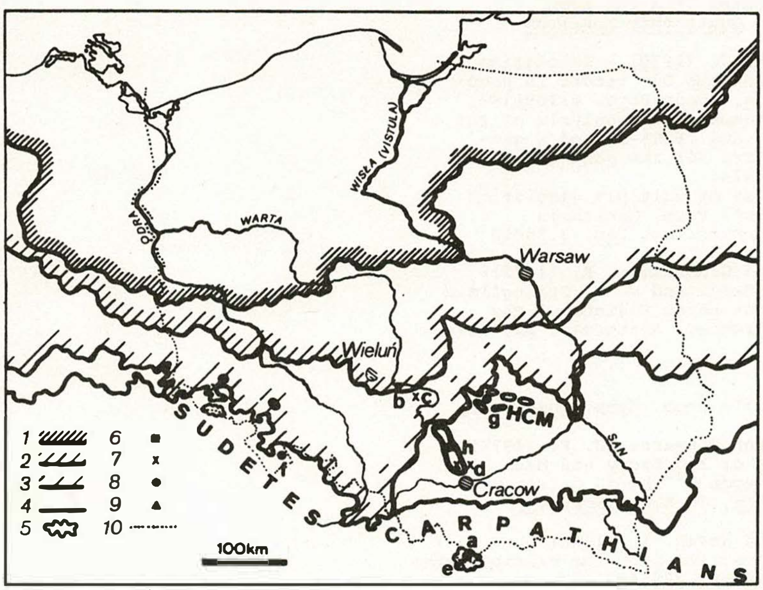

Figure 1: Limits of the Pleistocene glaciations of Poland's territory (according to Rozycki,1978) in relation to the investigated speleothem localities.
1-4 - Continental glaciations: 1 - Last (Vistulian, Weichsel), 2 - Penultimate (Warta, Warthe), 3 - Antepenultimate (Odra, Saale), 4 - "Maximal" (San Elsterian): 5 - Alpine glaciations (not separated): 6-9 - Dated speleothems of: 6 - Interstadial within Last Glaciation (around 60 ka), 7 - Last interglacial (about 100 - 130 ka), 8 - Penultimate interglacial (about 180-220 ka), 9 - Antepenultimate interglacial (about 300 ka): a-g - speleothem localities: a - Mietusia cave, b - Mala cave, c - Mokra quarry, d - Wierzchowska Gorna cave, e - Niedzwiedzia cave, f - Kozi Grzbiet quarry, g - Pietrowa Szczelina cave.

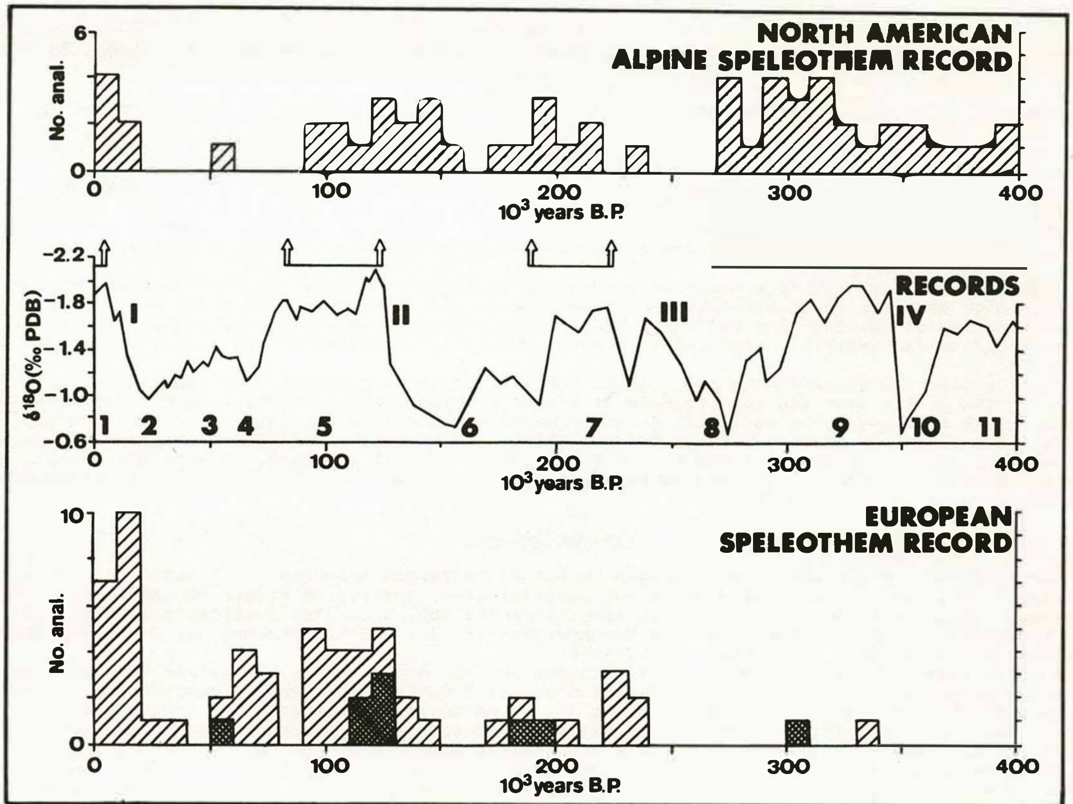

Figure 2: Speleothem chronologies for Europe and North America over the past 400,000 yr (Harmon in press). The data for the Polish speleothems reported in this paper are indicated within European record by chequered blocks. Shown for comparison are two marine records: 1 - the deep-sea foraminiferal oxygen isotope record of core V28-238 (Shackleton and Opdyke, 1973) showing the "stages" of Emiliani (1966), and the "terminations" of Broecker and Van Donk (1970) and 2 - the time of coral reef formation in Bermuda, the Bahamas, Barbados, Hawaii, and New Guinea. Times of maximum ^{18}O depletion (e.g. stages 1,5,7,9 and 11) and high sea level stand as indicated by the arrows bracketing major periods of coral reef development are considered to be interglacial periods. The terminations (I, II, III,IV) mark the glacial)interglacial boundaries. The observed distribution of speleothem ages implies that the process of speleothem deposition is most intense during periods of interglacial climate.

The Mineralogy of Castleguard Cave, Canada

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Abstract

A survey of more than 50 speleothems from between the Pools and Ice Passage in Castleguard Cave has revealed the presence of complex, mixed suites of both carbonate and sulfate minerals. Carbonate minerals identified (and number of occurrences) are: calcite (43), huntite (15), hydromagnesite (6), aragonite (4), and monohydrocalcite (3); sulfate minerals (and number of occurrences) are: gypsum (9), thenardite/mirabilite (2), and epsomite (1).

Massive dripstones and flowstones were observed to consist of only calcite, whereas smaller dripstones, chalky surface coatings on dripstones, thin flowstone crusts, erractics, and pasty wall deposits were commonly a combination of calcite plus huntite. Hydromagnesite and monodydrocalcite occur only as dry, crusty wall concretions (moonmilk). Aragonite is present mainly in crystalline wall concretions and as small anthodites.

The distribution of carbonate and sulfate minerals in Castelguard Cave is related to two factors, the thermal regime of the cave and the presence of discrete seepage inputs. Small calcite speleothems occur to some extent throughout the cave, but areas of massive dripstones and abundant decoration are restricted to sites of past and/or present seepage concentration. By contrast, sulfate mineralisation and the hydrated and magnesian carbonates are confined to the warm central core of the cave. Stable isotope and chemical data indicate that evaporation is the primary process responsible for the diversity of carbonate and sulfate mineralisation in Castleguard Cave.

Zusammenfassung

Eine Untersuchung von mehr als 50 Proben vonden Sintermassen zwischen den Teichen und der Eispassage der Castleguard Höhle zeigt das Vorhandensein von Komplizierten, gemischten Folgen von Karbonat - und - sulfatmineralen. Folgende Karbonatminerale (die eingeklammerte Zahl gibt ihre Häutigkeit): Kalzit (43), Huntit (15), Hydromagnesit (6), Aragonit (4) und Monohydrokalzit (3); und Sulfatminerale: Gips (9); Thenardit/ Mirabilit)2' und Epsomit (1) wurden identifiziert.

Es wurde festgestellt, dass massive Tropfsteine und Sintermassen nur aus Kalzit bestehen, während kleinere Tropfsteine, Kreidige Oberflächenschichten auf Tropfsteinen, dönne Sinterkrusten, Findlinge und pastenartige Abscheidungen an den Wänden meist aus einem Gemisch von Kalzit und Huntit bestehen. Hydromagnesit und Monohydrokalzit Kommen nur als trockene, Krustenartige Absonderungen an den Wänden vor (Mondmilch) Aragonit tritt hauptsächlich als Kristalline Wandabsonderung und in kleinen Anthoditen auf.

Die Verteilung der Karbonat-und Sulfatminerale inder Castleguard Höhle werden durch zwei Faktoven bedingt, dem Wärmehaushalt der Höhle und dem Vorhandensein von diskreten Sickerwasserausflüssen. Kleine Kazitsinterabscheidungen sind inder ganzen H-hle relativ häufig, aher ausgedehnte Tropfstein bildungen und verwandte Ablagerungen sind auf stellen Früherer/odergegenwartiger Sickerwasserausflüsse beschränkt. Im Gegensatz dazu dreten die Sulfatmineralbildung, sowie die hydratisierten und Magnesium-karbonate nur idem warmen, zentralen, innersten Abschnitt der Höhle auf. Stabile Isotopen - so wie chemische Daten weisen darauf hin, dass Verdampfung der primäre Prozessist, welcher Für die Vielfalt der Karbonat - und Sulfatmineralisation in der Castleguard Höhle verantwortlich ist.

Introduction

Castleguard Cave (Figure 1) is located at the southeastern margin of the Columbia Icefield in the Rocky Mountains of Canada. Despite its location in an alpine environment and the fact that it is formed beneath a glacier, the cave is in parts extremely well mineralized. Although Ford (1975) observed that carbonate speleothems were present and actively formed in several areas of the cave, also noting the presence of gypsum in 'First Fissure', this study is the first detailed description of the cave mineralogy. The climate within Castleguard Cave is characterised by low temperatures combined with a stron draft. Air flows out of the cave in summer and into it in the winter. Measurements made during the month of April in 1973 and 1979 indicate an airflow of about 150 m^3/min (Ford, 1975; this study).

Fig 2 shows temperature measurements for various sites within the cave made in April 1973, 1979 and 1980. In each case air temperature increased from a value below 0°C at the 'Entrance' to between 2.0 - 2.5°C ~1500 m into the cave at the '80'-Pot', and reaching just over 3.5°C ~4000m into the cave at the 'Grottoes.' The highest temperature measured in the cave is 4.2°C in the 'Next Scene', an abandoned, high-level passage with no appreciable air flow. Past the 'Holes-in-Floor' temperature declines slowly from about 3.3°C at the beginning of 'Second Fissure' to 1.8°C at 'The Crutch', finally reaching a low just above 0°C at the 'Ice Blockage.' It is interesting to note that small stalactites are furnished with seepage water and actively being deposited only 150 m from the 'Ice Blockage' where the air temperature is 0.8°C.

Also shown in Fig. 2 are relative humidity measurements made in April 1979. At this time air entering the cave had a relative himidity of 83% which increased to 94% at the 'Pools.' Past this point values approached 100% through the end of the 'Subawy' - 1500 m into the cave, then fluctuated between 96-100% up to 'Camp I.' Increases in relative humidity occurred in areas of localised groundwater input such as the 'Waterfall Room', decreasing in the intervening areas such as the proximal and distal ends of 'First Fissure' where the supply of seepage water is presumably insufficient to match the drying power provided by the warming air. In such areas the cave walls are extremely dry and effluorescent minerals are common.

Mineralogy

The aspects of mineralisation in Castleguard Cave which initially attracted attention were the massive carbonate flowstone deposits, the erratic dripstones, and the sulfate speleothems. Under authorization by Banff National Park, some 65 samples were collected over the period 1973-1980 for mineralogical study and $^{230}Th/^{234}U$ dating from areas of the cave between the 'Pools' and 'Ice Blockage.'

X-ray diffraction analysis indicated the presence of five (or possibly six) carbonate and three sulfate minerals. The carbonate suite includes calcite and aragonite ($CaCO_3$), monohydrocalcite ($CaCO_3 . H_2O$), huntite ($Mg_3Ca(CO_3)_4$), hydromagnesite ($Mg(CO_3)_4(OH)_2 . 4H_2O$, and possibly landsfordite ($MgCO_3 . 5H_2O$). The sulfate suite includes gypsum ($CaSO_4 . 2H_2O$), epsomite ($MgSO_4 . 7H_2O$), and thenardite ($NaSO_4$) which almost certainly occurs in the cave as mirabilite ($NaSO_4 . 10H_2O$). Table 1 denotes the forms and occurrences of these various carbonate and sulfate minerals.

Discussion

As is the case in most caves, calcite is the most abundant constituent of the carbonate speleothems in Castleguard Cave. A total of 48 of the 55 carbonate samples from the cave contain calcite with 32 of these being comprised entirely of calcite (Table 1). The only carbonate phase which did not occur associated with calcite was hydromagnesite. Calcite occurs in all common carbonate speleothem forms except as anthodites. Large flowstone and dripstones are comprised only of calcite. Smaller speleothems such as straw stalactites, erratics, pool deposits, wall concretions, and nodules tend to commonly be mixtures of calcite plus one or more of the other 'exotic' carbonate minerals.

The general problem of calcite deposition in Castleguard Cave has been investigated and will be published elsewhere. A study of climate, airflow, and water chemistry in the cave indicates that: (i) PCO_2 values for cave waters are close to those measured for the cave air, having a normal distribution about the atmospheric value at 2000 m of $10^{-3.64}$atm., thus ruling out degassing of CO_2 as an important mechanism of speleothem deposition, (ii) most waters in the cave are supersaturated with respect to calcite, but understurated with all other minerals found in the cave except aragonite, and (iii) the measured evaporation rate from the walls of the cave of 0.005-0.14 mm/day can account for only about 1-10% of the total volume of presumed Holocene-age carbonate speleothems in the cave.

It was also observed that the cave waters contain a proportionally large Mg^{2+} content which was derived from the dissolution of dolomite, as well as SO_4^{2-} probably derived from the oxidation of pyrite in the bedrock overlying the cave. Most waters just entering the cave are supersaturated with calcite, but undersaturated with gypsum, and in some cases dolomite also. It is postulated that calcite deposition occurs at constant PCO_2 as the result of additional dissolution of dolomite or sulfate uptake just prior to entering the cave as discussed by Wigley (1973). Givenn this mechanism for calcite deposition in Castleguard Cave, the formation of the other carbonate phases must be viewed in terms of processes other than degassing of CO_2.

Aragonite occurs as holocrystalline wall concretions (see Plate 8.5a of White, 1976) in the 'Grottoes' and as small anthodites in the farthest parts of 'First Fissure'. Because aragonite is 11% more soluble than calcite, it can only form from a $CaCO_3$ - supersaturated solution when the precipitation of calcite is inhibited. 'Poisoning' of crystal growth surfaces by ions such as Mg^{2+}, Sr^{2+} and SO_4^{2-} is one such prohibitive mechanism. Murray (1954) noted that the presence of Mg^{2+} favoured the depoeition of aragonite over calcite is precipitated from $CaCO_3$- saturated solutions with a Ca/Mg ration above 0.70, whereas between 0.70 - 0.24 both calcite and aragonite are coprecipitated, and below 0.24 aragonite is the only precipitate. Waters in Castleguard Cave have Ca/Mg ratios of 2.65 - 0.34 (Fig.3) with 9 of 29 (31%) waters saturated with respect to aragonite, suggesting that aragonite should be present, but not abundant, in the cave. That only 4 of the 55 carbonate samples examined contained aragonite (Table 1) confirms this view.

Huntite is the only other anhydrous carbonate phase present is Castleguard Cave. With ine exception it occurs as a minor constituent in numerous small calcite dripstones and flowstone crusts throughout the cave and in 'moonmilk'-type deposits in the central portion of the cave (Table 1.) This suggests that huntite in Castleguard Cave is primary, precipitating directly from Mg-enriched carbonate solutions.

Although most (72%) cave waters are saturated with respect to dolomite and some (28%) with magnesite, neither of these minerals were found in our mineralogical survey. Dolomite has been documented in Carlsbad Caverns, New Mexico where it is presumed to be an alteration product derived from the reaction of aragonite with high-Mg waters (Thrailkill, 1971) and in Jewel Caves, South Dakota where it occurs as primary crystalline overgrowths on calcite (Deal, 1962). Likewise, magnesite is known from Titus Canyon Cave, California (Moore, 1970). The likely reason for the lack of these minerals in Castleguard Cave is that at low temperatures dolomite precipitation may be kinetically inhibited, so that the hydrated basic carbonates are the Mg- carbonate phases formed as the result of extensive evaporation under such conditions (Fig. 3).

Hydromagnesite was present in 4 of the 55 carbonate samples, occurring only in 'moonmilk'-type deposits in the form of dry 'cauliflower'-like crusts or wet, pasty masses on bedrock walls in the 'Grottoes' and 'Holes-In-Floor'. From Fig. 3 it is seen that flow and seepage waters in the cave have Ca/Mg ratios which are too high to permit precipitation of hydromagnesite. Williams (1959) has noted that the occurrence of such 'moonmilk' may be biologically mediated, but such mechanism is not required to explain the occurrence of hydromagnesite in Castleguard Cave. Fig. 4 shows that hydromagnesite is a stable phase under the prevailing T-PCO_2 conditions of the cave once formed. Precipitation of thermodynamically stable huntite and metastable hydromagnesite may be accomplished as the result of extensive evaporation of typical Mg-enriched drip waters at constant PCO_2, but further documentation is required. The progressive decrease is Ca/Mg ratio of the residual fluid in such a case should produce the sequence of mineralisation; calcite aragonite huntite hydromagnesite which is that observed in Castleguard Cave.

Landsfordite, the pentahydrate, may also be present in 'moonmilk' deposits (Table 1). Such an occurrence would be compatible with temperature-PCO_2 conditions in the cave spanning the hydromagnesite-landsfordite boundary (Fig. 4).

Monohydrocalcite is the other hydrated carbonate mineral identified. It occurs with calcite and aragonite in crystalline wall concretions in the 'Grottoes' and with calcite in nodular speleothems in the 'Pools' area (Table 1). To our knowledge the only other reported cave occurrence of this mineral was from the Eibengrotte in western Germany (Fischbeck and Muller, 1971). These authors attribute its presence to aerosol transport of solutions and evaporation, a mechanism which would also appear to be applicable in Castleguard Cave given the stron airflow here.

The three sulfate minerals present occur in a variety of forms in the distal and terminal sections of 'First Fissure', in the 'Grottoes', and in 'Second Fissure' (Table 1). Gypsum is present as loose crystal aggregates between shard of mineral-activated breakdown at the cave wall interface, as aggregates of 2-3 on long tabular platelets, small crystall tufts, and rosettes on the surface of an within clay sediments, and as thin circular crystals and oulopholites extending from bare bedrock walls. Thenardite, which probably occurs in the cave as mirabilite, and epsomite are rare, occurring only in isolated patches of small acicular crystals on the surface of desiccated sediments which also contain abundant gypsym.

These eavporite minerals appear to be forming in Castleguard Cave in a manner similar to that described by White (1968) for sulfate mineralisation in the Central Kentucky Karst. Solutional uptake of Ca^{2+}, Mg^{2+}, Na^+ and SO_4^{2-} by groundwater occurs prior to entering the cave followed by depostion of sulfate minerals via evaporation as all waters are substantially undersaturated with all sulfate minerals. The occurrence of sulfate minerals in Castleguard Cave must be indicative of a long, sustained period of evaportaion., the sediments perhaps acting as wick for the water which must enter as seepage through the cave walls.

Variations in the oxygen and hydrogen isotopic composition of vadose waters deposition of the volumetrically minor suite of 'exotic' carbonate and sulfate speleothems. Spring waters from the area around Castleguard Cave which are representative of the average groundwater have mean δD and $\delta^{18}O$ values of -160°/oo and -21.5°/oo respectively. Most discrete flows and seepage waters in the cave fall close to this composition. However, drip waters from soda-straw stalactites and their catchment pools are slightly enriched in D and ^{18}O (δD = -154°/oo, $\delta^{18}O$ = -19.6°/oo, indicating that these waters have been to some extent affected by evaporation. In addition calcite deposited in equilibrium with water at $\delta^{18}O$ = -21.5°/oo at 3°C should have a $\delta^{18}O$ value of 11.1°/oo. However, the tips of four soda-straws from the 'Holes-In-Floor' have $\delta^{18}O$ values ranging from 12.5 to 14.6°/oo ($\bar{X}$ = 13°/oo), a feature which is also indicative of evaporation.

Summary

The distribution of carbonate and sulfate minerals in Castleguard Cave is related to two primary factors, the thermal regime of the cave and the presence of discrete seepage inputs. Small carbonate dripstones occur, to some extent, throughout the cave past the entrance zone which is subject to seasonal flooding. However, areas of massive speleothem development and abundant dripstone decoration such as the 'Helictite Passage', 'Next Scene', 'Grottoes', and 'Holes-In-Floor' are restricted to sites where groundwater seepage has been localised and concentrated. By contrast, sulfate mineralisation and the presence of 'exotic' carbonates is restricted to the warm, central core of the cave (Fig.2). In this area of the cave, it is common for gypsum to occur within centimetres of active dripstones and within tens of centimetres of floor streamlets. However, the areas of the warm central core of the cave without sulfate mineralisation are those where either discrete inputs of vadose flow or large amounts of seepage water enter the cave (e.g. the 'Waterfall Room' and 'Holes-In-Floor'.) In the winter cold air blows into the cave, warms up about -20° to -3°C, and causes signigicant evaporation in the middle section of the cave which results in the deposition of the suite of 'exotic' carbonate and sulfate minerals. In summer, cold air in the back of the cave at 0°C blows out of the cave but only warms up -3°. Thus evaporation is less at this time so that 'First Fissure' and the 'Grottoes' have more extensive evaporation-induced mineralisation than 'Second Fissure.'

Acknowledgements

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Table 1. Occurrences of carbonate and sulfate minerals in Castleguard Cave speleothems

CARBONATES	C	A	HM	C + H	C + MHC	C + A + MHC	HM + H + L (?)
massive dripstones	12	-	-	-	-	-	-
small dripstones	12	-	-	4	-	-	-
subaqueous pool deposits	2	-	-	-	-	-	-
cave pearls	1	-	-	-	-	-	-
thin flowstone crusts	-	-	-	2	-	-	-
crystalline erratics	1	-	-	1	-	-	-
chalky surface coatings	3	-	-	4	-	-	-
crystalline wall concretions	1	1	-	-	-	2	-
anthodites	-	1	-	-	-	-	-
dry wall crusts	-	-	1	1	-	-	2
pasty wall deposits	-	-	-	1	-	-	1

SULFATES	G	T (M)	G+ T (M)	G + E
bedrock wall crusts	1	-	-	-
oulopholites	1	-	-	-
upon-sediment miner-alisation	1	1	1	1
within-sediment mineralisation	4	-	-	-

OCCURRENCE	C	A	H	HM	MHC	L(?)	G	T(M)	E
total occurrences in 55 carbonate samples	48	4	14	4	3	3			
total occurrences in 10 sulfate samples							9	2	1

C = calcite; A = aragnoite; HM = hydromagnesite; H = huntite; MHC = monohydrocalcite; L = landsfordite; G = gypsum; T = thenardite; M = mirabilite; E = epsomite.

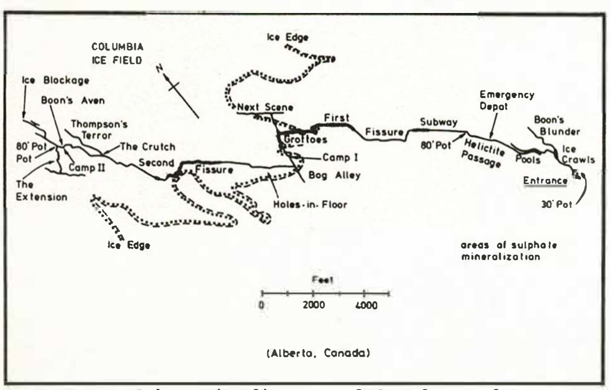

Figure 1, Schematic diagram of Castleguard Cave, Canada with key locations noted. Areas of sulfate mineralisation are indicated. Carbonate mineralisation occurs to some extent throughout the cave, but the 'exotic' suite is confined to the warm, central core of the cave between 'First Fissure' and 'Holes-In-Floor.' Also shown for reference is the surface boundary of the Columbia Icefield.

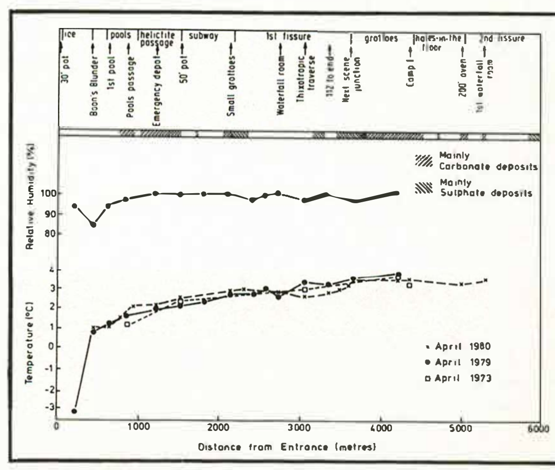

Figure 2. Temperature and relative humidity profiles for Castleguard Cave for April 1973 (Ford, 1975), 1979 and 1980 (this study). Areas of extensive mineralisation are noted.

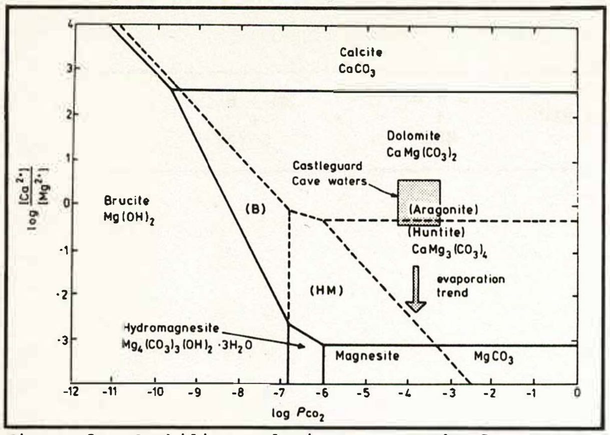

Figure 3. Stability relations among the Ca- and Mg-carbonate minerals as a function of Ca/Mg ratio and PCO_2 (after Carpenter, 1963) solid lines indicate equilibrium relations between stable phases; dashed lines show equilibrium relations for metastable phases named in brackets. Also shown is the field of Castleguard Cave waters and the trend followed by waters during evaporation and simultaneous precipitation of $CaCo_3$.

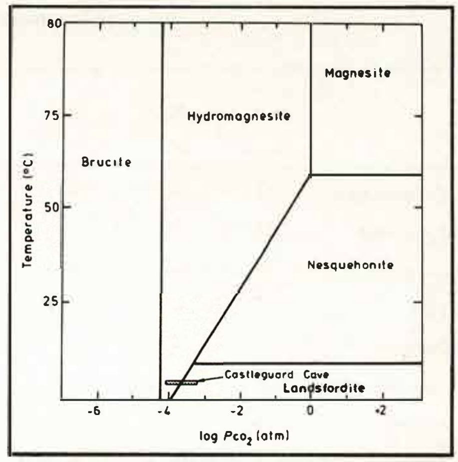

Figure 4. Stability relations among the Mg-carbonate minerals as a function of temperature and PCO_2 (after Langmuir, 1965). Also shown are the prevailing environmental conditions in the central section of Castleguard Cave between the 'Grottoes' and 'Holes-In-Floor'.

Geochronology of Speleothems from the Flint Ridge Mammoth Cave System, Kentucky, U.S.A.

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Abstract

$^{230}Th^{234}U$ ages have been measured for speleothems from various levels of the Flint Ridge-Mammoth Cave System. Major trunk passages fall into seven primary levels which can be correlated with surface terrace remnants and horizontally extended erosional land forms. These levels have been controlled by the erosional and depositonal history of the Ohio River drainage system during late Tertiary and Pleistocene time. Major cave levels formed when the Green Riber stood at a base level for prolonged periods of time, rather than being dtermined by stratigraphic or structural features. In general, the deposition of carbonate speleothems, occurred in erosional segments of the cave near or beyond the edge of the clastic cap rock which otherwise protects the underlying limestone sequence within which the cave system is developed from vertical circulation of vadose waters.

The age data for massive stalagmite and flowstone deposits in passages at elevations greater than 168m (550') indicate that Grand Avenue, Edwards Avenue, Davis Hall, and Collins Avenue and the sediments contained in them are in excess 350,000 y B.P. Smaller stalagmites and flowstone deposits from various portions cave yield finite ages in the range 125m000 to 250,000 y B.P. A flowstone carapice on a sediment bank in Mud Avenue, the lowest accessible portion of the cave at 143m(470'), dated at 140,000 y B.P. suggests that the lower levels of the cave system are young, most likely developed during the last two glacial episodes.

Zusammenfassung

$^{230}Th/^{234}U$-Alter wurden an Sintermassen von verschiedenen Niveaus des Flint Ridge-Mammoth Höhlensystem gemessen. Die grossen Hauptpassagen zerfallen in sieben primäre Niveaus, welche zu Oberflachenterrassen resten und horizontalen, errodierten Landformen in Beziehung gebracht werden können. Diese Niveaus wurden durch die Erosions - und Ablagevungsgeschichte des Ohio-River-Flussystems während des Jungtertiärs und Pleistozäns reguliert. Haupthöhlenniveaus entstanden höchst wahrscheinlich dadurch, das der Green River für lang Zeitspannen auf einem Grundniveau stand und wurden nicht durch stratigraphische und structurelle Gepräge bestimmt. Im allgemeinen entstanden die Ablagerungen von Karbonatsintermassen in den erodierten Abschnitten der Höhle nahe oder oberhalb der Grenze mit der lastischen Gesteinsdecke, diese schützt andererseits die darunter liegende Kalksteinsequenz, in welcher sich das Höhlensystem durch vertikale Zirkulation von Senkwasser (vadose water) entwickelt hat.

Die Daten Für das Alter massiver Stalgmiten und Sintermassen von Passagen mit einerhöhe grösser als 169m (550') deuten an, dass die Grand Avenue, Edwards Avenue, Davis Hall and Collins Avenue und die darin ent hallenen Sedimente älter als 350 000 y B.P. sind. Kleinere Stalagmiten und sinter massen von verschiedenen Abschnitten der Höhle ergeben Altersgrenzen im Bereich von 125,000 bis 250,000 y B.P. Ein sintermassenschild von einer Sedimentbank inder Mud Avenue dem tiefsten, zugänglichen Teil der Höhle bie 143 m (470'), datiert zu 140,000 y B.P. dies weist davauf hin, dass die tiefsten Niveaus des Höhlensystems jung sind und sich höchst wanrscheinlich während der beiden letzten glazialen Episoden entwickelt haben.

The Study Area

The Mammoth-Flint Ridge Cave System is located in Mammoth Cave National Park near Bowling Green, Kentucky (Figure 1) in the area known as the 'Central Kentucky Karst' (White et al., 1969). The physiology, geology, geomorphology and hydrology of this region have been decsribed by many workers (for Example see White et al., 1969: Quinlan 1970 and references therin; Miotke and Palmer, 1972; Hess and White 1974 and Quinlan and Rowe, 1977). Extensive cave systems have developed in the nearly flat-lying, 160m thick Mississippian age St. Genevieve and Girkin Limestone which are capped by erosion-resistant clastic sediments of Upper Mississippian to Pennsylvanian age. The cave systems represent an integrated subsurface drainage network which extends from catchment areas to the south on the Sinkhole Plain to discharge points along the Green River.

The Green River, a tributary of the Ohio River, is the master stream for the area and has dissected the Chester Cuesta to depths of 120-150 m. This river has represented the base-level to which the underground drainage and surface topography has tended to adjust throughout the complex erosional and despoitional history of the region.

The Cave System

Motke and Palmer (1972) have described the Mammoth-Flint Cave system and discussed its development in the context of the Pleistocene ice ages. Cave passages in the system fall into seven primary levels between -200 m and 120 m. These features can be directly correlated to river-terrace remnants and horizontally-extended erosional landforms on the surface. The levels of both surface and cave features have been controlled by the development of the Ohio River drainage system during Late Tertiary and Pleistocene time. Major cave passages formed during interglacial times when the Green River was entrenching or standing at a particular base level for a prolonged period of time, rather than being determined by stratigraphic or structural controls. By contrast, surface alluviation and the infilling of cave passages with sediment occurred during glacial periods, the ice front advancing to within about 200 km of the area.

Discussion

In their discussion, Miotke and Palmer (1972) place the geomorphic development of the 'Central Kentucky Karst' into the classic scheme of four North American Pleistocene glaciations. Recent paleoclimate work by Emiliani (1955) and Shackleton and Opdyke (1973) on deep-sea sediments and Kukla (1978) on terrestrial deposits has, however, clearly shown that there were at least 12 glacial/interglacial cycles during the Pleistocene. As Miotke and Palmer (1972) had no absolute age data upon which to base their correlations, that aspect of their work is speculative and open to question/ Here we present absolute age data for the Mammoth-Flint Ridge Cave System and attempt to place some temporal constraints on the development of the various cave levels.

An unfortunate feature of the geologic character of the cave system is that travertine deposits are rare, generally only occurring in erosional segments of the cave near or beyond the edge of the clastic which protects the majority of the cave system from the vertical circulation of vadose waters. However, absolute ages for speleothems in such areas place minimum ages for the particular cave passage in which located.

We have determined 17 $^{230}Th^{234}U$ ages for flowstones and dripstones from various levels of the cave system. Pertinent analytical data, ages and elevations for the locations sampled are presented in Teble 1. As seen from this data, it is clear that the older ages are associated with the higher cave levels and vice versa. Three specific points can be made as regards the age of particular levels of the cave system (Table 2).

(1) The highest levels of the cave at -207m (680') are in excess of 350,000 years old by U-series dating and in excess of 700,000 years old by the fact that flowstone sample 80561 from Collins Avenue has reversed magnetic polarity (Schmidt, personal communication):

(2) Cave Levels above 152 m (500') are greater than 350,000 years old;

(3) Cave levels near 143 m (470') are only slightly greater than -140,000 years old, as the sample 77538 is a thin flowstone carapice on a sediment bank in Mud Avenue only 3 m above present base level. These results confirm the antiquity of the Mammoth-

Flint Ridge Cave System. The highest cave levels between 213 m (700') and 183 m (600'), those assigned by Miotke and Palmer to the ancient "Teays River' system, are of likely Early Pleistocene age, Intermediate levels between 168 m (550') and 152 m (500') are of Middle Peistocene age and levels below 146 m (480') are of Late Pleistocene age. If it is the case, as generally assumed, that Sangamon time represents the last interglacial period in the North American record, then the contention of Miotke and Palmer (1972) that Mud Avenue at 143 m (470') is of Sangamon age is incorrect. The excavated sediment in this passage must have been emplaced prior to -140,000 years B.P., the penultimate glacial period, so that the cave passage itself probably was formed during the penultimate interglacial period at about 220,000 to 180,000 years B.P. If this is the case and approximately the lowest 10 m of the cave (the flooded portion) is presently infilled with sediments of last glacial age, then the entrenchment of the Green River over the past two glacial cycles occurred at a rate of -0.12 m/10^3y.

It is striking to us that there are approximately half as many cave levels as Pleistocene glacial/interglacial cycles. This suggest to us a sequence of development whereby large phreatic cave passages are initially formed during the latter stages of one interglacial period when river level was stabilised at a certain level, these were then to some extent infilled with sediment and the passages concurrently dissolved upwards at or near base level during the subsquent glacial period, and finally the major passages re-excavated and narrow vadose conyonds cut as a result of rapid river entrenchment during the next interglacial periods when hydraulic gradients were high. This rapid downcutting is terminated by alluviation and sedimentation during the next glacial period which partially infills the recently formed canyons. This sediment is quickly removed during the early stages of the third interglacial event in the sequence finally permitting a long episode of base-level erosion and conduit development late in this interglacial period. Thus there are approximately half as many cave levels as Pleistocene glacial/interglacial cycles.

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Table 1: U concentrations, isotope activity ratios, and calculated ages for speleothems from the Flint-Mammoth Cave System, Kentucky, U.S.A.

sample number	description	U conc. (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}U$	age (ky)	Elev. (ft.)	(m)
77540	stalagmite - Violet City entrance	0.32	1.07±.03	.07±.01	200	7±0.8	675	205
77544	stalagmite - Radio Room	0.27	1.09±.02	.69±.05	49	123±15	485	198
77545	stalagmite - Gothic Avenue breakdown	0.24	1.41±.02	.01±.001	7	2	600	183
77546	stalagmite - Mammoth Dome	0.16	1.62±.05	.31±.02	20	40±3	490	150
77547	stalagmite - end Audabon Avenue	0.22	1.50±.03	.13±.01	6	15±1	600	183
80501	flowstone - Collins Avenue	7.0	1.15±.03	1.024±.04	200	7350	680	207
71100	stalagmite - New Discover	1.5	1.15±.03	0.06±.01	47	6+1	?	?
77538	flowstone - Mud Avenue	5.3	1.11±.02	.74±.03	150	141±11	430	131
72035:1	flowstone (base) - Edwards Avenue	1.1	1.14±.03	1.02±.04	50	350	580	177
:2	flowstone (top) - Edwards Avenue	1.2	1.21±.02	.90±.04	24	350 213^{+33}_{-25}	"	"
72036:5	flowstone (base) - Davis Hall	0.28	.99±.01	1.054±.01	21	350	500	152
:4	flowstone (top) - Davis Hall	0.25	.97±.10	1.144±.08	75	350	"	"
72037:1	stalagmite - Colossal Dome	0.25	.99±.05	1.05±.08	20	350	"	"
72041:5	stalagmite (base) - Davis Hall	0.6	1.17±.02	.87±.03	61	202±21	500	152
:9	stalagmite (middle) - Davis Hall	1.3	1.12±.02	.79±.01	200	159±.10	"	"
:13	stalagmite (top) - Davis Hall	1.5	1.16±.02	.70±.02	37	121^{+5}_{-28}	"	"
74000:1	flowstone - Great Onyx	53.1	1.05±.03	.90±.02	200	247^{+}_{-22}	500	152

Table 2. Age-elevation relationships for the Mammoth-Flint Ridge Cave System, Kentucky

Elevation (meters)	(feet)	Typical Passage	Oldest Speleothem Age
207	680	Collins Avenue (top)	700,000 y B.P.
189	620	Dyer Avenue: Thomas Avenue	-
183-180	600-590	Edwards Avenue: Gothic Avenue	350,000 y B.P.
168	550	"L" Survey, Grand Avenue	350,000 y B.P.
159	520	Flat Room	-
152	500	Lost Passage, Davis Hall	350,000 y B.P.
146	440	Pohl Avenue, Radio Room	123,000 y. B.P.
143	470	Mud Avenue (top)	-
131	430	Mud Avenue (canyon)	141,000 y B.P.
128-125	420-410	Active and submerged levels	-

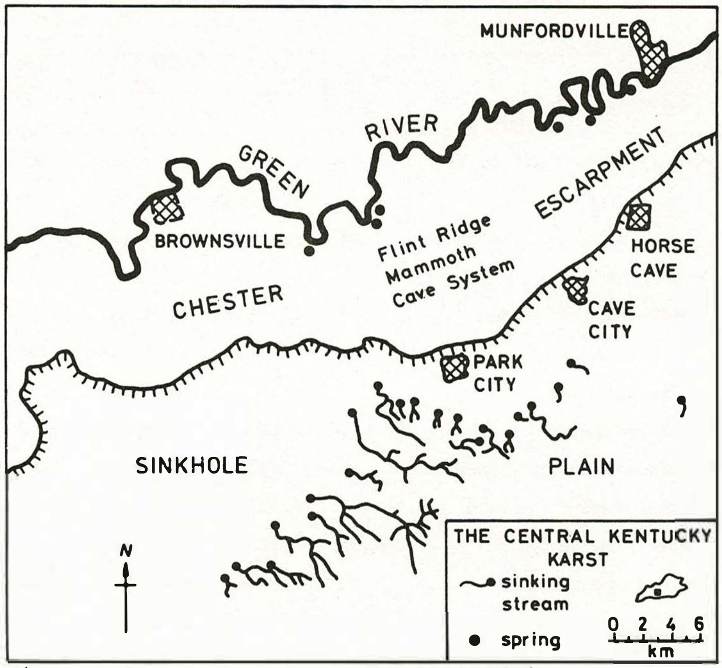

Figure 1. Location map of the 'Central Kentucky Karst'.

Die Eingriffe in die HÖhle von Postojns im Lichte des Umweltschutzes

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Abstract

Postjna Cave is the longest Jugoslave cave which has already been open to visitors for one hundred and sixty years. It is unique regarding its morphologic, hydrologic, and biospeleologic specialities, and world-famed regarding its karst formation richness. That is why it is protected like the first class monument. Therefore, every interference in this cave region is exceptionally delicate, nobody but the staff of the Postojna Cave and official security institutions may decide on it.

My lecture shows the unusual richness of the karst formations in the caves which had - at the time when the number of visitors was constantly rising - to make way to tourist routes and later to one- and double tracked railway line which was laid in 1872. At the same time the lecture deals with interfering in the cave world to improve the routes in the cave, to place the electric bodies in it and to establish the biospeleological station in the cave, and specially to erect administration building and adjust the cave entrances. The most difficult problem was how to lay down the double tracked circular railway line, which would make possible the cave to accept up to 12,000 visitors a day without interfering with the sintered cave galleries.

Zusammenfassung

Die Höhle von Postojna ist die längste und meist besuchteste Höhle Jugoslawiens, die schon vor 160 Jahren als Schauhöhle eingerichtet war. Sie ist wegen ihrer morphologischen, hydrologischen, biospeläologischen Eigenheiten und noch besonders wegen ihres Tropfsteinreichtums weltbekannt. Als solche stellt das Naturdenkmal ersten Ranges vor. Gerade deswegen war auch jeder Eingriff in diese Höhlenwelt sehr delikat und kann ihn die Höhlenverwaltung nur unter Mitwirkung der amtlichen Schutzbehörde ausführen.

Der Vortrag stellt den ausserordentlichen Tropfsteinreichtum der Höhle dar, der wegen des immer steigenden Besuches viele Eingriffe und Veränderungen des urspringlichen Naturstandes erlitten hat. Der ursprünglich reicher Boden der Tropfsteinetage der Höhle musste zuerst der eingeleisigen (im Jahre 1872) und später der zweigeleisigen Höhlenbahn (1964) Platz machen. Zugleich werden im Laufe der Zeit die Wege durch die Höhle verbreitet und die elektrische Beleuchtung verbessert. Spätere Eingriffe in die Höhle bedeuten die Einrichtung der biospeläologischen Station, des neuen Höhleninganges und der Bau des Vermaltungsgebäudes.

Trotz allen diesen Eingriffen in die Wunderwelt der Tropfsteine versuchte die Höhlenverwaltung schon vom Anfang an, das primäre Bild der Höhe je möglich mehr zu schützen.

Die Unterschriften an den Wänden der Eingangsräume in der Höhle von Postojns beweisen, dass sie schon im 13. Jahrhundert bekannt war (G. Volpi, 1821, 31). Die damals bekannter Teil der Höhle wurde von den Durchreisenden gelegentlich besucht. So haben wir aus der Zeit vor der Entdeckung der inneren Teile der Höhle bis zum Kalvarienber (heute genannt Velika gora = Grosser Berg) durch den Einheimischen Lukas Cec im Jahre 1818 einen interessanten Bericht des Naturforschers J. Seume aus dem Jahre 1803 (Spaziergang nach Syrakus im Jahre 1802). Den Wanderer begleiteten in die HÖhle gelegentliche Führer aus Postojna, die im Grossem Dom an der Felswand Strohbundel angezündeten. Die bis zum Jahre 1818 offene, nicht gesicherte und nicht beleuchtete Höhle, die auch keine ständigen Führer hatte, rückte damit ganz uberraschend zum Mittelpunkt des Karsttourismus. Die Lage an der Staatsstrasse Wien - Triest verbreitete ihren Ruhm im ganz Europa, sie wurde zum Inbegriff der unterirdischen Welt und behauptete durch lange Jahre ihren Vorrang als längste bekannte Höhle der Welt.

Die sofort nach der Entdeckung gegründete Höhlekommission versperrte den Höhleneingang, um die H-hle vor dem Abbrechen der Tropfsteine zu schätzen. Der erste tüchtige Sekretär der Höhlenkommission Joseph Jersinovic - Löwengreif und sein Machfolger Kreisingenieur Aloic Schaffenrath fanden im Naturfoscher und begeistertem Besucher der Höhle einen tüchtigen wissenschaftlichen Mitarbeiter in Person des Grafen Franz von Hohenwart. Das war eine aüsserst glückliche Symbiose der Praktiker mit dem Wissenschaftler. Vom Schaffenrath stammt der erste naturtreue Plan der Höhle, Plan der Strasse zur Höhle und Skizza für den künstlichen Eingang in die Höhle, der noch heute mit verzierter Eisentür versperrt ist. Um die neuentdeckten Höhlenteile zugänglich zu machen wurde schon im J. 1820 höhlzerne Brücgebaut, zu welcher von beiden Seiten in die Felswand ausgemeisselte Treppen führten.

Dank Schaffenrath malerischer Begabung sind uns durch seine 19 Guaschgemälde naturtreu damalige Verhältnisse in der Höhle zurüchkgeblieben. Diese wurden im berühmten "Wegweiser für die Wanderer in der berühmten Adelsberger und Kronprinz Ferdinande-Grotte bey AdelsbergÄ von Franz Graf von Hohenwart als Kupferstiche veröffentlicht. Darsus is ersichtlich, wie der damalige Höhlenboden reich an Tropfsteinbildungen war. Bei der Niederlegung der touristischen Wege arbeiteten damals Hand in Hand wissenschaftlicher Kenner der Höhle. Hohenwart und Praktiker Schaffenrath. Die Felsblöcken wurden entfernt und in kleinen Höhlungen und Vertiefungen abgelagert, so dass der Höhlenboden gangbar war. Das war damals enger Weg, der erst in den fünfzigen Jahren des vorigen Jahrhunderts wesentlich verbessert wurde. Doch blieb dabei der tropfsteinreiche Boden fast unversehrt, weil akke Wege längs der Wänden führten und kleine unebnungen mit steinernen Treppen wurden. Eine solche schwerste Stalle, wo am Anfang Besucher kriechen musste war bei dar Umgestürzten Säule. Bei diesen Arbeiten leisteten tüchtige Hilfe Bergleute aus Quecksilberbergwerk Idria, die enge Stellen wegen der Verbindung der Nachbargänge durchschlagen mussten.

Um die Höhle von Postojna vor Beschädigungen zu schützen, verbot die Grottenkommission schon nach der Eröffnung jedes Abbrechen und Abtragen der Tropfsteine. Weil aber die Nachfrage nach diesem Naturschmuck sehr gross war, legalisierte die Grottenkommission den Verkauf. So wurden Tropfsteinbildungen unter der Aufsicht des Grottensekretärs in den Neben nicht touristischen Höhlengängen abgebrochen und vor der Höhle als Souvenier verkauft. Dass dem Tropfsteinhandel schon vor dem ersten Krieg Einhalt geboten wurde, ist Verdienst sowohl des Speläologen J.A. Perko, nachdem er das Sekretariat der Höhlenkommission übernahm. Besuche des berühmten Speläologen Adolf Schmidl (A. Schmidl, 1854, 1-314) in der Höhle von Postojna und des Kaisers Franz Joseph im J. 1857 anlässlich der E Eröffnung der Südbahn Wien-Triest brachte Höhlenkommission dazu, die Höhle auf das glänzendste auszustatten. Die wichtigsten Arbeiten waren neuer Brüchkenbau im Groseen Dom und Verbindung der sogenannten Franz-Josephs-Höhle mit der damaligen Kaiser Ferdinads-Grotte.

Mit dem Globocnik Anton, der 1863 das Sekretariat der Hohlenkommission übernahm, begann goldene Zeit des Karsttourismus. So wurde neuer Weg auf dem Kalvarienberg gelegt, auf dem ganzen Touristenwege aber Pfeiler und Geländer aus Eisen gestellt. Aus dem Material des grossen Bergsturzes vor der Höhleaus der Ausräumungs-Material des neuren bis damals verschütteten Höhleneinganges entstand vor der Höhle ein grosses, geräumiges Plateau, das mit den Bäumen beflanzt wurde. Anstatt der alten Holzbrücke über den Pivkafluss wurde neue eiserne gebaut, der Eingang, der bis damals verschüttet war, wurde aber mit einem monumentalgen geschmiedeten Eisentor mit Jahrgang 1866 versperrt.

In dieser Zeit wurde für schwergehende und vornehme Gäaste Tragbahre organisiert. Weil aber mehrstündiger Fussweg für ältere Leute zy anstrengend war, kam es im Winter 1872 zur Ausführung der Shiebebahn in einer Länge von 2260 m. Sie begann bei "Priznica" (Predigstuhl bei dem Stiegenaufgange im Grossen Dom) und endete unter dem Kalvarienberg. Auf dieser Bahn verkehrten 2 Wägelchen mit je zwei Sitzplätzen, die von den Grottenführern geschoben wurden. Die Niederlegung der Eisenbahn in der Höhle war das grösste und zugleich das schicksalvollste Ereignis. Das war Anfang des successiven Prozesses der Vernichtung des Tropfsteinreichtums am Höhlenboden, der langsam den ganzen Boden eingenommen hat. Aus dem Wegweiser Hohenwarts und aus Schaffenraths Guaschen ist er ersichtlich, dass gerade Tropfsteinreichtum des Bodens typisch für die Höhle von Postojna ist. Das beweisen Tropfsteinbildungen auf dem

Grossen (-Kalvarien) Berg, im Bunten Gang, im Kristallgang und vielen anderen Nebengängen.

So war die Höhlenverwaltung gezwungen diesen prachtwollen Reichtum der Tropfsteine für den immer mehr steigenden Höhlentourismus zu aufopfern. Die damalige Kaiser Ferdinands Grotte (heute Stara jams) verlor viele Tropfsteinbildungen, weil der ganze Boden eingeebnet war. Die meisten beseitigten Stalagmiten endeten in den Stützmauern der Höhlenbahn, in der Verschüttung der Vertiefungen, oder sogar als Schmuckgestein in den Gärten der Postjonaer Bürger (J. Sajevic, 1974, 24). Gleichzeitig wurdem am Kal varienberg alle Stiegen durch Anlage eines weiter sushohlenden Weges beseitigt, in dem Höhlengang Franz-Josephs-Grotte (zur Zeit Italiens Braccio Mediano, heute Male jame) kam es zum Durchschlag enger Passagen und somit zur Einverleibung der Höhle in den Touristenweg. Der lief vom Eingang bis Kalvarienberg, in den Touristenweg. Der lief vom Eingang bis Kalvarienberg, führte durch damalige Franz-Josephs-Grotte bis zur Scheidewege, wo er wieder in die Kaiser Ferd inands Grotte mündete und beim Ausgang aus der Höhle endete.

Im Jahre 1911/12 wurde die Grottengahm bis zum Eingang verlängert. Mit der Einführung der Lokomotive auf Benzin im J. 1914 beginnt wegen des immer grosseren Verkehrs starke Verschmutzung der Höhle. Der Eintrittsbahnsteig war damals dort, wo heute as Verwaltungsgebäude steht. Im Jahre 1922 wurde stärkere Lokomotive ("Orenstein") die 25 kleine Waggons mit 150 Touristen zog, eingesetzt. Im J. 1928 baute man vor der Höhle das imposante Verwaltungsgebäude und verlegte man den zweigleisigen Eintrittsperron in die ausgehaute Felswand hinter dem Gebäunde.

Im Jahre 1963 wurde das doppelte Regime des Höhlenbesüches eingestellt. Der Besucher durfte sich für den Besuch der Höhle nur der Höhlenbahn bedienen. So konnte man mit drei Lokomotiven auf einmal 338 Touristen überfahren.

Wegen des immer grösseren Besuches der Höhle (shon damals mehr als 200.000 Besucher) hatte sie mit immer grösserer Verschmutzung der Höhle durch Lokomotiven zu tun. Dem Russ, der sich wegen Auspuchgasse an den Tropfsteinbildungen der Alten Höhle immer mehr häufte und damit auch Vernebelung und Gestank machten der Höhlenverwaltung immer grössere Probleme. Wegen solcher Verhälnisse wurde die erste biospeläologische Station der Welt in den Eigangsteilen der Höhle aufgelassen. Leider ist auch die Höhlenfauna fast bis zur Gänze vernichtet. Sie hat sich nur in einem Nebengang, in dem Bunten Gang, sowie in der unteren, von der Pivka durchflossenen Etage und in der Crna jama erhalten (E. Pretner, 1968, 74). In der letzten Zeit zeigt sich sogar in der unteren Etage starker Rückzug des typischen Tieres des Dinarischen Karstes, des Grottenolms, der nur noch in den engen Spalten des unterirdischen Pivka-Flusses lebt.

Im Jahre 1959 wurde in der Höhle die erste elektrische Akkumulatorenlokomotive eingeführt. Über eine halbe Million Besucher jährlich diktierte Einführung der zweigleisigen Kreisbahnstrecke mit dem Kunststollen am Eingangsperron im Jahre 1964. Demnach folgte im J. 1967 die Aushohlung des 422 m langen Tunnels unter dem Grossen Berg und der neuen Bahnstation unter dem Konzertsaal. Damit wurde das janze Verkehrssystem in der Höhle ausgearbeitet. Tägliche Kapazität der Höhlenbahn erhöhte sich dadurch auf 15.000 Besucher. Das war dringende Notwendigkeit, weil in den letzten Jahren die Besucherzahl schon auf 900.000 gestiegen ist, devon bis 80% Ausländer. Dreiviertel dieser Touristen besuchen aber die Höhlen im Sommersaison. Bei solcher Menge Besucher kommt immer häufiger zym Abbrechen der Tropfsteine. So haben wir bis jetzt nach dem zweiten Weltkriege schon über 200 Versuche des Diebstahls der Tropfsteine, vor allem in dem tropfsteinreichsten "Schönen Höhlen", die nach der Entdeckung im J. 1891 erst im J. 1925 für den Besuch eröffnet wurder. Hier musste Grottenverwaltung ein eisernes, mit der plastischen Masse überzogenes Schutzgeländer anbringen.

Der letzte Eingriff in die Höhle sind die heurigen Arbeiten im Grossen Saal (Velika dvorana), wo an der Endstation ein künstlich vertiefter Gang zum Ausgang führen wird.

Ausser der Höhle von Postojna wurde im Jahre 1926 durch den 500 m langen Kunststollen die Verbindung mit der Crna jama (Schwarze Höhle) hergestellt. Das ganze Schuttmaterial aus dem Tunnel wurde im Grossen Saal der Schwarzen H-hle abgelegt und eingeebnet, so dass heute die dortigen bis zu 12 Meter hohe Stalagmiten nur etliche Meter herausragen. Ebenso wurde in dieser zeit mit dem 100 m langen Kunststollen die Verbindung zwischen der Schwarzen-und Pivka-Höhle hergestellt.

Einige Art Eingriff in die Höhle bedeutet auch die Beleuchtung. Damit wurden die Tropfsteinbildungen wegen Russ immer schwärzer. Schon im Jahre 1825 verbot Grottenverwaltung Beleuchtung mit Pechfackeln, weil die stark Tropfsteine verschmutzten. (Hohenwart F., 1830, I, 8). Anstatt deren wurden Öllampen und Kerzen verwendet, die aber die Höhle auch langsam verschmutzten. Auch im Jahre 1884 eingeführte elektrische Beleuchtung störte mit den freistehenden Drähten das Höhlenbild. Erst in den dreissigen Jahren des 2+. Jahrhunderts wurden die Drähte in die Wand eingebaut.

Gerade bei der Höhle von Postojna begegnen sich scharf die Interesse der Ausnützung und des Umweltschutzes. Der heutige Stand ist eklatantes Beispiel des Kompromisses zwischen der Wirtschaftlichen Ausnützung der Höhle und der Notwendigkeit des Umweltschutzes. Schon von Anfang an begegnen wir uns bei der Höhle weltschutzes. Schon von Anfang an begegnen wir uns bei der Höhle mit der Tendenz der touristischen Ausnützung einerseits und des Höhlenschutzes andererseits. Im Interese des Höhlenschutzes war die Höhle sofort nach der Entdeckung gesperrt und damit geschützt vor dem Abbrechen der Tropfsteine. Die schon damals gegründete Höhlenkommission hat sich nicht nur der Ausnutzung sondern auch dem Höhlenschutz gewidmet. Glückliche Zusammenarbeit des Naturforschers F. Hohenwarts mit dem Praktiker A. Schaffenrath brachte positive Resultate in Hinsicht auf Höhlenschutz, wie auch auf Einrichtung der Höhle.

Durch Zusammearbeit der Projektanten, der Anstalt für Denkmalshutz der Sozialistischen republik Slowenien, der Speläologen und der Verwaltung der Höhle von Postojna kam es im Jahre 1978 auf Initiative der Höhlenverwaltung zur Ausgabe der Publikation "Gesamtausstattung der Höhle von Postojna (Celostha oprema Postojnske jame, 1978, 1-90, 52 fotografij).

Die Publikation umfasst geomorphologische und biospeläologische Studie über die Höhle, die Geschichte der touristischen Entwicklung der Höhle, die Schilderung der Eingriffe in die Höhle, Beschreibung der urbanistischen Einrichtung, Raumanalyses und Vorschläge für Kriterien und Kategorien, für den Katalog und Reglement der Höhleneinrichtungen.

Allen diesen Kapiteln folgt des interessante Kapitel über die Höhle von Postojna im Lichte des Umweltschutzes mit dem Vorschlag der Gemeinschaftsverifikation. Am Ende vervollständigt diese interessante Publikation Fotokatalog der Eingriffe in die Höhle von Postojna.

Ich meine, dass das Werk als Muster für die Einrichtung und für den Schutz der Schsuhöhlen dienen konnte. Das vor allem deswegen, weil es enthält viele nutzbara Ratschläge für touristische Einrichtung der Höhle.

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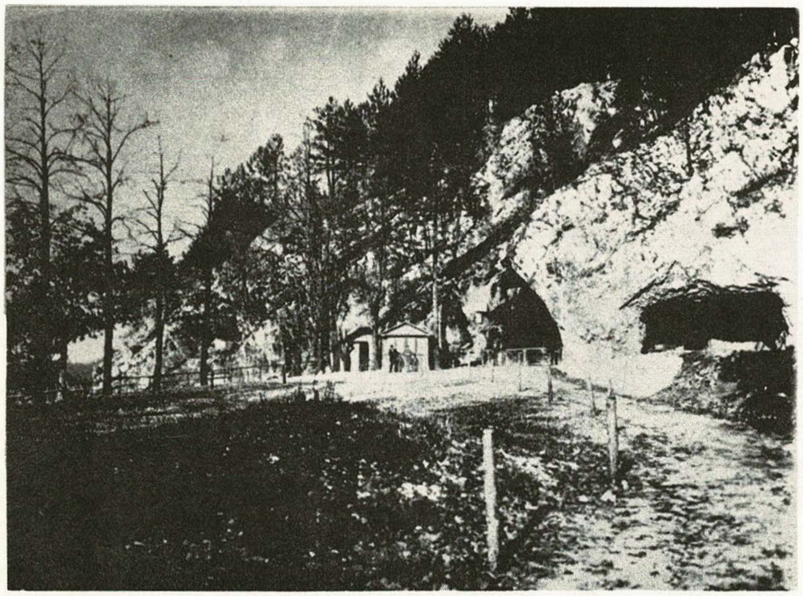

Bild 1: Eingange m dic Höhle von Postojna vor dem Jahre 1926 und Höhlenplateau.

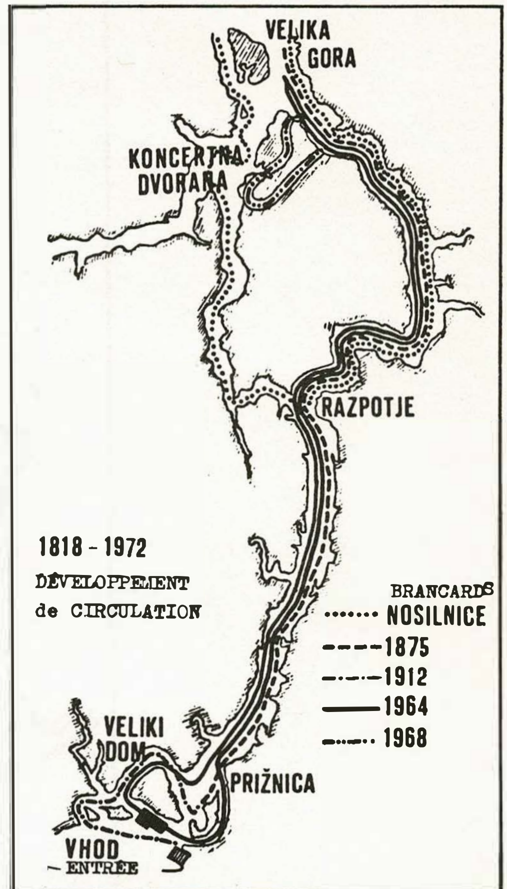

Bild 2: Le schéma montre le developpment de circulation dans la grotte de Postojna de 1818á 1972. Le schéma á été fait par Jospi Sajevic

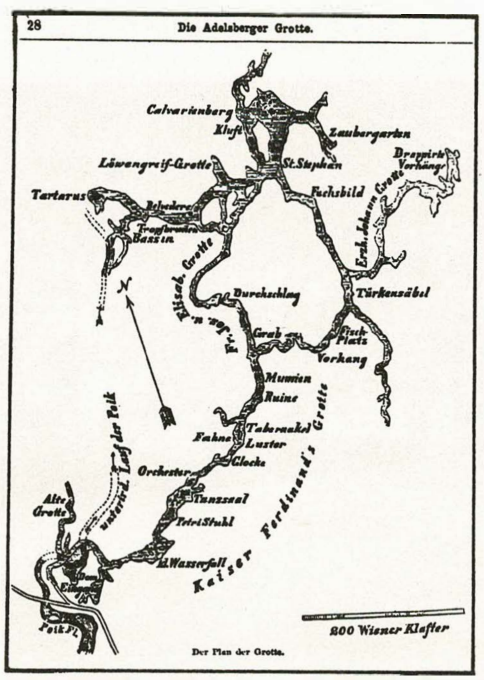

Bild 3: Aus dem Höhlenführer: P.v. Radics, Adelsberg und seine Grotten, Triest 1861.

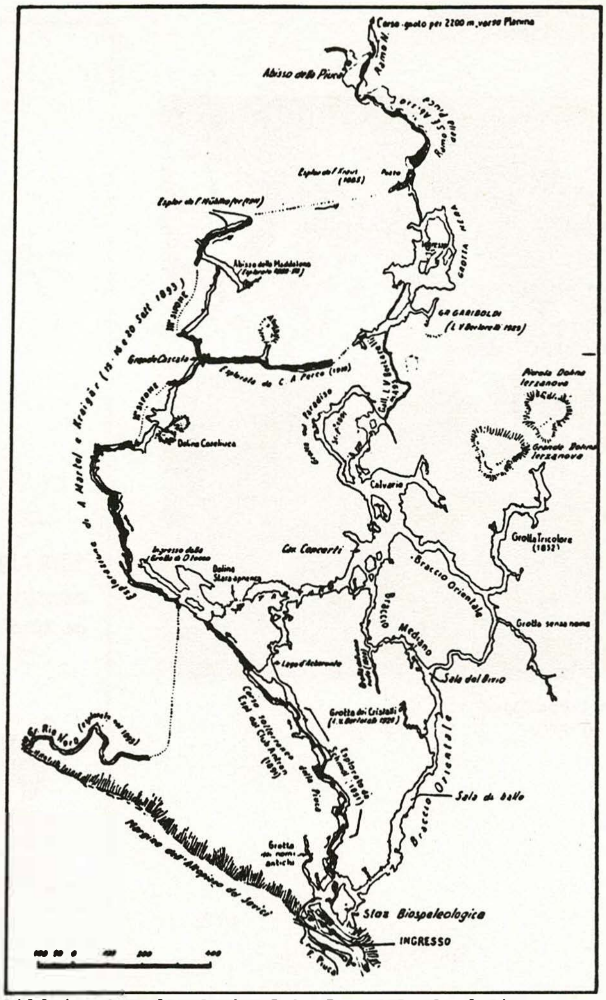

Bild 4: Aus dem Buch: G.A. Perco-S. Gradenigo, Postumia e le sue celebri grotte, 1942.

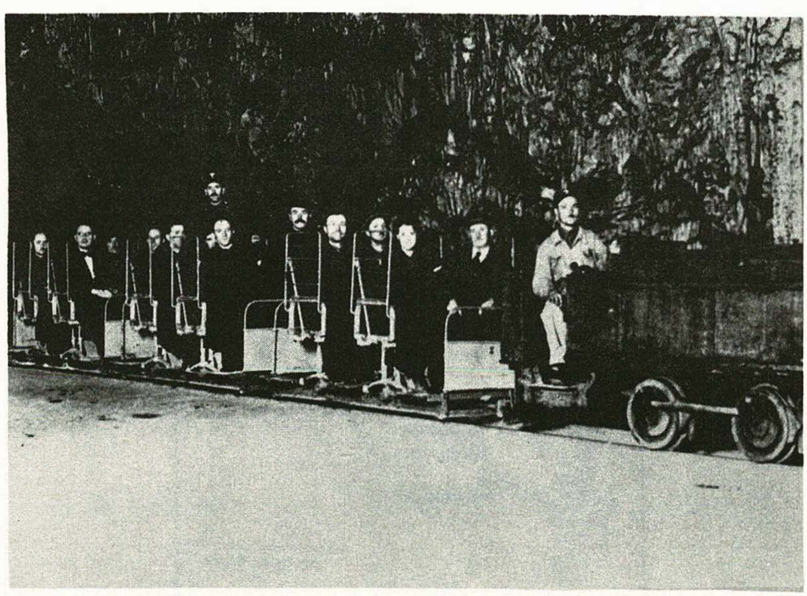

Bild 5: Erste Beufinlokomotive im der Höhle von Postojma 1914.

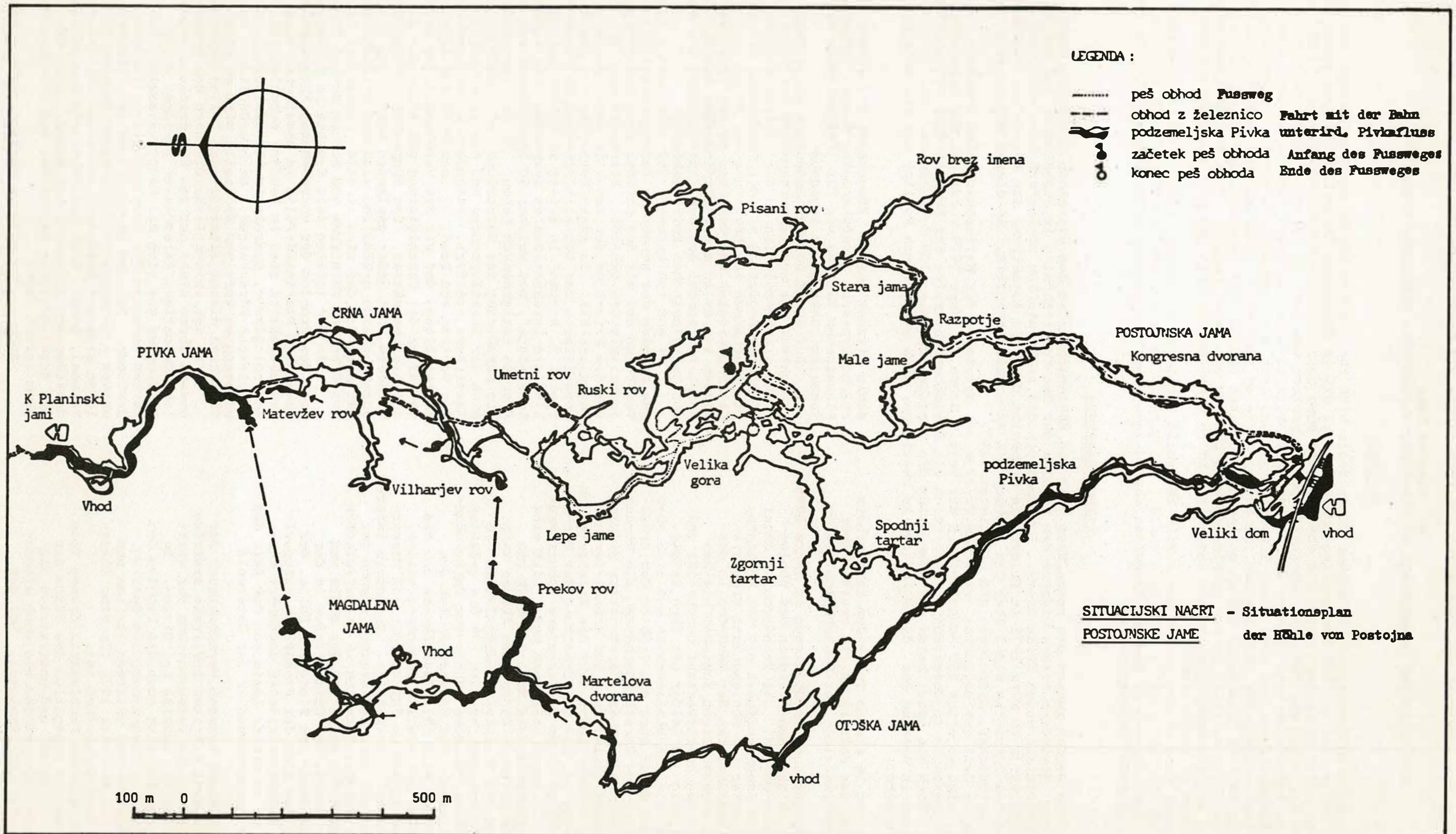

Bild 6: Poveto po karti Instituta ze raziskovanje
Krasa SAZU Postojna

Merili: Gallino, Petrini, Sartori, Hribar,
Michler

Sestavil: Gospodaric

Bericht Der Kommission für Karstschutz und Schauhöhlen der UIS

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Abstract

In his report of Commission the author first deals with the conclusions of constant protection of the caves, that had passed in 1975 the working conference of UIS in Obertraun (Austria)' it also shows how the care has been taken to protect karst and the caves in some countries which are the members of UIS! Among the problems following are the most important` how to protect the part of classical karst at Sezana, where a custom free industrial zone between Italy and Jugoslavija is being arranged; how to protect Skocijanske jame (The Skocjan Caves) and some other limestone regions that are important reservoir for drinking water Among important actions for that purpose the author gives an account of international symposium which was held in March 1979 in Trieste by UIS on making use of karst region` the symposium has - from scientific point of view - thrown light on the problem, how to protect the karst region. From the congress of UIS in Sheffield in 1978 special attention has been paid to karst waters that are put in danger because of the specifitics of karst ground.

The second part of the report deals with the world Catalogue of Tourist Caves. As it is known, there are about 650 tourist caves in the whole world. The questionnaire we have introduced only includes about 200 caves. The congress in America therefore should take charge of putting forward the normative for such a catalogue of world tourist caves.

Zusammenfassung

ImBerichte werden zuerst die Beschlüsse über den Höhlenschutz in den einzelnen Mitgliedsländern der UIS angegeben. Besonders Sorgen widmete dem Problem der San-Canzianhöhlen in Jugoslawien und den Kalkalpenräumen Österreiche wegen Trinkwasser. Zusammen mit den italienischen Höhlenforschern und unter dem Schutz der UIS wurde in März 1979 in Triest das Symposium über die Ausnützung der Karsträume durchgeführt. In der Mitte des Symposium stand aber das Problem des Karstwasserschutzes. An diesem Symposium nahmen über 80 Höhlenforscher, Hydrologen und Urbanisten teil.

Der zweite Teil des Berichtes wird dem Problem des Kataloges der Weltschuauhöhlen gewidmet. Wie es bekannt ist, gibt es circa 650 Schauhöhlenin der Welt. Schon im Jahre 1975 wurde bei der Arbeitstagung über den Höhlenschutz in Obertraun in Österreich ein Fragebogen betreffe der Angaben über Schauhöhlen eingeführt. Doch bis jetzt bekam die Kommission die Anagaben nur über 200 Schauhöhlen. Die Aufgabe des Kongresses in Amerika sei, die Normative zu bestimmen, nach welches ein Katalog der Weltschauhöhlen herasgegeben wird.

Der Bericht ist im ersten Teile dem Karstschutz und der Ausnützung der Karsträume, im zweiten aber dem Problem des Weltkatalogs der Schauhöhlen gewidmet.

Bei der Arbeitstagung in Obertraun im Jahre 1975 ist als ständige Aufgabe das Anliegen des Höhlenschutzes übernommen worden. Das Grundproblem dabei ist und bleibt die Zusammenarbeit mit den Behörden: für den Höhlenforscher ist Höhlenschutz Freizeit-Arbeit, für die Bediensteten der Behörden in der Regel Beruf. Die gegenseitigen Kontakte bleiben deshalb meist auf den Schrifverkehr beschränkt und sind recht langwierig und leider oft ohne Erfolg.

Unsere Sorge für den Höhlenschutz muß sich aber noch erweitern und dabei auch dem Problem der Erhaltung und dem Schutz von Karstlandschaften als Voraussetzung für die Reinhaltung des Karstwassers widmen. Die wachsende Industrialisierung und Urbanisierung der Karstgebiete bedroht immer mehr die Karstreserven durch Verschmutzung so, daß die Erhaltung der Wassergüte der Karstquellen immer umfassendere Schutzumaßnahen verlangt. In immer stärkerem Maße tritt eine Belastung der Karstlandschaft auf, die o ft zum Zusammenbruch des gesamten Ökosystems führen kann.

So enthalten zum Beispiel in Jugoslawien die unterirdischen Karstwasserreserven 60% des gesamten Trinkwassers. Diese Tatsache führte zum Forschungsprojekt "Karsthdrologie und Wasserreichtum des Karstes" bei welchem seit 1971 Jugoslawien und die Vereinigten Staaten von Amerika zusammenarbeitan. So wurde auch das Symposium "Hydrologie und Wasserreichtum des Karstes" veranstaltet. Besonders interessant ist der Bericht über den ersten Versuch der Feststellung der Autopurifikation im unterirdischen Pivka-Fluß zwischen dem Ponor vor der Höhle von Postojna und der Quelle des Unica-Flußes id der Planinska Jama am Rande des Planinski Polje. Der Versuch bewies, daß sich der Prozeß der Autopurifikation in den Karstwasserläufen ungestört entwickelt und daß er in erster Linie von der Zeit des Aufenthaltes der Wassermassen in der Unterwelt abhängt.

Als Beispiel einer krassen Verschmutzung der Reka-Timavo durch zwei Fabriken inTlirska Bistrica verursacht die unmögliche Verschmutzung der weitberühmten Höhle von St. Kanzian bei Divaca. Zu diesem Problem gesellte sich noch das Problem der Ausntzung des Dreiecks Sezana-Basovica-Opician, das nach dem Osimo-Vertrag zwischen Italien und Jugoslawien von 10. November 1975 für eine internationale freie Zone vorgesehen ist.

Mit der ökologischen Problematik dieser Zone befaßte sich schon die Delegation des Büros der UIS im Juli 1977 in Triest und unterstrich die Wirtschaftlichkeit, historische wie auch wissenschaftliche Bedeutung des Gebietes. Bei der Schlu sitzung des 7. Kongresses UIS wurden zanlreiche typiscne Karstphenomäne dieses Gebietes des Klassischen Karstes von der ilalienischen wie auch jugoslawischen Seite angegeben.

Auf Grund solcher Bedeutung diese Gebietes errichtete die Generalversammlung der UIS in Sheffield eine Resolution an die italienische und jugoslawische Regierung mit der Forderung, die notwendigen Mafnahmen zur Bewahrung des Ökologischen Gleichgewichtes des Gebietes zu treffen. Auf Grund dessen ist es zu einer Verminderung des Freizonen-Komplexes sowohl auf der italienischen wie auch auf der jugoslawischen Seite gekommen.

Da muß ich betonen, daß sich unsere Kommission für das Problem des genannten Karstgebietes mit vielen Vorträgen und mit den persönlichen Kontakten mit den jugoslawiscgen Behörden, besonders aber mit der Anstalt für die Frie-Zone der Republik Jugoslawien in Sevana stark engagiert hat. In enger Verbinung mit diesem Problem organisierte der Höhlenforscherverein "Commissione Grotte E. Boegan" in Triest im Rahmen der UIS im März 1980 ein internationales Symposium "Die Ausnützung der Karsträume", bei welcher 50 Speläologen aus Eropa und Amerika teilgenommen haben. In den Vorträgen wurde die Ausnützung der Karsträume, methodologische Prinzipien der Karstforschung und die Verschmutzung der Karsträume erörtert. Besonders Aufmerksamkeit erweckte der Vortrag von Prof. V. Caumartin aus Dijon mit der Feststellung, daß wir die Verschpmutzung der Karsträume vor allem der Urbanisierung und nicht der Industrie zuschreiben müssen. Das Symposium unterstrich die Tatsache, daß jeder geplanten Ausnützung der Karsträume vorausgehende gründliche wissenschaftliche Forschungen verlangt und daß sich in allen Fällen das Gleichgewicht zwischen dem Karstraum und seinem Schutz finden muß.

In der letzten Zeit tauchte im Klassischen Karst noch das Problem der vorgesehenen Akkumulation des bekannten Planinsko-Polje im shweischen Karst auf. Augenblicklich sind im Laufen: beschleunigte geologische, morphologische, hydrologische, speläologische und spelaobiolosche Forschungen. Nach gründlicher Erwägung der erforschten Vor- und Nachteile wird es sich endlich das Schicksal dieses einzigartigen Poljes entscheiden.

Es ist ersichtlich, daß nach dem Kongreß in Sheffield unsere Sorge nicht nur dem Höhlenschutz sondern auch dem lebenswichtigen Karstwasser gewidmet wurde. In dieser Verbindung muß sich die Hauptversammlung des österreichischen Vereines für Umweltschutz in Salzburg, März 1979, erwähnen. Bei dem Generalthema der Versammlung, "Karstwasser - Österreichs Trinkwasser-Reserve der Zunft" beteiligten sich mit Vorträgen vor allem Höhlenforscher wie Trimmel, Bauer, Fink und Habe, die das Problem des Karstwassers angeschnitten haben. Über die Verschmutzung der jugoslawischen Karstflübe und Versuche zu deren Reinigung sprach Habe.

Auch in den anderen Ländern wurde gerade das Problem des Karstwassers das leitenden Thema vieler Symposien. Solche Symposien wurden versnstaltet: im September 1978 in Granada, in Toulouse, in Budapest und im April 1979 in Bordenone und in Castelnuovo. Bestimmt sind bei dieser Aufzählung viele derartige Veranstaltungen unabsichtlich ausgefallen, doch bin ich überzeugt, daß alle Jahresversammlungen der Höhlenforscher in den einzelnen Ländern sich gerade dem problem des Karstwassers besonders widmeten. Am Ende dieses erstein Teiles meines Berichtes möchte ich noch folgendes unterstreichen: alle Eingriffe in den Karstraum verlangen auf der einen Seite langjährige, komplexe wissenschaftlich und technische Forschungen, auf der anderen Seite bedcutet aber der Karstraum ein schweres ökonomisch-soziologisches Problem. Relativ armes Karstland muß neben den Fragen der Energie auch der Nahrungserzeugung volle Aufmerksamkeut widmen.

Nach dem Vorschlag von V. Caumartin arbeitet im Rahmen unserer Kommission eine Subkommission für wissenschaftliche Forschung des Höhlenschutzes, die schon einige Erfolge erreichte. Der Vorschlag, unter der Mitarbeit aller Mitglieder der UIS, eine Karte der typischen Karstlandschaften der Welt auszuarbeiten blieb aber nur auf dem Papier.

Der zweite Teil meines Berichtes bezieht sich auch den Weltkatalog der Schauhöhlen.

Bekanntlich gabe schon der 4. Internationale Kongreß in Ljubljana 1965 die Anregung zu einer Übersicht der Schauhöhlen der Welt. Der 6. Kongreß in Olomous gab eine Definition einer Schauhöhle und faßte dabei den Beschluß auf Grund eines Fragebogens eine Liste der Schauhöhlen der Welt aufzustellen. Bis zur Arbeitstagung auf der Schönbergalpe in Obertraum im Mai 1975 sind 107 der einzelnen Fragebögen eingelaufen. Bis zum Kongreß in Sheffield aber 173: Südafrika, Österreich, Australien, Bulgarien, Groß-Britannien, Griechenland, Italien, Neusoeland, Holland, Tschechoslowakei, Schweiz und Jogoslawien. Nachträglich bekamen wir auch die Angaben über skandinavische Höhlen.

An dieser Stelle müssen wir unterstreichen, daß trotz allen Aufforderungen in der Zeitschrift "Die Höhle" und im "Bulletin-UIS", kein weiteres Material eingelaufen ist. In manchen Ländern fühlt sich niemand verantwortlich, in manchen Ländern weigern sich zu geben. Nach Trimmel dürfte auf der Welt 650 Schauhöhlen geben. Davon allein in Europa 358. Bei der Sitzung der Kommission ist es nötig festzustellen, welche Person im Lande für das Ausfüllen der Fregebögen über die Schauhöhlen verantwortlich ist. Inwieferne das nicht möglich ist, wird die Kommission gezwungen sein, verschiedene Publikationen und Prospekte des jeweiligen Landes zu berücksichtigen. Auf diese Weise werden wir aber ein heterogenes Material für den Katalog bekommen. Es muß betont werden, daß ein solcher Katalog im Interesse jeden Landes liegt und bedeutet nicht nur die erstklassige Werbung für den Höhlentourismus, sondern auch für die Wirtschaft und die Wissenschaft.

In Verbindung mit den Schauhöhlen ist am 10. June 1980 ein Vorschlag seitens der "Cave Research Foundation" in Washington eingelangt, die Mammoth-Cave in Kentucky als "Weltschauhöhle" auszurufen. Vielleicht wäre es wünschenswert, im Rahmen des Katalogs eine Liste der Weltschauhöhlen von alter Tradition, besonderer Schönheit und starkem Tourismus aufzustellen. Die Ausrufung sollte dann im Rahmen des 8. Kongresses in Amerika stattfinden. In dieser Verbindung muß ich berichten, daß unsere Kommission anläßlich der Feier des 160. Jubiläums der Höhle von Postojna im Jahre 1979 und 1980 zwei international Symposien organisiert hat. Das erste wurde der wissenschaftlichen Fotodokumentation des Karstes und der Höhlen gewidmet, das zweite aber brachte interessante Vorträge über die Rolle der Höhle von Postojna in der wissenshaftlichen und touristischen Hinsicht. Die Höhle von Postojna war einer der ersten Schauhöhlenbetriebe, der allen anderen Schauhöhlen in Europa bei der Höhlenerschließung als Muster diente.

Von 20, bis 22. März 1981 organisierte Gemeinde Borgio Verezzi, "Internationale Tagung über die Schauhöhlen", bei welchem in etwa 40 Referaten die Themen über wissenschaftliche, technische und ökonomische Aspekte der Schauhöhlen erörtert werden. Bei dieser Gelegenheit hat auch die Kommission für Karstschutz und Schauhöhlen im Rahmen UIS eine Sitzung der Delegierten der Kommission gehalten. Dabei wurden verschiedene Probleme des Schauhöhlenwesens vorgetragen.

The Cavernicolous Fauna of Ohio
Part I: Preliminary Report

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Abstract

The fauna of the caves and rock shelters of Ohio is represented by 59 species of invertebrates and 38 species of vertebrates. Only four species (4%) are troglobites (obligatory cavernicoles) and the remaining organisms are categorized by troglophiles (15%), trgloxenes (52%), and accidentals (29%). Data have been analyzed from 68 caves in 17 counties. Taxa represented and identified to date are (numbers refer to species): snails (3), clitellates (1), crustaceans (15), centipedes (4), insects (29), arachnids (7), amphibians (13), repitiles (4), birds (2), and mammals (19).

The bedrock strata of Ohio are composed of sequences of Palaeozoic rocks ranging in age from Ordovician to Permian. The Cincinnati Arch is one of the dominant structural features, consequently the older Ordovician and Silurian limestones and dolomites surface to the west and the younger, thinner, and dissected limestones, shales, and sandstones are situated in the eastern part of the state. Only a few scattered, small caves occur in easter Ohio, the majority developed in sandstone. The limestone terrain of western Ohio is generally inconspicuous and only intermittently caverniferous.

Tertiary drainage patterns were much different from those of the present due to extensive glacial activity. Thus, surface and subsurface dispersal of cavernicoles has been greatly disrupted and a multiple origin is postulated for both terrestrial and acquatic forms, resulting from a complex sequence of events during and following the Pleistocene.

Considerable field work is required and numerous taxa remain to be analyzed prior to a full understanding of Ohio's cave fauna.

Zusammenfassung

Die Fauna in den Hoehlen und Felseinbuchtungen des Staates Ohio weisen 59 Arten von wirdbellosen und 38 Arten von Wirbeltieren auf. Nur gerade vier Arten gehoeren zur Gattung der Troglobionten (4%), die restlichen Organismen fallen unter die folgenden Gattungen: Troglophile (15%), Trogloxene (52%), und Zufaellige (29%). Die vorliegenden, analysierten Daten stammen von 68 Hoehlen, verteilt ueber 17 Landkreise; und die bis heute aufgegundenen, identifizierten Taxa verteilen sich wie folgt (die Ziffern beziehen sich auf die Arten): Schnecken (3), Guertelwuermer (1), Krustentiere (15), Tausendfuesser (4), Insekten (29), Spinnentiere (7), Amphibien (13), Voegel (2), Reptilien (4), und Saugetiere (19).

Der Felsuntergrund im Staat Ohio besteht aus Schichtfolgen palaeozoischen Gesteins, das erdgeschichtlich in der Periode zwischen Ordovizium und Perm anzusiedeln ist. Die Cincinnati Woelbung (Cincinnati Arch) ist eine der dominierenden strukturellen Erscheinungen: die aelteren, ordovizischen und permischen Kalksteinund Dolomitsteinformationen sind im Westen zu finden, und die juengeren, duenneren und zersetzten Kalkstein-, Schiefer-, und Sandsteinformationen erscheinen im Osten des Staates. Hier gibt es nur vereinzelte, kleinere Hoehlen, -meistens in Sandstein entstanden. Der Kalkstein im Westen Ohios ist unauffaellig und nur an wenigen Orten mit Hoehlen durchsetzt.

Infolge der ausgedehnten Gletschertaetigkeit waren die Entwaesserungsnetze wesentlich verschieden von den heutigen, wodurch die Verbreitung der kavernicolen Fauna, ueber und unter der Erdoberflaeche, grossenteils unterbrochen wurde. Und man nimmt an, dass die terrestrischen wie die aquatischen Formen mehrfachen Ursprungs sind, dies aufgrund verschiedener, komplexer Ereignisfolgen, waehrend des Pleistozaens und hernach.

Es muss noch viel Feldforschung geleistet werden und zahlreiche Taxa muessen noch analysiert werden, um Ohios Hoehlenfauna voll erfassen zu koennen.

Introduction

Scattered references have appeared in the literature concerning the fauna of Ohio caves (see Hobbs, 1981); however, no analyzed summaries are available for species composition, distribution and abundance of Ohio's cavernicoles.

This preliminary report is the result of extensive field work since 1978 in various parts of the state (both glaciated and unglaciated regions) and includes a list of caves from which collections have been made (Table I) and a summary of Ohio cave invertebrates and vertebrates by taxonomic group (Table II). Included in these lists are fauna reported by previous workers as well as those collected since 1978. A number of Ohio "caves" are not of biospeleological-habitat significance, but, nevertheless, are included in this report.

Table I
Ohio Caves From Which Faunal Collections Have Been Made

County	Cave
Adams	1. Black Run
	2. Cave Hill
	3. Cedar Fork
	4. Davis State Memorial
	5. Devil's Den
	6. Fern
	7. Freeland's
	8. Hawkin's
	9. Lost Pack
	10. Morrison's
	11. Preston I
	12. Preston II
	13. Preston III
	14. Stanbury
	15. Stout Run
	16. Waggoner Ripple
Clark	17. Ferncliff
	18. Keith's Fracture
Delaware	19. Olentangy Indian
Franklin	20. Snow
	21. South Indian Run
Gallia	22. Alum
	23. Bandy's
	24. Carter
	25. Double
	26. Saltpeter
Geauga	27. Chesterland
Greene	28. Spider
Highland	29. Dry
	30. Hillsboro
	31. Kessler's
	32. Lawrie
	33. "Seven"
Hocking	34. Ash
	35. Bat
	36. Clear Creek
	37. Old Man's
	38. Rock House
	39. Saltpeter
Jackson	40. Canter's
Meigs	41. Bennet
	42. BunkerHill
	43. Horse
	44. Partlow
	45. Pencil
	46. Vineyard
	47. Warner

Table I continued

County	Cave
Miami	48. Painter Creek
	49. Thompson
Ottawa	50. Coil's
	51. Crystal's
	52. Duff's I
	53. Kindt's I
	54. Mammoth
	55. Sky Inn
	56. Victory
Pike	57. Cave near Byington
	58. Frost
	59. Sunfish Creek
Rose	60. Buckskin I
	61. Buckskin II
	62. Reif's
	63. Skull
	64. Trimmer's
Seneca	65. Seneca
Wyandot	66. Fredritt Pit
	67. Indian Trail
	68. Underground River

Methods

Sixty-eight caves in 17 counties have been sampled, most by direct hand collecting. In addition to this method, pit fall traps baited with various materials have been employed and Berlese extractions of leaf litter and other organic matter removed from caves were made. Many of the caves received repeated visits during different seasons. A total of 97 species has been identified.

Geology

Ohio is divided into three physiographic provinces: the Central Lowland to the west, the Interior Low Plateau (a small region in the south central part of the state), and the Appalachian Plateau to the east. The caves are foremd in Palaeozoic limestones, sandstones, and conglomerates ranging in age from Ordovician to Devonian. The limestone terrain of western Ohio is generally inconspicuous and only intermittently caverniferous. The Cincinnati Arch (anticline) is the dominant structural feature in the geology of Ohio (Carman, 1946). This long, north-south upward fold has its axis extending through western Ohio from immediately east of Cincinnati to the western part of Lake Erie. This broad fold dips gently to the east and west (approximately 12m per 1.7km) with the older Ordovician and Silurian rocks surfacing along the axis of the anticline. These older systems dip off to lower levels in the east with successively higher (and younger) systems appearing at the surface. To the west of the axis the same relations exist, however, this occurs largely west of the Indiana-Ohio state boundary. Figure 1 is a spot map indicating the location of each cave referred to in Table I.

Faunal Evolution and Dispersal

An overview of the history of the geology, climate, and topography changes that have occurred in central North America during the Tertiary and Quaternary is presented in order to better understand present faunal distributions in Ohio caves. Detailed descriptions of pre- and post-glacial dynamics can be found in Stout, Ver Steeg, and Lamb, 1943; Wayne, 1952, 1967' Coffey, 1958; Goldthwait, 1959; numerous chapters in Wright and Frey, 1965; Dorf, 1970; and Teller, 1973. Much of this discussion is an outgrowth of the ideas presented by Krekeler (1973) and Peck and Lewis (1978) and is in agreement with the theory that the origin of many of the troglobitic and phreatic faunas of Illinois, Indiana, and the few specialized cavernicoles of southwest Ohio can be traced to the Appalachians.

During the Tertiary the main pre-glacial drainage was the Teays River (and associated tributaries). This large stream system headed in the Appalachians and the Teays River proper flowed west across central Ohio, Indiana, and Illinois to the Mississippi Embayment (Fig. 2). This provided a corridor for the dispersal of aquatic forms and was not a barrier for terrestrial forms to enter Ohio from the south but did separate the southern and northern cave regions of the state. The main tributaries to the Teays River in south-central northern cave regions of the state. The main tributaries to the Teays River in south-central and southwestern Ohio were the Old Kentucky, Manchester, and Old Licking River (Figure 2). These were meandering streams that were incised to a depth of 30 to 60m below the upland level and Teller (1973) indicated the bedload carried by these streams had a distinctly southern source. Thus, these tributaries provided a direct corrider into Ohio from the south and terrestrial invertebrates could move north into Ohio withou encountering water barriers. At this time the Ohio River was only a minor stream heading in southern Indiana and draining westward to the Mississippi Valley.

During the Teryiary, forests were continuous across mid-latitudes of North America and these conditions would certainly have been favorable for the surface dispersal of the ancestors of terrestrial cave fauna (Barr, 1968). During mid- and late-Tertiary, cooling and drying disrupted these forests following the uplift of the Rocky Mountains and the formation of the Great Plains grassland (Dorf, 1970).

The aquatic cave faunas demonstrate varying levels of morphological adaptations, suggesting differing times of groundwater invasion. Caecidotea stygia Packard shows the greates degree of adaptation, lacking both pigment and eyes. Gammarus minus Say (Form III - see Holsinger and Culver, 1970) has greatly reduced eyes, and Lirceus fontinalis Rafinesque shows none of the morphological adaptations characteristic of specialized cavernicoles, indicating a more recent invasion of subterranean waters. If ancestors of any of the species were epigean at this time, surface dispersal would have been possible. If any were hypogean, the presence of continuous limestones and the ability of most acquatic crustaceans to move through phreatic interstices allowed for movement into the area (the presence of Caecidotea stygia and Gammarus minus in non-cave areas of southwestern Ohio gives credence to this theory - see Beckett et al., 1977; Bowman and Beckett, 1978; Hobbs, 1980.

Table II
Numerical Distribution of Ohio Cavernicoles by Taxonomic Group

Taxonomic Group	Number of Species
Annelida	
Oligochaeta	1+
Mollusca	
Gastropoda	3
Crustacea	
Amphipoda	3
Isopoda	
Aquatic	3
Terrestrial	8
Decapoda	1
Chilopoda	4
Insects	
Collembola	5
Thysanura	1
Ephemeroptera	1
Orthoptera	9
Plecopters	1
Hemipters	1
Coleoptera	2
Trichoptera	2
Lepidoptera	2
Diptera	5
Arachnida	
Pseudoscorpionida	3
Opiliones	2
Araneae	2
Amphibia	
Urodela	9
Anura	4
Reptilia	
Squamata	4
Aves	2
Mammalia	
Chiroptera	4
Lagomorpha	1
Rodentia	14

Pleistocene conditions remained favorable for the northward dispersal of invertebrates until the glacial advances. Although there are differing opinions concerning when the Teays River Valley was buried in central Indiana and Ohio and when the Ohio River became a major drainage for the glaciers, it seems certain that it occurred in pre-Illinoian time (probably at the time of the Kansan Glacier). The net result from the glacial covering was the establishment of a new west-flowing, deeply entrenched Ohio River extending from western Pennsylvania into southern Illinois by the Yarmouthan Interglacial (much of the present Ohio River course then being established). Populations of various terrestrial and acquatic species were thus isolated from populations to the south by the Ohio River barrier. Krekeler (1973:80) suggests that the ancestors of the troglobitic carabids Pseudanophthalmus ohioensis Krekeler and P. krameri Krekeler "must have moved between Kentucky and Indiana-Ohio prior to the Kansan glacial advance. Such movement could have been across the small pre-Kansan Ohio River and/or by way of the divide between the headwaters of the pre-Kansan Ohio (probably just east of Madison, Ind.) and the Teays River."

The fauna of the region undoubtedly migrated ahead of the glacier fronts to icefree areas to the south and/or west. By the Sangamon Interglacial, minor drainage changes had occurred and the course of flow for the Ohio River was essentially the same as it is today and the climate was warner and drier. This initiated invasion of caves by species whose surface habitats were deteriorating, ultimately resulting in epigean populations becoming extinct, and leaving cave populations geographically, and thus genetically, isolated. Gradual adaptations to caves occurred and species made transitions from trogloxenes to troglophiles and to troglobites. The majority of caves were undoubtedly crushed, filled, and/or buried by glacial dirft, only a small number in the southcentral part of the state (e.g., in Adams County) probably were available for colonization (as the Sangamon advanced, surface streams downcut the glacial plain and additional caves were excavated).

The advance of the Wisconsin Glacier and associated climate fluctuations forced most of the fauna to remain in the region below the Illinoian glacial boundary. Some species may have expanded their ranges along the drainages near the Ohio River and it is even possible that species, such as Caecidotea stygia, immigrated eastward from Indiana into their present ranges in Ohio.

A compilation of Ohio cave inhabitants is shown in Table II. The majority of the fauna moved into the cave environment well after the Ohio River becamse a major stream. The paucity of troglobite in this area is the direct result of repeated glacial advanced and associated climatic changes, which not only destroyed cave habitats, but forced either the extinction of species or a southerly migration of fauna from the region. The greatest species richness of cavernicoles occurs south of the Illinoian glacial boundary and it is probable that caves here served as glacial refugia for some species. Much additional field work is required prior to a full understanding of the evolution, dispersal, and distribution of Ohio's cavernicoles.

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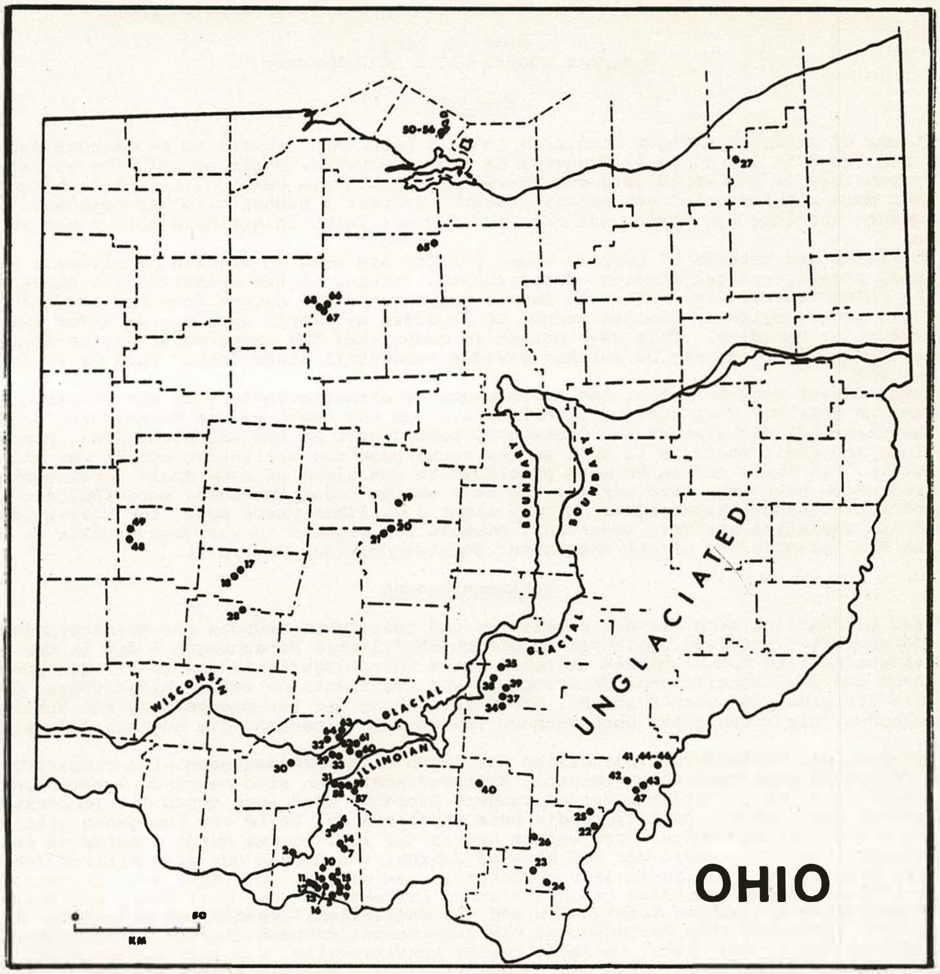

Figure 1: Map of Ohio Showing Location of Caves from Which Faunal Collections Have Been Taken.

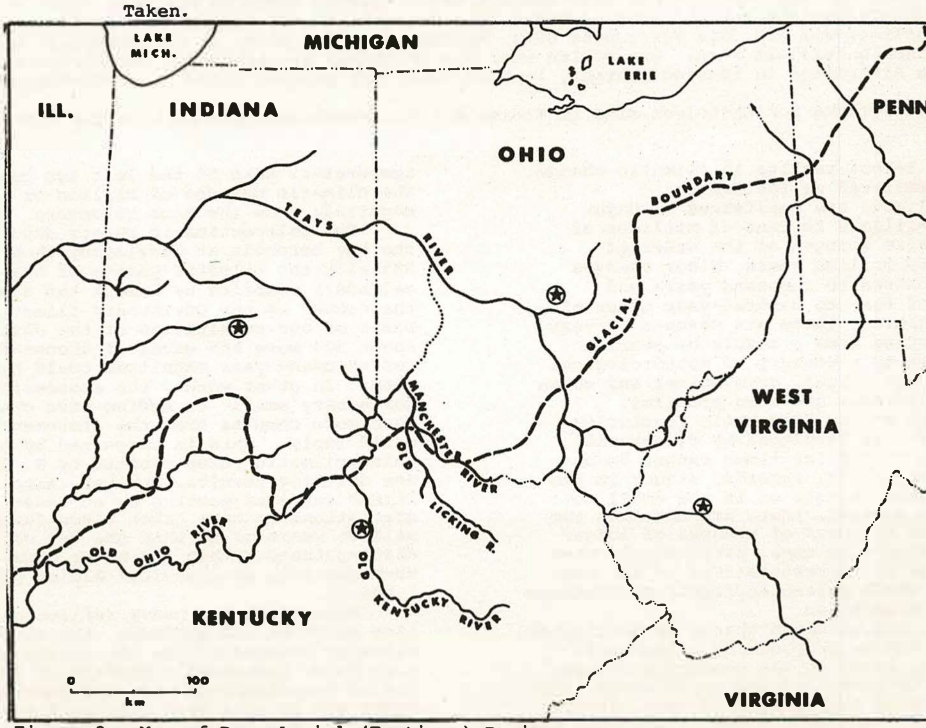

Figure 2: Map of Pre-glacial (Tertiary) Drainage In Ohio and Environs (after Thornbury, 1969 and Teller, 1973).

Quaternary Climatic Change and Speleostratigraphic Development

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Abstract

The problems of climatic changes discussed in this paper are similar to those considered by G. Bacsák in his study published in the Időjárás/Hungary/ in 1940. However, while in 1940 the secualr changes in the orbital parameters of the earth were considered to be the main cuase of climatic changes, today the results of much more sophisticated geonomical research suggest a number of other reasons. The results of the most modern absolute age dating methods are of great value in giving a more thorough analysis of these reasons.

The major fields and methods of geonomy whose results are used in studies of climatic changes are: Pollen analysis, stratigraphical studies of continental strata, of the Greenland ice sheet and of tropical ocean bed, the CLIMAP-curve, etc. The main result deducted by the author from his studies is that, contrary to the old ideas, climatic changes cannot be regarded as simple wave motion - for example of the yearly temperature or humidity. This wave motion is composite: The large waves may be divided into shorter partial waves, these, in turn, may be further divided into still finer ones. This is valid also for the climate of our age.

Another significant result is that the large waves of climatic changes in the Quaternary period were much more numerous than has been thought hitherto, e.g. on the basis of the Milankovic, Bacsák theory. Therefore, the classical division of the Quaternary period such as the Danubian, Günz, Mindel, Riss, Würm glaciations and their stadials as well as the terms used for the interglacials may all well be omitted in future. It turns out to be more practical to use names of some small local features, such as Brörup, Alleród which have been used earlier, as well as the names Denekamp, Hengelon, etc. The oldest pleistocene climatic changes happened in Hungary about 3 millions years ago. The cave evidences, speleostratas, with its varieties are very important, because its sequenc in the cave-profile is the same asymmetric, as the irregularity of the continetal stratas one (See Figure 1).

Zusammenfassung

Der Aufstaz beschäftigt sich mit der räumlichen und zeitlichen Ordnung der Klimaveränderungen im Quartär und entwickelt - aufgrund breiterer erdwissenschaftlicher Forschungen - die in der 40-er und 50-er Jahren entstandene Arbeite von G. Bacsák weiter. Diese Forschungsrichtungen sind: die geologische, paleontologische und pollenanalytische Untersuchung von kontinentalen Beckenablagerungen, die Einbeziehung des Bohrprofils der grönländischen Eisdecke, die Untersuchung der Zusammensetzung von Schlickschichten auf dem Ozeansboden, die korreletive Untersuchung von Höhlensedimenten, die Angaben des Paleomagnetismus, usw.

Die Folgerungen des Verfassers hinsichtlich der jugen Klimaveränderungen sind neauartig. Anstatt der von früheren Forschern angenommenen rhytmischen Klimaveränderungen sind mehrfach zusammengesetzte Wellen aufgetreten, z.B. im Sinne thermischer Veränderungen. Dasselbe wird auch durch die Temperaturschwankungen der beiden letzten Jahrhunderte bestätigt, die beim Studieren der Serie von homogenen mittleren jährlichen Temperaturwerten ersichtlich werden. Die untere Grenze des Pleistozäns wurde - aufgrund der grossen Klimaveränderungen - von Milankovic vor 600 tausend Jahren, von Bacsák vor eine Million Jahr gezogen. Zur Zeit kann diese Grenze auf 3 Millionen Jahr zurückgeschoben werden. Die Zahl sehr starker Klimaschwankungen - mit den dazwischenliegenden Perioden gegensätzlichen Charakters - war viel mehr, als die, aus der früheren Fachliteratur bekannten 4-5 grosse Vereisungen und die dazwischenliegenden interglazialen Perioden, bzw, viel mehr, als die 9-10 interstadialen Perioden und die dazwischenliegenden starken Abkühlungsperioden.

Die Beobachtung feiner Schichten, im Falle sowohl kontinentaler, wie auch Meeresablagerungsschichten und auch von Eisschichten, zeugt davon, dass den Ablagerungen, die unter milderen Klimaverhältnissen entstanden sind, oft Anlagerungen mit Kiskordanz folgen, die während starker Abkühlung entstanden sind. Umgekehrt, ist der Übergang zwischen Ablagerungen kälterer und der nachfolgenden wärmeren Perioden nicht so scharf. Wegen der Klimaveränderungen scheint es nicht begündet, die Nomenklatur für die feinere Gliederung des Pleistozäns aufrechtzuerhalten, wie z.B. die Verisungen Günz, Mindel, Riss und Würm, da sie eventuell auch räumlich nicht charakteristisch entwickelt sich. Man sollte eher die örtlichen Bezeichnungen der kleineren Perioden gebrauchen/ mit absoluten Alterdaten in tausend Jahren/, in Verbindung mit paleotologischen, archeologischen, usw. Benennungen.

Die Speleologische Schichtfolgen sind im Kreise der Klimaveränderungen ähnlich die wichtigste Dokumente (Figure 1).

The author's latest results in climatic change studies can be summarized as follows.

Changes in climate are manifested in major changes spanning millions to tens of millions of years, in medium-size changes of the order of hundred thousand to million years, minor changes of the order of hundred to thousand years and smallest changes of ten- to hundred-year order of magnitude. In addition, there are changes of very short duration varying from a couple of years to ten years, as shown by a century of meteorological data files and by geological, cryological and ocean bottom drilling evidence, and cave profiles.

The marked and rather systematic regularity implied by the theories developed by Milanković, Bacsák and Woerkom in earlier times cannot be observed in the geoshitorical records, either in the major or medium-sized changes or in the small to smallest ones. In general, there are not even two equal waves, either in terms of changes of longer duration or in medium-size ones, particularly when both the assemblage of representatives of the one-time bios and the whole palaeogeographic environment are taken into consideration.

Consequently, the climatic change is manifested, as opposed to the theory proposed by Milanković, Bacsák and Woerkom, based on the geometric changes of Earth's orbit, by so-called composite waves, and not by a succession of simple warm or cool climatic waves. Accordingly, the basic waves of greatest size are superimposed by second-order ones, the latter by third-order ones, and so on, every consecutive wave being of gradually smaller size, similarly to the case of the waves resulting from the homogeneous temperature sets of the last two centuries (Figure 4). The climatic changes of million or ten million order of magnitude show the same structure.

The palaeoclimatic phases deduceable from the log of the key borehole at Jászladány show an agreement of only 35% with the climatic phases of the Quaternary climatic calendars compiled by Bacsák and Woerkom. On top of that, the number of the Quaternary climatic waves is, on the basis of our revaluation of the Jászladány bore log, by about 50% more and waves of thousand, or sometimes even ten thousand-year magnitude could be identified among them. In other words, the succession order of the Quaternary small- to medium-wave changes in climate is much more complex than the aforementioned theories would imply. This is suggested by the behavior of the palaeoclimatic curve plotted by N. Shcackleton on deep-sea drilling results, further, also by that of the KLIMAP curve suggesting by at least twice more major glaciations to have taken place during the last one million years or so than the 8-9 waves of ice expansion distinguished within the major Günz, Mindel, Riss and Würm glacials of classical Alpine glaciology (Figures 1 and 2).

Because of the heavy reflection of thermal radiation by sheet ice surfaces, the so called feedback, the climatic changes of the ice fields appear--as suggested e.g. by W. Dansgaard's profile of drilling into the ice of Greenland--to have had considerably greater amplitudes and to have been much more complicated than it may been the case in nonglaciated than it may have been the case in nonglaciated areas, compare, for instance, the evidence of Greenland with A. Ronái's results from Jásladany.

The climatic changes of composite wave pattern characteristic of higher latitudes can be equally well detected in the tropical seas, the only difference being that the amplitudes, i.e. the fluctuations of water surface termperature, are smaller, as suggested, e.g., by drilling results from Greenland, Jászladány and by the drilling log from tropical sea environments studied by N. Shackleton.

Quaternary chronology reckoned with only four (or 8-8) major glacials which were distinguised by A. Penck and Eberl, respectively. However, according to the aforementioned borelogs, much more than 8-9 waves of intensive cold must have occurred which, in proper geographical environments (mainly in Antarctica, Greenland and in high mountains) could even result, though not everywhere at once, in glaciation. At mean latitudes even very short, 1 or 2 thousand year-long, chronologically isolated glaciations could be identified, e.g. 89 thousand years and 115 thousand years ago, in the Rocky Mountains, or, on the contrary, similarly short-lived hot spells, as e.g. the Mende Top or Mende Base soil horizons within the young loess sequences in Hungary.

Therefore, the terms Würm, Riss, Mindel, Günz, Danubian, etc. can be left in future use only as names of Quaternary stages, just by virtue of tradition and convention with exact absolute age indication, but they cannot be used as names of glacials. Their boundaries, when traced back in Quaternary history, might be successively 0.1, 0.3, 0.5, 1.0 and 1.5 million years to be followed in age by the Eopleistocene. The previous nomenclature of the interglacials and interstadials, e.g. Riss-Würm, etc., in turn, can be completely abandoned. Phase terms referring to minor independent time spans, e.g. Dryas-III, Loch Lomond cold phase, or icy phase or, on the contrary, the Alleröd mild phase, should, as expressions of the time concerned, be preserved.

Of the lithologic and cryologic bore logs, only the sediment of permanent sea bottoms and the complexes of continental basins affected by continuous subsidence and accumulation, further the fine layers of new ice increments in ice sheets may yield continuous climatic sequences and calendary successions, while other terrestrial accumulations are unsuitable for this. Of the latter it is maybe the cave sediments that may provide approximately complete Quaternary paleoclimatic chronologies for single, rather short Quaternary stages, and from this point of view, they are more reliable than the loess sequences that are for the most part very discontinuous.

The palaeoclimate had a composite wave pattern already in the early parts of the history of the Earth, as e.g. the ancient Permian, Ordovician and Eocambrian-Algonkian glaciations. The irregularity of the chronological succession of the very early glacials, the great fluctuations in their time spans and the dissimilar division of the single glacials into interglacials are facts that do not corroborate the palaeoclimatological model based on the secular changes of Earthäs orbital elements.

As a confirmation of E.Vadasz' explanation (see: "Earth's History and Evolution, 1957" only in Hungarian) the causes of the climatic changes manifesting themselves in more or less irregular phases or waves should be searched in increasing measure in different directions and realms such as cosmic, solar, solar system, Earth surface and terrestrial.

Single short-lived subwaves of a time span of hundred-year order can begin, both in the postive or the negative sense, practically at any time. Retrospectively, such rapid and sudden changes of a couple of thousand year duration into very cool climate during the last quarter of a million years of the Quaternary recurred about 13 to 14 times.

ontinued detecting of climate changes in the geohistorical past is conceivable and feasible provided that interdisciplinary efforts and methods are made at an increasing rate and the results of other disciplines are taken into consideration.

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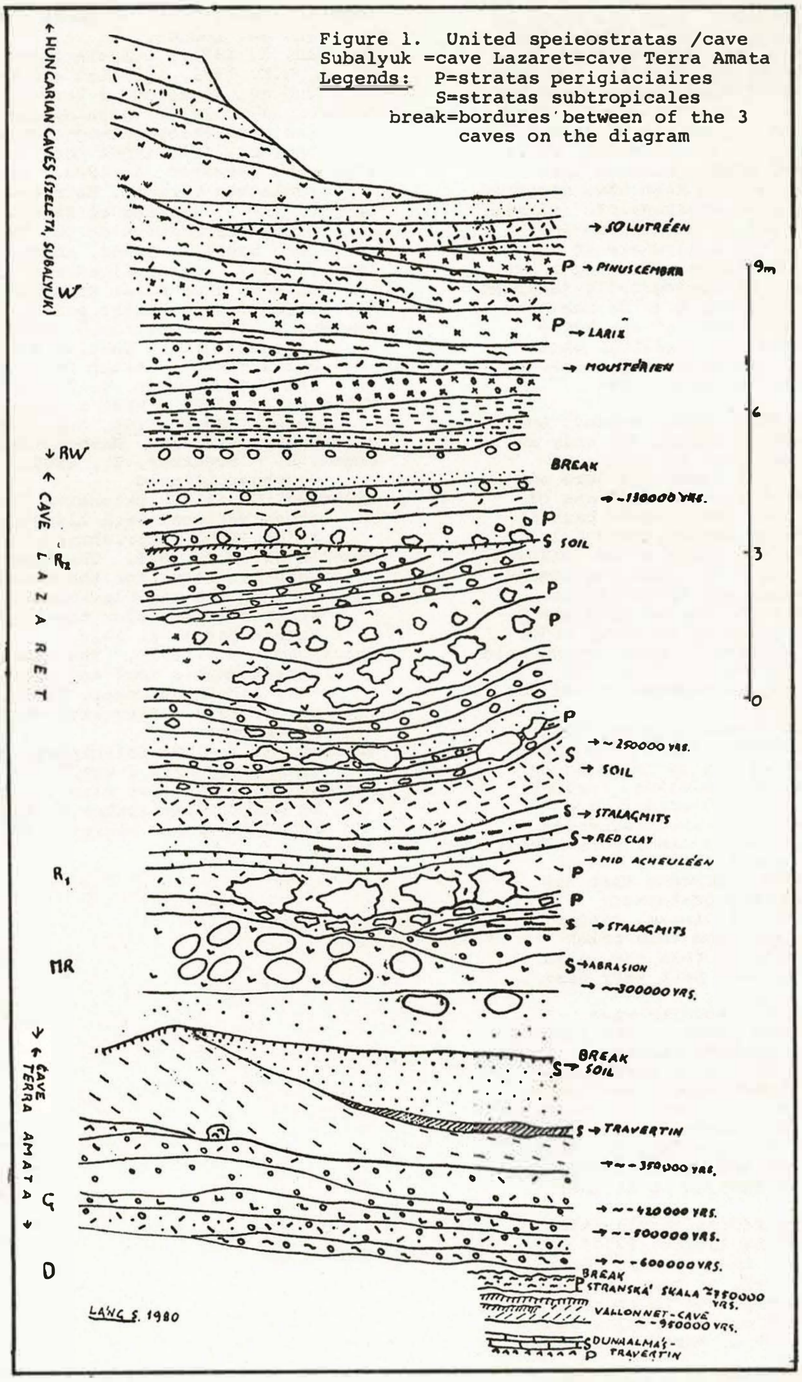

Figure 1. United speieostratas /cave Subalyuk =cave Lazaret=cave Terra Amata
Legends: P=stratas perigiaciaires
S=stratas subtropicales
break=bordures between of the 3 caves on the diagram

Demographic Characteristics of Carabid Cave Beetles

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Abstract

Populations of the troglobitic carabid beetles Neaphaenops tellkampfi, Pseudanophthalmus menetriesi and P. pubescens were studied in several caves in west central Kentucky. Data were collected on adult population size, teneral occurrence and sex ratio for all populations of these sympatric species. Preserved collections, made periodically from each population, were returned to the laboratory where the female beetles were dissected to obtain estimates of fertility and clutch size.

Pseudanophthalmus menetriesi and P. pubescens are nearly equal in adult body size and are both predators on small invertebrate species. Although both species have average clutch sizes of approximately 4.+ eggs/female, there are significant differences between the species in the timing of reproduction. The P. menetriesi populations were observed to have 80-100% of the females gravid at essentially all times of the year. Gravid female P. pubescens were observed only during the fall and winter months in P. menetriesi and in the spring months in P. pubescens.

Neaphaenops tellkampfi has a larger adult body size and a wider distribution than either Pseudanophthalmus species. The demographic characteristics of the nominate subspecies N. t. tellkampfi are greatly influenced by the prey availability in which cave cricket (Hadenaoecus subterraneus) eggs and nymphs are the primary prey, show differences in fertility and sex ratio from N.t. tellkampfi populations in lower level or near entrance habitats. Demographic patterns in the ~~three~~ peripheral subspecies N.t. henroti, N.t. meridionalis and N.t. viator have also been examined.

Zusammenfassung

Populationen der troglobitischen Carabiden Neaphaenops tellkampfi, Pseudanophthalmus menetriesi, und P. pubescens wurden in verschiedenen Hohlen des westlichen Zentral-Kentucky untersucht. Es wurden Daten über die Grösse der Populationen erwachsener Tiere, Vorkommen von Jungtieren und das zahlenässig Verhältnis der Geschlechter für alle Regelmässig von jeder Populationen gesammelte Exemplare wurden in das Labor überführt und die weiblichen Käfer seziert, um abgeschätzte Werte für die Fruchtbarkeit und die Gelegegrosse zu erhalten.

Pseudanophthalmus menetriesi und P. pubescens sind nahezu gleich in der Körpergrösse erwachsener Tiere und leben beide räuberisch von kleinen Invertebraten. Obwohl beide Atten eine durschschnittliche Gelegegr-sse von 4 Eiern/Weibchen haben, gibt es in der Jahreszeitabhängigkeit der Reproducktion signifikante Unterschiede zwischen den Arten. Es wurde beobachtet, dass in P. menetriesi Populationen zu praktisch allen Jahreszeiten 80-100% der Weibchen fruchtbar waren. Fruchtbare Weibchen von P. pubescens wurden dagegen nur während der Herbst- und Wintermonate beobachtet. Ausgewachsene Jungtiere traten bei P. menetriesi im Herbst, bei P. pubescens im Früchjahr auf.

Neaphaenops tellkampfi übertrifft beide Pseudanophthalmus Arten in der Körpergrösse erwachsener Tiere und ist weiter verbreitet. Die demographischen Charakteristiker der Unterart N.t. tellkampfi werden weitgehend von der lokalen Verfügbarkeit von Beute bestimmt. Populationen in höheren Lagen der Höhlen, wo Eier und Nymphen der Höhlengrille (Hadenoecus subterraneus) die hauptsüchliche Beute darstellen, zeigen Unterschiede in der Fruchtbarkeit und im Zahlenverhültnis der Geschlechter im Vergleich zu Populationen in tieferen Lagen und in der Nähe von Eingängen. Die demographischen Merkmale der drei peripheren Unterarten N.t. henroti, N.t. meridionalis und N.t. viator wurden abenfalls untersucht.

The most abundant predators in the terrestrial cave communities of west central Kentucky belong to the carabid tribe trechini. These are blind cave restricted (i.e., troglobitic) species which are in fact the top predators in their communities. Pseudanophthalmus menetriesi, P. pubscens and Neaphaenops tellkampfi are three of the more frequently occurring species in caves in and around the area of Mammoth Cave National Park, Kentucky. Pseudanophthalmus menetriesi and P. pubescens are the ecologically most similar of the three species. They are nearly equal in adult body size (Barr, 1966) and are both predators on small invertebrate species (e.g., collembola, dipteran larvae, oligochaetes). Neaphaenops tellkampfi has a larger adult body size and is more widely distributed than either Pseudanophthalmus species (Barr, 1966, 1979). The preferred prey of N. tellkampfi are the eggs and nymphs of the common cave cricket Hadenoecus subterraneus, but N. tellkampfi will use alternative prey in the absence of cricket eggs and nymphs (Norton et al., 1975).

Method

During a four year period, five populations of N. tellkampfi, four populations of P. menetriesi and three populations of P. pubescens were studied in caves in and aroudn the area of Mammoth Cave National Park, Kentucky. Using visual census and pitfall trapping techniques, data were collected on adult population size, teneral occurrence and sex ratio for all populations of these sympatric species. Preserved collections (FAA solution, Knudsen, 1972), made periodically from each population were, returned to the laboratory where the female bettles were dissected to obtain estimates of fertility and clutch size.

The five caves which were selected for this study all lie near the center of the ranges of the three bettle species. Great Onyx and Parkeräs Caves are upper level passages and both contain extensive habitats with uncompated snad substrate. These are primary oviposition sites for H. subterraneus. Walnut Hill and Hanson's Caves are lower level passages, both of which contain active streams and are susceptible to occasionally severe flooding. Little Beauty Cave is a small upper level cave which contains a variety of substrate types. Some minor flooding can occur in this cave in winter and spring from seepage at the entrace. These five caves provide a good sample of the habitat heterogeneity which the carabid species face over their ranges.

Results and Discussion

All three carabid species occur in Hanson's, Walnut Hill and Parker's Caves. Permanent populations of N. tellkampfi and P. menetriesi were also observed in Little Beauty Cave. However, P. pubescens was absent in this habitat. The only carabid species occurring in the habitat studied in Great Onyx Cave is N. tellkampfi. This habitit is located approximately one kilometer from the cave entrance and is an extensive area of loose sand substrate in which cricket eggs and nymphs are the major, if not the sole, prey items.

All three species exhibited seasonal and some year to year fluctuations in poulation size. In the case of N. tellkampfi these fluctuations were the least severe in Great Onyx Cave. This population was the largest of the five N. tellkampfi populations studied.

One of the fertility parameters that was measured was the percentage of females in each collection which had mature eggs. The four P. menetriesi populations were observed to have 60-100% of the females carrying mature eggs at virtually all times of the year. By contrast, the P. pubescens populations in Hanson's and Walnut Hill Caves contained large proportions of fecund females only in the fall and early winter months (approx. September-January). At other times of year few, if any, females in these populations contained mature eggs. No gravid P. pubescens females were ever collected from Parker's Cave.

Neaphaenops tellkampfi populations, like P. menetriesi, contain a significant proportion of gravid females at all times of the year. There do appear to be differences from cave to cave in the size of this proportion, however. In Hanson's, Walnut Hill and Little Beauty Caves, 60% or more of the females carry mature eggs at almost all times of the year. In Parker's and Great Onyx Caves the proportion of gravid females is generally less than 60%.

Clutch size was determined for each species by dividing the total number of females that contained at least one mature egg. Clutch sizes of P. menetriesi and P. pubescens are not significantly different (Table 1).

Neaphaenops tellkampfi, however, posses an average clutch size which is significantly larger than those of P. mentriesi or P. pubescens by nearly a factor of two (Table 1).

Table 1

Tukey's HSB Comparison of Clutch Size Differences Between Carabid Species. Values Shown are Mean Number of Eggs Gravid Femal ± 1 SD.

P. menetriesi	P. pubescens	N. tellkampfi
3.98±1.04	3.99±1.58	7.56±2.59
	P <0.0.1	

The clutch size data were also analyzed for differences between populations of the same species. In the two caves in which gravid P. pubescens females were collected, there was no significant difference in clutch size using a t-test (P 0.05). Clutch size of P. menetriesi in Parker's ave is statistically smaller than clutch size in Walnut Hill Cave. However, there is a large amount of overlap in clutch size among the four caves sampled. Therefore, it is difficult to attribute any great significance to this one difference.

Neaphaenops tellkampfi populations show between cave differences in clutch size (Table 2) which are consistent with the between cave differences seen in the proportion of gravid females. Walnut Hill, Little Beauty and Hanson's Cave populations have larger clutch sizes than N. tellkampfi populations in Parker's and Great Onyx Caves. The only exception to this is a slight overlap in clutch size between Great Onyz and Walnut Hill Caves.

Table 2

Tukey's HSD comparison of Neaphaenops tellkampfi clutch size differences between caves. Values shown are mean number of eggs/gravid female ± 1 SD. Mean values not connected by the same line are significantly different (P=0.05).

Cave				
PARKER'S	GREAT ONYX	WALNUT HILL	LITTLE BEAUTY	HANSON'S
5.41±1.43	6.52±1.92	8.24±2.45	9.01±1.97	9.72±2.56

Neaphaenops tellkampfi shows between population differences in sex ratio (Table 3). In Great Onyx and Parker's Caves, the prime cricket egg habitats, N. tellkampfi populations have sex ratios of 1"1 or with significant female majorities. In Hanson's, Little Beauty and Walnut Hill Caves, N. tellkampfi populations have sex ratios biased toward male majorities.

Table 3

Sex ratios of the five Neaphaenops tellkampfi populations studied. Data were collected between 1973-1975.

CAVE	MALES	FEMALES	X^2
GREAT ONYX	1250	1575	37.39***
PARKER'S	481	431	2.74
LITTLE BEAUTY	232	159	13.63**
HANSON'S	452	207	91.08***
WALNUT HILL	202	158	5.38*

***=p<0.005 **=p<0.01 *=p<0.05

The differences in timing of reproduction observed between P. pubescens and P. menetriesi would appear to be due to dietary differences between the two species. Pseudanophthalmus pubescens is a more riparian species than P. menetriesi which occurs more frequently in upper level dry passages (McKinney, 1975; Van Zant et al., 1978). The reproductive patterns of each species were consistent among all populations observed. By contrast, N. tellkampfi appears to show two distinct life history strategies. It is plausible to suggest that these different life history patterns result from a difference in mortality factors among the habitats studied. Flooding, temperature and humidity depression, parasitism by fungi, and perhaps predation on carabid larvae are the most severe in Hanson's, Walnut Hill and Little Beauty Caves. These factors are less severe in the physically more stable and biologically more simplified environments of Parker's and Great Onyx Caves. The relative food abundance in the latter two caves, however, is undoubtedly less than that in Hanson's, Walnut Hill and Little Beauty Caves.

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Neue Genetische Probleme Bei Laughöhlen Nach Entdeckung Der Bedeutendsten Gipshöhle In Den Alpen

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Zussammenfassung

Die Entdeckung der größten Gipshöhle in den Alpen brachte vollständig jenen Formenschatz, der von Biese aus alten Gebirgen Mitteleuropas beschrieben wurde: Strenge Horizontalität, Laugdecken und Laugfacetten. Anders als dort liegt jedoch diese alpine Höhle in 1465 m Seehöhe in einem engen Gebirgstal mit großem Relief. Weder petrographisch noch morphologisch ist in dieser Position erklärlich, wiese die laugenden Höhlenbäche hier ebenfalls eine horizontale Höhle erzeugt haben: Das Gipslager reicht noch tief de Steilhang hinab und Anzeichen für ein genetisches Niveau sind nicht vorhanden. Deshalb wird die Hypothese aufgestellt, daß die Horizontalität auf ein dynamisches Gleichgewicht zwischen Laugung und Produktion von Laugrückständen zurückgeht. Diese Ansicht bietet gleichzeitig eine leichtere Erklärung der allgemein konstatierten Vielfalt der Höhlen und derselben Räume. Eine Durchrechnung der Lösungsbeträge hat ergeben, daß sich Gipshöhlen in sehr kurzer Zeit bilden und daß ihre Lebensdauer äußerst gering ist. Die rezent aktive Gipshöhle enthält kein Stehwasser, das bisher für die Entstehung von Laughöhlen im Vorfluterniveau ver antwortlich gemacht wurde. Vielmehr hängt die Raumbildung, die die Ausbildung der Laugdecken, der Laugfacetten und der Fließfacetten von Höhlenbächen ab. Diese Vorstellung hat neuerdings Völker vertreten.

Abstract

The discovery of the biggest gypsum-cave in the Alps brought here eactly the same collection of forms, as it was described formerly by Biese from caves in old parts of Central Europe: Exact horizontality, corrosion-ceilings and corrosion-facetts. But this alpine cave in 1465 m above sealevel exists - differently - in a narrow mountain-valley with big relief. Neither petrografically nor morphologically it can be explained in this position, how the corroding cave-brooks made also here a horizontal cave: The deposit of gypsum dips deeply further down the steep slope and any signs for a genetic niveau do not exist. Therefore, the hypothesis is made, that dynamic equilibrium of corrosion and of the production of not-corroded residues as sediments is responsible for horizontality. This opinion simultaneously offers a more simple explanation for the normally seen multiplicity of levels of ceilings within the same caves and same galleries. A calculation of corroded amounts yields, that gypsum-caves develop in very short time and their span of life is very small. This active gypsum-cave holds no standing water (what was up to now made responsible for the origin of corrosional caves in the water-level). The development of galleries, of corrosion-ceilings, of corrosion-facets and of facetts appropriate limestone depends rather from cave-brooks. Voler stated this conception recently.

In einem steilen Seitental in Vorarlberg wurde die streng horizontal angelegte Trübbachhöhle entdeckt. Sie zieht sich vom Eingang in 1465 m Seehöhe in ein mächtiges Gipslager, das an der Oberfläche eindrucksvolle Dolinen trägt. Die drei kleinen Höhlenbäche, die sich erst nace dem Eingang vereinigen, stellen die Entwässerung dieses Versinkungsagebietes dar. Das Gipslager ist mindestens 100 m mächtig, morphologisch zeigt es sich als eine langgezogene Aufbuckelung im Hang. Es handelt sich um ziemlich unreinen, fein gebänderten Gips, nur an wenigen Stellen der Höhle sind einige Alabasterkugeln erkennbar.

Gips wird durch physikalische Lösung angelaugt, sodaß fast ohne Rücksicht auf geologische Strukturen im Gestein Lösungsformen entstehen, die dem Verbruch in hohem Maß ausgesetzt sind. Die laugung gent sehr rasch vor sich und das Karstwasser als Lösungsmittel kann große Mengen von Gips, nämlich bis zu 2g/l, mit sich führen. Wenn der vorerst anstehende Anhydrit im Knotakt mit Wasser vergipst, dann resultiert ein starker Quellungsdruck.

Da der Gips meist unrein ist, sammeln sich die Laugrückstände (überwiegend Tone und Sande), decken angelaugte Flächen ab und schützen sie vor weiterer Anlaugung.

Die leichte Löslichkeit bedingt, daß der Sättingungspunkt rasch erreicht wird. Das unterirdische Wasser fließt also bereits nach kurzer Strecke in gesättigtem Zustand und kann sich an der Höhlenbildung nicht beteiligen. Die Entstehung längerer Korrosionshöhlen im Gips ist demnach prinzipiell schwer vorstellbar.

Raumbeschreibung

Mit geringer Steigung, die dem natürlichen Gefälle der Höhlenbäche entspricht, reicht die Höhle mit zwei Armen in den Berg. Auch der kürzere Südgang ist auf seine ganze Länge von 60 m von einem klei nen Bach durchflossen, an etlichen Stellen wachsen an der Decke bis zu kubikmetergroße Laugrückstände heraus.

Auch der 359 m lange Hauptgang zeigt meist Raumbreiten um 4 m. Lediglich in hintersten Teil sind breit gespannte gewölbte Decken mit 8 - 10 m vorhanden. Neben Schottern bilden größen Sandlager die Höhlensohle, geschichtete Lehme mit sandigen Zwischenlagen stellen an seitlichen Positionen etwas höhere, vom Bach angenagte Sedimentlagen dar. Verstürtze sind an Klüfte gebunden, sowie an den Eingangsbereich, soweit die winterliche Frostzone zu reichen scheint. Unter den außergewöhnlichen alpinen morphologischen und klimatischen Bedingungen zeigt die Trübbachhöhle als Horizontalhöhle den gesamten Formenschatz des Laughöhlentyps, der vor allem vom Harz beschrieben ist.

Raumformen in Gipshöhlen

Laughöhlen zeigen auffallend eben Deckenflächen, die als Laugdecken bezeichnet werden und die auch unterhalb von Wandvorsprüngen im selben Profil mehrfach übereinander auftreten können. Ihr seitlicher Abschluß ist eine Hohlkehle, die in der Trübbachhöhle in den meisten Fallen 10 cm hoch ist, und von dieser springen unter Winkeln von 30 - 45° einheitliche Schrägen höhleneinwärte ein. Diese sich ofters lang hinziehenden schrägen Flächen werden als Laugfazetten bezeichnet. Nicht nur in der Trübbachhöhle sind sie in gleicher Neigung von lehmigem Sediment in einigen Zentimeter Mächtigkeit bedeckt. Auch die Laugfazetten können innerhalb des gleichen Profils mehrfach übereinander angeordnet sein.

In Laughöhlen sind überdies Fließfazetten beobachtet worden. Sie kommen in der Trübbachhöhle ausschließlich in Raumverengungen, die mit benachbarten Verstürzen in Zusammenhang stehen, vor.

Die Verstürze zeigen einen anderen Charakter als in Kalkhöhlen: Grobblockige Einbrüche treten zurück, das Blockwerk scheint vielmehr in vielen kleinen Einzelbrüchen mehr oder weniger knotinuierlich in den Raum zu kommen, wo es vom Höhlenbach schließlich wieder weggelaugt wird.

Über Laugdecken und Laugfazetten als typische Fromelemente von Gipshöhlen wurde bereits vielfach gearbeitet. K. Gripp setzt die Höhe der Laugdecke mit der Spiegelhöhe stehenden Wassers gleich. Kemp kommt zum gleichen Ergebnis, auch in seinem Konzept sind Laughöhlen nicht durch freifließende Gravitationsgerinne entstandden. Er rechnet bei der Versorgung mit Frischwasser vorwiegend mit vertikalem Wasserdurchsatz an Firstklüften. Mehrfache Laugdecken übereinander mußten dann allerdings mit verschiedenen Wasserständen und als Ergebnis von Verstellungen des Wasserspiegels durch tektonische Vorgänge oder der Höhe des Vorfluters gedeutet werden. Der häufige Befund, daß sich Laugdecken auch innerhalb benachbarter Höhlenteile kaum zu einheitlichen Niveaus zusammenfassen ließen, blieb ohne Erklürung. Biese führte die verschiedene Höhlenlage benachbarter Laugdecken folgerichtig auf die Wirkung lokaler Auslaugungstektonik zurück, ohne von einer genauen Bindung der Laughöhlen an den Vorfluter abzurücken, denn tatsächlich ist diese im Harz evident.

Allerdings sind daneben auch flach gewölbte Decken nicht nur in der Trübbachhöhle in enger Verbindung mit den flachen Laugdecken typisch, sondern auch in anderen Gipshöhlen. Biese läßt sie durch Verbruch aus Laugdecken hervorgehen, was mechanisch schwer vorstellbar ist. Denn ebene Decken, die in einem wenig widerstads fahigen Gestein verstürzen, würden zu eher steilen, domartigen Gewölban umgeformt werden. - Aus solchen weit gespannten Gewölbedecken wittern oft dünne Schalen vom Gipskörper ab, bilden aus der Decke gekrümmte Kulissen und bereiten sich zu blockigen Nachbrüchen vor. Biese bringt diese charakteristische Erscheinung mit dem Quelldruck bei der Umwandlung von Anhydrit in Gips in Zusammenhang. In diesem Fall müße die Vergipsung an der Höhlendecke auf eine dünne Gipshaut über Anhydrit beschränkt sein.

Die Erklärung der charakteristischen Laugfazetten steht mit der Erklärung der Laugdecken in untrennbaren Zusammenhang: Ihre Schräge wurde als Abbildung der Schichtung des Wassers nach seinem spexifischen Gewicht angesehen. Denn das leichtere, weil reinere Wasser als die oberste Schicht des stehenden Wasserkörpers entfaltet wesentlich mehr Lösungsaktivität als das mit gelöstem Gips belastete und deshalb schwerere Wasser tieferer Schichten. Wegen der erwähnten Schwierigkeiten durch häufiges Vorkommen von Mehrfachfazetten und Mehrfachlaugdecken und weil der Neigungswinkel der Fazetten ziemlich knostant ist, "soweit keine Störung durch fließendes Wasser vorliegt", verwirft Reinboth einen ursächlichen Zusammenhang mit einer niveauabhängigen Laugintensität und erklärt die Fazettenneigung mit der Schutzschicht durch Lösungsrückstände in Form von Lehmlagen. Die Schräge entspricht also dem natürlichen Abrutschwinkel der Lösungsrückstände unterhalb des Wasserspiegels. Danach können sich Doppelfazetten und Mehrfachlaugdecken überall dort bilden, wo diese lehmig Schutzschicht verletzt ist. - Eine wohl für konkrete Einzelfälle, kaum aber eine für die Erscheinung allgemein anwendbare Theorie liefert Völker, der die Hinterlaugung von Klüften und das Abscheren von Versturzblöcken für schräge Seitenflächen verantwortlich macht, die dann nach nur geringfügiger Überformung als Laugfazetten in Erscheinung treten sollen. Die Befunde in der Trübbachhöhle widersprechen einer solchen Genese jedenfalls, da dort zwischen Laufazette und Laugdecke eine deutliche vertikale Hohlkehle allgemein vorhanden ist.

Laugrückstände, die aus Decken gelöst werden, sammeln sich im Sediment der Höhlensohle. Dessen gröberes Korn besteht vorwiegend aus den Lösungsrückständen Kalk und Hornstein in einem durchfeuchteten Gipsschlamm. Es ist evident, daß innerhalb dieser Sedimentschichten, die sich von Lösungsrückständen und Verstürzen ernähren, weiterhin intensive Lanugprozesse stattfinden. Wohl auch nur so ist ein ausgereiftes Längsprofil der Gerinne trotz zwischengeschalteter Verstürze verständlich.

Für eine grobe Abschätzung des Höhlenbaches dürfte eine mittlere Wasserführung von 20 l/sec realistisch sein, der Bach ist mit Gips fast gesättight: Bei mittlerer Wasserführung enthält 1 m^3 Wasser 1,6 kg gelösten Gips. In grober Hochrechnung würde die befahrbare Höhle unter Berpcksichtigung der vermuteten Sedimentmächtigkeiten und der Annahme, daß 90% der Laugung schon in den nicht begehbaren Zubringern des Wassers und nicht in der Höhle selbst stattfindet, eine "Lebensdauer" von nur etwa 100 Jahren haben. Demnach hat es keinen Sinn, nach morphologisch anderen als einwandfrei rezenten Bildungsbedingungen zu suchen.

Höhlenbildung

Entsprechend dem geschilderten Formenschatz ist die Trübbachhöhle eine typische Laughöhle. Anders als diese wird sie jedoch von richtigen Bächen gravitativ durchflossen und besitzt keinen Vorfluter, sondern mündet in einen Steilhang, der noch weit hangabwärts aus Gipsgestein besteht. Tortz des hohen Anteils an Laugrückständen verzichten die bisheringen Entstehungsmodelle von Gipshöhlen auf jede mechanische Schleppkraft zum Tranport ungelösten Materials.

Diese allgemein geübte Modellvorstellung diskutiert erst Völker neuerlich. Er bestreitet die seit Gripp 1913 angenommene Ausschließlichkeit von Korrosionvorgängen in Laughöhlen und gibt auch der Erosion bei ihrer Bildung wesentlichen Raum. Schließlich mißt er der Erosion auch einen Anteill bei der Laugfazettenbildung, die ja nach seiner Ansicht von Sedimentationswechseln abhängt, bei. Diese Fragen stellen sich erneut, da bei der Trübbachhöhle kein Vorfluterniveau vorhanden ist und doch jedes Anzeichen für eine Tieferlegung der Höhlengänge durch Laugung oder Tiefenerosion fehlt.

Eine Hypothese bietet sich in einer Einregelung der Eingangshöhe durch häufige, aber keline eingangsnahe Verstürze an: Das frostempfindliche Gipsmaterial kann hier ständig zu einem Aufstau der Höhlenbäche führen, und die gleichzeitige Anlaugung der Verstürze würde einen Rückkoppelungsffekt bewirken, da die Versturztätigkeit umso schwächer wird, je mehr Versturzmaterial den Höhlenraum füllt. An Stelle eines bei Kalkhöhlen üblichen Eingangs-Schuttkegels kann hier somit ein selbstregulierender höhenkonstanter Mechanismus ablaufen. Allerdings ist dies über langere geologische Zeiträume weder wahrscheinlich noch notwendig, denn Gipshöhlen sind wohl relativ kurzlebige Objekte.

Bin zweiter Erklärungsversuch für die strenge Horizontalität bei gleichzeitig fehlendem Vorfluter ist ein dynamisches Gleichgewicht zwischen Laugung und Produktion von Laugrückständen: Eine geginnende Tieferlegungstendenz würde sofort zy einer massenhaften Freisetzung Gipsbrie in den Schottern der Höhlensohle, daß langsame Laugungsvorgänge trotz hochgradiger Sättigung des Sedimentwassers weiter ablaufen. Da die Höhle in ihren Lösungsrückständen bisher nicht erstickt ist, sind am Austrag von Sediment an den Tag neben den Laugvorgängen zweifellos auch Schleppkräfte an den schwer löslichen Schotterkörnern tätig. Der Austrag des Sediments kann beim Höhleneingang in Form von Schottern, die sich bei stärkerer Strömung im Hochwasser bewegen, direkt beobachtet werden.

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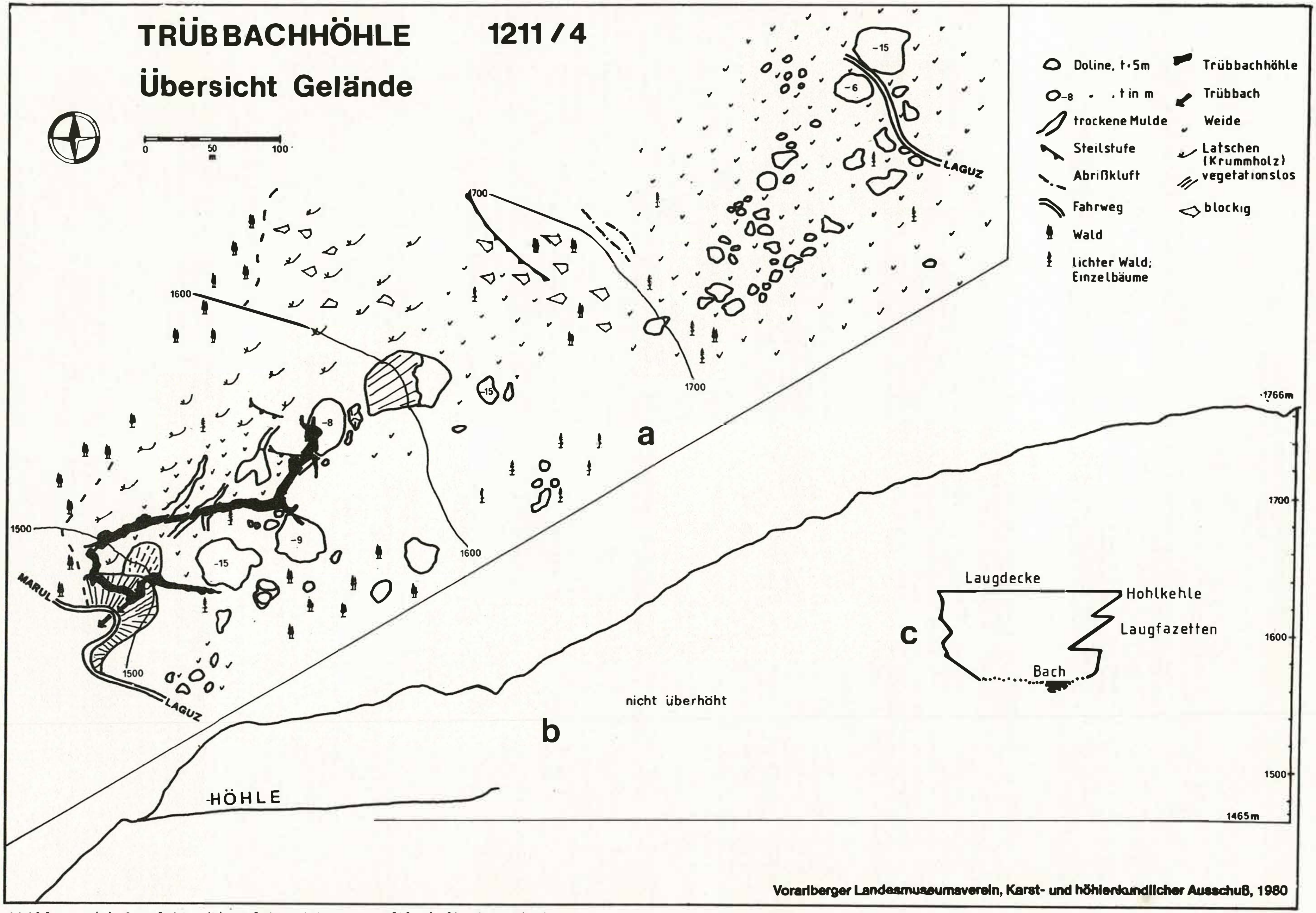

Abbildung: (a) Grundriß, (b) Aufriß, (c) Querprofil, halbschematisch.

La grotte de Geraniou à Réthymon - Crète

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Résumé

Lors de la percée d'une nouvelle avenue dans la région de la "Côte Bleue" à six km. de Réthumon en Crète, une grotte fut découverte. Son entrée naturelle avait été obstruée par un éboulis de roches.

D'après les recherches faites, il est certain que cette grotte offre un intérêt paléontologique, préhistorique, archéologique et touristique. En effet, les fouilles ont mis à jour des traces de l'homme préhistorique: ossements, outils, morceaux de poterie, statuettes, etc... de la période néolithique. Furent trouvés également des ossements d'animaux: ossements d'éléphants, crânes de cerfs.

On estime actuellement que cette grotte fut le gîte d'animaux, puis l'habitat d'hommes primitifs et par après un lieu de culte de l'époque minoenne.

La découverte des restes d'un escalier taillé dans la roche et conduisant à l'entrée naturelle de cette grotte ainsi que les riches décorations merveilleuses des six salles qui s'y succèdent tentent de prouver cette assertion.

Abstract

During the excavation of a new avenue in the area of "Kyane Akti", 6 Klms. from the city of Rethymnon, Crete, a cave was found where the natural entrance had been closed by a fall of rocks.

In the following search the cave was found to be of prehistoric paleontological, archeological and touristic interest.

The archeological excavation brought to light signs of prehistoric man: bones, tools, earthenware pots, figurines etc. of the neolithic period. There were also animal remains which included deer skulls and those of elephants. It seems therefore, that this cave may have been inhabited not only by animals and primitive man, but was also regarded as sacred during the Minoan epoch.

The latest theory, resulting from the removal of the debris covering the natural entrance, showed traces of sculptured steps cut into the face of the rock and also wonderful and rich decoration in the successive rooms of the cave.

Preface

Au cours de l'ouverture de la nouvelle route nationale Réthimnon-La Canée et à une distance de 6 km. environ de Réthimnon, en-dessous et à gauche du pont de la "Côte d'Azur" de Géraniou, a été découverte une grotte préhistorique extrêmement digne d'intérêt.

Son entrée se trouve à une altitude de 23 m. et à une distance de 200 m. environ des côtes de la mor de Crète, avec vue sur celle-ci. La grotte demeurait incennue jusqu'en 1969, car son entrée naturelle avait été obstruée par un éboulis de roches probablement provoqué par une forte secousse sismique. Elle fut mise au jour pendant les travaux d'ouverture d'une route de déviation, en-dessous du pont ci-dessous mentionné, qui provoquèrent le détachement d'une partie de la paroi de la grotte, créant ainsi une entrée artificelle.

C'est tout d'abord de l'intérieur, puis de l'extérieur, que l'on y repéra l'entrée naturelle, grâce à la découverte des vestiges d'un escalier minoën creusé dans le roc solide et aboutissant au point où existait initialement l'entrée naturelle.

Au cours des recherches préliminaires effectuées par MM. Ch. Macris et E. Platakis, docteur en lettres classiques et sciences physiques, on prit conscience de l'intérêt que présente la grotte du point de vue paléontologique, préhistorique, archéologique et touristique en raison des vestiges d'hommes et d'animaux qui y furent découverts, et par sa beauté remarquable.

Description de la Grotte

La grotte est en calcaire dans sa cavité, avec une longueur totale de 55 m., une largeur maximale de 17 m., et une hauteur qui va de 3 m. à 4,50 m. Elle couvre une surface de 1.200 m^2, séparés en six compartiments. Cinq d'entre eux se succèdent dans le sens de la longueur, se trouvant séparés l'un de l'autre par des colonnes et des stalagmites merveilleuses. Leurs plafonds sont ornés de stalactites multicolores très denses et de toute beauté. Le sixième compartiment, admirablement orné aussi, est parallèle au premier. C'est là que se trouvait l'entrée naturelle de la grotte, qui comme nous l'avons dit plus haut, a été obstruée par un éboulement.

La température de la grotte était de 16° C. et son humidité de 95% en août 1980.

Decouvertes Prehistoriques

Les fouilles réalisées par la Commission Archéologique de La Canée sous la direction de l'archéologue J. Tzédakis, ont mis au jour des objets préhistoriques appartenant aux trois stades de la période néolithique.

Dans la première partie de la grotte, fut découvert un atelier d'outils en os, comportant une grande quantité d'os d'animaux destinés à être travaillés, ainsi que des bois et des cranes de cerfs destinés au même but; ces objets constituent de précieuses trouvailles pour les chercheurs, étant donné en outre qu'on n'avait jamais découvert en Crète, jusqu'à présent, de traces de cerfs datant de la période néolithique (5ème - 3éme millénaire av. J.C.). On trouva également au même endroit plusieurs aiguilles et autres outils en os façonné, des outils en pierre et en obsidienne, et quatre idoles dont trois sont en pierre et une en terre cuite. L'une des idoles de pierre, de type de stéatopygie, représente une mère: la "Déesse de la Nature". Une autre découverte encore est celle de nombreux tessons de vases en terre cuite, faits à la main en glaise grossière et cuits à feu ouvert - mal cuits pour la plupart -, ainsi que de tessons d'excellente qualité de fabrication et de cuisson, qui proviennent évidemment d'une époque plus récente.

En poursuivant les fouilles dans les compartiments du centre de la grotte, on vit clairement apparaître les trois stades néolithiques, avec des couches intermédiaires formées de la matière propre aux stalactites et d'épaisseurs variées. Dans les trois couches ci-dessus mentionnées, on trouva des outils, en pierre pour la plupart et en os pour quelques autres. Les sections restantes de la grotte contenaient également de semblables outils, mais en nombre décroissant jusqu'à disparition totale avant le fond de la grotte.

A part les os d'hommes et d'animaux dispersés en surface, en découvrit aussi, dans un état de conservation relativement bon, trois squelettes humains qui se trouvaient entre une colonne et la paroi droite de la partie centrale de la grotte, qui comporte une voûte assez basse. La découverte en surface de ces squelettes humains, et surtout au même point, nous suggère pour l'instant deux hypothèses. Selon la première, il s'agirait là d'un lieu de sépulture pendant la période minoenne, hypothèse qui toutefois nous semble très audacieuse. Quant à la seconde, elle nous fait supposer que ces personnes auraient été emmurées puis mortes de faim alors qu'elles se trouvaient dans la grotte - peut-être pour un acte d'adoration, à l'époque minoenne -, au moment fatal où l'entrée fut bouchée pour les raisons mentionnées plus haut (éboulement de reches dû à un séisme). Nous considérons cette hypothèse comme la plus plausible, sans pour cela en exclure tout autre qui nous sera certainement fournie par la datation ultérieure des trouvailles de la grotte.

Decouvertes Paleontologiques

Alors que je travaillais à l'étude d'une mise en valeur touristique de la grotte, en août 1980, le géologue M. Em. Dermintzakis vint la visitor: il découvrit en observant le sol, parmi des pierres qui provenaient de couches plus profondes du compartiment de l'entrée naturelle, des fragments pétrifiés d'os d'éléphant.

Cette découverte surprenante éveilla à juste titre un immense intérêt chez les apléontologistes de la S. S. de Grèce, qui établirent aussitêt un plan de recherches systématiques. Mais pour des raisons techniques, celles-ci durent être remises à plus tard, à l'année 1981.

Les déductions qui seront tirées de ces recherches, pourront probablement résoudre aussi le problème de l'évolution de la grotte. Car si l'on ne retrouve que des merceaux d'os de l'animal, cela signifie peut-être qu'ils ont été transportés par des hommes primitifs ou,

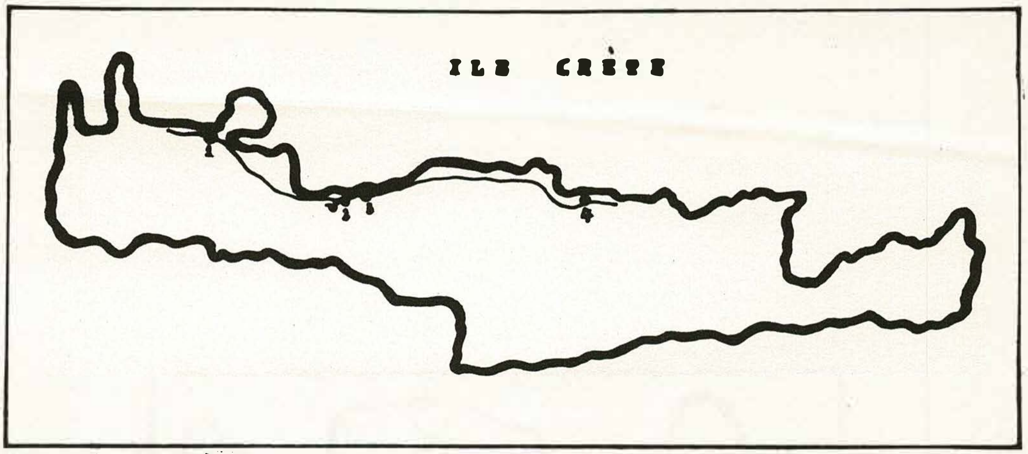

Figure 4. Ile Crète
1. Hania 2. Jeranion 3. Rethimnon 4. Iraklion

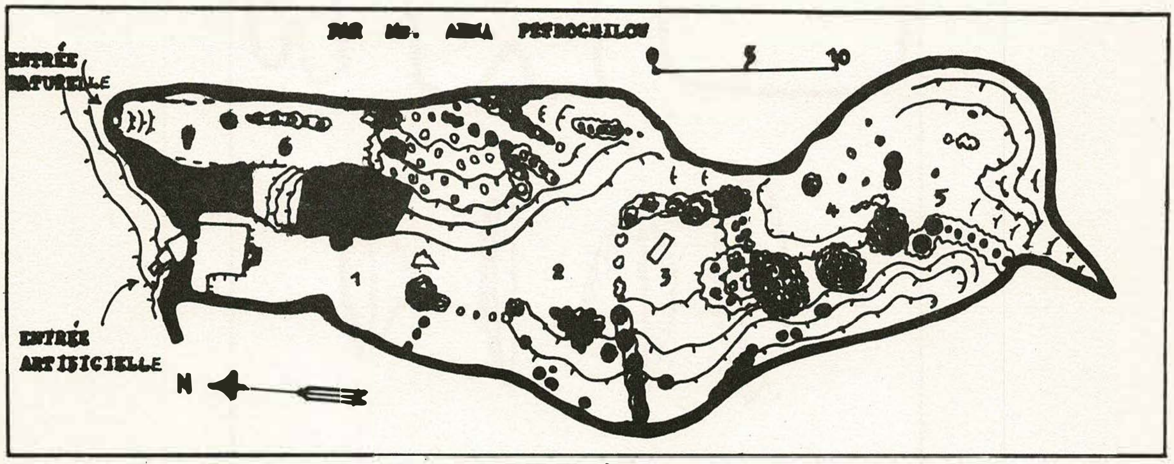

Figure 5. La grotte de "Jeranion" de Rethimnon; Crète. N. 3553

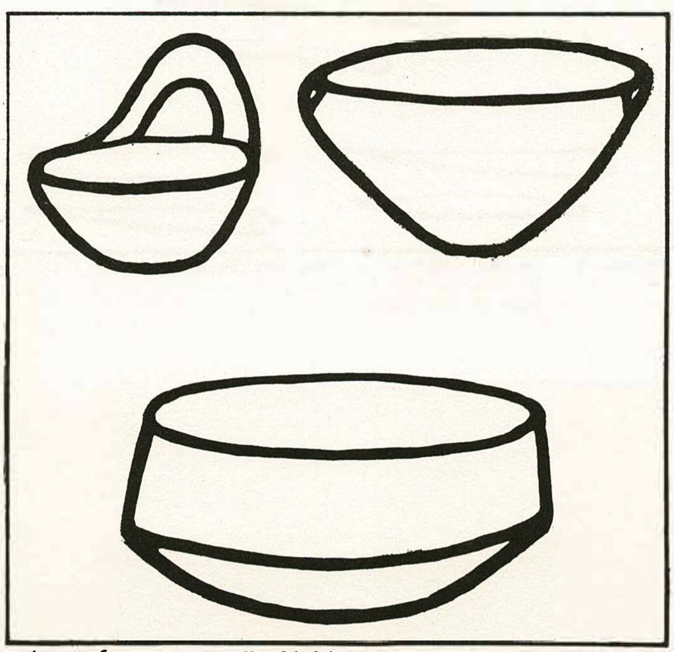

Figure 6. De vases Neolithiques moyens--
Museum Rethimnon

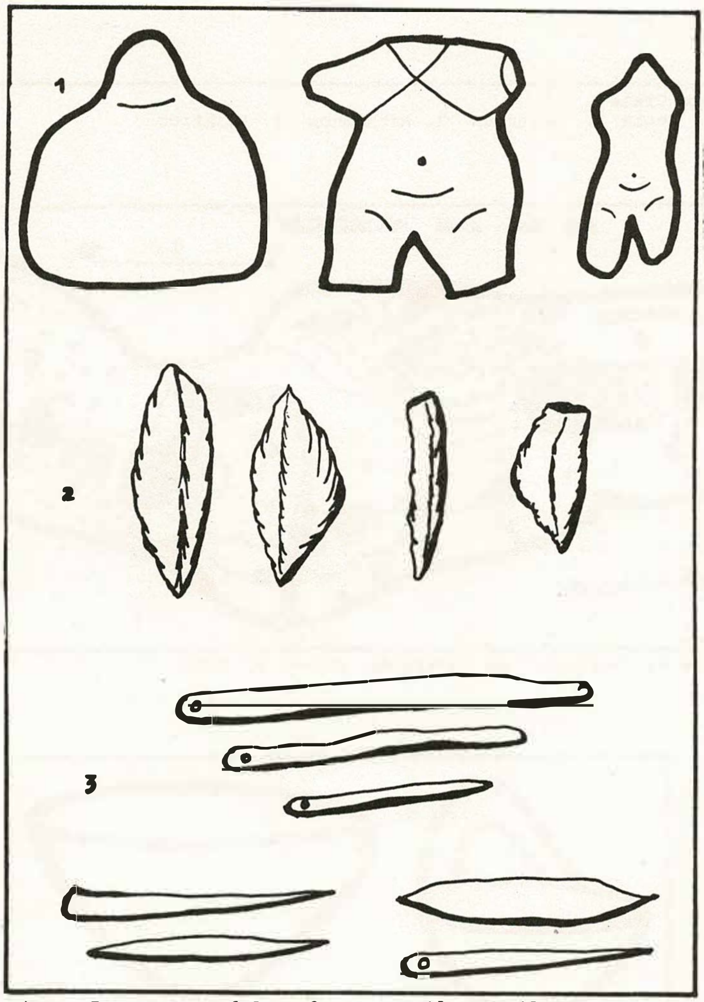

Figure 7. 1- Des Idoles 2- Des outils en silex
3- Des outils en os,
Museum Rethimnon

à une époque plus reculée, par des animaux carnivores, pour leur nourriture. Mais si l'on trouve des es d'une grande partie du squelette de l'animal, il faudra en déduire que la grotte actuelle ne représente qu'une part d'une grotte plus étendue et comportant une assez grande entrée, qui s'est affaissée.

Cette hypothèse est confirmée par la pensée qu'un animal aussi gros que l'éléphant, n'aurait pu passer par un lieu aussi restreint, même s'il ne voulait y entrer que pour mourir. Comme on le sait, beaucoup d'animaux sauvages en effet se retirent dans des lieux secrets ou dans des cavités lors-qu'ils sentent la mort approcher.

Si c'est le deuxième cas qui s'est produit pour l'éléphant de la grotte de Géraniou, il faudrait que l'entrée naturelle ait été de dimensions beaucoup plus importantes que celles que nous évaluons aujourd'hui, et qu'avec le passage du temps elle se soit progressivement réduite par suite des éboule ents.

Toutes ces questions que fait naître la découverte de restes d'hommes et d'animaux, seront résolues, nous l'espérons, grâce aux recherches paléontologiques qui vont bientôt commencer.

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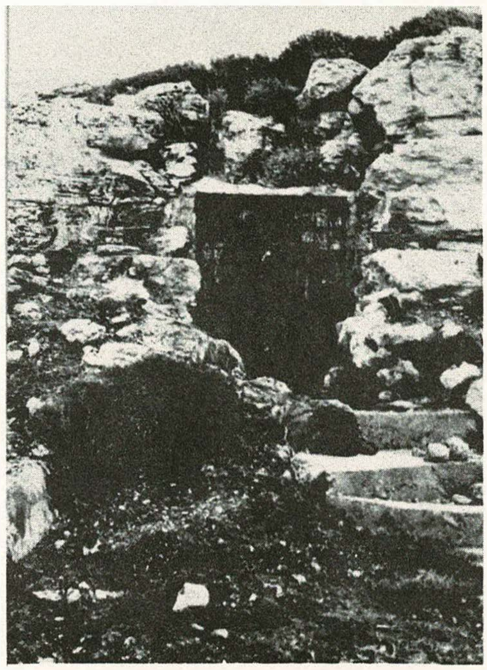
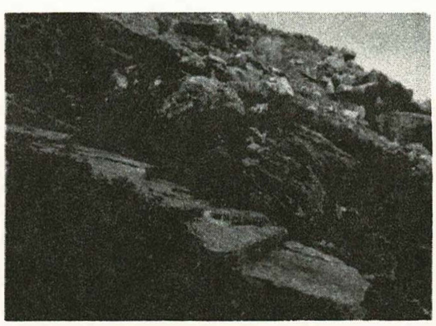
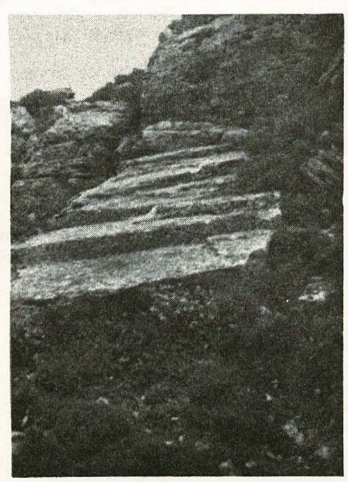


1) L'entrée artificielle de la Grotte "Gerani".





2-3) Des escaliers sculptees sur la roche, qu'elles conduisent a l'entrée naturelle.

Un pionnier de la spéléologie: le peintre suisse Caspar Wolf (1935 - 1783)

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Résumé

Peintre assez renommé de son vivant, Caspar Wolf n'a été redécouvert que tout récemment. Willi Raeber a publié en 1979 un important catalogue de ses oeuvres et le Kunstmuseum de Bâle lui a consacré une grande exposition durant l'été 1980.

Caspar Wolf était avant tout paysagiste; il a beaucoup voyagé en Suisse et il a visité et peint des grottes du Jura et des Alpes. Caspar Wolf est considéré comme un précurseur de la peinture romantique; il faut également le considérer comme un pionnier de la spéléologie.

Abstract

Rather famous when he was alive, Caspar Wolf has been rediscovered very recently. Willi Raeber published in 1979 a complete book about him and the Kunstmuseum of Basel (Switzerland) exhibited a great number of his paintings during the summer of 1980.

Caspar Wolf painted mostly landscapes; he travelled extensively in Switzerland and visited and painted caves in the Jura mountains and the Alps. Caspar Wolf is considered like a forerunner of romantic painting; he must be considered too like a pioneer in speleology.

Caspar Wolf est né à Muri (canton d'Argovie) en 1735; il est mort à Heidelberg en 1783. Durant ses années d'apprentissage il a surtout été un peintre décorateur ornant ou s'attachant à la réfection de cemeures seigneuriales. Plus tard il acquit une assez grande notoriété en tant que paysagiste; ce n'est cependant pas particuliérement ses toiles qui furent connues de ses contemporains, mais ses recueils de gravures représentant les montagnes de la Suisse. Il fut l'un des premiers peintres à s'aventurer dans les régions montagneuses et lors de ses voyages il eut également l'occasion de visiter quelques grottes. C'est pourquoi on peut le considérer comme un pionnier de la spéléologie.

Son oeuvre oubliée pendant près de deux siècles a été redécouverte par Willi Raeber qui a publié en 1979 une importante monographie à son sujet. Durant l'été 1980 une grande exposition au Kunstmuseum de Bâle a permis à chacun d'apprécier l'importance de Caspar Wolf en tant que précurseur de la peinture romantique. Un catalogue préparé par Yvonne Boerlin-Brodbeck a été édité à cette occasion. Dans un chapitre de ce catalogue intitulé "Die Höhlenbilder Caspar Wolfs" l'auteur étudie l'importance de la grotte au point de vue symbolique, puis montre la très grande place qu'occupe la caverne dans l'oeuvre de Caspar Wolf. Dans une première période Caspar Wolf a peint des grottes imaginaires; plus tard, à l'occasion de ses premières excursions dans les Alpes, il a figuré des grottes réelles, celles visitées ou explorées par lui.

Le rôle de Caspar Wolf en tant que précurseur de la peinture romantique et la place occupée dans son oeuvre par les grottes ayant été mis en évidence par Raeber et Boerlin-Brodbeck, il reste à voir quelle fut son importance en tant que pionnier de las spéléologie. Si l'on élimine les grottes imaginaires et quelques abris peu profonds, l'activité spéléologique de Wolf se résume en la visite de trois cavités: Beatushöhle et Chorbalm dans les Alpes, Bärenhöhle dans le Jura. C'est peu, mais cela indique cependant de la part de Wolf un intérêt très vif pour le monde souterrain, chose fort rare à l'époque où il vivait.

Les deux premières grottes visitées par Wolf sont bien connues et elles seront décrites ci-dessous. La troisième, la Bärenhöhle près de Welschenrohr, ne semble pas être imaginaire, mais il n'a pas été possible de la localiser; le paysage a beaucoup été modifié en deux siècles!

Beatushöhle

Cette grotte est située à proximité de la rive nord du Lac de Thoune, à environ 6 km. à l'ouest d'Interlaken. Connue depuis fort longtemps, elle est partiellement aménagée pour le tourisme. Son développement est actuellement de 8,4 km. Elle est parcourue par un important cours d'eau. Caspar Wolf a peint à de nombreuses reprises la Beatushöhle, qui fut l'un de ses sujets favoris. Toutes ces vues montrent l'entrée de la cavité; cependant Caspar Wolf a bien pénétré à l' intérieur de la grotte, ainsi que le prouve ce texte d'un prospectus de Wagner, éditeur de plusieurs séries de gravures:

"C'est la caverne de la source d'eau, qui entre à près de 500 pas dans la montagne, le peintre l'avoit lui-même mesurée; on se trouve souvent dans la nécissité d'entrer dans l'eau, ou de ramper sur la pierre unie, ce qui rend l'entrée assez pénible; le ruisseau qui sort de la montagne, qui est d'une pierre à chaux, fournit en abondance de l'eau excellente."

Chorbalm

Cette grotte se trouve près de Lauterbrunnen, à 10 km. au sud d'Interlaken. Elle consiste en un vaste abri se continuant par une galerie ascendante longue d'une trentaine de mètres. Caspar Wolf a beaucoup voyagé dans la région de Lauterbrunnen, mais il n'a consacré qu'une aquarelle à la Chorbalm.

Bärenhöhle

Comme dans toute la chaîne du Jura, il existe aux environs de Welschenrohr un certain nombre de grottes. Wolf en a figuré une qu'il nomme Bärenhöhle. Il n'a pas été possible de déterminer l'emplacement de cette cavité ni même de savoir si elle existe encore actuellement.

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Recherches biospéologiques dans l'île de Ceylan

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Résumé

L'île de Ceylan est pauvre en roches calcaires; les phénomènes karstiques y sont donc peu développés et les grottes sont de faibles dimensions. Ces grottes abritent une faune abondante que les auteurs ont eu l'occasion d'étudier et de récolter lors d'un voyage effectué en 1970. Les animaux les plus fréquents dans les grottes de Ceylan appartiennent aux groupes suivants: Isopodes, Diplopodes, Araignées, Opilions, Amblypyges, Pseudoscorpions, Acariens, Collemboles, Diploures, Orthoptères, Hémiptères, Diptères, Coléoptères, Chiroptères.

Abstract

Limestone is scarce in the Island of Ceylon; karst phenomena are little developped and caves are generally small. In 1970, the authors collected an abundant fauna in the caves of the island. Animals of the following groups were mostly collected: Isopoda, Diplopoda, Spiders, Opilionida, Amblypygida, Pseudoscorpions, Mites, Collembola, Diplura, Orthoptera, Hemiptera, Diptera, Coleoptera, Bats.

Introduction

L'île de Ceylan est pauvre en roches calcaires; les phénomènes karstiques y sont donc peu développés et les grottes sont de faibles dimensions. Dans le nord de l'île de petites cavités généralement verticales sont creusées dans des calcaires miocènes. Dans les régions montagneuses du centre et du sud, on connaît un certain nombre de grottes dans des calcaires cristallins précambriens. On trouvera dans le travail de Mitter (1979) une carte montrant les principaux éléments constitutifs de Ceylan.

Peu de travaux sont consacrés à la spéléologie de Ceylan. Des grottes sont parfois citées dans des notes se rapportant à la géologie, la géographie, l'archéologie ou la paléontologie de l'île, mais elles ne sont généralement ni décrites, ni même localisées avec précision. On peut considérer que la note publiée par Deraniyagala en 1956 constitue le premier travail vraiment spéléologique; dans cette note est décrite et figurée Istripura Cave. Plus tard, en 1965, Deraniyagala publie un intéressant résumé sur les grottes de Ceylan.

En 1961, le spéléologue français Siffre explore un certain nombre de grottes; le récit de son voyage ne sera publié qu'en 1975. En 1970, les auteurs effectuent une campagne biospéologique dans l'île; la présente note est un résumé des recherches effectuées.

Enumération des Grottes visitées

Nous décrivons ci-dessous les 5 grottes que nous avons visitées et dans lesquelles nous avons récolté une faune d'invertébrés. Au cours de notre voyage, nous avons également récolté des chiroptères dans d'autres grottes peu importantes (abris semi-obscurs ou réseaux de fissures). Ces cavités sans réel intérêt biospéologique ne sont pas décrites ici. Il s'agit de: Mahakande Cave, Vavul-lena, Rajagiri-lena, Mihintale Caves.

Les cartes topographiques utilisées pour la localisation des grottes font partie de la série CEYLON: ONE INCH (Echelle 1 : 63,360). La position de Stripura Cave n'a pu être donnée avec précision, car lors de notre voyage nous n'avions pas à notre disposition les cartes topographiques se rapportant à cette région.

Rawanaella Cave

Situation: Près de Ella.
Carte NUWARA ELIYA : 6° 51'19'' N / 81° 03'23'' E
Altitude: 1.050 m. (altimètre)
Date: 16 janvier 1970.
Description: Large entrée au sommet d'une paroi de rocher. Couloir ascendant allant en se rétrécissant et long d'une centaine de mètres. Dans la zone profonde: nombreux nids de *Collocalia* au plafond du couloir.
Température: 22°5.
Faune:
Araignées (BRIGNOLI, 1972), Pseudoscorpions, Orthoptères, Hémiptères (VILLIERS, 1970), Coléoptères, Oiseaux: *Collocalia unicolor* (Jerdon), Chiroptères: *Rousettus* sp.

Istri-gal-lena

Situation: Près de Welimada.
Carte NUWARA ELIYA : 6° 57'57'' N / 80° 54'15'' E
Altitude: 1.380 m. (altimètre)
Date: 17 janvier 1970.
Description: Il y a deux grottes qui communiquent peut-être entre elles. On pénètre dans la première par une entrée basse qui donne accès à 3 couloirs ascendants parallèles. Développement: environ 150 m. La seconde grotte s'ouvre par un puits peu profond. Ce puits donne accès à 2 galeries, l'une ascendante, l'autre descendante. Ces galeries assez vastes sont parcourues par un petit ruisseau. Développement: environ 600 m.
Température: 23°.
Faune:
Araignées (BRIGNOLI, 1972), Collemboles, Orthoptères, Batraciens : *Rana gracilis* Gravenhorst, Chiroptères : *Hipposideros* sp.

Istripura Cave

Situation: Près de Pannala.
Carte HANGURANKETA : 7° 09'56'' N / 80° 53'34'' E
Altitude: 240 m.
Date: 19 janvier 1970.
Description: Une grande salle d'entrée semi-obscure communique par un étroit couloir descendant avec une salle bien concrétionnée et, par endroits, recouverte de guano de chauves-souris. Après un rétrécissement on parvient dans une dernière salle occupée presque entièrement par un lac peu profond.
Températures:
Salle d'entrée: 23°5 (air)
Salle concrétionnée: 25°5 (air); 25° (eau de petits gours)
Salle du lac: 27° (air); 27° (eau du lac)
Faune:
Diplopodes, Araignées (BRIGNOLI, 1972), Amblypyges, Orthoptères, Hémiptères (VILLIERS, 1970), Diptères, Coléoptères, Batriciens : *Bufo melanostictus* Schneider, Chiroptères : *Hipposideros* sp.

Stripura Cave

Situation: Près de Kuruwita.
Cartes RATNAPURA et HATTON : 6° 46'30'' - 6° 50' N / 80° 21' - 80° 23' E
Altitude: 275 - 300 m. (altimètre)
Date: 22 janvier 1970.
Description: Entrée étroite au pied d'une paroi de rocher. Grotte horizontale formée par une succession de passages parmi des blocs éboulés. Développement: environ 50 m.
Température: 24°.
Faune:
Chilopodes, Araignées (BRIGNOLI, 1972), Opilions (ŠILHAVY, 1974), Acariens, Collemboles, Diploures (PAGÈS, 1977), Orthoptères, Hémiptères (VILLIERS, 1970), Coléoptères (SZYMCZAKOWSKI, 1972), Chiroptères : *Hipposideros* sp., *Rhinolophus* sp.

Lunuge Cave (= Lunuhinda Cave)

Situation: Près de Nalanda.
Carte NALANDA : 7° 39'34'' N / 80° 39'7'' E
Altitude: 290 m. (altimètre)
Date: 25 janvier 1970
Description: Un puits peu profond donne accès à une chambre descendante; nombreux blocs éboulés et grands amas de guano de chauves-souris. Plusieurs galeries peu importantes partent dans diverses directions.
Température: 26°.
Faune:
Mollusques, Isopodes, Diplopodes, Araignées (BRIGNOLI, 1972), Amblypyges, Collemboles, Orthoptères, Batraciens : *Rana (Euphlyctis) cyanophlyctis cyanophlyctis* Schneider, *Rhacophorus microtympanum* Günther, Reptiles : *Ptyas mucosus maximus* Deraniyagala, Chiroptères : *Hipposideros* sp., *Rousettus* sp.

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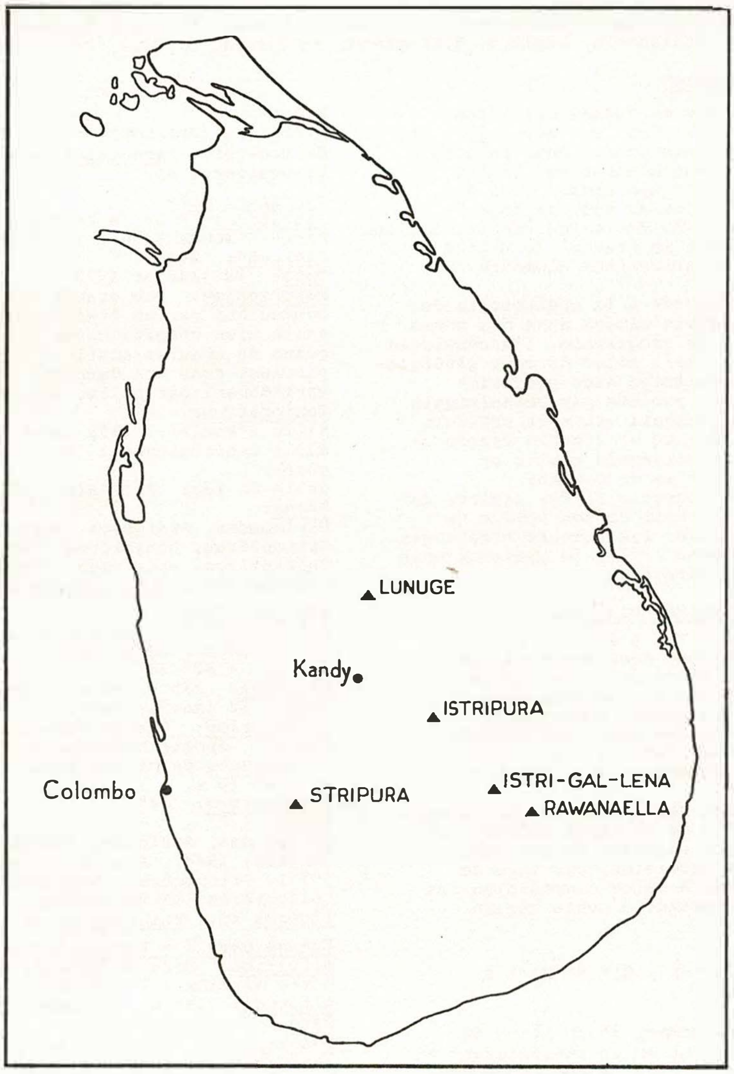

Légende de la figure: Situation des grottes visitées en 1970 dans l'île de Ceylan.

Resultats Des Observations Conduites Sur Le Site Experimental De La Grotte Du Lamalou
(Causse de l'Hortus - France méridionale)

présentés par H. Paloc[1]
avec le concours de H. Bonin, M. Bonnet, J. Guizerix, A. Lallemand - Barres, J. Margat et D. Thiery
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Résumé

L'étude dont les résultats sont exposés ci-après, a été réalisée par le Bureau de Recherches Géologiques et Minières entre 1978 et 1980 sur le site de l'exutoire principal d'un système hydrogéologique bien défini constitué de calcaires massifs fissurés et karstifiés.

L'objectif de la recherche était de déterminer, sur la base d'observations de terrain, les lois physiques qui régissent d'une part les écoulements dans la zone saturée (et en particulier les interactions entre la matrice fissurée et les conduits karstiques) et d'autre part l'alimentation du massif à travers la zone non saturée. On avait en vue la mise au point de modèles de simulation capables de reproduire le comportement du karst pour chacune des séries de mesures effectuées.

Les expériences réalisées ont été de deux types:

- Pour l'étude de la zone saturée:

. Etude fine des variations de niveaux piézométriques se produisant dans un "volume élémentaire de référence" (cube de roche calcaire de 50 m d'arête, enveloppant le chenal karstique) : les niveaux piézométriques étaient mesurés en 9 forages situés de 10 à 20 m du chenal karstique principal.

. Mesure de la perméabilité locale au moyen de pompages, d'injections et de chocs hydrauliques (slug test) dans chacun des forages.

. Etude des réactions des piézomètres aux variations du niveau de l'eau dans le chenal karstique, sous l'influence des pluies ou d'actions provoquées sur l'émergence par pompage ou relèvement de seuil.

- Pour l'étude de la zone non saturée:

. Mesure de l'état de la saturation et de la succion dans la matrice fissurée au cours d'averses naturelles ou artificielles (aspersions).

. Mesure du débit infiltré au cours de ces mêmes évènements dans une salle du chenal karstique située à l'aplobm de la zone d'aspersion de façon à établir un bilan d'eau.

Les expériences réalisées et l'exploitation de leur résultats ont permis de mettre au point un modèle déterministe par blocs homogènes, en fonction du comportement de chaque piézomètre, modèle permettant une simulation correcte des échanges entre chenal karstique et zone fissurée. Un autre modèle (modèle à réservoirs) a permis de reproduire les débits et les bilans d'eau mesurés dans la salle sous la zone d'aspersion.

Abstract

The study whose results are expounded later, has been realised by the "Bureau de Recherches Géologiques et Minières" between 1978 and 1980 on the site of the main spring of a clearly defined hydrogeological system formed of fissured and karstified massive limestones.

The aim of the study was to well define, according to land's observations, the physical laws that govern the flows in the satured zone (and particularly the interaction between the fissured matrix and karstic conduits) on the one hand, and the feeding in water of the massif through the unsatured zone on the other hand.

The intention was to realise models of simulation able to reproduce the behaviour of karst for every one of the series of effected measures.

The experiments were of two kinds:

- Study of the satured zone

. Precise study of the piezometric variations of water that happen into an "elementary mass of reference" (cubic calcareous block, which arete is 50 meters long, envelopping the karstic conduit) : the piezometric levels were measured by 9 boreholes situated from ten to twenty meters from the main karstic conduit.

. Measure of the local permeability by pumpings, injections and hydraulic shocks ("slug test") in each of those boreholes.

. Study of the reactions of piezometers according to the water-level in the karstic conduit, under the influence of rains, or actions caused on the spring by pumping or elevation of the ground water level.

- Study of the unsatured zone

. Measure of the state of saturation and of the suction into the fissured matrix during natural (by rains), or artificial showers (by watering).

. Measure of the infiltrations during the same events in a hole of the karstic conduit situated below the zone of watering as to establish a water-balance.

The effected experiments and the exploitation of their results have permetted to realize a determinist model by homogeneous blocks, according to the behaviour of each piezometer, model which permits a correct simulation of the exchanges between the karstic conduit and the fissured zone.

An other model (with reservoirs) has permitted to reproduce the out flows and water-balance measured in the hole under the zone of watering.

Introduction

Le besoin de plus en plus grand de devoir utiliser un peu partout dans le monde des réservoirs aquifères calcaires pour l'alimentation en eau potable, conduit à déterminer au plus près possible un taux optimal d'exploitation pour chacun d'entr"eux qui soit à tout moment compatible avec les possibilités de reconstitution des réserves - sauf bien sûr lorsqu'on désire volontairement les épuiser ce qui est notamment le cas pour une exploitation minière - tout en assurant la conservation de la qualité de l'eau.

C'est ce que l'on cherche à faire à l'occasion de toute étude, préalablement à l'exécution d'aménagements, mais il est parfois difficile d'atteindre à une prévision correcte à moins de disposer de longues périodes d'observation ou de moyens financiers très importants, ce qui est tout à fait exceptionnel.

Par contre, les évaluations souhaitées pourraient être plus facilement réalisées si l'on savait mettre en oeuvre des procédés de simulation, adaptables à chaque cas, et qui, en s'appuyant sur les paramètres physiques effectivement représentatifs du milieu aquifère, permettraient de déterminer à l'avance les effets d'un prélèvement - ou d'un déficit pluviométrique - et d'organiser ainsi la gestion rationnelle d'un réservoir souterrain.

De tels procédés (modèles mathématiques, modèles physiques, ...) sont actuellement couramment en usage dans les milieux aquifères poreux ou fissurés avec des rendements satifaisants.

Dans les aquifères karstiques, la présence de chenaux qui introduisent dans le milieu une dimension et une organisation de vides tout à fait exceptionnelles, complique la compréhension des conditions d'écoulement de l'eau et par là même la mise en oeuvre de ces modèles a été limitée à quelques rares cas avec des résultats variables.

C'est pour essayer de réduire les difficultés qu'offrent encore ces formations - sinon la totalité des calcaires, en tous cas beaucoup d'entr'eux - à la simulation et à la gestion et pour tenter des approches originales destinées à mieux caractériser les hétérogénéités de ce type de roche et leurs effets hydrodynamiques, que le Bureau de Recherches Géologiques et Minières a procédé à l'étude, dont les résultats sont ici exposés, du principal exutoire du Causse de l'Hortus, la grotte-source du Lamalou.

Cette étude s'est étalée sur une période de deux ans, entre 1978 et 1980, et sa réalisation n'a été permise que grâce à l'aide financière qu'a bien voulu apporter au BRGM la Délégation Générale à la Recherche Scientifique et Technique.

Deux thèmes de recherche avaient été retenus:

- Le premier de ces thèmes a permis de mettre au point un modèle mathématique des écoulements en milieu karstique, c'est à dire d'établir les relations hydrodynamiques entre conduits karstiques et milieu environnant dans diverses situations naturelles - telles que période de recharge ou de décrue - ou artificielles en agissant sur les émergences.

- Le deuxième de ces thèmes a fait suite au précédent, et a permis d'analyser le comportement des parties dénoyées en permanence ou temporairement et que l'on pourrait qualifier de "zone non saturée karstique". Un modèle global pluie - volume infiltré a permis de rendre compte des mécanismes de transfert entre la surface du sol et la partie noyée dans diverses conditions d'alimentation par précipitations naturelles ou artificielles et pour diverses conditions de drainage par les conduits noyés.

La présente note rend compte du dispositif de mesure qui a été mis en oeuvre, et des enseignements qui ont été retirés de l'interprétation des diverses données recueillies durant ces deux années.

Rappel Des Conditions Hydrogeologiques Du Causse De L'Hortus (Cf. figure 1)

Le Causse de l'Hortus est situé à la partie méridionale de la France, à une vingtaine de kilomètres au nord de la ville de Montpellier; il est constitué par plusieurs niveaux calcaires, d'âge Valanginien supérieur, dont la puissance et l'extension sont variables : le plus important et le plus épais de ces niveaux (de l'ordre de 150 mètres) occupe une superficie totale d'environ 50 km^2. Ces calcaires reposent sur une épaisse série de marnes (Valanginien inférieur et Berriasien) qui les isole d'une autre série calcaire, d'âge Jurassique supérieur, série qui constitue un très important réservoir aquifère régional. Les calcaires valanginiens de l'Hortus se trouvent ainsi en position perchée sur la plus grande partie du pourtour du causse, sauf vers le Sud Ouest où ils s' ennoient et se bisautent sous les formations argileuses d'un petit bassin d'âge Eocène, le bassin de St Martin-de-Londres.

Compte tenu de la structure, la plus grande partie des écoulements souterrains est drainée vers le bassin de St Martin-de-Londres et les sources les plus importantes se trouvent situées au voisinage de la limite d'ennoyage des calcaires valanginiens sous les marnes de l'Eocène. Deux de ces sources sont pérennes (la grotte-source du Lamalou et la source du Crès), deux sont temporaires (l'évent des Camps et l'évent du Rouet). Toutefois, il en est deux autres plus éloignées de cette limite, qui jouent le rôle de trop-plein par rapport aux précédentes (évent de la Liquisse, évent du Puits Bâtit).

Enfin, quelques autres sources se trouvent en d'autres points de la bordure du causse, les unes temporaires (grottes de Baume, de Beaugrand, de Gorniès et des Lauzières) qui sont des réseaux de trop-plein plus ou moins anciens et désorganisés), les autres pérennes (Foux de Pompignan et Foux de Lauret) et qui ne paraissent drainer que la partie calcaire située au nord-est du causse (zone III de la figure 1).

Toutes ces sources ont fait l'objet d'observations directes de leur morphologie souterraine par reconnaissance spéléologique, par plongée ou par pompage. Les réseaux souterrains ont ainsi été reconnus en étiage (c'est-à-dire en période de plus bas niveau d' eau) sur les distances suivantes :

. plus de 700 m à la grotte-source du Lamalou, dont près de 300 m en plongée et jusqu'à 45 m sous le niveau d'eau (plongées HYDROKARST en 1977 et 1979); plus de 600 m à la grotte de Gorniès (pompage du BLGH en 1975, et plongées d'une équipe belge de Namur en 1977); près de 50 m à la grotte de Baume (pompage du BRGM en 1978); près de 300 m en plongée et jusqu'à 18 m de profondeur à la Foux de Pompignan (plongées SCM en 1950, ASN et GEPS en 1972, Spéléo-Darbouns en 1978 et pompage de l'ASN en 1979), source très voisine de la grotte des Lauzières découverte par l'ASN en 1976 et explorée à ce jour, sur près de 4 000 m; près de 4 000 m à la Foux de Lauret (pompage du SCAL en août 1967), diverses plongées ultérieures (GERSAM - GEPS), et découverte du SCAL en 1979; près de 2 000 m à l'évent de Beaugrand (pompage réalisé par le BRGM et le GERSAM en juillet 1978); 24 m de profondeur à l'évent des Camps dont 18 m sous le niveau d'eau (plongées GERSAM et HYDROKARST en 1977); 85 m de profondeur à l'évent du Rouet dont 75 m sous le niveau d'eau (plongée HYDROKARST en 1977).

Des relations hydrauliques - ou l'absence de relations - ont en outre été mises en évidence entre certains de ces points, soit par pompages, soit par traçages (relation évent de la Liquisse - source du Lamalou; relation perte de Juoilles - source du Crès et évent du Rouet; relation évent des Camps - évent du Rouet - source du Crès; relation perte de Borniès - source du Lamalou; relation grotte de Baume - source du Lamalou).

Du point de vue de leur régime, ces diverses sources sont toutes sujettes à de grandes variations de débit, conséquence directe de la distribution irrégulière et de l'importance variable de la pluie qui tombe sur le causse (1 200 mm en moyenne par an), la région étant sous l' influence des conditions climatiques du midi méditerranéen français.

En période d'étiage prononcé, les débits observés sur les sources pérennes du causse sont assez bien en rapport avec les surfaces respectives des trois secteurs qui ont été distingués sur la figure 1 :

. 1 à 2 l/s pour la source du Crès qui draine le secteur I (environ 7 km^2); 5 à 6 l/s pour la grotte-source du Lamalou qui draine le secteur II (environ 33 km^2); 2 à 3 l/s au total pour les Foux de Lauret et de Pompignan qui drainent le secteur III (environ 10 km^2).

En période de crue, les débits peuvent dépasser:

. 500 l/s pour la source du Crès; 5 000 l/s pour la grotte-source du Lamalou; 500 l/s pour chacune des Foux de Lauret et de Pompignan; 500 à 1 000 l/s pour les autres sources temporaires citées.

La Grotte-Source Du Lamalou Et Son Dispositif De Mesures (Cf. figure 2)

La grotte du Lamalou est située au fond d'une petite reculée, d'environ 200 m de longueur et au pied de laquelle se trouve l'entrée naturelle, pénétrable en basses eaux, qui donne accès au réseau souterrain. Une vingtaine de mètres environ à l'aval se trouve la source pérenne dont le niveau du plan d'eau peut être réglé par ouverture ou fermeture de vannes d'un petit barrage aménagé plus à l'aval. Le plan d'eau de cette source est le même sur toute l'étendue du réseau souterrain actuellement reconnu, si bien que l'on peut agir à volonté, en période d'étiage, sur le niveau de l'eau dans ce dernier. Enfin, à une trentaine de mètres à l'aval du barrage, et sur la rive gauche, se trouve l'orifice d'une source temporaire (source de la Rabassière) qui entre fréquemment en activité en période de pluie.

La partie du réseau utilisée pout les expériences est développée selon un plan de stratification à une vingtaine de mètres environ au-dessous de la surface topographique. Un puits a tout d'abord été aménagé pour permettre l'accès en tout état de régime, ainsi que la mise en place et l'exploitation d'équipements de mesures tant dans le puits lui-même que dans la salle principale de la grotte (15 tensiomètres pour mesurer les succions, 11 cellules pour réaliser les prélèvements d'eau, des entonnoirs pour mesurer des débits d'égouttement locaux, un bac jaugeur permettant de mesurer le débit global d' alimentation de la salle à travers la zone non saturée). Au dessus de cette salle a été aménagée une aire d' aspersion de 500 m^2 de superficie permettant de reproduire des pluies pouvant atteindre jusqu'à 80 mm d' intensité horaire et dont on mesure les effets d'une part à l'arrivée de l'eau dans la salle (temps de réponse, volumes restitués, qualité), d'autre part, dans la tranche des calcaires de 18 m d'épaisseur qui surplombe cette salle, par mesures, à la sonde à neutron, de la teneur en eau le long de deux sondages (S1 et S2; 50 mm de diamètre), et par observations des équipements de la salle et du puits.

Plus à l'amont du réseau, 9 foragés (longueur totale : 376 m; diamètre 140 mm), et un puits de pompage (assurant notamment l'alimentation de l'aire d'aspersion) ont été exécutés qui permettent de suivre, en les comparant, les fluctuations, naturelles ou provoquées, de l'eau souterraine dans le conduit karstique et dans son milieu environnant : on s'est ici intéressé à un "volume élémentaire de référence" de 50 m de long x 50 m de large x 50 m de haut et désigné V.E.R. dans le texte qui suit. Enfin, un pluviographe et une cabane servant d' abri-laboratoire et équipée d'une adduction électrique (24 V, 220 V, 380 V, de puissance 10 KVA) complètent le dispositif.

Experiences Et Essais Realises

Ils ont consisté en:

Pour l'étude de la zone saturée:

- Observation du comportement du volume de roche calcaire (V.E.R.) ausculté par les piézomètres en réponse aux précipitations naturelles.

- Observation du comportement sous l'effet de pompages dans le conduit karstique et de relèvement du niveau de l'exutoire.

- Essais ponctuels sur les différents piézomètres (chocs hydrauliques ou "slug tests" et essais d'injection ou de pompage).

Pour l'étude de la zone non saturée:

- Observation des effets de la pluie ou des aspersions provoquées (12 au total), dans la roche calcaire entre la surface topographique et la salle sous-jacente à l'aire d'aspersion : les intervalles entre pluies et aspersions ont variés de 1 à 50 jours, une intensité moyenne voisine de 20 mm ayant été choicie pour les aspersions.

- Mesures de teneur en eau à la sonde à neutron dans les deux sondages de 18 m (S1 et S2), exécutés entre l'aire d'aspersion et la salle, et mesures de pression d'eau (positive ou négative) sur les 15 tensiomètres installés dans le puits d'accés (11) et dans une cheminée (4) de 15 m de hauteur s'ouvrant à la voûte de la salle.

- Observation des temps de réponse (= "temps de percée"), de la répartition, de la durée et de l'importance respective des volumes d'eau atteignant la salle, par mesures d'égouttements et ruissellements.

- Analyses chimiques (11 cellules de prélèvement) et traçages, les résultats des diverses expérimentations en cours d'achèvement conduites dans ce domaine n'étant pas encore intégralement exploités.

Analyse Des Resultats Et Interpretations

Etude de la zone saturée:

On a constaté que si certains forages avient un comportement directement comparable à celui du chenal karstique, soit parce qu'ils l'avaient atteint effectivement (cas de F1 et de F7), soit parce qu'ils avaient intercepté de grosses fissures en relation évidente avec ce chenal dans la zone noyée (cas de F2 et de F7bis), par contre les autres de ces forages (F3, F4, F5, F6 et F8) ne présentaient aucune réaction:

. aux pompages d'essaie dans le chanal,

. aux essais d'injection ou de pompage dans les autres forages,

. aux modifications du niveau d'émergence de la source.

En outre, les niveaux d'eau dans ces derniers étaient beaucoup plus élevés que celui du chenal, et évoluaient de façon plus ou moins indépendante.

- Du point de vue quantitatif, les observations piézométriques et l'interprétation ponctuelle des essais réalisés ont fait apparaître un certain nombre de résultats résumés ci-dessous:

. la transmissivité identifiée au cours d'un essai de pompage dans le chenal et au cours des expériences de relèvement du niveau d'émergence est de l'ordre de 10^{-2} m^2/s,

. la transmissivité identifiée lors des expériences de chocs hydrauliques, d'injection et de pompage dans les forages est de l'ordre de 5.10^{-7} m^2/s,

. le coefficient d'emmagasinement identifié lors des expériences réalisées dans les forages est de l'ordre de 10^{-6} à 10^{-4},

. le coefficient d'emmagasinement déduit de la remontée du niveau suivant une précipitation isolée est de l'ordre de 1 à 5 %,

. le niveau de base dans le chenal karstique est situé approximativement à la cote + 192 NGF; les tarissements observés dans les piézomètres font apparaître des niveaux de base différents, de + 195 à + 205 NGF.

- Modelisation:

Pour tenter d'expliquer le comportement du système ainsi défini en tenant compte des résultats ponctuels obtenus lors des essais, on a cherché à établir un modèle hydrodynamique conceptuel inspiré du modèle utilisé pour simuler le comportement de la Fontaine de Vaucluse (Bonnet, M., 1977), modèle qui assimile le système aquifère à une matrice poreuse recoupée par des chenaux karstiques très transmissifs.

Mais, comme on pouvait s'y attendre, en raison des différences de comportement observées sur les deux groupes de piézomètres, il est apparu qu'on ne pouvait pas simuler à la fois:

. le comportement dans le chenal karstique,

. le comportement dans les forages

avec des valeurs cohérentes des paramètres.

On a alors envisagé une modélisation par blocs homogènes, le niveau piézométrique dans chaque forage étant simulé séparément en considérant à chaque fois un bloc de calcaire alimenté par sa surface et dont la vidange de ses petites fissures, par écoulement laminaire, se fait par de plus grosses fissures, verticales à sub-verticales, aboutissant directement au chenal karstique (Cf. figure 3) : en période de crue ce sont ces grosses fissures qui permettent un transit rapide d'une partie de la pluie efficace jusqu'au conduit, déterminant crue et décrue dans un délai relativement bref; en période d'étiage, le débit de l'écoulement du chenal n'est plus assuré que par le tarissement des petites fissures par l'intermédiaire des plus grosses, leur point de confluence déterminant un niveau de base local, plus ou moins perché par rapport au niveau de l'eau dans le chenal.

L'analyse mathématique du fonctionnement des blocs a été détaillée dans les rapports de fin de recherche cités en bibliographie. On retiendra que des calages satisfaisants ont été obtenus avec les valeurs suivantes de paramètres:

. coefficient d'emmagasinement : entre 0,6 et 6 % avec une valeur médiane de l'ordre de 2 %,

. niveaux de base différents, entre + 192 et + 206, ce qui confirme l'hypothèse de non continuité hydrodynamique du système étudié,

. réserve disponible pour l'évapotranspiration pratiquement nulle (0 à 10 mm),

. seuil de ruissellement : entre 60 et 120 mm/jour,

. constante de temps d'alimentation : entre 0,5 et 1,5 jours,

. constante de temps de vidange : 2,4 jours dans le chenal; 30 à 140 jours dans les forages,

. perméabilité verticale de l'ordre de 3.10^{-8} m/s (avec une zone fissurée de l'ordre d'une dizaine de mètres),

. débit spécifique d'étiage déduit des baises observées sur les forages, compris entre 1 et 4 $l/s/km^2$ (moyenne 2,5 $l/s/km^2$).

Etude de la zone non saturée:

- D'une manière générale, les tensiomètres sont plus sensibles à une modification de l'état hydrique que la sonde à neutron : en effet, très peu de fissures ayant été observées dans les sondages S1 et S2, exécutés en carottage continu, la sonde à neutron paraît n'avoir mesuré que la teneur en eau de la matrice rocheuse, alors que la plus grande partie des tensiomètres est implantée en zone de fissuration privilégiée (puits et cheminées).

- La teneur en eau de la roche est extrêmement faible, voire nulle à certains endroits, ce qui n'a rien d'étonnant si l'on se réfère aux mesures de porosité et de perméabilité réalisées en laboratoire:

. porosité totale : 1,84 % (macroporosité : 0,59 % - microporosité : 1,25 %),

. perméabilité à l'eau : pas de débit mesurable à une pression de 180 bars.

Les mesures de tension pour les tensiomètres de la matrice montrent que la roche ne se sature que très progressivement (les teneurs en eau à saturation étant inférieures à 2 %).

- Après de longues périodes sans pluie, l'évaporation est importante dans la partie superficielle et la réhumidification du sol instantanée : l'évaporation se fait sentir jusqu'à 2,50 m après 45 jours sans pluie. Les communications entre surface et grotte sont extrêmement rapides et se font exclusivement par les fissures. En profondeur, de l'eau subsiste dans certains joints ou dans des fissures ainsi qu'en témoignent les succions nulles observées pour certains tensiomètres; par contre, d'autres fissures se vidangent en période sèche.

- Un calcul de stock d'eau entre 1 m et 18 m effectué à partir d'un profil de teneur en eau sur le sondage S1, donne une valeur de l'ordre de 76 mm. Ceci est un ordre de grandeur de la réserve de la matrice rocheuse entre la surface du sol et la grotte.

- L'observation des arrivées d'eau dans la salle de la grotte a permis de préciser:

. les modalités de réapparition de l'eau infiltrée par comparaison du débit du bac jaugeur collectant la totalité des apports de la salle avec les débits recueillis par des entonnoirs et un pluviographe,

. la surface efficace de l'aire d'aspersion au profit de la salle : 300 m^2 environ pour une aire d'aspersion de 500 m^2,

. des déficits de restitution d'eau (pour des aspersions d'égale intensité horaire), compris entre 3 et 87 mm selon les périodes, fréquences et durées d'aspersion,

. des temps de réponse (= temps de percée), compris entre 1 et 4 heures et des vitesses de saturation comprises entre 2 et 7 heures, selon la teneur en eau de la roche, les tarissements après aspersion étant sensiblement constants, ce qui est logique, chaque aspersion étant poursuivie jusqu'à saturation.

- Modelisation:

Seules les mesures réalisées au bac jaugeur se prêtent bien à des bilans hyrauliques, et à la modélisation, car elles intègrent une surface notable (300 m^2).

Un modèle schématique d'interprétation 'modelé à réservoirs) a pu ainsi être mis au point qui permet de calculer le débit au bac en fonction de l'évapotranspiration potentielle et des précipitations ou aspersions de tous les jours précédents : l'évapotranspiration a été calculée par application à tous les jours de la formule mensuelle de L. TURC, aux données journalières de température à St Mathieu-de-Tréviers, et d'insolation à Montpellier.

Les meilleurs résultats ont été obtenus pour une capacité de réservoir équivalant à 90 mm : en supposant une porosité efficace de 2 %, cette capatité correspond à une épaisseur de terrain de 4,5 m.

Les observations qualitatives ayant montré que le "temps de percée" variait de 2 heures (pour un sol saturé), à 4 heures (pour un sol présentant un déficit de 90 mm), la modélisation a été complégée par un deuxième réservoir dont le remplissage était nécessaire pour que l'écoulement commence, les meilleurs résultats étant obtenus pour une capacité équivalant à 30 mm.

Enfin, les opérations de calage ont conduit à retenir des temps de 30 minutes pour le temps de montée, et de 2 heures pour le temps de tarissement.

Conclusion

L'interprétation détaillée et comparative de tous les résultats a clairement montré que pour un karst typique comme l'Hortus - c'est-à-dire présentant une matrice rocheuse compacte - il n'est pas possible de proposer un modèle continu de simulation hydrodynamique.

Un tel système karstique doit être décomposé en:

. un réseau de fissures reliées entre elles et avec le réseau karstique proprement dit constitué de conduits à très large section. Cet ensemble doit se comporter comme un réseau de canalisations, libre ou captif, et devrait pouvoir être simulé par n'importe quel modèle d'écoulement utilisé pour ce type de réseau. Mais le problème reste d'identifier les paramètres;

. une zone fissurée perchée par rapport au réseau karstique, qui peut être représentée par un assemblage de blocs indépendants pour lesquels peut être proposé un modèle qui peut se caler relativement bien à partir des comportements piézométriques observés sur des piézomètres indépendants du réseau karstique.

Une conséquence pratique importante de ce schéma hydraulique est que la zone perchée ne peut être sollicitée par pompage ou abaissement du seuil d'émergence, la capacité des prélèvements étant limitée dans le cas présent à celle, relativement faible, du réseau de chenaux.

La recherche a également permi d'établir qu'il était possible de modéliser sans trop de difficultés le débit transitant à travers la zone non saturée du karst de l' Hortus à la suite de précipitations ou d'aspersions.

Bien entendu, il faut être prudent quant à la généralisation des conclusions révélées sur le site de la grotte du Lamalou à l'ensemble de son bassin d'alimentation (33 km^2 environ) : les caractéristiques aquifères doivent y être très variables selon les secteurs et il est probable que le réseau karstique se développe de façon privilégiée selon des discontinuités peu représentatives de l'ensemble du bassin. C'est ce que l'on s'efforce d'établir par d'autres voies de recherche en vue d'une plus complète connaissance du comportement hydrodynamique de ce remarquable système aquifère.

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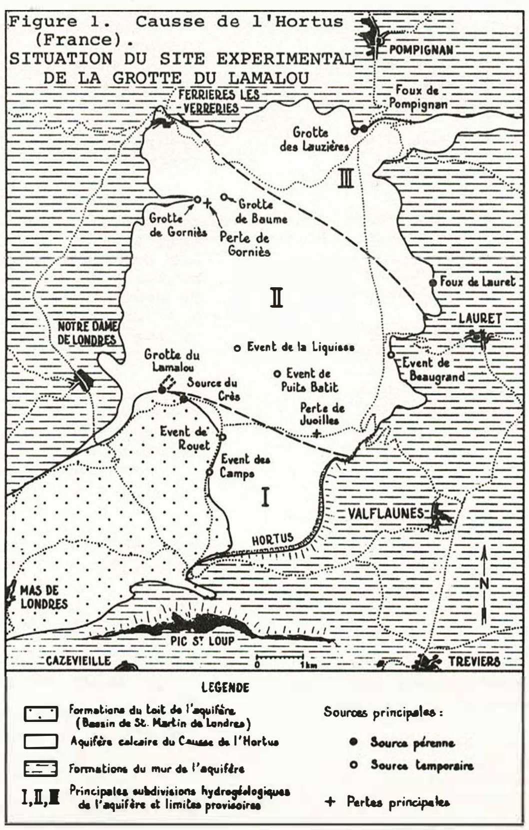

Figure 1. Causse de l'Hortus (France). SITUATION DU SITE EXPERIMENTAL DE LA GROTTE DU LAMALOU

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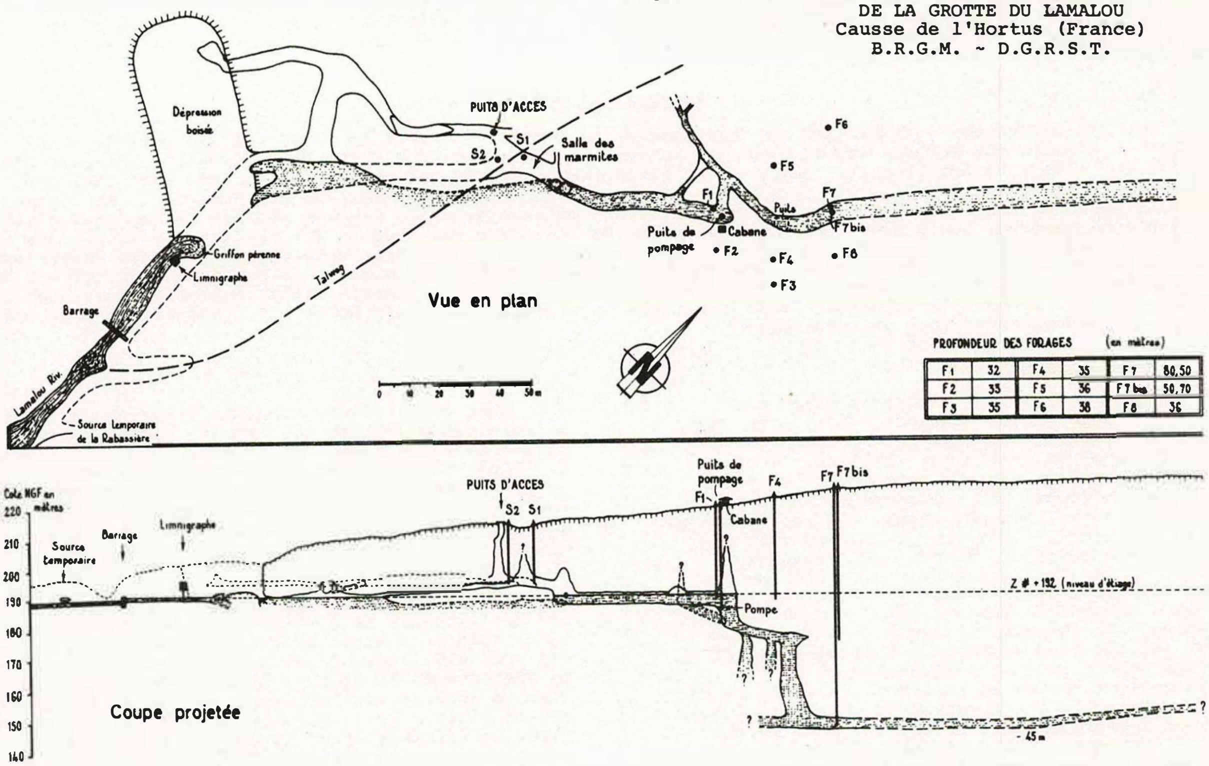

Figure 2. SITE EXPERIMENTAL D'ETUDE HYDROGEOLOGIQUE
DE LA GROTTE DU LAMALOU
Causse de l'Hortus (France)
B.R.G.M. - D.G.R.S.T.

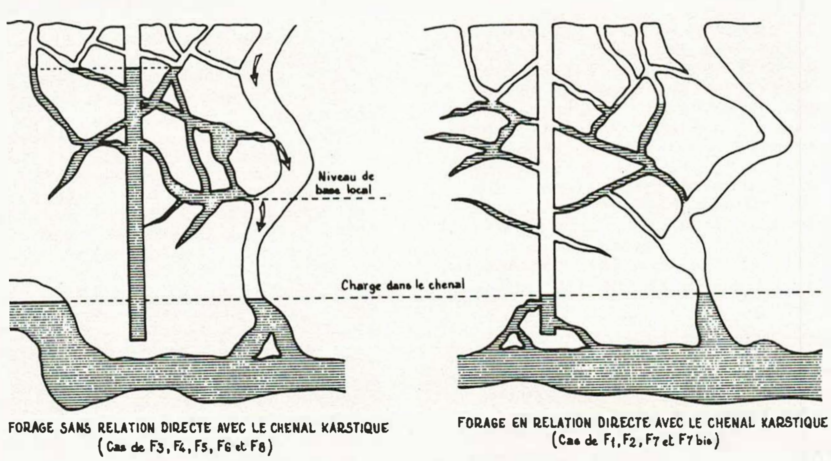

Figure 3. SCHEMA DE FONCTIONNEMENT

The Resource Potential of Transvaal Caves

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Abstract

The resource potential of karst caves in the Transvaal is assessed in terms of both the positive and negative aspects of interaction between Man and the cave environment. Caves in the area have had uses varying from places of shelter, to sources of fertilizer and to tourist attractions. Superimposed on these positive aspects of the ecosystems are the hazards to Man, which are of varying significance in different caves. These negative features include the occurrence of Histoplasmin spores, and of high concentrations of both Carbon Dioxide and of Radon. With recognition of the balance between the positive and negative aspects of the resource, and with sound management practices, the potential of the individual cave ecosystems may be realized. This potential will increase over time as population pressures on wilderness areas increase and as cultures adapt to changes in lifestyle. It is imperative therefore that the total resource potential of the cave systems in the Transvaal should be acknowledged, and that thereby mismanagement of the resource should be avoided.

Zusammenfassung

Die Erschliessungsmöglichkeiten von Karsthöhlen im Transvaal werden in Bezug auf die positiven und negativen Aspekte der Wechselwirkung zwischen Mensch und Höhlenumgebung untersucht. Höhlen wurden in diesem Gebiet auf vielfache Art benutzt. Sie dienten als Unterkünfte, Düngerquellen und Touristenattraktionen. Neben diesenpositiven Aspekten des Ökosystems bestehen auch Gefahrenquellen für den Menschen. Das Ausmass solcher Gefahren hängt von den einzelnen Höhlen ab und umfasst negative Aspekte wie das Vorhandensien von Histoplasmin Sporen, sowie hohe Konzentrationen von Kohlendioxyd und Radon. Ein Ausgleich zwischen den positiven und negativen Aspekten und eine ordentliche Bewirtschaftung sind erforderlich, um die Ökosysteme der einzelnen Höhlen zu erschliessen. Die Erschliessungsmöglichkeiten werden mit dem zunehmenden Druck der Bevölkerung auf die Wildnisgebiete und Anpassungen in der Lebensweise verschiedener Kulturen in der Zukunft zynehmen. Es ist deshalb notwendig, alle Erschliessungsmöglichkeiten der Höhlen im Transvaal zu untersuchen, um eine Fehlbewirtschaftung zu verhindern.

Introduction

Resources, consituting materials which are useful or valuable to Man (Haggett, 1975) have been recognized throughout the time Man has been on the surface of the earth. O'Riordan (1971, p. 3) has pointed out that this concept is now more complex, being rather a "functional relationship that exists between Man's wants, his abilities, and his appraisal of his environment". They vary in nature from the dominant finite resources to scarcer renewable resources. Being restricted in their usefulness by Man's abilities, most have both positive and negative values with the former predominating and rendering it of value. It is this relationship between the positive and negative aspects of a resource which determines its potential usefulness.

The goals involves in assessing resource potential are related to the improvement of environmental quality or themore equable distribution of social welfare (O'Riordan, 1976). In particular, in the case of natural resources such as karst caves, this must relate to the optimisation of wilderness areas essential for leisure-time pursuits. Karst caves as sheltering places, and subsequently with more diverse uses, have been recognized as resources for about the last three million years. Their potential is limited according to their finite nature.

In the Transvaal, South Africa, approixmately 200 caves are known in the Precambrian Malmani Dolomite, a true dolomite rich in manganese and iron. They are distributed in an arcuate belt (Figure 1) surrounding the Bushveld Igneous Complex, and are dates as having opened as much as 3.7 million years ago (Partridge, 1973). The area is located in a summer rainfall region, varying from semi-arid to sub-tropical in character.

The intention of thepresent paper is to examaine the resource potential of Transvaal karst caves. The past and present use of the ecosystems are considered prior to assessing the future situation. Both the positive and negative aspects of the resources are considered in an attempt to arrive at a fair evaluation. Management practices are alluded to in the light of the future resource potential.

Transvaal Karst Cave Resources

Karst caves in the Transvaal tend to be limited in occurrence and dimension varying from systems barely penetrable by Man to a maximum of 11 km of passage. Entrances vary from single to multiple, and from sinkhole to walk-in or crawlway. The caves are characterized by collapse features, by old, largely-inactive stalactitic decoration with a predominance of aragonite, and by a general lack of water. Deep cave temperatures approximate 18^{o}C and relative humidity 98%. The caves are characteristic karst cave ecosystems, but due to limited passage dimensions and porosity of the host rock, tend to be very stable and hence very vulnerable.

Most of the caves occur in areas remote from centres of population (Figure 2), and are themselves generally of limited access because of their small dimensions. In addition, the cultures of the Afrikaans nation and of the local African tribes have been responsible for limiting the full development of cavern resource potential. Both groups, particularly the latter, are superstitious of the underground world and hence are reluctant if even willing to venture inwards.

The resource potential of a karst cave or of a suite of caves is dependent upon system characteristics and upon its relationship to developers. The potential of the system itself is limited by its carrying capacity, including its accessibility, and by its threshold and resilience level to disturbance (Krutilla, 1971). The occurrence of obstacles such as health hazards and of cultural limitations act to limit a cav's potential. The use of resources is also inextricably bound to environmental perception and cognition (Simmons, 1974), which in turn are dependent upon knowledge and awareness. Environmental resource pressures and the question of supply and demand are also fundamental in the determination of resource potential. All these factors are determinants of cavern resource potential in the Transvaal.

Uses of Transvaal Caves:

For the last three million years Transvaal caves have had Varying uses, typical of those throughout the rest of the world. These have ranged from places of shelter and sources of minerals and other raw materials, to recreational centres and natural laboratories. Optimisation of the resource has however been limited particularly by inaccessibility, lack of awareness and cultural considerations.

The local use of accessible caves and especially of entrance areas has been extensive as places of shelter throughout the history of mankind. The earliest known hominid fossils have been excavated from cave sites such as Sterkfontein. Subsquently many caves have provided places of refuge for the local peoples during times of conflict, as at Makapansgat and Sudwala during the mid-nineteenth century. Currently caves in remote areas are used by guerrillas for shelter and arms caches.

The local peoples have had many additional uses for the colomite caves. These range from burial sites to witch-doctor's retreats. The Rain Queen of the Venda people reportedly lives in a cave. Medicinal substances are frequently stored underground. Most caves are attributed with strange mystical qualities and with the presence of ancestral spirits.

The Krugar Millions are yet rumoured to be buried in a cave. More tragically, in many farming areas caves remain important refuse pits. A local game reserve uses a cave on its property as the lair for its leopard. On occasions one of the western Transvaal gold mines dumps slimes into a cave on its property.

As sources of minerals the caves are limited in value. Deposits are not generally economically viable, although calcite was mined for building purposes early in this century. Dolomite is quarried, sometimes intruding into cave systems, for flux for the iron and steel industry. Guano is removed intermittently for fertiliser. One of the most profitable sources of income from caves in recent years has been the sale of speleothems. Water which does occur in the lcoal caves is mainly of water-table origin, and is occasionally used for irrigation.

The aesthetic attraction and consequent recreational use of Transvaal caves started in 1904 with guided tours of Sterkfontein. This venture had a chequered career utnil it was taken over by the University of the Witwatersrand in 1958. Echo and Sudwala caves were opened to the public during the 1960's. Speleological organizations have been active in the area since 1956, and currently three small groups operate. They are concerned mainly with the sporting and conservation ascptects of the science. Other parties including nature conservation and wildlife societies have recently become interested in the cave resource, for educational and protection purposes. It is presently in the recreational sphere that the major use is made of Transvaal caves.

Natural laboratories have flourished in local caves in the palaeontological, archaeological, geomorphological and geological fields. More recently climatological, bat and environmental studies have been undertaken. The biological resources are apparently fairly extensive, but little work has been done in this field so far.

Many of these undertakings have resulted in damage to the ecosystem, in some cases irrevocable. Plans have been mooted for future oil storage in some of the cavernous dolomite. In addition more reliacne must be placed on the water resources for increasing food production. The major future resource potential of this suite of caves lies mainly in the recreational and scientific fields. There are presently plans to open two further caves to the public - Wolkberg to tourists, and one on a nature reserve for educational purposes. However this method of wilderness optimisation in the face of increasing pressures can only provide a valuable resource if it is carefully managed. Balanced against these uses of caves must be the problems involved in the development of the resource.

<u>Negative aspects of Transvaal cavern development:</u>

The negative aspects of the cave resource are not unique to the Transvaal are, but possible occur with varying relationships to those in other regions. They are related to both the damage caused to the ecosystem by intrusion, either direct or indirect, and the detrimental impact of the cave system on the human visitor. Until it reaches extreme proportions when the ecosystem, and therefore the resource itself, is destroyed, disturbance of a cave is perhaps the least obvious of the obstacles to resource development. In most instances this resource potential, or at least the detail, cannot be recouped because of the long time periods involved.

The occurrence of sinkholes upon dewatering of compartments with mining operations has resulted in spectacular damage in the West Rand area. The town of Bank was abandoned in 1971 after major subsidence. Instability within a cave system, accentuated by long undisturbed periods, is a common feature evidenced by rock breakdown and boulder chokes. Inexperienced persons endeavouring to negotiate such features are the most exposed to these dangers. Inexperienced persons falling or becoming lost within a cave are possibly the most frequently encountered hazards.

The entrance areas of caves, especially sinkholes, may intermittently host poisonous snakes such as cobras, which are usually more hazardous for having fallen into the cave, being unable to escape and being short of food.

Diseases contractable by humans include Benign Pulmonary Histoplasmosis, which has been responsible for at least three deaths in the Transvaal during the last five years - generally through incorrect diagnosis. However in msot cases an immunity to the recurrence of the disease is the result. Fungal skin infections, believed to be Sporotrichosis, for which there is presently no known cure, have occurred as isolated cases during the last two years. Hypothermia and exhaustion are possibilities in all caves under conditions of prolonged exposure, prolonged submersion or injury.

The most common of the hazardous gases recorded is carbon dioxide. Concentrations of up to 3.5% have been measured, although these may be exceeded under poor ventilation conditions. Such concentrations are particularly hazardous to the inexperienced visitor, such as the local farmer attracted by guano deposits, who is unfamilar with the physical effects and associated hazards of the gas.

Recent preliminary studies of the occurrence of the radioactive α-emitting Daughters of Radon have indicated that prolonged exposure to the atmosphere in certain caves could be dangerous. Working levels of up to 1.6 have been recorded during Spring in the remote areas of some caves. It is anticipated that these levels could increase during Summer when ventilation is decreased and is usually outward in direction.

These negative aspects are obviously of particular significance to speleologists, scientists and tourist cave personnel, who through prolonged exposure are subjected to considerable risk. They are of little concern to the occasional tourist visitor to a cave.

<u>The Resource Potential of Transvaal Caves</u>

In assessing the potential of any resource, the positive features of that resource must be balanced against those which are negative. In order to do this effectively, cave must be considered individually and as members of the general suite of caves in the area.

When considering the suite of know Transvaal caves it is apparent that they are a definite resource. However, the resource value varies between caves with one positive aspect usually prevailing. When aesthetically attractive caves are reasonably accessible, several have been or are being developed for tourists. Such high intensity recreational use, while usually devasting the ecosystem, is beneficial for the wilderness experience of recreation, the educational and the commercial ventures, and thus the sacrifice of the ecosystem may in certain circumstances be deemed worthwhile. Others which are particularly vulnerable or dangerous have been gated to prevent vandalism or accidents. Scientists and speleologists find other caves attractive for research or the athletic and psychological challenges provided. A number of caves are subjected to limited disturbance, or if they are presently unknown to virtually no disturbance, in order to promote the ecosystem itself.

The resource potential must increase as the increasing pressures of population, and leisure time, and the reduced cultural barriers place greater demands on karst cave wilderness areas. These will be both intentional and unintentional pressures in the form of direct intrusion into the cave and disturbance through surface alternations.

The very occurrence of karst caves in the Transvaal - in dolomite and under low rainfall conditions - dictates limitations to the resource. The number, magnitude and accessibility of the caves are all compounded by the hazards which are prevalent to a greater or lesser degree in all of them. Such factors are seldom encouraging to visitors. With sufficient economic or other incentives, the level of resource development can be high, although it can be contained by scientific management through education and sound administration.

Despite the negative aspects of the Transvaal cave resource, the potential for use remains high. Differences between caves must continue to be recognized in order to optimize their individual potential which must, of necessity increase over time. With sound management practices, damage to the ecosystems can be contained, and the exposure of visitors to hazards may be controlled, both leading to optimisation of the total resource.

<u>Conclusion</u>

The resource potential of Transvaal karst caves is considerable, but must be recognized in terms of individual systems as well as in terms of the known suite of caves. It must be further recognized in terms of the balance between the positive and negative aspects of the resource.

Although the karst cave resource has been variously used in the Transvaal for the last three million years, the future increased pressured anticipated will dictate tha these uses are limited mainly to the recreational and educational fields and that due cognisance is taken of the various hazards involved. Such can only be done within the framework of sound environmental management, according to which the resource potential is optimised. Education and awareness are the basic requirements for such administration.

Acknowledgement

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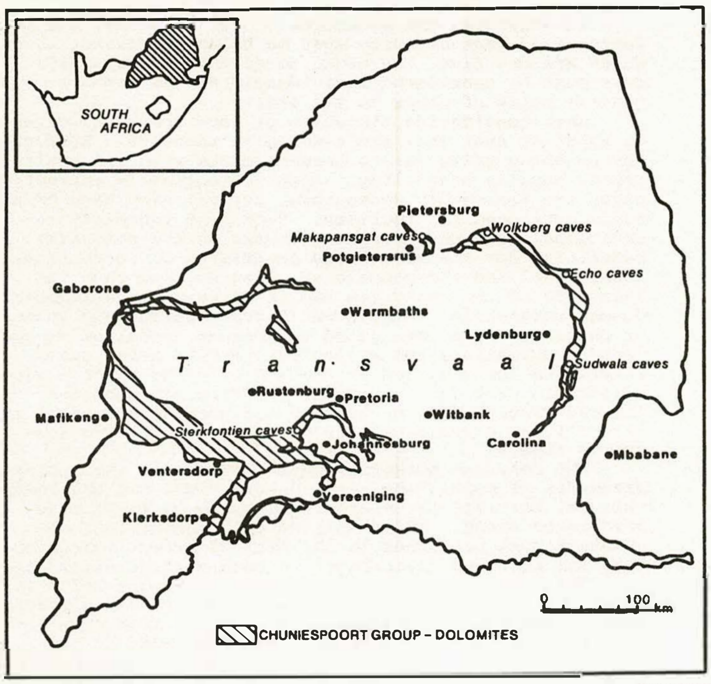

Figure 1. The Distribution of the Malmani Dolomite in Which the Karst Caves of the Transvaal, South Africa, Occur (after Truswell, 1977).

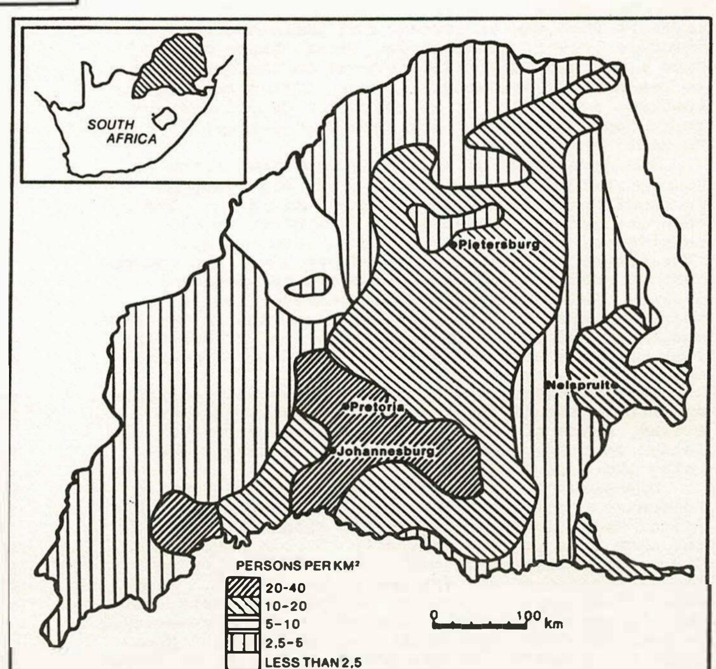

Figure 2. The Distribution of Population in the Transvaal.

Problems of Management of Transvaal Caves

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Abstract

The management of karst caves is interpreted as the process which optimises the resource potential of the cave. This process varies considerably between caves, from an undistrubed ecosystem to commercial development. The problems involved is such management are considerable. They vary from common problems of awareness of involved parties and exploitation of the resouce to problems more specific to the Transvaal area. These latter include aspects such as culture, population distribution and minimg practices. Contrary to these problems there are few current positive aspects to management. It is imperative that the most pressing of the problems, in the fields of awareness, distribution and administration, should be minimised as soon as possible. The problems of management are not seen as being insurmountable, but rather as long-term undertakings on the part of all concerned parties.

Zusammenfassung

Unter der Bewirtschaftung von Karsthöhlen im Transvaal versteht man den Vorgang, das Erschliessungspotential einer Höhle zy optimieren. Lieser Vorgang ändert sich von Höhle zu Höhle, von der Erhaltung des Ökosystems bis zur wirtschaftlichen Entwicklung. Bei der Bewirtschaftung entstehen beträchtliche Problem, von allgemeinen Kenntnis- und Erschliessungsproblemen für alle Beteiligten bis zu ortsspezifischen Problemen im Transvaal, wie Kultur, Bevölkerungsvertailung und Abbauverfahren. Neben diesen Problemen gibt es wenig positive Bewirtschaftungsaspekte. Es ist erforderlich, die dringendsten Probleme auf dem Bebiet deur Kenntnisse, der Verteilung und Verwaltung auf ein Mindestmass zy verringern. Obwohl die Bewirtschaftungsprobleme nicht unüberwindlich erscheinen, erfordern sie doch langfristige Verpflichtungen seitens aller Beteiligten.

Introduction

During the last 15 years, Man's perceived need for control has led to a change in approach to the natural environment. Conservation has become strategic management, the process whereby a predetermine objective is obtained ¢Devereaux, 1978). This involves the wise use or optimisation of resources (Usher, 1973), including raw materials, amenities, recreation and scientific interest (Black, 1964). Such an approach is effectively a compromise providing the best means of serving all interests (Wilmut, 1972), but is essential particularly where finite resources are involved. Problems of awareness and implementation of such management are considerable throughout the world, but are perhaps most critical in the developing nations where degradation of the environment is serious.

Awareness of the problems associated with and of the necessity for management of karst caves is a relatively new concern involving few of the general population. The general inaccessibility and ecosystem stability of karst caves are such that few people recognize their fragility or resource potential. In the Transvaal cave numbers and locations, and population awareness necessitate management of the ecosystems. Their potential is considerable, but only in as far as it is recognized and optimized. As the population pressures increase (currently at approximately 3.5% p.a.), so do the pressures on tourist amenities and therefore on wilderness areas. In order to avail future generations of the cave resource, the problems inherent in sound management practices must be minimized. These problems are not unique to the Transvaal area, but serve to illustrate those which must be acknowledged and those of priority.

The necessity for and problems confronting the successful management of Transvaal karst cave are examined in the present paper. The possible methods of overcoming such hindrances are alluded to. The general principles are transferable to other karst cave areas.

The Necessity for Karst Cave Management

The necessity for management of karst caves is obvious only to those persons actively involved in scientific studies or recreational pursuits within cave ecosystems. Amongst these few it is generally accepted that management is necessary in order to derive the best possible value from the site, although this value is relative depending upon time, place and circumstances (Whitfield, 1980).

Caves form one of the best and possibly last wilderness resources (Stitt, 1976) available to Man, but unlike natural areas their extent cannot be increased (Wilmut, 1972). They belong to all Men, who are entitled to at least a limited share of their resource value. With the increasing demand for outdoor recreation, and therein a growth in the number of cavers and other interested persons (Clawson, 1966; Hamilton-Smith, 1967; Wilmut, 1972), management is essential. Man has no moral nor ethical right to deprive future generations of the resource, though damage which mars beauty and is irreparable, or which deprives society of knowledge through the destruction of specimens or data (Hamilton-Smith, 1967). Each cave ecosystem must be recognized as an individual resource which has a limited carrying capacity in terms of disturbance to the ecosystem. It is according to the carrying capacity that each system must be managed in order to achieve optimal returns.

The objectives of hte management programme must be clearly defined in terms of the level of impact acceptable to the cave manager (Fletcher, 1980). Ideally this should entail a reversal of ecosystem damage to pristine conditions (Ela, 1976), requiring the integration of the cave and surface area management plans. Such is seldom possible and a compromise situation has to be accepted. The case for many caves is too late as they have been few positive actions. Consequently the situation now is basically one of rescue as available preventive measures are inadequate.

The Present Status of Transvaal Cave Management

The present status of karst cave managemet in the Transvaal is based upon national and provincial legislation of 1978-1979, pertaining to the defacement and preservation of cave formations. Indirectly this act protects most of the ecosystem as it relates to atmospheric disturbance and the introduction of foreign materials. The provincial legislation forms a subsection of the Nature Conservation Ordiance for the Transvaal, and as such falls within the jurisdiction of that department. It has not yet been tested but is strongly supported by speleologists and Nature Conservation officials.

Apart from these persons and the associated legal control, various other parties are or should be involved in the management of local caves (Table 1). Most cave owners, public or private, exercise some control over their caves (Larson, 1977).

In all instances at present management tends to be sporadic and uncoordinated. The general public, from amongst whom problmes of the casual visitor are derived, are not involved. Where parties are aware of the implications of disturbance, steps are being taken to minimize damage to the ecosystem while at the same time promoting the wise use of the resource. Problems are greatest where commercial gain is involved. In the 'wild' caves there is evidence of wear and tear from cavers, still at a low level as most caves are subjected to less than four visitors per month. In certain particularly vulnerable instances caves have been gated to prevent further wanton destruction.

The hesitancy of the local population to venture underground is an additional positive factor, without which disturbance is likely to likely to have been much greater. This characteristic extends to most private cave owners, who are also hesitant about promoting the disturbance by others of their subsurface property. The isolated nature of many individual caves also assists to some extent in their protection.

Cooperation and communication between involved parties is one of the most vital aspects of management. Locally this situation is advantageous in that there is some cooperation between most cave owners, scientists, speleologists, the provincial authorities and conservations.

The present management situation is one of a lack of coordination, based mainly on limited awareness. The machinery exists for the initiation of a management programme, and the officials are receptive to advice. However, there remain several problems to the successful management of Transvaal caves.

Table 1
Parties to Whom Cave Management is of Concern in the Transvaal

Party	Established Area of Concern
Department of Water Affairs, Forestry and Environmental Conservation	Permits to enter forest and water reserves
National Parks	Act protecting geological forms
Historical Monuments	Act protecting individucal sites e.g. Sterkfontein Cave
Department of Defense	Permits to enter military areas
Homeland Governments	Permits to enter
Peri-urban Board	Deterrent notices at caves
Provincial Nature Conservation	Legislation and ranger control
Environmental Organizations	Conservation areas e.g. South African Wildlife Society
University Scientists	Restricted access to sites
Speleological Organizations	Conservation - cleaning, gating
Gem and mineral clubs	Speleothem supplies
Gemstone retailers	
Private property owners	Subjective control e.g. Sudwala

Management Problems in the Transvaal

The successful management of karst cave resources is a complex task. It involves both tangible and intangible disturbances. Surface and subsurface intrusions, both intentional and unintentional, must be recognized and controlled according to the merits of each cave. This is obviously particularly difficult where population pressures are high corresponding with complex surfaces alterations and multiple subsurface disturbances.

There are two basic considerations in the management of karst caves (Godfrey, 1976), namely the destruction of the resource itself and the management of people, both of which are interrelated, the more so at the actual management stage. In the Transvaal these problems may be grouped into four main areas.

Geographical considerations:

Geographical problems are some of the most difficult to control in the Transvaal as they are allied to distribution and to politics. The major concentrations of caves are remote from the main population centers, and correspond with areas of rough terrain (Figure 1). The resultant limited assessibility further complicated by the surface climate and vegetation characteristics, and by the small and inaccessible nature of the caves themselves, renders them particularly difficult to control.

Many of the dolomite areas occur within the independent homelands of Venda, Lebowa, Gazankulu and Bophuthatswana (Figure 2). This situation renders decentralized administration and control, as well as appreciation of the problem major issues. Currently, only the Transvaal and Lebowa authorities appear concerned about some of the caves within their jurisdiction - both being directly involved through possession and at least partial recognition of a number of valuable cave resources.

Physical considerations:

Physical and biological considerations relate to the destruction of the resource itself, particularly as it is irreplaceable and unextendable. Pollution of the system or of the surrounding environment, particularly water and atmosphere, are major problems. They are usually long-term and initially unnoticed, resulting in the destruction of a habitat especially fauna which by virtue of their small numbers are already endangered (Stitt, 1976). The occurrence of Daughters of Radon, high carbon dioxide concentrations, Histoplasmosis and other physical hazards are also regarded as management problems. All of these factors contribute to the carrying capacity of the system.

Social considerations:

Perhaps the most urgen problem facing the successful management of Transvaal caves is that of lack of knowledge and awareness. As with all other facets of the environment, concern is slow to be realized, and is generally manifest only in certain centers. This leads to a failure on the part of most persons to recognize the significance of the cave resource (Nieland et al, 1980). In addition, because of the lack of information and understanding as well as the haste usually involved in resource development (Fletcher, 1980) the details of disturbanc are unappreciated. Hence much damage results. The education process is slow in such a situation and time is of the essence in any successful management programme. The dispersion, diversity and non-involvement of the general population renders their awareness of and concern for the karst cave resource almost non-existent. Three small speological groups in the area provide little contact with persons who are actively involved or concerned. The three tourist caves are taken for granted, and there is little more concern for the issue in general. In addition, speleology is not recognised as a science (Hubart, 1976), and thus has little official support. As Usher (1973) concludes therefore perhaps the most part of any management programme is the education of the educational user. This would obviously be most effective through the use of sound interpretation programme. At the same time however the short duration of interest of conservation-committed speleologists does not provide continuity for any management programme.

All resource management problems are related to the increased leisure time and mobility of the population. The result is an increased recreational demand from both the greater total population and the changed characteristics of society itself. The situation is further compounded by the paucity of karst caves in the rest of South Africa. Most of the ever-increasing South African population and many foreign visitors are forced to rely upon the Transvaal caves.

Related to the problem of lack of awareness is thoughtless exploration resulting in abuse of the resource. This applies to both the causal visitor and the trained speleologist. Wear and tear on system is dependent upon organization and control. More severe is the intentional destruction which results from speleothem collection. Industrial and construction impacts, which have economic and political backing, are more difficult to combat, but precedents in terms of the preservation of scientific sites have been set throughout the world.

Local problems are also rooted in the cultural diversity of the area. Peoples of at least six Black and four White groups each with its own language, beliefs, traditions and superstitions occupy the area. Of these only the White Enlgish-speaking peoples are really involved, thus rendering numbers limited and management practices few.

Economics of control and exploitations are involved in all management problems. A resource which provides an economic return is frequently considered more valuable than one which has no obvious return or requires investment. In addition, the expenditure of large sums on control or other management measures is often regarded as being of limited value because of the low priority rating of the resource.

Management programme considerations:

A sound management programme can only succeed with planning, control and effective implementation.

Management programme problems are essentailly those of trained manpower and expertise, although other problems such as economics cannot be ignored. The major manpower source is nature conservation officials and active speleologists. Expertise is required initially for compiling a comprehensive cave resource inventory. Thereafter management alternatives must be considered and priorities established, according to the pre-determined management objecties. Legal protection is of particular importance at this stage.

None of these problems are mutually exclusive. They must be considered for the total suite of caves, and for individual systems. They are multiple and complex, far exceeding the prevailing positive factors. With enlightened leadership and the correct controls they are not insurmountable. Given a sound management framework which recognizes the necessity for compromise, the most urgeng problem is education, which must form an integral part of the on-going management programme. The initial input must be rapid and thereafter must be long-term and dynamic, and must interpret the cave resource as a viable portion of the total environment.

Conclusion

The problems of karst cave management are similar throughout the world, although each area has certain uniquw aspects. In the Transvaal the basic has been laid for future management programmes. All concerned parties must be involved in order to enhance the cooperation and communication potential of specialists. Recongition of the urgency for a comprehensive, dynamic, long-term plan for the entire resource is vital, and will provide guidelines for individual systems. The greater the dealy the greater the potential for future management initiation and progress.

Acknowledgement

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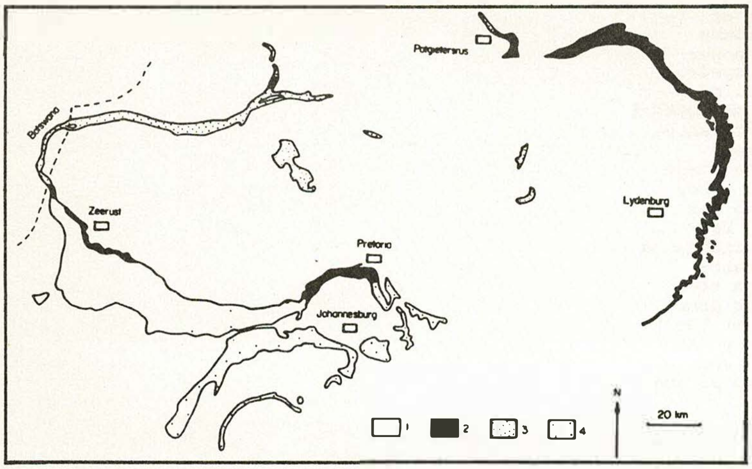

Figure 1. Morphological Types Associated with the Dolomite.
(1) Plateau type, (2) Escarpment Type, (3) Bushveld type, (4) Vaal River Type. The escarpment topogray (2) is particularly borken and inaccessible. (After: Martini and Kavalieris, 1976).

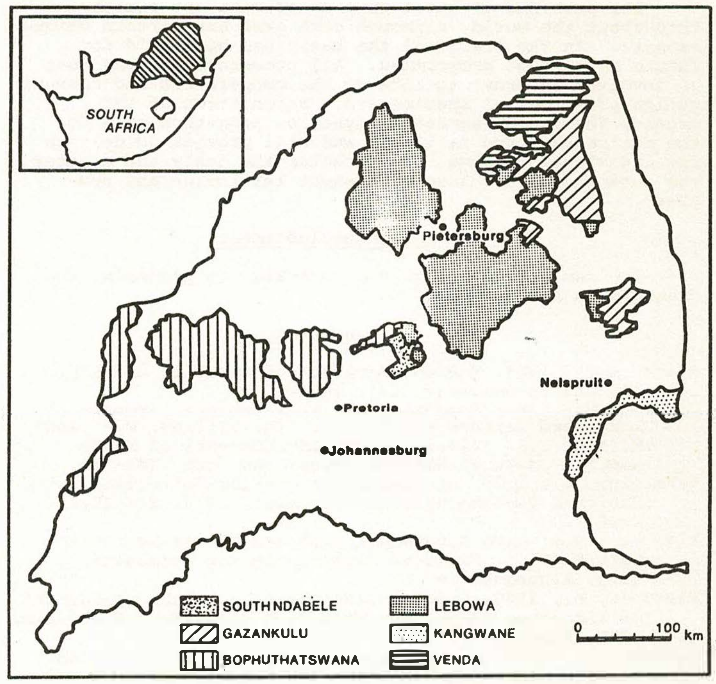

Figure 2. The Location of Homeland Areas in the Transvaal.

Karst Cave Management Modelling in the Transvaal

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Abstract

The necessity for a management model for use in Transvaal karst cave areas is evident from the occurrence of both intentional and unintentional exploitation of cave resources. Such modelling is complex, depending on the specific region and the individual cave to which it is applied. The concern of the paper is with the general requirements, nature and feasibility of such modelling. Both physical and social environment considerations are incorporated. The model is based on the most extreme conditions of suscentibility to disturbance of a cave system, that is on a static cave. Its nature varies from descriptive to mathematical. The success of the model as a management tool is dependent upon its flexibility permitting modification for individual applications and ease of interpretation. Many of the general principles are transferable to caves in other rock types and/or in other geographical regions.

Zusammenfassung

Da die Karsthöhlengebiete im Transvaal entweder absichtlich oder unabsichtlich erscholossen werden, ist ein Bewirtschaftungsmodell für diese Höhlen erforderlich. Die Aufstellung eines solchen Modells ist ein komplexer Vorgang, der nicht nur vom spexifischen Gebiet, sondern auch von den einzelner Hohlen abhangig ist. Dieser Vortrag behandelt die allgemeinen Voraussetzungen, die Grundsatze und Moglichkeiten eines solchen Modells und berucksichtigt dabei physische, soziale und umweltsbedingte Faktoren. Als modellgrundlage dient eine statische Höhle, mit Bedingungen, unter denen ein Höhlensystem extreme empfindlich ist. Das Modell wird sowohl deskriptiv als auch mathematisch behandelt. Der Erfolg eines solchen Modells bei Bewirtschaftungsmassnahmen hängt weitgehend von seiner Flexibilität ab, d.h. von seiner Fähigkeit, sich an Einzelfälle anzupassen und diese entsprechend auszulegen. Die allgemeinen Grundsätze können vielfach auch für Höhlen aus anderen Gesteinen oder in anderen geographischen Gebieten angewandt werden.

Introduction

Models are tools used in scientific research or in planning and control to represent reality. They are subjective approximations consisting of 'a simplified structuring of reality which presents supposedly significant features or relationships in a generalized form' (Haggett and Chroley, 1969, p. 22). They are valuable in that they obscure much of the detail of the system, allowing the basic components of reality to dominate, thus facilitating understanding and behavior prediction of the system (Lee, 1973). Models have been used in the environmental field for about the last 20 years (Deininger, 1973), where they have achieved some measure of success (Vansteenkiste, 1978). Resource systems are always models or abstractions and simplifications of reality. They have great potential value, if only to compare decisions with the optimum situation (O'Riordan, 1971).

To date there have been few attempts to model total environmental systems (Deininger, 1973; McHarg, 1973; Spofford, 1973). Karst cave ecosystems have been particularly neglected. Systems of classifyin caves according to their contents and hazards have been devised (Larson, 1980; Trout, 1978). Several studies, as for example in the Waitomo area of New Zealand (Nelson, 1975), have provided recommendations for improvements to individual caves. Forssell (1977) and Stitt (1977) have respectively considered carrying capacity in realtion to management, and the human surface and subsurface impact on caves based on the countryside model proposed by Nicholson (1972).

A model, while used as a reference or ideal situation, must include some compromise in terms of individual applications, while demanding that disturbance of the system is minimized. Such modelling is as complex as the ecosystem in question, but is essential in the optimisation of any natural resource, particularly those of a finite nature.

The karst cave resource potential in the Transvaal is limited, requiring appropriate planning and management. Management must embrace the whole ecosystem and not only isolated facets. Although caves approximate closed systems, cognisance must be taken of the surrounding systems upon which they are dependent.

The intention of the present paper is to examine the general objectives, requirements, nature and feasibility of such a model, as it applies to the Transvaal suite of karst caves. Many of the general principles are applicable in other karst regions.

Construction and Objectives of the Model

The construction of dynamic enviornmental models involves four fundamental stages (Devereaux, 1978; Vansteenkiste, 1978):

- The determination of model objectives, requirements and structure based on available experience.
- Parameter identification and development of a strategic management plan.
- The design and installation of monitoring control systems, and the initiation of action.
- Validation of the mdoel by testing it against reality.

The validation of the model is the most difficult step in its construction because of the puacity of available data, particularly for a total environmental system. Consequently it is a step which is frequently omitted, although it is only once a model as been tested against reality that it can be used with any confidence.

The objectives defined in a karst cave management model should be designed to initiate comprehensive planning for environmental quality (McHarg, 1973), and thereafter to provide the guidelines for future management practices. They should be idealistic while maintaining some degree of realism. The ideal of reversing the ecosystems to pristine conditions is obviously unrealistic in this situation. More judicious would be the optimisation of the resource through its wise use, tending towards multipurpose use, thus helping to alleviate land demands. Any alternation to the existing biological and geological features of a cave must thereby be minimized (Palmer, 1980). Such a policy allows for three levels of cave disturbance, each being selectively encouraged. These levels are the undisturbed ecosystem, the controlled or limited access system, and the commercially developed cave. In terms of an optimisation policy emphasis is on the first two categories, with limited but important recognition of the third in a few selected cases. Under no circumstances should uncontrolled exploitation of the resource be tolerated.

Such objectives are demanding on the nature of the model for successful resource management.

Requirements of the Model

The requirements of any model involving ecosystems are dependent upon the nature and resource potential of the ecosystem.

The model must be comprehensive in all respects. It must encompass planning and environmental quality considertations, as well as ~~the total environment~~, including both physical and social aspects. In the case of cavern systems the disturbance of the physical environment by Man (as part of the social environment), intentionally or unintentionally (Figure 1) is the primary concern of the model. These can only be incorporated into a total ecosystem model by using appropriate invidividual subsections within the framework of the total management model.

The intention of the model must be to allow for the most extreme case, that of a sack cave with restricted entry, a situation typical of most Transvaal caves. Such an ~~ecosystem~~ is particularly vulnerable to any disturbance, the major controls being atmospheric and hydological. This vulnerability is enhanced in Transvaal caves by limited rock porosity and passage dimensions resulting in poor ventilation.

The model must be based on the existing management structure consisting of involved parties, and machinery such as commercial controland legislation. Within this framework allowance must be made for three existing levels of management - national, provincial and individual clubs, caves and speleologists. These should be viewed as important foundations for the creation of awareness amongst both the general and involved population, and upon which overseas experiences may be based.

It is essential that the model should embrace an understanding of the biophysical environment involved. Relatively little is known about cave management (Gallagher, 1980), a situation which necessitates immediate amelioration through research.

The model must be as objectives as possible.

The model must be dynamic, being continually imporved according to ~~the latest kno~~wledge and experience gained. This is in accordance with the dynamics of the ecosystem itself.

The model must be flexible in that each system is to a greater or lesser degree unique. However, this flexibility should not supersede the management objectives of the model.

The model must be stringent in its provision of controlling guidelines for all aspects of the resource. However, a balance must be sought in order to preserve the flexibility.

Each of interpretation, facilitating utilization and communication, is essential in order to optimise the model as a management tool for both laymen and experts. However, oversimplification which reduces the value of the model must be avoided.

These requirements for a karst cave management mdoel may appear idealistic. In terms of the objectives of the model they are essential premises upon which to work. In reality some compromise has to be accepted, but these at least would provide the initial guidelines.

The Nature of the Model

In accordance with other models of environmental systems, a model of karst cave management requires an heuristic approach (Vansteenkiste, 1978), using smaller units in its construction, but being validated in situ against a complete system. The model should essentially be analytical, but should include ~~systems analysis~~ and simulation in appropriate sections.

Some of the major modelling problems are encountered indefining and quantifying environmental qualities and other public policy objectives (Deininger, 1973). In its overall framework the model would comprise a number of both descriptive and mathematical sections. The descriptive sections are the most subjective and hence are the weakest link in such a tool. They pertain for example to the problem of vandalism. They must be minimised, but are essential members as they provide the only method of including such system features. In addition, they are probably the most easily interpreted sections of the model, and as such are vital, particularly to the non-sepeialist.

Numerical sections are more precise, therefore more objective, and are consequently the most valuable modelling techniques. They are dependent upon exact measurements, for example of temperature, humidity and carbon dioxide. On the basis of these measurements various characteristics may be calculated. Thence visitor hazards and ecosystem impacts may be interpreted, prior to compliance with the remainder of the management objectives.

Descriptive and mathematical components contribute to one major management model. The flexibility of the mdoel is thereby enhanced, while its subsection stringency is preserved. The application of the mdoel will vary according to the nature of the individual ecosystem. In general stringency will be reduced in most systems as vulnerability is decreased through ventilation or management policy. In most instances in the Transvaal application will vary through larger systems as conditions, for example in entrance zones, are different from those in deep cave areas.

Feasibility of Successful Modelling

Successful modelling of ecosystems is essential in sound management practices, but the features required to render a model successful are several and complex.

The flexibility of the model is perhaps the most important consideration. Both in itself and in its application and usage it must be versatile. Without this feature a rigid model is of little use. It provides no guidance and allows no exception.

The model itself may be perfect in its stated form, but may collapse completely with ineffective or inappropriate utilization. Man must derive the relationships and select the inputs for the model (O'Riordan, 1971). The effectiveness of this process is a function of the framework within which it is being used, as well as of the objectivity of the user. Without a background of sound ecological and management principles in this utilization, the model cannot be successful, through no fault of its own.

The dynamics of ecosystems demand that management models should also be dynamic. The incorporation of research results into the model must be timeous, very often a difficult undertaking in terms of data processing and of communiction of modification.

The feasibility of karst cave management modelling in the Transvaal is dependent on the model itself and the competency of the user, in objective interpretation and implementation. The model is regarded as a feasible necessity for the optimisation of finite resources. Its successful use is possible depending upon human objectivity at all stages of development and utilization of the model. Its overall success is directly related to understanding of the complexity of the ecosystem.

Conclusion

At the present time there is no single solution to the cave management problem. The only certain method is one which is applicable to a single cave at a particular moment in time (Wilmut, 1972). However, it may be concluded that a management model is essential for the optimisation of the karst cave resource potential in the Transvaal. Its success depends largely on the comprehensiveness and flexibility of the model, and on the ecological objectivity of the resource developer.

An environmental management modle is complex. It may appear to be totally impractical, but the compensations in terms of the benefits derived therefrom far outweigh the problems. There are problems in the development and utilization of any such tool, but the task is not impossible. The model building and associated management practices are long-term undertakings which will benefit both the physical and social components of the environment.

Acknowledgement

The assistance of Mr. P.J. Stickler in preparing the diagram is gratefully acknowledged.

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Figure 1
Intentional and Unintentional Disturbance of the Cavern Ecosystem by Subsurface Intrustion and Surface Alteration

Disturbance of the Cavern Atmosphere and Ecosystem

- Unintentional
  - Surface
    - Alteration:e.g. pathways, air and water percolation
    - Pesticides, herbicides: destruction of ecosystem
    - Construction: e.g. blasting-alter ventilation
    - Hydological schemes: e.g. boreholes-dehydration
    - Sewage disposal: contamination, gas accumulation
  - Subsurface
    - Human visitor: heat, moisture, CO_2, compaction, foreign materials
    - Gate: alteration of air flow and trogloxene activity
    - Enlarging acces points: alteration of air flow-dehydration
    - Mining and quarrying: access from surface-dehydration
- Intentional
  - Surface
    - Tourist amenities e.g. walls, stairs: percolations
    - Mining and quarrying: alteration of air flow dehydration
  - Subsurface
    - Tourist facilities, e.g. lights, heat: photosynthesis
    - Foreign materials: bacteria, fungi
    - Enlarging access points: alteration of air flow-dehydration

Hydrology of the Rio Camuy Caves System, Puerto Rico

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Abstract

The Río Camuy, a major river on the northwest coast of Puerto Rico, flows underground for a straight-line distance of about 6 kilometers. This underground journey through part of the 15-kilometer long Río Camuy Caves System is perhaps the most spectacular in the western hemisphere.

Analyses of data collected from streamflow and rainfall stations installed within the study area revealed that (1) the travel time of Río Camuy through the underground passages fluctuated from 2 1/2 to 9 hours; (2) the maximum intake capacity of the river's swallow hole was determined to be on the order of 2,000 to 3,000 cubic feet per second, constituting therefore a massive and the most important natural flood control structure in this rivèr basin; and (3) at least two of four recently discovered sinking streams were identified from the stream hydrographs as contributing to the total flow of Rio Camuy at the known resurgence of the system. The discovery of a new passage of the cave in February 1980, has demonstrated the existance of a second resurgence through which Río Camuy overflows to the surface. Dye tests, hydrochemical analyses and numerous cave surveys, conducted during the course of this investigation, have proven the existance of two hypothetical connections, and others that were previously unknown.

Resumen

El río Camuy, uno de los principales rios en la costa noroeste de Puerto Rico, discurre subterraneamente por espacio de unos 6 kilómetros en distancia lineal. Esta travesía subterránea, através de algunos de los 15 kilómetros de pasillos del Sistema de Cavernas del Río Camuy, es quizas la màs espectacular en todo el hemisferio occidental.

Datos obtenidos de las estaciones de flujo y precipitación pluvial, instaladas en el àrea de estudio, indicaron que (1) el tiempo de travesía del Río Camuy a lo largo del sistema de cavernas fluctuó desde 2 1/2 hasta 9 horas; (2) la capacidad maxima de descarga del orificio o cavidad donde el río desaparece está en el orden de 2000 a 3000 pies cúbicos por segundo. Esta constricción ofrece resistencia masiva al flujo y constituye la más importante estructura de control de inundaciones en la cuenca; (3) por lo menos dos de cuatro quebradas que desaparecen subterràneamente han sido identificadas en los hidrogramas y contribuyen así al flujo total del río en la resurgencia conocida del sistema. El descubrimiento de una nueva porción del sistema en Febrero de 1980, ha demostrado la existencia de una segunda resurgencia através de la cual Río Camuy desborda hacía la superficie. Pruebas de tinte, análisis hidroquímicos y numerosos trabajos espeleológicos han indicado la existencia de dos conexiones postulades y otras antes desconocidas.

Photomonitoring as a Management Tool

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Abstract

Cave photomonitoring is a term used to describe precise photographs of selected points within the cave taken on a regualr basis. These photographs can be used for inventory, as a record of change and as a basis of information for management decisions.

The system discussed has evolved from the work of others, from four years of use in Horsethief Cave, Wyoming plus two additional years of monitoring in the same cave by the author. Items to be considered are; types of equipment, location of photopoints, camera set up, film processing and analysis of photographs to give objective, permanent and repeatable results. Some examples of the results are obvious at a casual glance, while others require a thorough knowledge of the system and the subject matter in order to be discerned.

As a management tool, photomonitoring seems to have found favor with cavers and both private and government cave managers due to its objectivity, permanence, repeatability and low cost.

Zusammenfassung

Das Hoelenphotomonitorsystem ist ein Verhahren das genaue Photoaufnahmen von gewaehlten Punkten einer Hoehler beschreibt, die in bestimmten Zeitabschnitten aufgenommen wurden. Diese Aufnahmen koennen fuer Inventarzwecke oder als Grundlage fuer auftretende Wechsel oder fuer Informationen von Verwaltungszwecke verwendet werden.

Das zur Eroerterung stehende System entwickelte sich aus einer vierjaehrigen Studie der Pferdediebhoehle bei einer anderen Person und einer zweijaehrigen Studie des Avtors von derselben Hoehle, die in Wyoming liegt. Spezifische Punkte, die in dieser Studie besprochen werden sind: verschiendene Ausruestungen, Lage der Punkte von wo die Bilder aufgenommne wurden, Informationen an benuzten Kameras, der Filmentwicklung sowie eine Analyse der Aufnahmen, die objektive, dauerhafte und wiederholungsmoegliche Resultate geben. Einige Beispiele der Resultate sind schon bei einer oberflaechlichen Betrachtung augenfaelling, andere verlangen eine gewissenhafte Kenntniss des Systems und der Materie um wahrgenommen zu werden.

Das Photomcnitorsystem ala Verwaltungsmittel scheint bei Hoehlenforschern privater und staatlicher Art Anwendung zu finden, da es objektiv und dauerhaft ist und auf einer oekonomischen Base wiederholt werden kann.

Definition and Objectives

Cave photomonitoring can be defined as a series of precise photographs of selected points within the cave which are taken on a regular basis. These photographs can be used for inventory, as a record of change and as a basis of information for management decisions.

A cave inventory in written form, or even combined with an accurate map is often inadequate. Written descriptions can be long, ambiguous and often incorrect. A photograph, if well taken, is compact, to the point and accurate. However, a photograph without written commentary is subject to the interpretation of the viewer and his experience with the subject. Also, photographs used for inventory purposes are almost useless unless they can be related to a map of the cave so that precise locations can be established. For inventory, a combination of photographs and written commentary related to an accurate map should cover the needs of the cave manager.

As a record of change within the cave, photographs can not be excelled. Written descriptions can vary depending on the author and can not approach the detailed accuracy of photos. On a precise photograph, measurements can be made which may be undetected by the human eye. Also, changes can be shown graphically by a comparison with previous photos.

Photographs, written reports and an accurate map are important cave management tools. The photos are a permanant record of the cave when management personnel are changed and can be duplicated precisely by anyone, regardless of their interests or training. The same series of photos, taken at intervals over a period of time, can provide an objective view of the cave which is virtually impossible with written records. After the initial photographs are taken and analyzed, an update on the conditions in the cave can be obtained by repeating the same series of photos at any later date. The use of photographs can be an inexpensive method of obtaining consistant data without extensive training of unfamiliar individuals in methods of cave inventory.

The system described has been used by the Worland, Wyoming District of the Bureau of Land Management and was developed over a four year period. All of the methods discussed have been tried, and, when necessary, modified to give usable results.

Equipment

Camera-A single lens reflex 35 mm camera is used due to its availability, compactness, reliability and simplicity. Lens-A standard lens for the 35 mm SLR camera (i.e.; 50 mm) was found to work best for most of the monitoring photos. A wide angle (28 - 35 mm) lens may be useful in certain situations. Tripod-The tripod is essential for properly locating and orienting the camera. It must be sturdy and compact to withstand the abuse of travel through the cave. Film-For monitoring photos a color print film seems to be the best choice. Color prints show changes in size and shape as well as color changes in the cave. Prints are also easily compared and direct measurements can be made from them. Black and white prints are less expensive but subtle changes in the cave environment may be harder to detect. Changes such as accumulation of dust on formations and the presence of moisture on the walls or floor of a passage show up much better in color. Transparencies are not recommended because of the difficulty of viewing them and the problem of making measurements on them. Plumb bob-used to locate the camera directly over the photopoint marker.

Tape-A 50 or 100 foot steel tape or equivalent is necessary to measure distances. Care must be taken to record the units of measurement or confusion will result such as mistaking inches for tenths of a foot or meters for feet. If it becomes necessary to convert from one unit to another, it should be done beforehand, not while setting up the photo in the cave. Brunton Compass-A brunton compass or other method of ascertaining bearing and inclination is necessary to orient the camera and strobe. As with the tape, be sure units of measurement are consistant and the compass is calibrated the same as for previous photographs. Grey Card-A standard photographic grey card and/or color scale should be included in each photo as a reference for film processing. In addition there should be space for a scale and photo identification information. Data Forms-All data for each photo should be included on a standardized form (Figure 1) and a notebook should be included for additional written commentary. Copies of previous data and photos-It was found useful to have copies of the previous photos as well as the data for each photopoint when setting up the camera for subsequent photos.

Strobe-A strobe has been found to be the most reliable and most economical source of illumination. The strobe should have an open flash provision and can be either manual or automatic. An automatic strobe seemed to provide more consistant results than a manual one in most situations. Cable release-A cable release which can be locked open is necessary for best results.

Carrying Box-All of the equipment with the possible exception of the tripod will fit in a surplus .50 caliber ammunition box, which is readily available and provides excellent protection for the equipment. More or less protection may be required depending on the cave being photographed. Miscellaneous-Items used in general photography such as spare batteries for the camera and strobe, lens cleaning equipment and other items should be includes as necessary.

Additional Equipment for Setting Photopoints

Brass Markers-The material used to mark the photopoints is 3/8 inch diameter brass rod 1/2 to 1 inch long. Other markers could be used as long as they are permanant and can be relocated over a period of several years. Hammer and Drill- A hammer and a 3/8 inch starr drill are used to drill a hole deep enough to place the markers almost flush with the surface. Adhesive-Aluminum solder was used to fix the brass markers in the holes.

Methods

Photopoints can be selected to monitor most aspects of cave use. Trails can be monitored for deterioration, formations can be checked for deterioration or damage and invironmental conditions such as water levels or bat populations can be monitored.

When the subject is determined, the camera is is set up on the tripod and oriented for the best view. the plumb bob is used to locate the photopoint on the floor and a brass marker is installed (Figure 2). The elevation of the lens above the marker is noted, and the bearing and inclination of the camera are measured and noted. A point is selected for the strobe to give the optimum illumination and this point is also recorded using distance, bearing and inclination from the marker. It is also useful to have distances from the photopoint and from the strobe to the subject. If the cave is surveyed, the photopoint marker is connected to a convenient survey station with compass and tape to aid in the relocation of the marker. If the cave is unsurveyed, distance and bearing from the marker to at least two distinct landmarks should be recorded. The photograph is then taken and information on camera settings is recorded. For the first series of monitoring photographs it may be necessary to bracket the exposures to determine the best one. A subsequent series of photos can be taken from the same set of photopoints by using the recorded data to re-establish the camera and strob in an identical position.

All photographs should be processed and printed by a competent photo lab. The grey card and/or color scale can be used as a check to determine that all prints are processed to the same standards.

All photographs should be analysed as soon as possible and a written report on each photopoint prepared. The report should include any information discerned from the photograph plus any information included in the written field notes.

Examples

The first example is from a Wyoming cave. Figure 3 was taken in 1970 before the photomonitoring system was begun, but was taken from nearly the same location as the photopoint which was established in 1975. Figure 4 was taken from the photopoint in 1979 and shows considerable enlargement of the passage opening. In the color prints a large amount of dust accumulation on the walls can also be detected.

The second example was to have shown traffic across the pool. Figure 5 was taken in 1977 while Figure 6 was taken in 1978 and shows that little traffic has crossed the pool as there are no marks or dirt on the wall. However, the water level in the pool has risen several inches. In subsequent years, the water has receded to its former level and, as yet, no signs of traffic have appeared.

There are numerous other examples of monitoring photos showing increased use of areas of the cave as determined by trail width and depth. In another example, an area of flowstone has been observed, by the use of monitoring photos, to have become more active over a period of several years. Other photos show the breakage of formations from one year to the next.

Summary and Conclusions

The use of precise, repeatable monitoring photographs, along with other management tools, has helped managers make critical decisions affecting the cave environment. This system has been used by the Bureau of Land Management in Wyoming and a similar system has been used in the past by private cave owners. The expanded use of cave photomonitoring should be encouraged to aid managers in making decisions involving cave use and will provide a valuable record of caves which may be viewed by future cave users and managers alike.

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◁ PHOTOMONITORING DATA ▷

LOCATION: PP# 31 DATE: 2 JUL 80

SUBJECT: Carbide lamp

(ASA 64)

CAMERA: OM-1 FILM: Kodachrome 64

LENS: 50 mm. f1 1.8

APERTURE #1 8 #2 ____ #3 ____ #4 ____

SPEED #1 B #2 ____ #3 ____ #4 ____

LENS to SUBJECT: Dist. 7'2" Brng. 129° Inc. -38°

HEIGHT of LENS: 3'2"

GREY SCALE LOCATION: Lower Center

LIGHTING

TYPE #1 Strobe #2 ____ #3 ____ #4 ____

FLASHES #1 1 #2 ____ #3 ____ #4 ____

PP to FLASH: Dist. 6'10" Brng. 189° Inc. +37°

FLASH to SUBJ: Dist 5'8" Brng. 89° Inc. -27°

LOCATION: TO A26

Dist. 26'4" Brng. 49° Inc. +2°

NOTES: lamp was not lighted at time of photo.

FotoForm 15, 1980

Figure 1

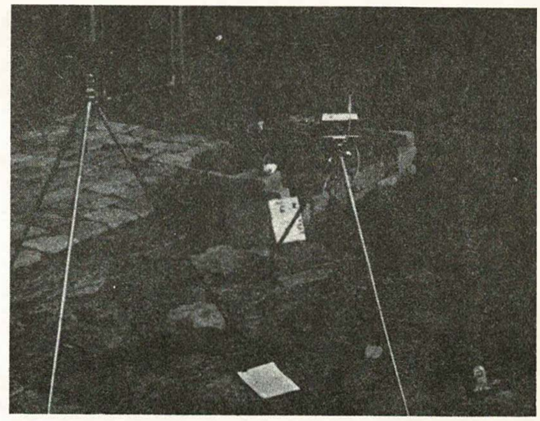

Figure 2

Figure 3

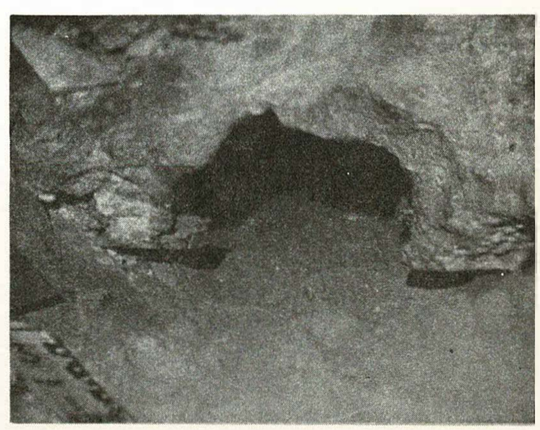

Figure 4

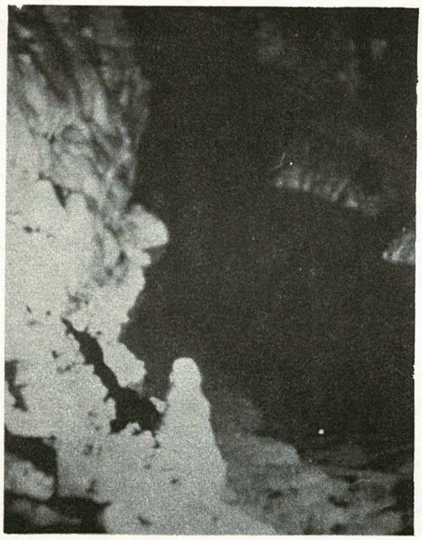

Figure 5

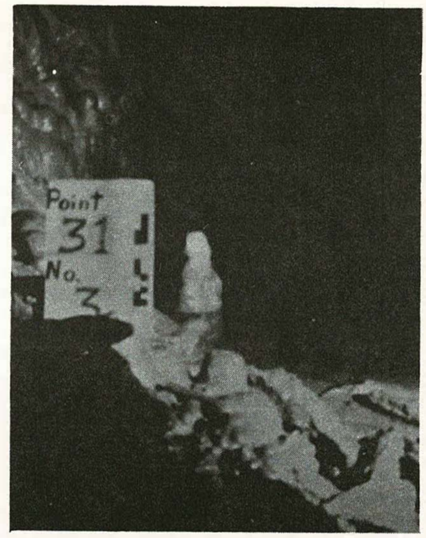

Figure 6

The Foot Caves in the Tropical China

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Abstract

The karst morphological evolution in trophical China may be summed up as following:

In the region where the underground water moves in vertical direction, the karst morphology appears mainly to be the sinked morphology. When the region is dominated by the horizontal movement of the underground water, the karst morphology appears to be the rivers and plains, while the limestone plateau is dissected into rock mountains. The foot caves always appear at the foot of the rock mountains.

The morphological charecters of the foot caves may be summed up as following:

1) The top of the foot caves have a very flat plane, correspondant to the flood level of the underground rivers,

2) There are many "rock bell", "rock kettle" on the top planes of the foot caves,

3) The top planes of the foot caves are lower than that of the river flood level,

4) On both sides of the foot caves there are some "side trough", showing the levels of the underground rivers alter during different seasons,

5) The dripstone formations are not fully developed.

Résumé

Ma thése peut se synthétiser en grandes lignes là dessous:

Dans la région aù de l'eau souterraine coule verticalement, la topographie du karst se distingue par ses topographies enfoncées. Quand la région est derminée par de l'eau coulant horizontalement la topographie du karst se distingue par des rivieres et des plaines, alors que le plateau calcaire est divisé en montagnes rocheuses. Les cavernes du pied se distinguent toujours dans les pied se distguent toujours dans les pieds de ces montagnes rocheuses.

On peut caratiriser la topographie de ces cavernes du pied là-dessous:

1) Le faîte des cavernes a un plafond plat qui reste baissé par rapport au niveau de l'inondation,

2) Il y a des "cloches rocheuses" et des "marmites rocheuses" sur le plafond des cavernes,

3) Le platfond plat du faîte est plus bas que le niveau des rivières débordees,

4) Aux deux côtés d'une caverne, il y a des "anges laterales" où altère le niveau de l'eau souterraine pendant les différentes périodes saisonnieres,

5) La stalactite topgraphique ne développe pas dans les cavernes.

Knots for Single Rope Techniques

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Abstract

This paper deals with the application to SRT of the Bowline, Figure 8 knot, Figure 9 knot, Butterfly knot, Overhand Bend and the Fisherman's knot. Reference is made to some recent test results.

Résumé

Cet article décrit les noeuds employés pour la technique "SRT" tel le noeud de chaise, le noeud huit, le noeud neuf, le noeud papillon, le noeud vahce et noeud de pêcheur. Nous réferons aux résultats quelques tests récents.

Ecology of Malheur Cave Harney County, Oregon

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Abstract

Malheur Cave, a 1100 meter long lava tube, is very unusual in several significant ways. Cave adapted animals discovered there include: a pseudoscorpion, a flatworm, an amphipod, isopods, a palpigrade, and several species of collembola and mites. Malheur Cave contains a lake which has a maximum depth of 7 meters, a length of 400 meters, and a width of 3 to 12 meters. Numerous measurements have been made in this cave since 1973 in the attempt to understand the presence of cavernicoles in a region where most other lava caves apparently lack a specialized fauna. The single entrance of the cave is 2 by 9 meters wide and the passage is unobstructed for the first 185 meters of the tube. Air temperatures of the true Dark Zone are 16.0 to 18.9°C and the water temperatures are 16.0 to 17.5°C, all within the range of the nearby geothermal springs. These unusual temperatures in Malheur Cave come from upwelling geothermal waters mixed with cool ground waters.

Résumé

La Grotte de Malheur, une tube de lave longue de 1100 métres, est peu commune à plusieurs égards significatifs. Des animauz cavernicoles ont été découverts ici: un pseudoscorpion, une planaire, une amphipode, une isopode, une palpigrade, et plusieurs colleмboles et acariens. Dans la Grotte de Malheur il y a un lac qui a une profondeur maximum de sept métres, une longueur de 400 métres, et une largeur de trois à treize métres. Depuis 1973 on a fait des mesurages nombreux dans cette grotte pour essayer de comprendre la presence des cavernicoles dans une région où la plupart des autres tubes de lave n'ont pas apparemment des animaux spéciaux. La seule entrée est deux métres. Le lac dans la grotte maintient une temperature aérienne de 16.0--18.9°C et une temperature d'eau de 16.0--17.5°C. Ces temperatures inhabituelles dans la grotte proviennent des eaux géothermiques qui sourdent et qui se mélangent avec les eaux frais de la terre.

Introduction

Of the 230 caves reported for Oregon, 93 are separately named lava cave segments (Larson and Larson, 1976; Larson, 1977). Even though cave adapted species are gradually being discovered in Oregon caves, they are reported from less than a dozen caves (Hyman, 1937; Shoemaker, 1942; Chamberlin, 1962; Benedict and Malcolm, 1973; Peck, 1973; Kamp, 1973; Holsinger, 1974; Benedict, 1979, 1980). Malheur Cave, an 1100 m long unitary lava tube in southeastern Orgeon (Figs. 1-3) contains a specialized subterranean fauna which includes the flatworm, *Kenkia rhynchida* Hyman; the amphipod, *Stygobromus hubbsi Shoemaker*; an aquatic isopod; a terrestrial isopod; the pseudoscorpion, *Apochthonius malheuri* Benedict and Malcolm; a palpigrade; several species of mites and several species of collembola. The Malheur Cave Research Project was initiated in 1971 to determine how Malheur Cave differs from other lava tubes of the region. During our study, we have described the geologic features of the cave (Benedict and Barnhart, 1975); determined the physical dimensions; measured direction and velocity of air flow; measured air, water, soil and rock temperatures; calculated relative humidities and analyzed water chemistry (Palmer, 1975). We are currently conducting a survey of the epigean and hypogean invertebrate species of the region.

Malheur Cave is located at 1,250 m above sea level in the semiarid Northern Great Basin Desert of the western United States. The annual precipitation (ppt) at the surface averages 28 mm, with a low annual ppt recorded of 15 mm and a high annual ppt of 41 mm; one third of the ppt falls as snow. The mean annual surface temperature (MAST) is 8°C with a minimum recorded temperature of -32° and a maximum of 40°. Frosts can occur during any month of the year. Under such harsh climatic conditions, delicate cave invertebrates have difficulty surviving on the surface.

This cave is a simple, unitary lava tube (Fig. 3) with a single entrance which is 2 m high and 9 m wide. The single, large passage descends almost due north for approximately 60 m and then bends sharply to the east, ending in a large cave lake. The lake is 400 m long, 7 m deep and from 3 to 12 m wide. The lake rises 1 m vertically and 260 m horizontally between the end of October and the middle of May each year. Passage height of the tube ranges from 2 to 11 m and the overburden has been calculated to be from 2 to 7 m thick.

The thin overburden, the single large entrance and the relatively unobstructed, large descending passage all suggest that Malehur Cave is a cold air trap, and that temperatures in the deep interior zone should be lower than the MAST of 8° (see discussion of factors in Tuttle and Stevenson, 1977). Also, ice stalagmites begin forming in the first 60 m of the cave whenever surface temperatures fall below -12°. The thousands of measurements taken since 1973 confirm the pattern of cold air drainage in Malheur Cave. Yet despite the evidence that Malheur Cave is a cold air trap, temperatures as much as 11° higher than the MAST occur in the deep interior of this cave (Fig. 4). In August 1976, temperatures as high as 18.9° were measured at 1 m above the lake surface at 915 m downtube from the entrance. Palmer (1975) consistently measured lake temperatures which ranged from 16.0 to 17.5°; these temperatures are within the range recorded for geothermal springs of the region. Ion and geothermometric analyses reveal that some of the cave water upwells from a geothermal reservoir which is located at depths between 600 and 1500 m below the cave. Palmer calculated the minimum temperatures of this geothermal reservoir at 75°. The water apparently mixes with cool ground water which explains why the cave is not warmer than it is. In addition, cool air drains in from the surface, cooling the warm and moist air rising from the cave lake.

Almost all other caves in Oregon have temperatures below the MAST of the region in which the cave is located. Fig. 4 presents comparative horizontal temperature profiles for three descending lava tubes: Malheur, Skeleton and Derrick Caves. Both Derrick and Skeleton Caves trap cold air and exhibit temperatures below the MAST. Derrick Cave is inhabited by the cryophilic milliped, *Plumatyla humerosa*, which has been reported from several other cool caves and mines. Cryophilic species are presumed to be relictual from the Pleistocene ice ages (Kamp, 1973; Peck, 1973; Shear, pers. comm.). Skeleton Cave which is relatively dry appears to be barren of cave biota. Such caves are biologically important as refugia for vertebrates (Benedict and Forbes, 1977) and may contain invertebrates which are vertebrate-nest associates (Benedict and Malcolm, 1977) even though the vertebrates are not cave adapted. Data such as those in Fig. 4 suggest that some of the populations in Malheur Cave could be thermophilic relicts from warm and moist climatic periods.

Acknowledgments

This study was supported in part by 1974 and 1979 Research Advisory Committee grants from the National Speleological Society. We gratefully acknowledge the help of numerous individuals who gathered data for the Malheur Cave Research Project, especially John E. Palmer and Patricia L. Barnhart Silver. We appreciate the use of research facilities at the Malheur Field Station and at Portland State University. Malheur Cave is owned by the Masonic Order of Burns, Oregon, and is currently closed to public visitation.

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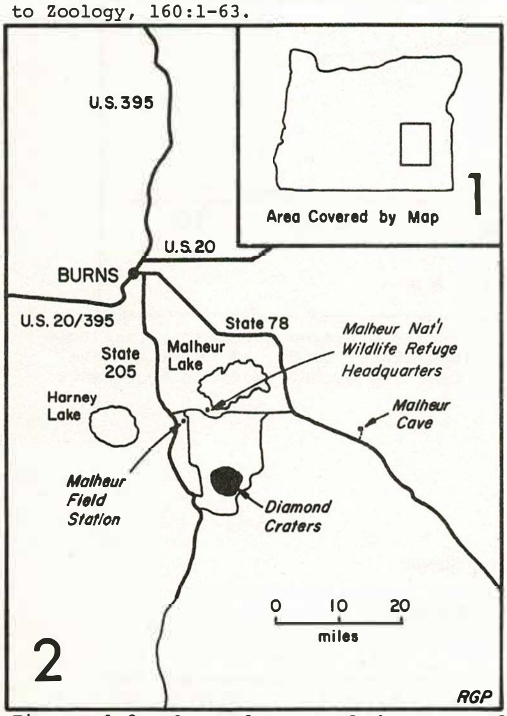

Figures 1-2. 1. Index map of the state of Oregon, USA. 2. Local area map showing geographical relationships in the area of Malheur Cave, Harney County, Oregon, USA.

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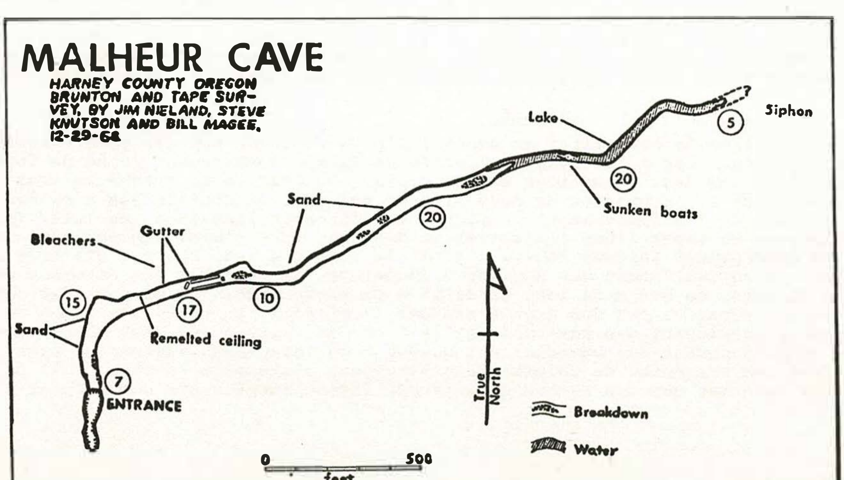

Figure 3. Plan map of Malheur Cave.

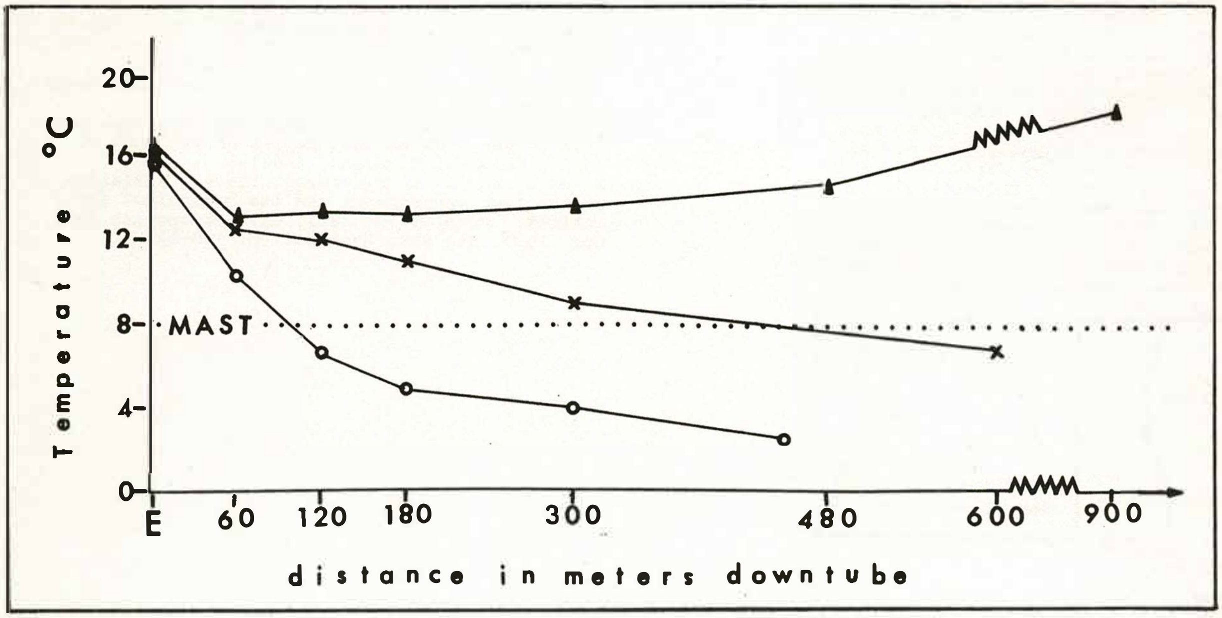

Figure 4. Horizontal temperature profiles at 1 m above the floor or lake surface of three descending lava tube caves in eastern Oregon, USA, where MAST (mean annual surface temperature) is 8°. ▲ Malheur Cave (20 August 1976), X Skeleton Cave (24 August 1976), O Derrick Cave (28 August 1976), E = entrance.

Evaporite Karst Gypsum Plain, Culberson County, Texas

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Abstract

The Gypsum Plain is a low relief, east-sloping surface drained by a few ephemeral streams and many sinkholes. East-dipping bedrock comprises the Castile and (?)Salado Formations; both are gypsum at the surface. The Castile grades downward into anhydrite, usually below 30 m. Subrosion of two salt beds in the Castile has removed them many kilometers downdip. Unusual linear scarps, some of which are in facing pairs, strike downdip in areas where salt has been removed. The west-facing scarp along the Yeso Hills is the result of solutional undercutting by stream runoff from the Guadalupe Mountains. Caves are generally small, up to 350 m long and 25 m deep. Those found so far occur mainly in clusters ("efforts") with large intervening areas where no caves are known. Base level for most caves is the bottom of incised valleys, where a few small springs occur. Cave development is guided by fractures, both tectonic and hydration, and by sub-horizontal calcite laminae in the gypsum. Enlargement is mostly by capture of surface runoff. Caves in the carbonate rocks above the gypsum resulted from collapse into openings in the gypsum.

Résumé

La Gypsum Plain est une surface de bas relief en pente à l'est, vidangée par quelques ruisseaux ephèmères et de nombreux éffondrements. Les formations de Castile et Salado comprennent roche de fond plongeant vers l'est. La superficie des deux formations est du gypse. La Castile se gradue en aval en anhydrite, normalment au-dessous de 35 m. Subrosion de deux lits de sel dans la Castile les a enlevé sur quelques kilomètres à l'aval-pendage de l'affleurement. Quelques escarpements linéaires insolites (plusieurs desquelles se trouvent en paires en front l'une à l'autre) se dirigent vers l'aval-pendage dans les zones où le sel a été enlevé. Un escarpement faisons face à l'ouest le long des Yeso Hills a été crée du souscanage en solution par l'eau de ruissellement des Montagnes Guadalupe. En général, les cavernes dans le Gypsum Plain en Texas sont petites, de 350 m de long et de 25 m de profondeur. La plupart des cavernes connues se trouvent en groupes, separées par des grands espaces intermédiaires où il n'y a pas de cavernes connues. Niveau de basse pour la plupart des cavernes est le fond des vallées incisées où se trouvent quelques petites sources. Developpement des cavernes est gouverné par diaclase, tectonique et hydratation (?), et par intecalation fine subhorizontal de calcite dans le gypse. Extension resulte de la prise de l'eau de ruissellement. Les cavernes dan les roches carbonatées furent formées par écroulement à travers cavités dans le gypse.

Ecology of the New Zealand Glowworm *Arachnocampa luminosa* (Diptera: Mycetophilidae) in Caves at Waitomo, New Zealand

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Abstract

The caves at Waitomo attract tourists from all the world, to view the glowworms' bioluminescent display. My work was part of a multidisciplinary study to investigate deterioration in the natural cave environment. Quantitative sampling techniques showed that the glowworm life cycle was continuous, with considerable variability in the speed of development through the five larval instars, peak emergence occuring in spring. Mortality was caused by opiliones, cannibalism and a fungal pathogen *Tolypocladium* sp. (Moniliales), the latter occuring only in summer. Food insects originated from the stream benthos within the cave. The decline in glowworm numbers in recent years is thought to be due to unfavourable climatic conditions.

Résumé

Des touristes de tous les pays viennent visiter les cavernes de Waitomo, célèbres par le spectacle bioluminescent qu'offrent les larves cavernicoles de mycétophilidés. Mon travail s'intégre au sein d'un programme de recherche multidisciplinaire institué dans le but d'enrayer la détérioration écologique de cet habitat. Les techniques d'échantillonnage quantitatif démontrent que le cycle biologique des insectes est continu, l'émergence atteint un sommet à la fin de l'hiver. Le cannibalisme, la présence de deux espéces d'opilions et celle d'un champignon pathogéne, *Tolypocladium inflatum* (Moniliales), sont les plus grands responsables de la mortalité. Les infections dues au champignon sont manifestes seulement durant l'été. La nourriture provient presque entiérement de la caverne. Le déclin des populations de mycétophilidés durant les derniéres annés est probablement tributaire des conditions climatiques défavorables.

Introduction

The Glowworm Cave (Lat. 38° 16'S, Long. 175° 06'E) at Waitomo is one of the main tourist attractions in New Zealand, the highlight being a boat ride through the Glowworm Grotto (Fig. 1), to view the bioluminescent display.

A multidisciplinary cave research programme was set up in 1975, in response to growing concern that the cave was showing signs of a deteriorating natural environment. The long term survival of the troglophillic glowworm population, was of prime importance.

The cave is developed on three main levels and has upper and lower entrances (Fig. 1). The lowest level (60 m a.s.l.) carries the Waitomo stream through a limestone ridge which forms a natural barrier across the valley. Normal stream flow is about $1 m^3 s^{-1}$ although rates in excess of $50 m^3 s^{-1}$ have been recorded.

The New Zealand glowworm is a dipterous larva, the blue-green bioluminescence arising from a posterior light organ. The larva is suspended horizontally from the cave roof inside a transparent mucus tube attached to which are single threads, adorned with droplets of sticky fluid. Some larvae produce over 100 of these 'fishing lines' which are used to trap flying insects, the main food source.

Glowworms are common throughout New Zealand, their normal habitat being amongst vegetation on shaded stream banks. Their bioluminescence attracted naturalists towards the end of the last century, which has resulted in an extensive literature on their life cycle, habits, taxonomy and anatomy. The cave glowworms at Waitomo were first reported by Humphries (1889), but detailed information was not published until Richards (1960). Starting with this considerable body of discriptive information, a more intensive, quantitative ecological approach was followed in the present study, an overview of which is presented in this paper.

Methods

Field trips to Waitomo were made at fortnightly intervals from 1978 to 1980. Temperature was measured in the cave using robust maximum/minimum thermometers with an accuracy of ± 0.5°C, and thermohydrographs were installed at three sites. Evaporation rates were recorded with 28 cm diameter evaporimeters. Observation of fifty-seven, 0.1 m^2 fixed quadrats in the Glowworm Grotto gave information on the life cycle and causes of mortality. Quadrats were marked by chalking the wall or, in the roof, by delineating with wire frames embedded in the calcite (Mitchell 1971). Counts of glowworm lights were made in other areas.

Food insects were quantified in different parts of the cave using sticky traps. Emergence traps, equipped with a battery operated light source, were floated in the Grotto lake, and a 'closing box' type of sampler designed to study the benthic fauna.

Food supply

Food insects were present throughout the year but with considerable variation in the timing and magnitude of peak numbers. Few insects were recorded in winter. Freshwater insects (mainly chironomids) predominated, the number and biomass falling with increased distance from the Waitomo stream. Few insects flew very far into the cave entrances, the glowworm population feeding almost entirely on imagos emerging from the Waitomo Stream within the cave system. It is suggested that the reason for the dense population of glowworms in the Grotto is the settling out of stream drift caused by the ponding effects of the cave lake (Vinikour 1980).

Air currents that flow betwen the two cave entrances influence the distribution of food insects, allowing glowworm populations to thrive at some distance from the stream, the primary food source.

Life Cycle and Mortality

There is a predominantly annual cycle throughout the cave, with greatest numbers occuring in spring (Fig. 2). There is a considerable overlapping of the five larval instars, with wide variation in the speed of individual development. In common with most New Zealand insects (Roberts 1977), the glowworms at Waitomo did not diapause.

During the study there was a decline in the number of glowworms in the cave (Fig. 3). The relative effects of different causes of mortality, i.e. predation by opiliones, cannibalism and the fungal pathogen *Tolypocladium* sp., is unknown because of the difficulty in identifying the causitive agent. The opiliones *Megalopsalis tumida* and *Hendea myseri cavernicola*, the latter a troglobite, were not considered to cause widespread mortality, their numbers remained low and constant throughout the study period.

The fungal disease has been present in the glowworm population for many years. The epizootic that occured during the summer of 1978-79, is in contrast with the comments made by Richards (1956, 1960) suggesting that this a recent problem. Cadavers only appear in summer, and preliminary experimental evidence shows fungal growth and sporulation to increase rapidly over a similar temperature range now recorded in the Glowworm Grotto in summer (Fig. 4). With the possible exception of cannibalism, it seems that *Tolypocladium* sp. is now the primary cause of mortality.

Climate

The mean annual temperatures recorded at intervals through the Glowworm Cave are much higher than would be expected in a typical nontourist cave (Fig. 5). Comparison with the 1955-56 data (Richards 1956, 1960) shows that the present climate is characterised by lower relative himidities (Fig. 6a), wider temperature ranges and colder winters (Fig. 6b,c,). These changes, by contrast, have not occured in another tourist cave at Waitomo (Fig. 6d). High evaporation rates in winter (Fig. 3e) cause noticeable dyring of the passage walls.

One of the main conclusions of the study is that many of the present problems with the glowworm population can be traced to the unfavourable climate that now exists in the cave.

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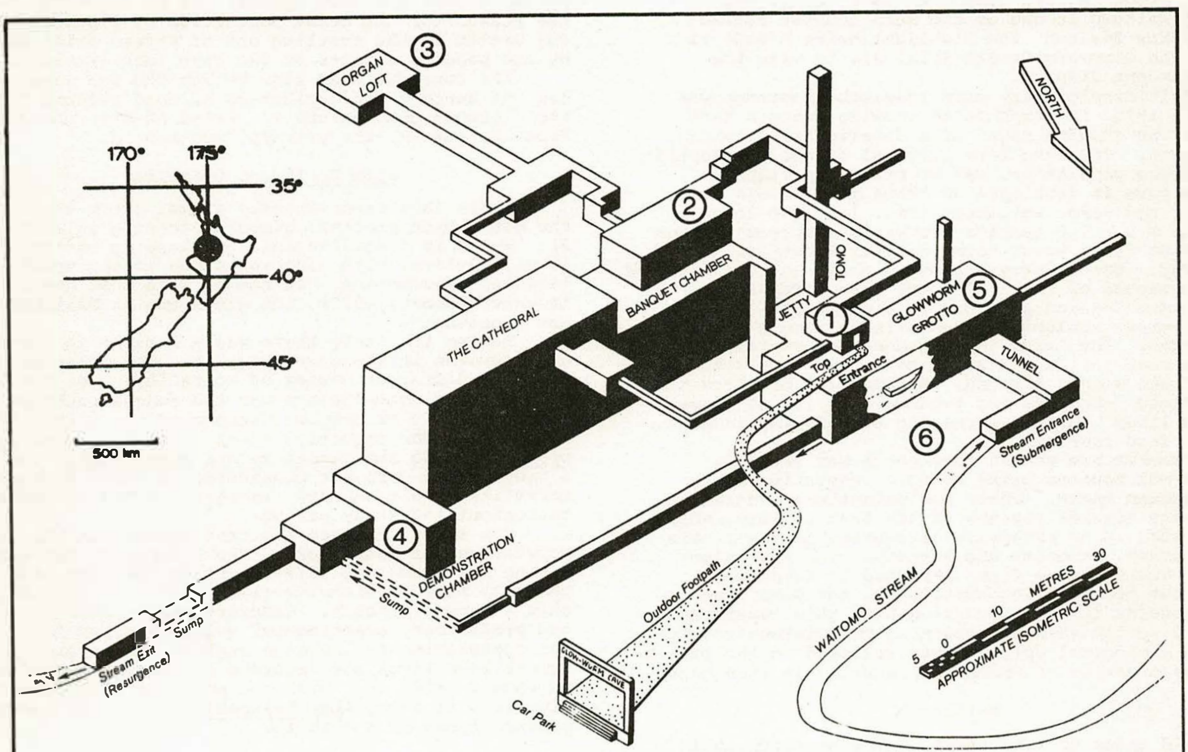

Fig. 1. Location map and isometric diagram of the Glowworm Cave showing tourist route (nos. 1-6).

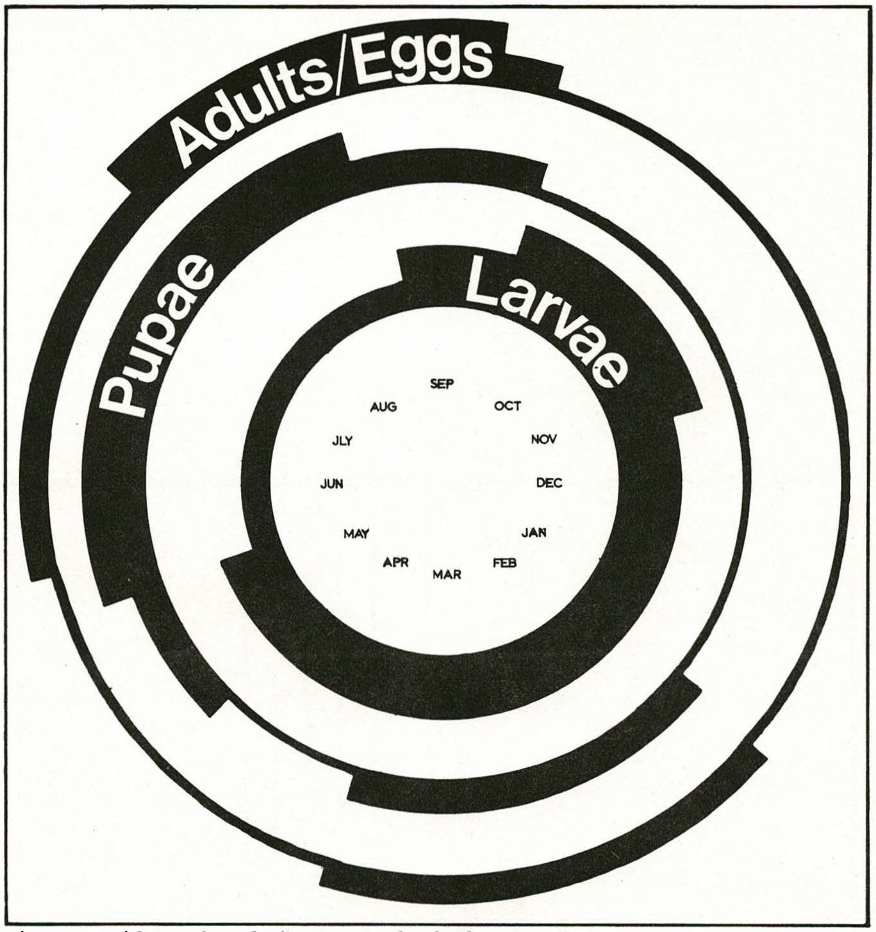

Fig. 2. Life cycle of the New Zealand Glowworm Archnocampa luminosa (Skuse) (Diptera: Mycetophilidae) in the Waitomo Glowworm Cave 1977-1980.

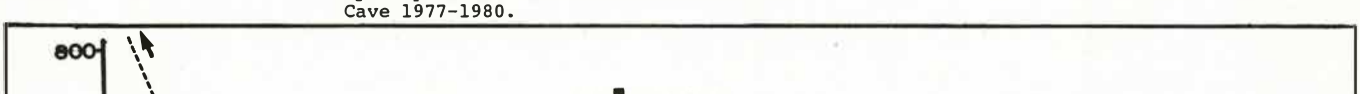

Fig. 3. Decline in the glowworm population on a section of the Glowworm Grotto wall 1977-80.

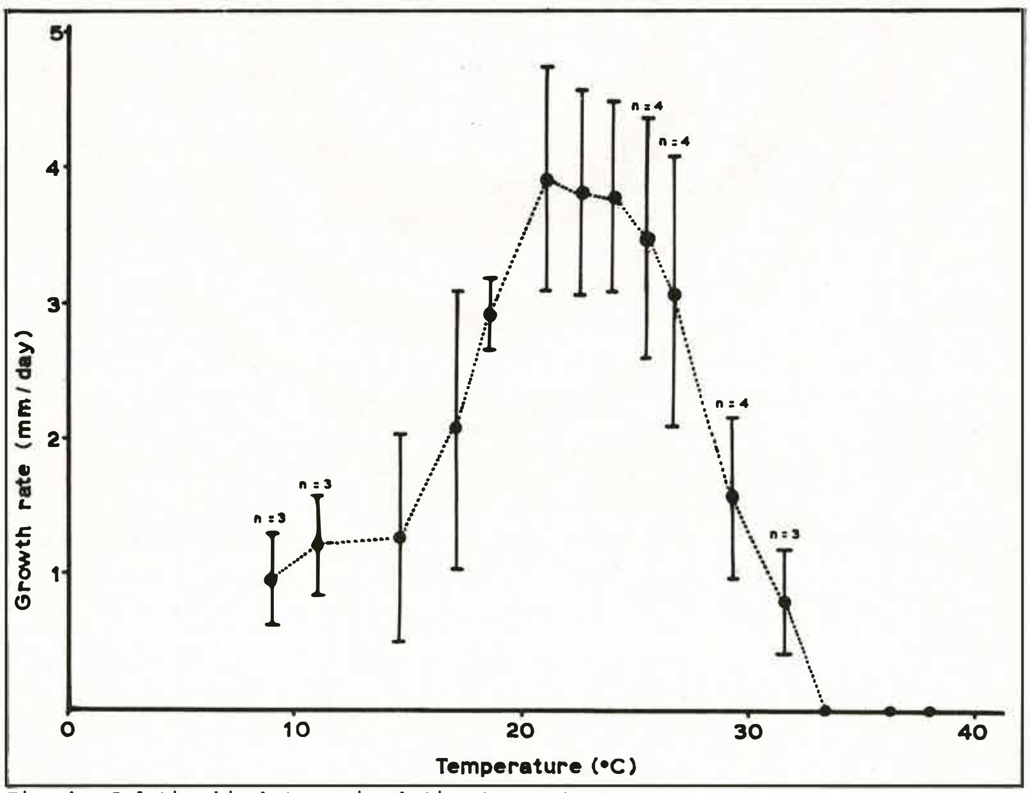

Fig. 4. Relationship between incubation temperature and growth rate of Tolypocladium sp. (Moniliales) in culture. Unless otherwise stated n=5.

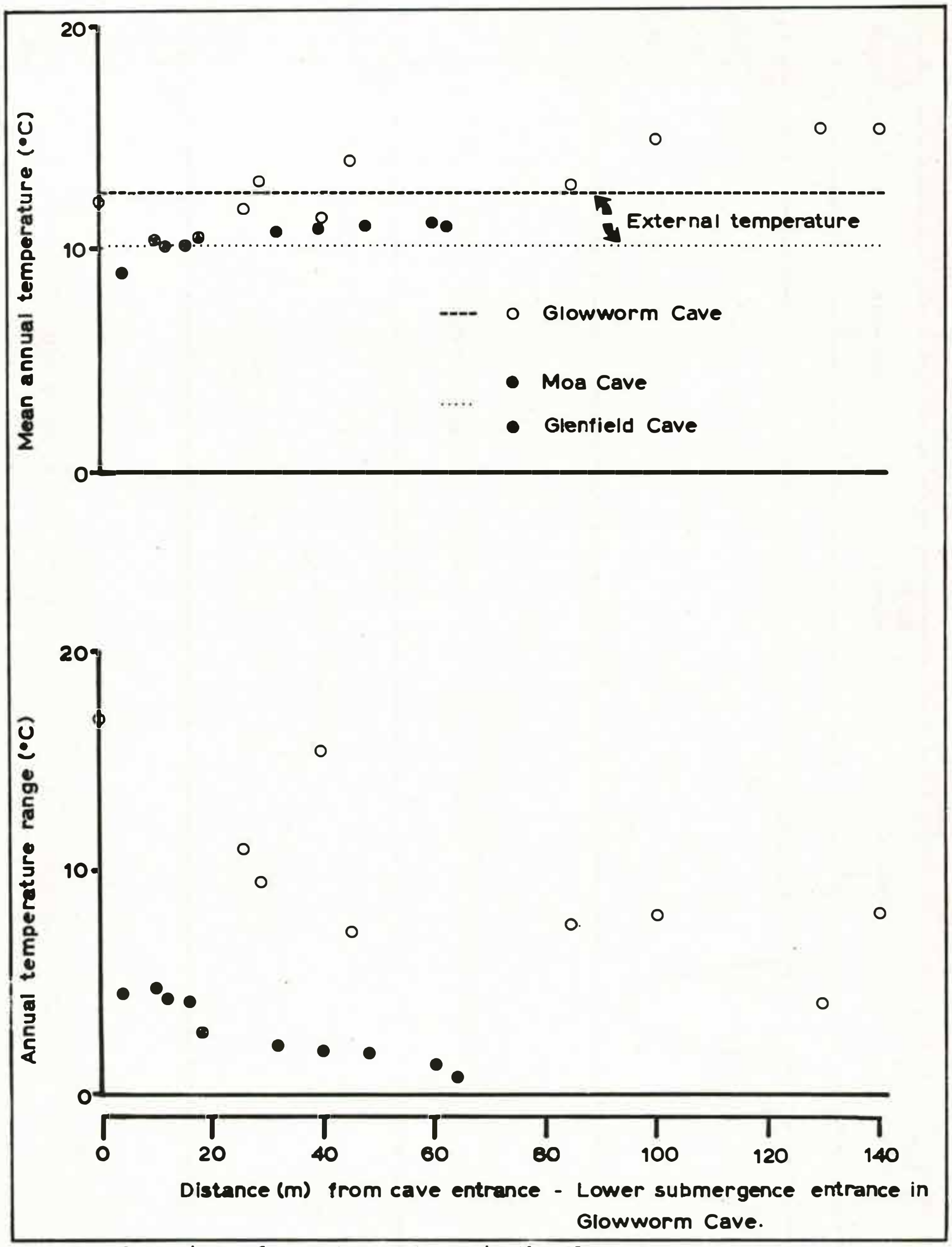

Fig. 5. Comparison of cave temperatures in the Glow-worm Cave with two nontourist caves near Waitomo.

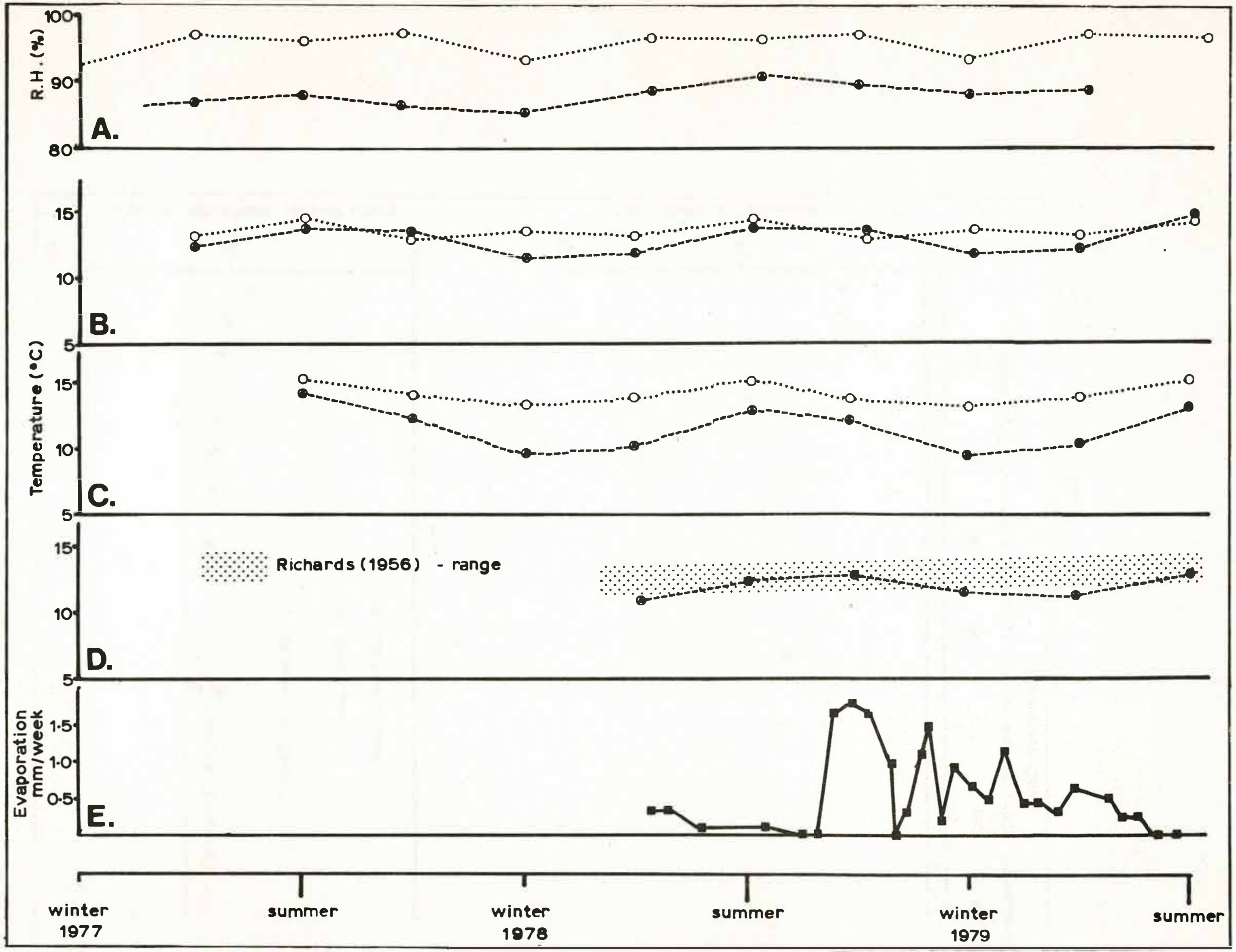

Figure 6. a–c. Comparison between the climate (seasonal means) in the Glowworm Cave in 1955-56 (stippled line, unfilled circles) with that during 1977-80 (dashed line).
a. Relative humidity Glowworm Grotto,
b. Temperature Glowworm Grotto,
c. Temperature Banquet Chamber,
d. Comparison of cave temperature range in another tourist cave at Waitomo (Ruakuri) in 1955-56 with seasonal means (dashed lines, filled circles) during 1977-80,
e. Evaporation rate measured in the Glowworm Cave (Banquet Chamber).

Management of a Biological Resource - Waitomo Glowworm Cave, New Zealand

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Abstract

In 1975 the Waitomo Caves Research Programme, a multidisciplinary study, was initiated. This action resulted from the recognition that after more than eighty years of tourist traffic the Glowworm Cave was showing signs of a deteriorating natural environment. As part of the programme a study of the ecology of the glowworm population was carried out, the aim being to establish management procedures to ensure their long term survival. It was concluded that climate and food were the key factors for the maintenance of a large, healthy glowworm colony. A fungal pathogen Tolypocladium inflatum (Moniliales) thrived in the warm, humid conditions found in the cave in summer, and caused a significant reduction in the number of glowworm larve. Reasons for the closure of the cave for three months in 1979 are discussed. It was recommended that the almost continous air flow through the cave be reduced by sealing the top entrance, except when ventilation was vital during times of peak tourist traffic.

Résumé

En 1975, le programme de recherche de Waitomo Caves, à tendance multidisciplinaire, a été institué; en effet, apres plus de 80 ans d'exploitation commerciale, il a été constaté que la caverne présentait de sérieux signes de détérioration du milieu naturel. Une étude de l'écologie des populations de mycétophilidés est intégrée au programme afin de mettre au point une méthode d'aménagement qui assurera leur survie à long terme. Le climat et la nourriture constituent les principaux facteurs de maintien d'une colonie nombreuse et en santé. En été, un champignon pathogéne, Tolypocladium inflatum (Moniliales) est favorisé par les conditions chaudes et humides de la caverne et réduit le nombre de larves de mycétophilidés. La fermeture de la caverne pour trois mois en 1979 a été imposé par le nombre réduit de larves, normal en cette saison, et par l'absence de bioluminescence chez la plupart des larves présentes. La principale recommendation du programme est de réduire la circulation presque continue de l'air dans la caverne en obstruant l'entrée supérieure, sauf lorsque la ventilation est indispensable durant les périodes où caverne est trés achalandée par les touristes.

Introduction

Waitomo Caves had been a popular international tourist attraction since the turn of the century. The key to it's success is the silent boat ride across the Glowworm Grotto, beneath the star-like display of glowworm lights.

The New Zealand glowworm (Arachnocampa luminosa (Diptera: Mycetophilidae)) is the larvae of a delicate gnat, its blue/green bioluminescence being produced by an organ at the posterior end. The larva suspends itself from the cave roof in a transparent mucus tube from which it hangs threads, adorned with droplets of sticky fluid. Some larvae produce over 100 of these 'fishing lines' which are used to catch the flying insects on which it feeds (Richards 1960).

The New Zealand Tourist Hotel Corporation (THC) is responsible for the management of the Glowworm Cave (Fig. 1) and surrounding scenic reserves. In 1975 it became clear to many interested groups, that the natural environment of the cave was showing definite signs of deterioration. This resulted in the formation, and funding by the THC, of a multidisciplinary research group, consisting of scientists from universities and government research departments. The terms of reference were "to provide from scientifically sound data, practical advice to the Minister of Tourism on procedures that would ensure the long term conservation of the Waitomo tourist caves".

Based on the results of a preliminary report, problems requiring research were identified. In most cases the THC sponsored postgraduate students at universities who were supervised by members of the research study group. Meetings to discuss progress, management recommendations and future plans were held twice a year.

Of prime importance to the successful management of the cave, was to learn more about the ecology of the glowworm, the long term survival of which was crutial to the whole tourist operation at Waitomo. Other topics included in the research programme were: cave cleaning, cave visitors and calcite corrosion, control of the lampenflora, cave lighting practices and plant growth, Waitomo Stream catchment management, hydrological and sedimentological process in the cave, cave microclimate and glowworm fungal disease.

The aim of this paper is to summerize the main findings from my study of flowworm ecology, and to emphasize management problems and recommendations made to reverse the recent decline in glowworm numbers.

Methods

Fortnightly field visitors to Waitomo were made during 1978 and 1979. Cave climate was monitored using maximum/minimum therometers, thermohygrographs and evaporation pans, placed at sites throughout the cave. Food supply was monitored in several ways. Sticky traps, made from stainless steel sheets coated with an adhesive grease 'Tangle-trap' were suspended at various points in the cave roof. On the Glowworm Grotto lake (Fig. 1), emergence traps were used to quantify insects emerging from aquatic larvae from the lake bottom.

To follow the glowworms' life cycle, 0.1 m^2 quadrats were marked out at random on the Grotto roof and walls, and observations made of the enclosed areas. The total number of glowworm lights counted in different areas of the cave was used to follow overall population changes.

Results

Climate:

The climate in the Glowworm Cave shows much greater variability than would normally be expected in a typical cave environment. Two main factors are responsible: heat generated by the electric lighting and tourists; the ease with which the cave atmosphere mixes with the surface air.

Typically in winter, when the cave is warmer than the surface, cold air flows into the lower entrance and is warmed and moistened by its passage through the cave. Warm air therefore blows out of the upper entrance (Fig. 2a). Besides lowering temperatures, this 'winter' air current causes the drying out of the cave walls, i.e. the rate of evaporation increases. In summer the air flow reverses (Fig. 2b).

Comparison with Richards' (1956, 1960) climatic data, shows that the climate was much more uniform then, than it has been in recent years. At that time, and until 1975, a solid door prevented the free flow of air between the two entrances (Figs. 2c,d).

Glowworm life cycle and mortality:

An annual life cycle occurs in the cave (Fig. 3). Peak glowworm numbers occur in spring, dropping rapidly through summer to a low in autumn and winter.

During the study the number of glowworms in the Grotto fell (Fig. 4). One of the main causes of mortality amongst larvae and pupae is a fungal disease Tolypocladium sp. (Moniliales), which in summer results in the appearance of white cadavers on the cave walls. Preliminary experiments show that the growth rate of this fungus increases rapidly over the range of temperatures reached in the Grotto in summer. Other causes of mortality include cannibalism, practiced mainly by early larval stages, and predation by opiliones (harvestmen).

Food

The majority of the food supply consists of freshwater insects (mainly chironomid midges), which emerge from aquatic larvae on the muddy bottom of the stream (Fig. 5). Few insects enter the cave from outside, most enter as larvae carried into the cave by the stream. The fact that glowworms usually flourish in the cave is almost certainly related to the abundance of food provided by the cave lakes, which act as traps for aquatic insects drifting downstream. Very few glowworms occur away from the stream passages, those that do must rely on insects flying from these areas. Air currents may well play an important role in distributing food in the cave.

Discussion

During the winter of 1979 the cave was closed for three months when the glowworm display was inadequate as a tourist attraction. The excellent, but inaccessible display in the Demonstration Chamber (Fig. 1) downstream of the Grotto, indicated that other parts of the cave were unaffected. Although the glowworm population in the Grotto is usually low in winter, this was not the main problem. This was that the few flowworms that were present in the Grotto roof had stopped glowing. The only explanation for this unusual behaviour was that it coincided with very dry conditions in the cave.

Cave glowworms, unlike those that live in the bush, have no defense against desiccation, in that they cannot retreat from dry air by retreating into 'burrows'. There is a possibility that larvae may turn off their lights in response to high evaporation rates. However, this hypothesis still awaits experimental verification.

The cause of the general decline in the glowworm display in recent years is because of a number of complex interacting factors, some of which are discussed below.

An adequate food supply is provided by the Waitomo Stream, but future planning should ensure that any changes in the catchment do not jepardize the glowworms' food source. The effects of air currents, and periodic desilting operations to keep the Grotto navigable, may however upset the distribution, quantity and seasonal availability of the glowworms' food supply.

The fungal disease is present in other caves in the Waitomo district, but cadavers are rare. What little is known of the ecology of the fungi suggests that in the Grotto, a combination of draughts, to carry the airborne spores, high summer temperatures and relative humidity, make for ideal conditions in which it can flourish.

Many of the current problems can be linked to the change in climate, caused in part by the opening of the top entrance in 1975. The installation of the open grille was done to relieve an earlier problem, that of the build up of carbon dioxide and stale air in the cave when tourtist traffic was high. The increased ventilation and the re-routing of tour parties away from the Organ Loft (Fig. 1), the main problem area, has been successful. However the decision to errect the grille was made before the full consequences of its affect on cave climate and the glowworm population, were realised. This exemplifies the importance of researching the effects of any manipulation of the cave environment, before and after, it is put into action.

To resolve the cave ventilation problem, a research programme was started to study cave meteorology. Until the results of this work are known, plans for further modification of the top entrance have been able in abeyance. It was recommended that the top entrance be kept sealed unless tourist traffic was high enough to warrant ventilating the cave.

The Waitomo Caves research programme has now been running for six years. The liaison between the THC management and researchers has been excellent. The caves are already recovering from the problems of the early 1970's, as results and recommendations from the study group have been put into practice. The interest in, and help given to research work, by THC staff and local people, has resulted in an increased awareness of the problems facing cave management. This knowledge based in the Waitomo community, may well be the most effective defense against future decline in the glowworm population, or deterioration in the cave environment.

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Richards, Sols M. 1960. Observations on the New Zealand glowworm Arachnocampa luminosa (Skuse) 1890. Trans. R. Soc. NZ, V. 88, pp. 559-74.

Figure 1. Location map and isometric diagram of the Glowworm Cave showing tourist route (nos. 1-6). See Figure 1 of previous article.

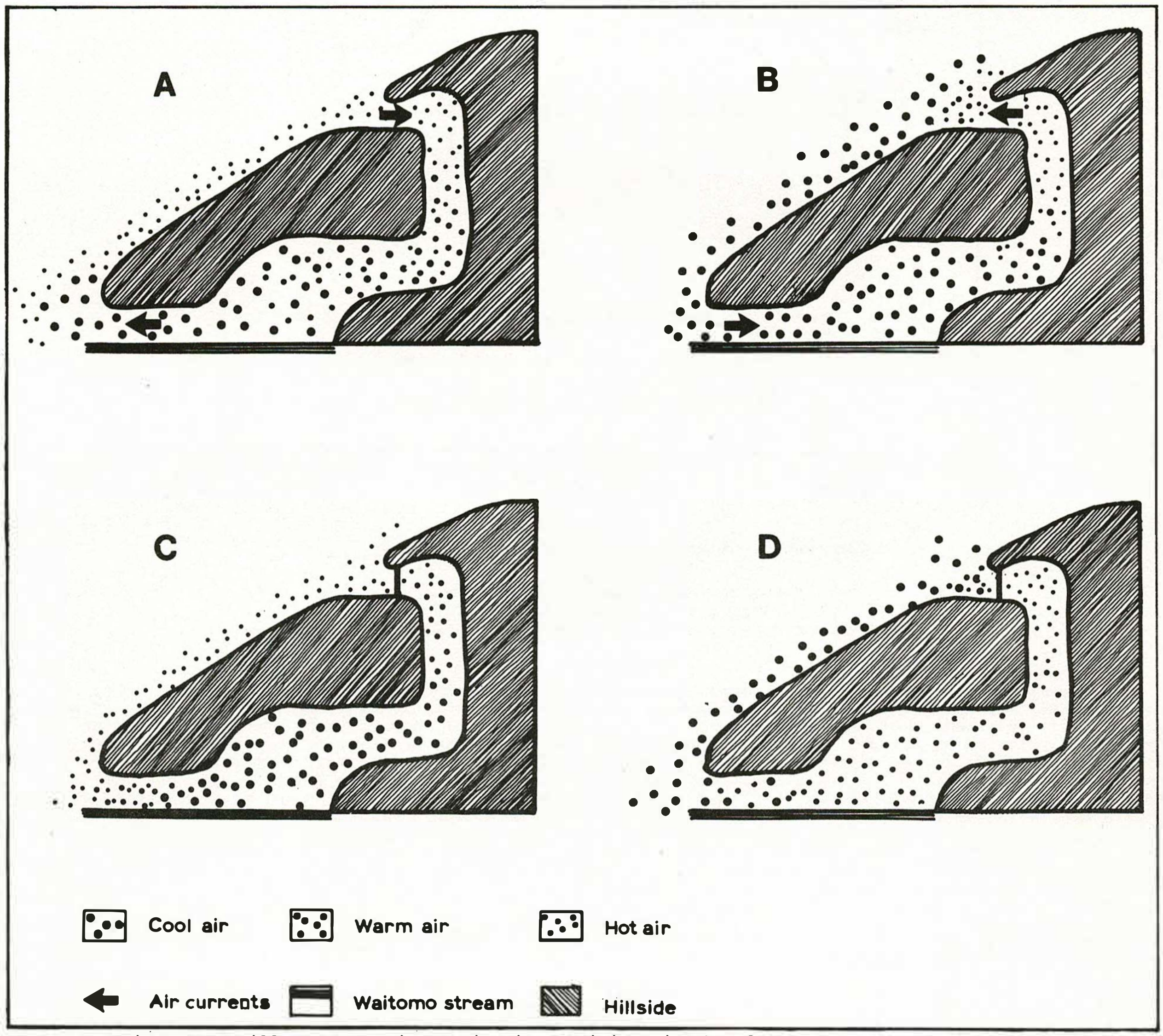

Figure 2. Diagrams to illustrate typical climatic conditions in the Glowworm cave with and without top entrance open. a. 'Winter' conditions 1977-80, b. 'Summer' conditions 1977-80, c. 'Winter' conditions predicted if top entrance sealed, d. 'Summer' conditions predicted if top entrance sealed.

Figure 3. Life cycle of the New Zealand Glowworm <u>Arachnocampa luminosa</u> (Skuse) (Diptera: Mycetophilidae) in the Glowworm Cave of Waitomo. See Figure 2 of previous article.

Figure 4. Decline in the glowworm population on a section of the Glowworm Grotto wall. See Figure 3 of previous article.

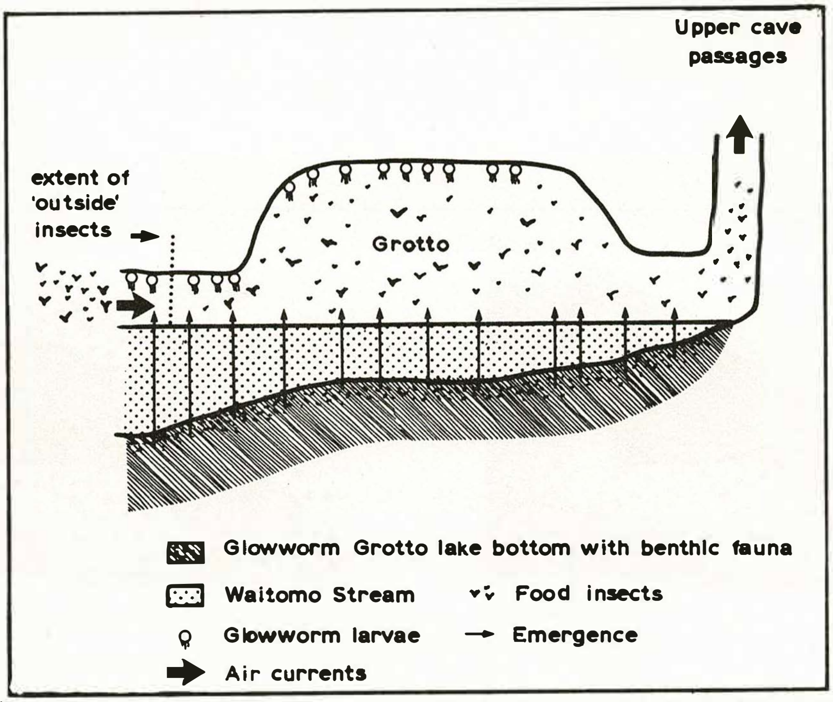

Figure 5. Diagram to illustrate the ecological relationships in the Glowworm Grotto.

Cooperation of Speleologist and Microbiologist

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Abstract

Cave samplings on Easter Island prompted us to develop a co-operation protocol for speleomicrobiological studies. The project clusters the following activities: 1) aseptic samplings, 2) collection of surface data, 3) measurement of cave parameters. To avoid environmental contamination, the microbiologist must have a priority of action. Human and animal activities on the surface should be noted. Animals with day or night activities are often responsible for surface microorganisms in caves. After attachment of the first polygon point by the speleologist at the entrance, the microbiologist proceeds with air, konimetric, floor, parietal and ceiling samplings. The second polygon point marks the end of twilight zone. Temperature, relative humidity, air-current measurements; mineralogical, plant and animal samplings are taken. A sketchy map is prepared. Former samplings and measurements are repeated, with additional measurements of carbon dioxide, gamma radiation and pH of aerosol condensate. If underground water is present, water temperature and current are measured, aquatic plants and animals collected. Among indicator microbes for human and animal fecal pollution, coliforms should be compared to resistent enterococci and yeasts. From pathogenic bacteria the search of Salmonella is recommended. It is compulsory to attempt the isolation of Histoplasma and cultures of amoebas in warm water. Actinomyces often produce antibiotics, also its isolation from cave flora could yield new, potent producers. A Thermoactinomyces isolated from adhering cave mucus needs further research.

Résumé

Les échantillonnages des cavernes à l'île de Pâques nous ont inspirés pour développer un protocole pour la coopération dans les études spéléomicrobiologiques. Le projet groupe les activités suivantes: 1) échantillonnages aseptiques, 2) collection de données à la surface, 3) mesurage des paramètres de la caverne. Pour éviter la contamination de l'environnement, le microbiologists devrait avoir la priorité d'action. Les activités humaines et animales sur la surface devraient etre enregistrées. Les animaux montrant des activités le jour ou ua nuit sont assez fréquement responsables pour des microorganismes de surface dans les cavernes. Après l'attachement du premier polygone par le spéléologiste à l'entrée, le microbiologiste s'avance avec les échantillonnages de l'air, konimétrique, plancher, pariétale et plafond. Le deuxième polygone indique la fin de la zone crépusculaire. On reèlise le mesurage de la température, l'humidité relative, courant d'air et on prend les échantillons minéralogiques, de la flore et de la faune. On prépare une carte d'esquisse. Les échantillonnages et mesurages antérieurs sont répétés avec mesurage additionnel d'anhydride carbonique, radiation gamma et le pH d'aérosol condensé. Si l'eau souterrraine est présente, la température de l'eau et le pH d'aérosol condensé. Si l'eau souterraine est présente, la température de l'eau et le courant sont mesurés, des plantes et animaux aquatiques sont collectés. Parmi les indicateurs microbiens de la pollution fécale, les coliformes devraient être comparées avec les entérocoques et levures résistantes. A partir des bactéries pathogènes, la recherche de Salmonella est recommandée. Il est obligatoire d'essayer l'isolement de l'Histoplasma et de faire des cultures d'amibes d'eau chaude. Les Actinomyces produisent souvent des antibiotiques, ainsi son isolement de la ~~flore ca~~vernicole pourrait fournir de nouveaux et puissants producteurs. L'isolement d'une Thermoactinomyces d'un mucus adhérent dans une caverne demande des recherches plus poussées.

Une Methode Graphique Pour Analyser Les Grottes "Phreatiques"

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Résumé

Vu que la grotte "phréatique" ne représente qu'une partie du réseau existant lors de sa genèse sous le niveau de la nappe aquifère, il est proposé d'étudier la géométrie de l'espace qui l'enveloppe horizontalement et verticalement. Cet espace représente, plus exactement que la grotte pénétrable, la zone de la roche encaissant où les eaux phréatiques ont creusé. D'un point de vue graphique, ce que nous appelons "l'Espace Karstifié" est limité par les extrémités de la grotte et les points le plus haut et le plus bas. Si cet espace est rabattu dans le plan vertical parallèle à la direction du pendage, il apparaît comme un ou des polygones allongés horizontalement qui peuvent être comparés au pendage vrai. L'analyse des éléments de ce polygone permet de distinguer les diverses phases de creusement du réseau autant "phréatiques" que "vadoses" lorsque le réseau est complexe. La méthode est appliquée à trois grottes du karst subarctique de la Nahanni au Canada.

Abstract

Since the "phreatic" cave is only a part of the network that existed at the moment of its genesis under the level of the water table, it is suggested that we study the geometry of the space that completely surrounds it. This space defines more accurately than the cave what part of the rock has been escaved by the phreatic water. From the graphic point of view, what is called the "Espace Karstifié" if bordered by the extremeties of the mapped cave and by the highest and the lowest points. If this space is projected on the vertical plan, which is parallel to the dip, its looks like one or more horizontally stretched polygons that may be compared to the true dip. The analysis of these polygon elements makes it possible to distinguish the many phases of the "phreatic" or "vadose" escaving of the network when it is a complex one. This method is applied to three caves of the subarctic karst of the Nahanni (Canada).

La Methode

Comme dans beaucoup de grottes, les remplissages bouchent les réseaux, et qu'une partie non négligeable en reste impénétrable à l'homme, il faut les étudier comme un échantillonnage du réseau potentiel. Lorsqu'il est évident que la partie connue est d'origine phréatiaue il est possible d'en étudier l'évolution de la manière suivante.

Puisque ce type de grotte résulte de dissolution par les eaux d'une paléo-nappe aquifère, on substitue à la grotte connue le volume géométrique enveloppant, qui statistiquement correspond mieux à l'espace affecté par la spéléogenèse. Cet "Espace Karstifié" (E.K.) est limité en plan (coordonnées X et Y) par les extrémités du réseau et en hauteur (Z) par les points les plus hauts et les plus bas de la grotte (fig. 1). L'E.K. correspond à l'espace minimum creusé dont fait partie la grotte et qui comme elle, doit varier en fonction de deux familles de contrôles: ceux résultant de la nature et de l'architecture de la roche encaissante et ceux dûs à la dynamique des eaux souterraines, fonction de l'évolution géomorphologique régionale. Le pendage concrétise le contrôle dû à l'érosion différentielle et à l'allure des bancs. Pour le comparer à l'E.K., ou rabat la projection horizontale de ce dernier dressée à partir du plan de grotte dans un plan vertical dont l'azimut est celui de pendage (fig. 1). L'E.K. y apparaît comme un ou des polygones allongés avec des côtés parallèles ou non au pendage vrai. Les parallélismes prouvent l'adéquation du réseau à cette contrainte, tandis que les éléments horixontaux (donc recoupant le pendage) reflètent le contrôle exercé par une nappe aquifère stable favorisant un creusement prédominant par dissolution et le développement de réseaux subhorizontaux. Par contre, un encaissement de l'hydrographie de surface et l'abaissement subséquent de la nappe aquifère provoquent quand ils ne sont pas trop rapides, un enfouissement du réseau. Le polygone projeté de l'E.K. en témoigne par des pentes plus fortes allant jusqu'à recouper le pendage vrai.

Comme le montre l'exemple fictif de la fig. 1, la réduction de la grotte à la géométrie de son E.K. contribue à accentuer la présence ou l'absence de pentes et niveaux comparables au pendage. La géométrie de l'E.K. projeté de la grotte fictive (fig. 1) montre que la partie supérieure est parallèle au pendage, et que l'inférieure le recoupe par 2 pentes s'accentuant vers la sortie. La partie supérieure de l'E.K. a été creusée par dissolution mettant en évidence le pendage. Cette partie est "phréatique". Tandis que la partie inférieure hachurée recoupe le plan de stratification et provient d'une phase de creusement "vadose" d'abord modérée puis plus vive consécutive d'un abaissement de la nappe aquifère. L'E.K. projeté permet en plus de situer l'altitude de ces diverses phases de creusement.

L'Espace Karstifie (E.K.) Des Trois Grandes Grottes De La Nahanni (T.N.O. Canada)

La grotte Valérie (16C), longueur 2 002 mètres

Ce réseau permet de tester la méthode. Il se compose de longues galeries rectilignes, parallèles, descendant vers trois entrées et d'une galerie sinueuse qui les recoupe. Le pendage moyen est 8.2°. Fait simplificateur, les points les plus hauts et les plus bas se situent sur le contour du polygone délimité par 7 stations dont les 3 entrées (fig. 2). La projection verticale de cet E.K. est un polygone d'un seul tenant dont la limite supérieur est subhorizontale et recoupe la stratification, correspondant aux galeries les plus hautes qui aboutissent à l'entrée principale (côté ouest du réseau). Par contre la limite inférieure du polygone présente une pente s'accentuant vers la sortie la plus basse et la plus à l'est du réseau. Quant au côté le plus au fond de l'E.K. compris entre les stations 5 et 6, il se situe dans le prolongement exact de la sortie du milieu et en parallèle à la limite supérieure du polygone (côté entre les stations 2 et 3). Ce qui permet de diviser le polygone en deux parties. La partie supérieure comprise entre les stations 2, 3, 4, 5, 6 et 7, quasi parallèle au pendage correspond à un réseau "phréatique" peu profond, creusé lors d'une période stable de la nappe aquifère sur une hauteur de 16,5 m. Et la partie inférieure entre les stations 6, 7 et 1 correspond à un abaissement lent de la nappe aquifère passang progressivement à des écoulements "vadoses". Cette interprétation est confirmée par la morphologie de détail des galeries. Enfin les 3 entrées (stations 2, 7 et 1) constituant le seul côté du polygone parallèle avec le pendage, prouvent qu'elles ont été contrôlées non seulement par l'abaissement piézonmétrique mais aussi par la structure. L'encaissement du réseau a été suffisamment lent pour entraîner son déplacement latéral. Il faut donc dater cette grotte d'une période de stabilité de l'hydrographie proche de l'altitude supérieure du réseau.

La grotte Andrée (35B), longueur 1 205 mètres

Cette fois la grotte est en bordure d'un affluent de la Nahanni à 4,2 km à vol d'oiseau de la précédente. Elle se compose d'une importante galerie subhorizontale que prolongent deux réseaux de gabarit plus modeste et situés plus bas. Le pendage est exactement le double (17,5°) de celui de la grotte Valérie. La figure polygonale de son E.K. projeté se décompose en trois: un polygone allongé sous lequel se greffent deux polygones triangulaires. Ce polygone subhorizontal prolongeant l'entrée de la grotte et recoupant fortement le pendage, définit la partie du réseau creusée en régime "phréatique" sur une hauteur de 14,5 m. Par contre, le plus petit des deux triangles se compose de deux petits réseaux superposés développés à contre-pendage. Comme sa partie supérieure est horizontale et sa base parallèle au pendage, il s'est développé en régime "phréatique" stable prolongeant l'enfouissement du réseau de 20,5 m, mais qu'entrave le pandage. Tandis que l'autre triangle se composant d'une galerie vers l'aval-pendage réussit un enfouissement de 38 m adapté remarquablement au pendage cette fois favorable dans sa partie supé'ieure et le recoupant subhorizontalement par sa base dont l'altitude correspond à la fin de la période de creusement "phréatique" local. L'enfouissement de tout le réseau (52,5 m) est proche de celui de la grotte Valérie (41,5 m) et rigoureusement à la même hauteur. Ce qui suggère une spéléogenèse régionale de même âge.

La grotte Mickey (47B), longueur 2 270 mètres

La plus grande grotte de la région, proche de la première sur les rives de la Nahanni est entourée de cavités plus petites qui constituent un réseau total de 3 700 m de longueur. La projection verticale de leur E.K. se divise en deux à une altitude nettement inférieure à celle des 2 autres grottes. Le principal polygone englobe les grottes les plus profondément creusées dans le massif (fig. 3, stations 17, 13, 15, 2, 3, 18, 6, 14 et 9) et s'y encaisse sur 30 m de profondeur en suivant le pendage modéré (8,7°), ce qui dénote son origine "phréatique" prédominante. Le haut et le bas du polygone sont quasiment parallèles et distants de 45 à 50 m. Donc, au début de cette phase de creusement, le niveau piézométrique était supérieur à 565 m, altitude de la station la plus haute (15), puis s'abaisse progressivement jusqu'à 50 m audessus de la station 18 la plus basse. Le contrôle du pendage modéré est effectif, comme pour la grotte Valérie entrainant aussi un déplacement latéral de la zone en cours de cavernement. Cette adaptation à la structure atteste de la lenteur de l'abaissement de la nappe "phréatique". De plus, entre 535 m et 515 m, les conditions de creusement ont perduré durant tout cette phase de spéléogenèse (fig. 4), ce qui y fait apparaître la plus grande densité de galeries. Enfin, la constance de l'épaisseur de ce polygone (50 m) suggère que c'est dans cette fourchette que la spéléogenèse en condition "phréatique" a été efficace puisque les matériaux sont tout aussi solubles au-dessus qu'en dessous.

Le reste du polygone projeté (fig. 3) consiste en triangles imbriqués sous le polygone principal. S'y retrouvent toutes les petites grottes satellisant le réseau profond. La décroissance de ces triangles vers le bas suggère une inhibition progressive des conditions de creusement de type "phréatique" qu'on peut associer à un abaissement plus rapide du niveau de base régional tel que le montre la géomorphologie de surface.

Conclusion

Par le biais du concept nouveau, les "Espaces Karstifiés", l'importance du contrôle du plan de stratification est mis en évidence, d'autant plus drastique que le pendage est faible, ce qui entraine un développement latéral du réseau. La spéléogenèse en condition "phréatique" responsable des 3 plus longues grottes de la Nahanni a eu lieu lors de 2 phases de stabilité de la nappe aquifère qu'il a été ainsi possible d'identifier, de même que les seuils d'efficacité du régime noyé et les variation de la vitesse d'abaissement de la nappe durant ces niveaux de stabilité. Pour les grottes inférieures à 1 km de développement connu, les résultats sont aberrants, ces objets karstiques se situant alors sous le seuil de perception de la méthode, ce qui en précise le niveau d'application.

Reference

J. Schroeder, 1979 - Le développement des grottes dans la région du Premier Canyon de la rivière Nahanni-Sud, T.N.O., Thèse de Ph.D., Université d'Ottawa, Canada.

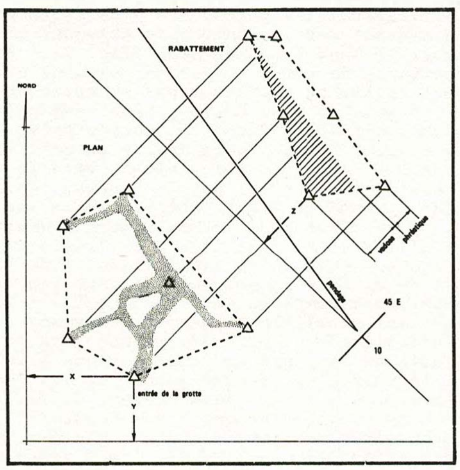

Figure 1. Grotte fictive dont on retient les stations extrêmes pour délimiter son "Espace Karstifié" qui est rabattu dans le plan vertical du pendage. L'allure du polygone ainsi projeté, donne des indications sur le développement du réseau: la partie du polygone parallèle au pendage contient le réseau "phréatique" et celle inférieure (hachurée) qui recoupe le pendage contient le réseau "vadose".

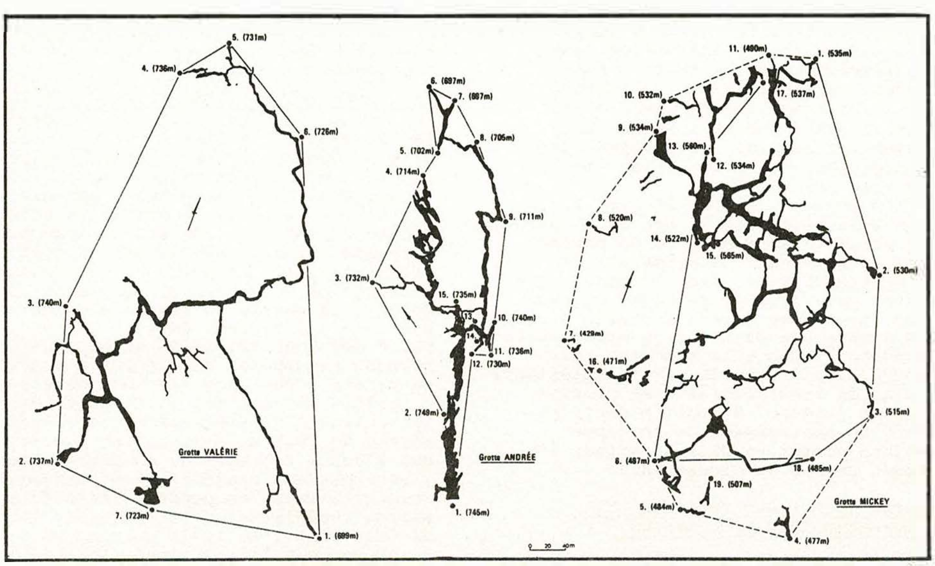

Figure 2. Les grottes Valérie, Andrée et Mickey et leur "Espace Karstifié", avec leur altitude au-dessus du niveau de la mer.

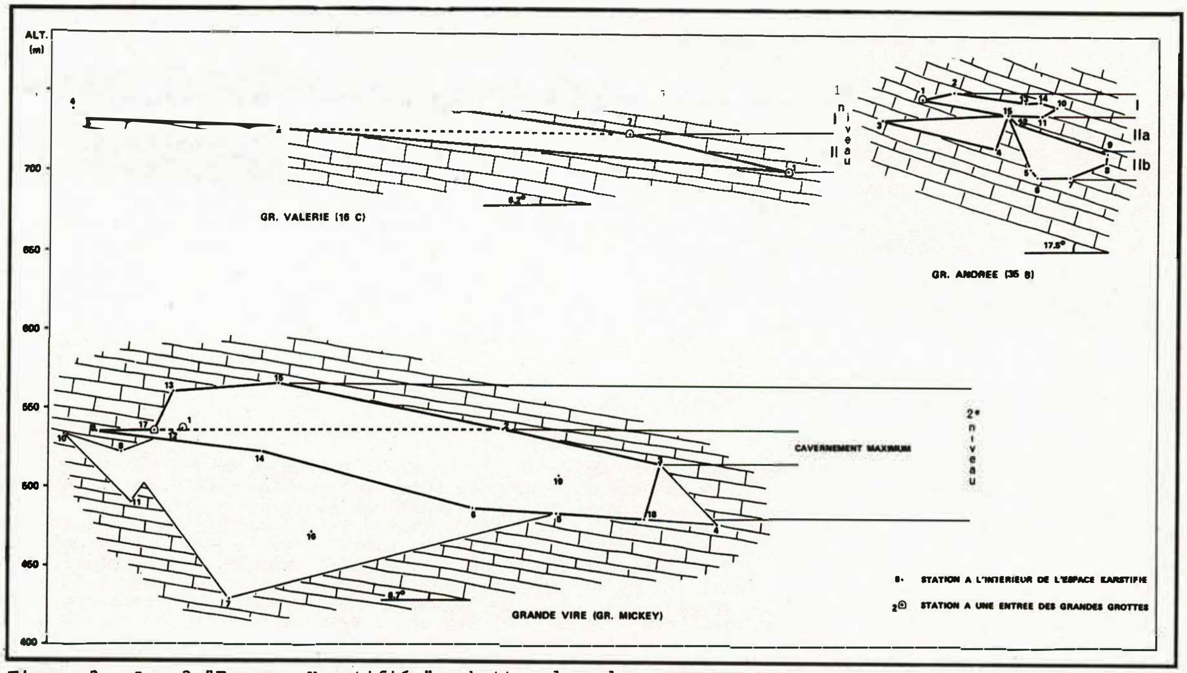

Figure 3. Les 3 "Espaces Karstifiés" rabattus dans le plan vertical du pendage et disposés suivant leurs altitudes.

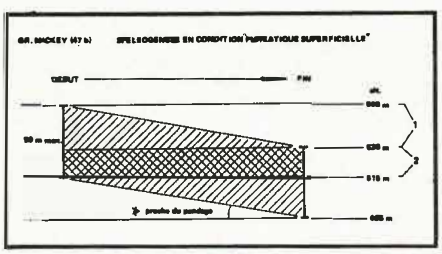

Figure 4. Dynamique de la spéléogenèse en condition "phréatique superficielle" de la grotte Mickey (47B). La dénivelée de la grotte est d'un bord à l'autre de son "Espace Karstifié" de l'ordre de 50 m. Ce qui illustre l'abaissement faible (30 m) de "l'Espace Karstifié" 1) et par conséquent du niveau phréatique lors de la spéléogenèse. C'est la zone de "l'Espace Karstifié" comprise entre 535 et 515 m qui a subi les conditions de creusement les plus longues 2) (du début à la fin de la spéléogenèse). Donc c'est entre ces altitudes que le réseau doit présenter son développement maximum en plan. Ce qui est le cas et est confirmé par la position horizontale de la limite interne du réseau (St. 17-2-3) dans la projection de "l'Espace Karstifié" (fig. 3).

Les Sediments Clastiques De La Grotte De Castleguard

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Résumé

Du point le plus haut de la grotte, ouvert sous la calotte Columbia, jusqu'au puits de 80 pieds, les sédiments clastiques ont été observés sur près de 7 km de longueur. A l'amont sous le glacier, le plancher est couvert de débris mécaniques et cryoclastiques avec des blocs glaciaires émoussés parfois collés aux parois en poudingues. Viennent ensuite, des silts argileux (92 à 99% du total < 37μ, dont 4 à 21% < 4μ) le plus souvent varvés (1 à 3 mm d'épais) ou en lits massifs (10 à 15 cm d'épaisseur). Les lits sont gris, beiges ou beige clair. Discussion des résultats des calcimétries et des diffractions X. Malgré les changements locaux de faciès, il semble que la sédimentation s'ordonne en une séquence en trois niveaux. 1) A la base, on trouve des plages (sporadiques) de galets arrondis ou de cailloutis anguleux le plus souvent calcaires, soit cimentés soit emballés dans les silts, ou des plaquettes silteuses concassées sur une épaisseur de 30 cm maximum. 2) Puis vient au niveau de silts argileux varvés et/ou massifs localement perturbés par des plissotements de gravité et des chenaux large d'un mètre au plus. Il se termine par une surface d'érosion indurée parfois couverte d'un lit fin de galets calcaires. Epaisseur totale moyenne 1 m et plus. 3) La partie supérieure est aussi composée de silts argileux varvés et/ou en lits épais, mais se termine par une surface d'arrêt de sédimentation. Epaisseur 1 m et plus. Une chronologie est proposée.

Abstract

From the highest point of the cave, that opens up under the Columbia Icefield, to the 80' Pot, clastic sediments have been analyzed on 7 km of galery. Upstream under the glacier, the floor is covered with mecanical and cryoclastic debris including erratic boulders sometimes adhering to the walls. Then, there is silt with clay (92 to 99% of the total < 37μ, of which 4 to 21% < 4μ) mostly varved (1 to 3 mm thick), and sometimes in thick beds (10 to 15 cm thick). The beds are either grey, beige or pale beige. Discussion of the calcimetries and the X diffraction data. Despite the local changes in the facies, the sedimentation seems to include three levels. 1) At the bottom level, there are, here and there, local deposits of rounded or angular limestone pebbles (except at one place), either cemented or coated with silt, or crushed silty plates. Maximum thickness = 30 cm. 2) The next level is composed of varved and (or) massive bedded clayed silts, comprising gravity plications and channels 1 meter wide at the most. The top of this level is an indurated erosional surface sometimes covered with a thin layer of limestones pebbles. Average total thickness = 1 meter or more. 3) The upper level is also made up of varved and (or) bedded clayed silts but it is topped off by a sedimentary surface. Average total thickness = 1 meter or more. A chronology is suggested.

Au cours de l'expédition d'avril 1980, les sédiments clastiques ont été observés du point le plus haut de la grotte ouvert sous la calotte Columbia jusqu'au puits de 80 pieds proche de la sortie, soit sur près de 7 km de galeries. Puisque ces sédiments appartiennent à une même phase ancienne de remplissage (Ford, 1971; Ford, et al., 1976), leur présente analyse vise à en préciser les étapes, par une description en fonction de la topographie. La zone étudiée se divise alors en trois: le réseau proche du "Ice Blockage", les environs de la "Deuxième Fissure" et la "Première Fissure" prolongée jusqu'au puits de 80 pieds (figure 1).

Dans le réseau proche du "Ice Blockage" le plancher des galeries est presque partout couvert de débris anguleux calcaires. Les plus gros blocs avec des volumes autour du mètre cube proviennent de l'effondrement des voûtes et des murs. Les plus petits mesurant le décimètre cube résultent de l'éclatement des premiers soit lors de leur chute soit par cryoclastie pour ceux au centre et dans les points les plus bas des galeries. Dans ce cas, le processus doit être encore actif et alimenté par des écoulements estivaux ou sporadiques d'eaux sous-glaciaires comme le prouve la glace de recristallisation qui ferme la galerie et scelle la blocaille. Tandis que les effondrements sont causés par des ruptures aux voûtes non équilibrées car proches de la surface du substratum et sensibles à la masse et aux déplacements du glacier. Comme la grotte est bien antérieure à l'Holocène (Ford, 1971), la fatigue mécanique à la paroi des galeries doit être importante et accentuée par la décompression résultant de l'amaigrissement glaciaire global durant l'Holocène.

Dans ces débris, de rares blocs calcaires au minimum pungilaires présentent un émoussé glaciaire. Proches du "Ice Blockage", ils subsistent en conglomérats fossilisés aux murs à parfois plus d'un mètre au-dessus du plancher actuel (position I sur la figure 1). Ces dépôts attestent que la galerie, à cet endroit et avec un gabarit proche de l'actuel, a été colmatée par injection de matériel morainique à une période où le glacier était plus dynamique qu'aujourd'hui, soit durant une phase anaglaciaire. Alors que l'équilibre dynamique actuel en favorise l'évacuation par des eaux de fontes. Les conglomérats sont fossilisés par une matrice calcaire, tandis que les blocs glaciaires isolés dans les débris mécaniques du plancher, témoignent de l'agressivité des eaux de fontes subactuelles, car ils sont généralement dépourvus d'encroûtement secondaire. Au fur-et-à-mesure qu'on s'éloigne du "Ice Blockage," les débris anguleux diminuent, tandis que les blocs émoussés prédominent sur le plancher, sporadiquement et en plaquages conglomératiques. Rapidement le diamètre maximum des blocs diminue pour se situer entre 1 cm et 30 cm et l'émoussé évolue vers l'arrondi (cf. infra). Par contre, les galeries latérales à l'abri des écoulements venant du "Ice Blockage" sont colmatées de matériaux fins stratifiés fossilisant les blocs. Ainsi à l'injection de matériel morainique succède la sédimentation de silts le plus souvent varvés (1 - 3 mm d'épais) ou en lits épais de 10 à 15 cm.

Ces silts gris, beiges ou beige clair qui constituent maintenant l'essentiel des dépôts, contiennent 92% à 99% de particules < 37μ, dont 4% à 12% d'argile soit les particules < 4μ leur limite granulométrique; tandis qu'un seul échantillon de silts en lit épais donne 21% d'argile (figure 2). Comme la fraction 10μ - 37μ contient plus de la voitié de chaque échantillon, les carbonates y sont mesurés par calcimétrie et en représentent en moyenne 62%, avec des extrêmes de 45% à 90%. Ce que confirment et précisent les diffractions X sur la fraction < 10μ en identifiant 60% à 85% de calcite avec un maximum de 5% de dolomite; tandis que les illites se retrouvent partout (5 - 15%) ainsi que les chlorites (3 à 15%) avec des traces de quartz et parfois de minéraux gonflants. Ces silts ont été mis en place par des eaux fluvio-glaciaires riches en carbonates par l'effet combiné de la dissolution du substratum et du lessivage de la farine glaciaire. Les résidus insolubles du substratum ont probablement donné les éléments argileux.

Entre la zone du "Ice Blockage" et la "2e Fissure", le réseau se caractérise par des effondrements de gros blocs (> 1 m^3), sur les plus hauts desquels subsistent parfois des silts varvés en place profondement ravinés (fig. 1, H). Ce fait prouve l'antériorité des effondrements par rapport au remplissage silteux et l'efficacité locale, ici du ravinement en cours par égouttement, et plus bas d'une érosion linéaire qui sectionne dépôts et substrat (fig. 1 B) ou provoque la suffosion.

Plus bas, la fissure subverticale qui contrôle le développement de la galerie, est occupée par un filon siliceux qui subsiste autant dans les sections creusées par l'eau que dans celles où l'altération mécanique prédomine (fig. 1, F). A l'aval, les débris bruns, rougeâtres, se retrouvent sans forme de galets aplatis (L < 5 cm) couverts de manganèse et constituent une base de < 10 cm (fig. 1, G-1), sur laquelle se succèdent des silts varvés concordants, beiges avec des passées rougeâtres (fig. 1, G-2). Le sommet de la coupe semble avoir été érodé ultérieurement.

Par contre, la coupe suivante (fig. 1, E) a conservé tous ses faciès. La base limitée par une surface d'érosion se compose soit de silts gris (fig. 1, E-1) soit d'un "conglomérat" de plaquettes silteuses grises et beiges, avec des débris anguleux de calcaire, du filon siliceux et de concrétions cassées (fig. 1, E-2).

Au-dessus, des silts beiges s'accumulent sur plus d'un mètre avant d'être limités par une surface d'érosion indurée (fig. 1, E-3). La coupe se termine par des silts varvés concordants qui débutent par un lit épais de 15 cm et finissent par une surface d'arrêt de sédimentation (fig. 1, E-4). A partir de cet endroit, chaque fois que la coupe subsiste au complet, ces trois niveaux sont identifiables.

Ainsi, la coupe D débute par des silts varvés beiges, contenant des galets calcaires, au plus pungilaires, que limite une surface d'arrêt de sédimentation indurée (fig. 1, D-1); puis on trouve un plancher stalagmitique partiellement redissout, couvert de galets centimétriques calcaires et siliceux et des silts varvés concordant, beiges avec des chenaux de silts gris (fig. 1, D-2). Le niveau suivant débute par une surface d'érosion couverte de galets centimétriques calcaires et siliceux puis de varves beiges, arrêtées par une surface de sédimentation indurée (fig. 1, D-3). A partir de cet endroit, les dépôts vont progressivement s'épaissir grâce au nombre croissant de lits épais de 10 cm à 15 cm intercalés dans les varves ou seuls, comme le confirment les dépôts de l'extrémité d'aval de la "2^{e} fissure".

Ici, la base de la coupe se compose à nouveau d'un "conglomérat" de plaquettes silteuses (fig. 1, C-1) que surmontent des lits épais alternant avec des varves localement perturbées par des plissotements de gravité. Cette fois, ce niveau finit par une surface d'arrêt de sédimentation indurée sur 0.5 cm d'épaisseur avec des fissures de dessication. Le suivant présente la même alternance varves-lits épais et se termine aussi par une surface d'arrêt de sédimentation cette fois surcreusée par un chenal rempli de silt gris. Enfin, la coupe et le substrat ont été entaillés par un écoulement subactuel qui laisse une "tranchée vadose" profonde ici de 1 m (fig. 1, C-4) mais ailleurs atteignant les 10 m (fig. 1, B).

Entre la "2^{e} fissure" et la première, la coupe type se compose de plages cimentées de galets calcaires (fig. 1, A-1), que surmontent des varves limitées par une surface d'érosion soulignée de galets calcaires (fig. 1, A-2) et que terminent des silts varvés et lités subhorizontaux. Dans la "1ère fissure", là ou ils subsistent, les dépôts clastiques montrent les mêmes types de faciès, les galets calcaires étant cependant de plus en plus sporadiques à la base.

Les galets présents sous le puits de 80 pieds ont un indice d'émoussé variant de 0,5 à 1,0 ($\bar{X}$ = 0.7, n = 14, indice de Petitjohn). Ils sont donc arrondis à bien arrondis et proviennent de débris cubiques (8 sur 14) ou parallèlipipédiques (6 sur 14, méthode de Zingg) comme on les trouve dans la moraine injectée à l'amont.

Ainsi, au-delà des modalités explicables par la topographie locale, les sédiments clastiques de la grotte de Castleguard s'ordonnent en une séquence qui varie d'amont vers l'aval et de bas en haut. L'injection de matériel morainique est suivie de son lessivage donnant des plages de galets de mieux en mieux roulés mais de plus en plus rares auxquelles s'intercalent une sédimentation fine localement détruite et reposée en "conglomérats" de plaquettes silteuses. Suit un arrêt des écoulements irréguliers et violents qui permet, ici l'induration de la surface des dépôts, là l'apparition d'un plancher stalagmitique. La phase suivante se caractérise par des écoulements plus modérés qui fossilisent le premier niveau de dépôts sous des silts le plus souvent varvés. Cependant, ces écoulements sont à leur début assez compétents pour trailler localement une surface d'érosion et des chenaux tapissés de galets et de silts gris. Enfin, après un nouvel arrêt, une troisième phase d'écoulement lent aboutit à la sédimentation d'autres silts varvés et lités avant de se tarir. C'est ainsi que peut se moduler actuellement la phase majeure de remplissage clastique qui semble correspondre à une période anaglaciaire où le débit et la compétence diminuent glabalement. Plus tard, probablement à l'Holocène, la grotte draine à nouveau des eaux fluvio-glaciaires qui entaillent et les dépôts et le substrat.

Remerciements

D.C. Ford m'a invité à joindre son équipe sur le terrain en avril 1980. L'étudiant F. Sylvestre a réalisé les sédimentations et les calcimétries. M. Preda a fait les diffractions X et M. Cloutier les indices d'émoussé. André Parent a dessiné les figures.

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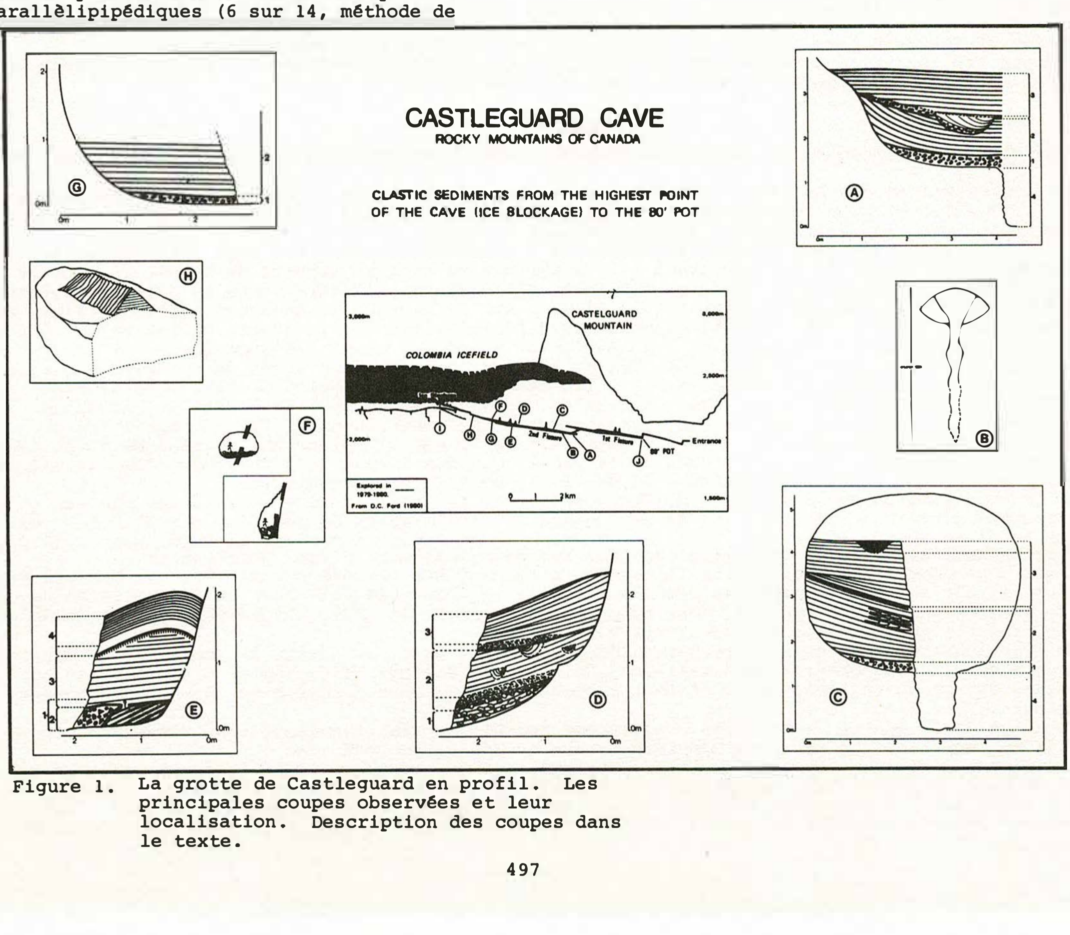

Figure 1. La grotte de Castleguard en profil. Les principales coupes observées et leur localisation. Description des coupes dans le texte.

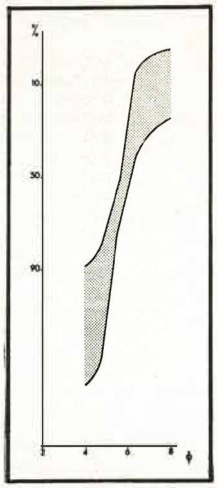

Figure 2. Enveloppe comprenant les quatorze (14)
courbes granulométriques des silts.

Applications of Speleology in Civil Engineering Works in Turkey

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Abstract

Speleological research is extensively used in civil engineering works in Turkey, particularly on applications like the construction of dams and hydroelectric power stations, irrigation projects, water supply for urban settlements. Some examples are examined in the sequel:

1. Detailed investigation of Petek Cave system which is situated on the trajectory of underground water leaking from the large reservoir lake of the Keban dam (Elazig).
2. Speleological explorations related to the construction of the Oymapinar dam (Antalya), such as:
   a. Dumanli underground river system whose resurgence is in fact one of the largest in the world.
   b. Exploration of the Akpinar Cave situated at 35 Km of the dam and related to it by an underground river.
   c. Investigation of the 6.5 Km long Tilkiler Cave situated at 2 Km from the dam whose discovery played a crucial role in the grouting works which followed.
3. Explorations in the karstic regions around Kadincik II dam (Tarsus) including an aven of 90m depth which substituted a 100m borehole project by revealing the underground geological structure.
4. Exploration of Maraspoli underground river (Konya) which is used as source of energy and water supply for the nearby town Ermenek.
5. Explorations of Karasinir and Felengi caves providing important clues about the underground water system of Konya Plaine.
6. Exploration of Yerköprü Cave (Konya) related to the construction of Yerkörü-Göksu dam.
7. Water supply for the village Dalyan Köy and a neighbouring holliday village is obtained through speleological explorations from an underground lake situated nearby.

Résumé

Les recherches spéléologiques ont été excessivement importantes dans les travaux du génie civil en Turquie.

Dans les constructions des Barrages et des Centrales Hydroélectriques, l'établissement des grands projets de l'Irrigation et pour fournissement de l'eau potable aux villes et à des villages on a recours souvent à des recherches spéléologiques. Voyons quelques exemples:

1. Aprés la construction du grand barrage de Keban, il y a eu des fuites d'eau très importantes du lac du réservoir. Une de ces fuites s'ouvrait sur un système de grottes (Grotte de Petek) et pour le calmotage de ces grottes il a fallu faire une carte d'taillée de l'intérieur de ce système souterrain.
2. Le grand barrage-voûte que l'on construit actuellement sur la rivière de Manavgat près d'Antalya, on a profité des explorations des Spéléologues; d'abord l'exploration de la grotte de Dumanli d'où sort une des plus grandes sources karstiques (Vauclusieene) du monde, ensuite l'exploration de la grotte d'Akpinar qui se trouve à une distance de 35Km du barrage, on a fait un essai de coloration sur la rivière souterrain qui parcourt cette grotte. Troisiemment, l'exploration de la grotte de Tilkiler qui se trouve à 2 Km de làxe du barrage, les spéléologues ont démontré l'absurdité du rideau de l'injection. Avant l'exploration de cette grotte qui a une longueur de de 6.5 Km, les ingénieurs du barrage voulaient construire un rideau d'injection, puis par l'ampleur et le grand développement de ce système souterrain, ils ont renoncé de ce projet qui était absurde à cause de l'impossibilité de combler les grands vides souterrains avec du ciment ou d'autres matériaux.
3. Pendant la construction de la Centrale Hydroélectrique de Kadincik II il y avaient des grottes et une de ces grottes c'etait un aven de 90 m de profondeur. L'exploration de cet aven a fourni des renseignements d'une grande importance et ainsi on supprimé de faire un sondage de 100m, pour voir dans quelle profondeur se trouvait le contact de deux faciès du calcaire d'ages différentes.
4. Le village d'Ermenek (Konya) se ravitaille en eau potable d'une rivière souterraine qui circule dans une grotte située sur une falaise, au pied de laquelle se trouve le village. La récupération de l'eau de la grotte par des tuyaux forcées au moyen d'un tunnel de 192m, et son utilisation comme source d'énergie fournit actuellement l'électricité à ce village.
5. Pendant les recherches des eaux souterraines dans les bordures de la plaine de Konya, les recherches spéléologiques dans les grottes de Karasinir (Çumra) et de Felengi (Cihanbeyli) ont donné des renseignements de grande utilité, et ainsi on a renoncé de faire deux sondages de 200m de profondeur d'au moins.
6. L'exploration de la grotte de Yerköprü a également fourni des renseignements très utiles aux ingenieurs qui ont construit la Centrale Hydroélectrique de Göksu-Yerköprü.
7. Le petit hameau de Dalyan Köy (izmir) et le petit village de vacances qui se trouve à quelques kilomètres de prés, prennent leur eau potable d'un petit lac souterrain qui se trouve dans une grotte non loin de la mer. C'est grâce à l'exploration spéléologiques que ce projet fut réalisé. Car, sans cela, par un pompage excessif on aurait invité l'eau salée de la mer qui se trouve à 35 m seulement de la grotte.

Study of Features of the Karstic Depression in South China

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Abstract

Fenglin and cockpit that widely distribute in South China are characteristic of tropical karst. The cockpit is an isolated hydrological system in which exists a subterranean drainage system formed by seepage water. Especially when flood pours into the cockpit, some features occur in association with the subterranean rivers. The approach to these features developed in this study is called depression analysis which is of some significance in predicting subterranean rivers and investigating the evolution of karst.

a. Features of lower depression zone and their relation to subterranean rivers

Every depression is associated with a subterranean drainage system, and the elevation of its bottom decreases in the direction of the flow. Thus, the contours may be drawn and intensive dissection of the depression may be made by the elevations of the bottoms on a topographic map. The zone consisting of depressions with lower bottom elevation is called the lower depression zone. The depressions with higher bottom elevation is called the lower depression zone. The depressions with higher bottom elevation between two lower depression zones form the higher depression zone which implies the subterranean divide. This reveals the main characteristic of subterranean drainage system.[1]

The longitudinal profile of the lower depression zone can be drawn by linking the bottom elevations of all the depressions in it, and all profiles, whether concave or covex, are consistent with and relate to the subterranean rivers. The relation equation is $\hat{Y} == 8 \times 10^{-4} + 0.81 X$
and the relation graph is shown in figure 2. The gradient (Jm) and length (L) of the lower depression zone can be obtained from the topographical map. The elevation of underground water outcrop being known, the elevation of the subterranean river can be predicted by the following relation

$$Hw' = Hw \pm Jm\ L$$

b. The relationship between the gradient of the lower depression zone and the type of karst

It has been found in the investigations of small drainage basin that the size of depression increased downstream in the basin with concave profile and decreases in the basin with convex profile. Of two factors -- gradient and discharge -- influence the size of depression, the former is more important. When the gradient of the lower depression zone is less than 5‰ , polje develops; when it is 5 - 13‰ , polje is replaced by cockpit and uvala; and when greater than 13‰ cockpit is dominant. The characteristics of subterranean passage-way are different from one type of depression to another. It indicates that each type of depression has its particular hydrodynamic process, and is dependent on the strength of downcut of rivers induced by tectonic movement. This hypothesis may also be applied to larger basins. South China is mainly in the Pearl River Basin with the greatest strength of downcut in the Middle reach and the strength gradually in both downstream and upstream. As a result, karst geomorphology may be divided into five zones, that is, a) Guang Tong-Guang Xi karstic plain zone; b) Polje and karstic valley zone in central Guang xi; c) Gui Zhou - Guang Xi cockpit zone; d) Yun Gui plateau polje zone; and e) Yun Gui plateau Shen Pen zone. The type of depression in upstream and that in downstream are symmetric with cockpit zone as the central link, but different in evolution directions. Yun Gui Plateau polje zone and Shen Pen zone is in the process of destruction of the retrogressive erosion.

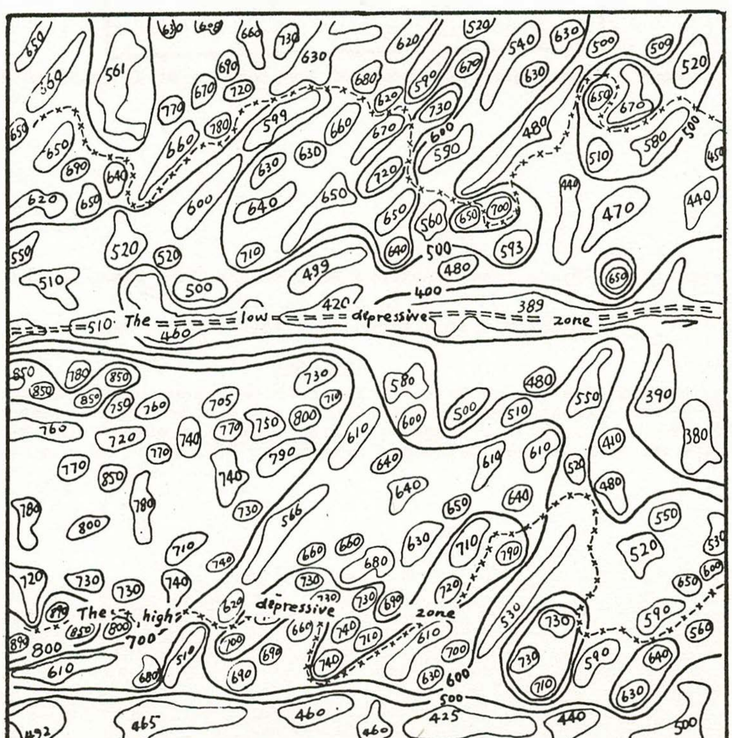

Figure 1 A Map of Depression Analyses

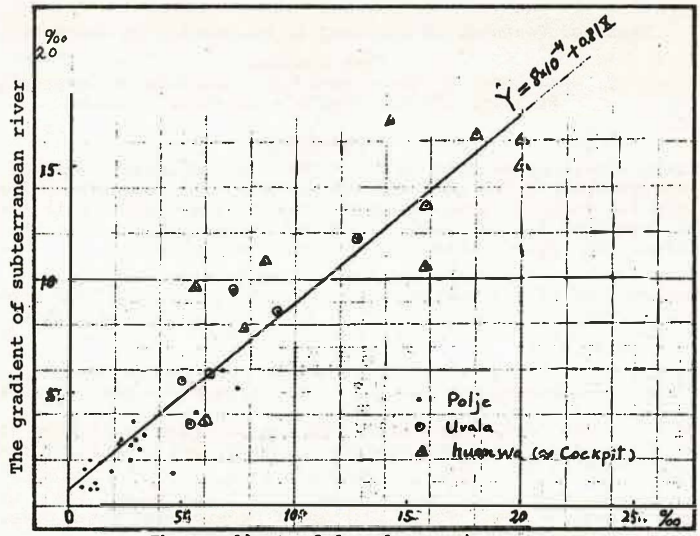

Figure 2 The Relation Between Gradient of Subterranean River and of Low Depressive Zone.

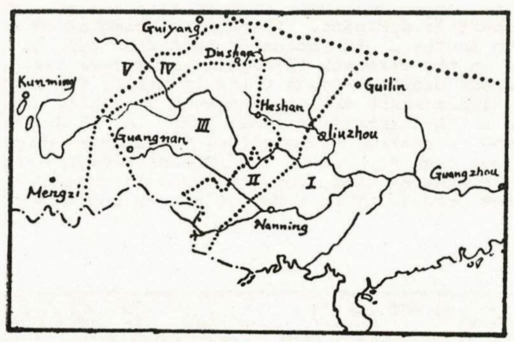

Figure 3 The Distribution Map of Tropical Karst in Southern China.

Canonical Analysis in the Genus Troglocharinus Reitter and Some Other Related Taxa (Col. Catopidae)

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Abstract

Application of kluster analysis trying to solve the problem risen by the collection of species of the genus Troglocharinus, REITTER, 1908. Recently before the complex was divided in two genus: Speophilus JEANNEL, 1911 (=Perrinia REITTER, 1885) with 13 species or sspp. and Troglocharinus with 7 species and perhaps 12 or 13 sspp. All these taxa live in the NE of Spain, in Catalonia except two of them in Aragón.

The Geological, Geographical, and Environmental Setting of Cave Faunal Evolution

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Abstract

It seems that most terrestrial cave invertebrates have evolved from cryptozoic faunas of forests. It is proper to know the histories of the forest environments and how these may have shaped the major patterns and processes of evolution and distribution of cave-associated taxa. Specialization of taxa to montane "temperate" forest litter probably began with renewed uplift of the Appalachians, producing cool-moist forest habitats, in the early Tertiary if not the Mesozoic. Early or mid-Tertiary erosional dissection probably drained caves, but few terrestrial species may have occupied them. With major Tertiary peneplanation, caves would have become fewer in number. Renewed Plio-Pleistocene uplift produced a new set of terrestrial cave habitats at the time that Plio-Pleistocene climatic fluctuations allowed pre-adapted montane litter faunas to come into the cave-containing lowlands during glacials. Faunas were restricted to caves as isolated populations during interglacials. This allowed the evolution of cave-limited taxa, which may have been able to disperse overland in later long-duration glacials.

Introduction

It is my belief that a knowledge of the geological, topographical, climatic, and vegetational history of central and eastern North America, especially in the Tertiary and Quanternary, is necessary to permit a meaningful interpretation of taxonomic and distributional data on terrestrial troglobites. To understand the cave faunas we must understand much more than just the cave faunas. I take the view here that the terrestrial cave faunas are a special subset of soil and litter faunas of forests. To understand the faunas requires understanding the ancestors of the faunas and the history of the forests. This seems to me to be a fairly widely held and orthodox view, but discussion and dissent is certainly welcome in this symposium.

Much of eastern North America has been a permanently terrestrial site for the origin and evolution of terrestrial biotas since at least the Paleozoic. It is well known as a major center for the evolution of clams, crayfishes, and salamanders. The caves, of which over 10,000 are known, primarily occur in the Paleozoic limestones in and flanking the major Appalachian geological systems. Discussion will mostly stress the eastern Appalachians, but can be logically extended to include the Ozarks and Texas as well. Introductions to regional geology and geomorphology can be found in King (1977) and Thornbury (1965).

The Appalachians of our concern were uplifted in the Alleghenian orogeny, originating from the collision and marginal crumpling of the proto-American with the proto-European and African plates from about 300 million to about 250 million years ago. This formed the supercontinent Pangea. By this time some higher taxa of terrestrial invertebrates had already evolved in this area such as extant orders and families of land snails (Solem, 1979).

The Mesozoic

Mesozoic events pertinent to cave faunas remain speculative. The most significant was the breakup of Pangea, from about 250 million to about 200 million years ago, resulting in the formation of the Atlantic Ocean, and the separation of the then continuous floras and faunas of eastern North America and western Europe. There are several cave invertebrate groups (mostly aquatic or marine crustacean relicts) that show American-European relationships that may date to this time. Evidence is slight in terrestrials, but may include the bicontinental affinities of *Xenotrechus* and *Pseudanophthalmus* carabids, and amauropsine pselaphid beetles (Barr, 1974), and the collembolan species group of *Tomocerus missus*. Direct land connection to Europe was last severed by the Eocene rupture of a northern connection via the DeGeer Bridge across the north Atlantic. Predominant habitats were fairly widespread lowland tropical or paratropical forests. The excellent review of Matthews (1979) should be consulted for elaboration of all topics considered here, for it is the best available background summary for an evolutionary biogeography of North American terrestrial invertebrate faunas.

The Tertiary

If North American cave faunas are derived from ancestors most closely associated with mixed mesophytic forests, the history of these forests is a guide to understanding the impact of change on their faunas. In the early Tertiary, the biotic connections of "Appalachia" were more to the westward, to western North America, and with the "Arcto-Tertiary Geoflora" of the Bering Bridge into eastern Asia. Many examples occur in taxa with such disjunct distributions and are remnants of former and more continuous distributions from the Appalachians (and Ozarks) to eastern Asia. These Tertiary forests lay at mid-latitudes from North America across the Bering Straits to Eurasia (Wolfe, 1975, 1978). Mid and late-Tertiary cooling and drying fragmented these forests through the uplift of the Rocky Mountains, the development of their rain shadow, and the formation of the Great Plains. The mesic forest connections to Mexico were reduced after the Oligocene. Increasing aridity in the Miocene and Pliocene eliminated the plains forests and restricted the ranges of the forest arthropods to eastern, western, and southern (Mexican) localities. Forest habitats were in transition from subtropical to warm-temperate in characteristics. Examples of taxa with distributions broken by the extinction of intermediate forests are the millipeds *Tingupa*, *Austrotyla*, and *Ergodesmus*, and the diplurans *Eumesocampa* and *Metriocampa*. For litter arthropods (as for the forest itself) it may be that the Appalachians contain a climatically improverished biota which has persisted with less change and less extinction in Mexico.

The familial diversity of the present terrestrial North American invertebrate fauna was established by the late Cretaceous, the generic diversity through the Tertiary, and many (if not most as shown by insect fossils from Pleistocene peats) of the existing epigean species had evolved by the start of the Pleistocene. A point to be considered is whether or not most Pleistocene evolution of cave faunas was at the species level.

The Pleistocene

A prevailing view of cave faunal evolution, championed by Jeannel and colleagues in France, sees the fluctuating climates of the Pleistocene as a prime factor in promoting the occupation of caves from ancestors that were (cryophilic) inhabitants of deep litter or soil of montane forests and which were preadapted for life in caves (Barr, 1967, 1968). The interglacials were the times of isolation of the faunas in caves because of unsuitable epigean temperature and/or moisture conditions. The general biotic impact of the Pleistocene is well documented (in reference to cave faunas see Peck and Lewis, 1977; Peck, 1978, 1980). There is no need of a review of the idea here. These climatic fluctuations have prime responsibility for producing the community makeup and species distribution patterns observed today.

Schools of Geomorphology

If the Pleistocene was important in promoting cave occupation, an implication is that there would not have been much of a terrestrial cave fauna preceding the Pleistocene, when the effects of climatic fluctuations were less. Caves themselves may or may not have been as prevalent a habitat as they are now depending on the resolution of two conflicting views of geomorphic history. Following a C. K. Gilbert view (Hack, 1965, 1969) of dynamic equilibria, caves would have been about as common as now. As Mesozoic and Tertiary erosional downwasting of the Appalachians occurred, the elevation of the range was probably maintained by isostatic uplift. The alternate school of W. M. Davis is one of erosional cycles of uplift and peneplanation. With extensive Tertiary peneplanation and low topographic relief, there would be available terrestrial cave habitats. Only with Plio-Pleistocene uplift and downcutting would they become exhumed, drained, and available.

How much montane evolution (and preadaptation) of acestral stocks took place in the Appalachians depends on their former elevation and climatic characteristics. The Davis interpretation would have discontinuous existence of upper elevations, less climatic zonation, and little topographic relief to support habitat diversity. In the late Mesozoic the Schooley peneplain, formed from degradation of the original mountains, was arched to heights reaching well over a kilometer, producing the highland block from which the present mountains were carved. Two Tertiary erosion surfaces were developed at lower levels.

The dynamic equilibrium concept would have continued uplands, more climatic zonation, and a continued rough topography (giving much geographical habitat diversity) - all assuring a higher biotic diversity. The widespread occurrence along the Appalachians of lignitic deposits ranging in age from Cretaceous to Pleistocene suggest the continued presence of sphagnum peat bogs and thus of uplands along the Blue Ridge throughout the Tertiary (Hack, 1969). The conifers *Abies fraseri* and *Tsuga carolineana* are perhaps endemics of upland Tertiary origin, ~~judging from the ge~~nerally slow rates of evolution in conifers. Other floristic endemics (few at the family and generic levels) are more lowland (Little, 1970) and say little on this problem. The diversity of montane salamanders probably argues better than many groups for the presence of Tertiary Appalachian uplands and for the presence of some climatic-biotic zonation.

Glacials-Interglacials

Again, in the face of few invertebrate fossils, it is necessary to refer to the paleobotanical record, which is now allowing generalizations about the biotic impact of the cycles of Pleistocene glacials and interglacials in the southeastern United States. Modern reviews are Delcourt and Delcourt (1979), Delcourt (1980), and Watts (1980a, 1980b). In summary, these show the virtual elimination of mixed mesophytic forests from the Appalachian area during full glacials, and its replacement by a drier and more open boreal forest.

The Pleistocene is now generally seen as 1.6 million years in duration. The emerging pattern of climatic cycles is one of more complexity than the classic North American concept of four glacials and three interglacials, but the timing and number of cycles remains uncertain. Also, the Pleistocene is now being seen (through the record of deep ocean cores) (Wright, 1976; Beaty, 1978) as a sequence of long-lasting glacials of 80,000 to 100,000 years punctuated by significantly shorter interglacials of 10,000 to 15,000 years, We must be careful not to think that present interglacial conditions have been the norm, but rather the exception.

Short interglacials give comparatively short periods of population isolation and genetic differentiation in caves. Long glacials give increased opportunity for overland dispersal through deep forest litter or moss mats. Thus, if the interglacials were the times of maximum population isolation and evolution, the process could have been a rather rapid one. Morphological specialization may not have been so extreme in a low level "troglobite" of an interglacial to prevent it from acting as a troglophile in more favorable glacial conditions through potential to reoccupy suitable epigean litter or moss habitats and to use them for dispersal.

The upland sites of Tertiary evolution of a preadapted cryophile deep-litter or soil fauna were displaced to lower elevations where they existed for longer (glacial) periods of time. Lowland caves and other protected habitats like cool and protected gorge forests were the important refugia for this fauna during interglacials, rather than the alternative of retreat to the more distant and higher elevations of the Appalachians themselves.

Taxon Pulses

Cave colonists were isolated at about the same time near the beginning of each interglacial. Thus there were synchronous and repeated pulses of cave occupation. This process was repeated and formed a generally repetitive and taxonomically patterned assemblage of species from site to site because of the similarity of the colonizing ancestral species. The whole cave community was sequentially built up this way (Peck, 1980). The relative sequence of the pulsed entry of taxa into caves should be indicated by several lines of evidence. Degrees of both morphological and geographical separation from relatives can proportionally reflect the passage of time since cave colonization.

In the preparation of a cladogram of the evolution of cave taxa it should be possible to recognize the sequentially older speciation events. If the climatically controlled speciation model is correct, it should be possible to suggest points in time for the separation of clades of some groups of terrestrial cave occupants with more accuracy than will be possible for most epigean invertebrates. A case of this in *Ptomaphagus* cave beetles will be given elsewhere.

Community Ecology

The historical scenarios as proposed have implications for understanding the ecology of cave communities. The most significant would be that species interactions have been continually changing through the Pleistocene as new colonists occupy caves and others go extinct. Also, caves may be interglacial refugia, but need not be evolutionary traps for they may be ecologically "escapable" in the following glacial. The development of a historical ecology of cave faunas must take into account the differing species mix between each set of glacials and interglacials. Cave communities are additive collections of different species, not intergrated interacting superorganizations, and have not gone through time as a climatically determined "Clementsian" climax community with fixed associations. Rather, they are a set of species, each of which acts in an individualistic manner in response to change. The community cannot be considered to be in a state of equilibrium.

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Evolution of Cave Cholevinae in North America (Coleoptera: Leiodidae)

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Abstract

Staphylinoid beetles with internal antennal sensory vesicles can be grouped into the apparently monophyletic family Leiodidae. The habits of the five subfamilies vary but most are forest litter inhabitants and scavenge or feed on fungi. Only the subfamily Cholevinae has extensively occupied caves. Within the rich cholevine fauna of Europe a remarkable troglobite radiation has occurred in the tribe Bathysciini. In contrast, other tribes of Cholevinae occur in caves but troglobites are known only from North America, where 23 (out of 58 known) species of Ptomaphagus (Adelops) are troglobites (19 in the southeastern U.S.). Cave occupation has occurred separately in the genus in at least three major lineages. The troglobites are judged to be descendants from five non-troglobitic (edaphophilic) ancestors in temperate and tropical (montane?) forest areas. A phylogeny is proposed. Regressive evolution is prominent and reliable transformation series based on shared, derived, complex characters are not easily detected. Species at different levels of cave adaptation can be placed into clusters that may indicate relative times of isolation and adaptation in repeated cycles of vicariant climatic isolation in caves during interglacials. Some distributions are best explained by overland dispersal of low-level troglobites through "boreal" forest moss-litter mats during glacials.

Introduction

Leiodids are the most important and diverse family of scavenging beetles in almost all temperate cave habitats. The family as used here contains the colonids, catopids and leptinids of European usage. All these share many characters, including the synapomorphic internal antennal sensory vesicles (Peck, 1977a; Acordi and Sbordoni, 1978) defining a monophyletic family of Staphylinoidea. Zeick (1979) shows that Cholevidae has priority over Catopidae. Leiodids generally are scavengers in soil and litter of forest ecosystems, and as such are eminantly suited for cave occupation. More general biology of the North American genera is given in Peck (1982). I will discuss cave occupation in leiodids in a phylogenetic sequence.

Subfamily Leiodinae

Most leiodines are winged and eyed soil and inhabitants, feeding on fungi (some wingless and eyeless species are edaphobites, or parasites of stingless bee nests). Aglyptinus occurs as a troglophile in tropical America, especially in the West Indies. Cave populations in Jamaica are wingless, while the same species in epigean lowlands is fully winged. With increasing elevation of epigean habitats a greater frequency of winglessness occurs (Peck, 1977b).

Subfamily Catopocerinae

Limited to North America, all members of the group are eyeless and wingless. The edaphobitic genus Catopocerus has 14 described species, of which two are known only from Alabama caves (Peck, 1974). Glacicavicola bathyscioides Westcott, a remarkable example of convergence to European bathysciines, occurs in limestone and lava tube caves in Wyoming and Idaho (Peck, 1981a). It has the largest range for a North American troglobitic beetle.

Subfamily Cholevinae

This equals Catopidae or Leptodiridae of other usage. Jeannel (1936) is the standard reference although many advances have been made since. The tribe Bathysciini is the great group of European cave scavenger beetles. Classifications and counts vary, but a remarkable radiation has produced about 580 species in about 120 genera. Some are soil and litter species, but most (80%) are troglobites (Laneyrie, 1969). Vandel (1965) summarizes their evolution. The only North American species (Platycholeus) live with ants and termites in the Pacific Northwest. They have the most ancestral character states for the tribe. North America is probably not their site of origin, but a refuge for a primitive Asian lineage that made a Tertiary crossing of the Bering Bridge. The nearest known Asian relatives are near Vladivostok. Their absence in eastern North America suggests their presence or origin in Europe after the opening of the North Atlantic at the beginning of the Tertiary.

The tribe Eucatipini of tropical America contains Eucatops which occasionally occur in caves as troglophiles.

The tribe Ptomaphagini is the prime New World cave-occupier, and ecologically mirrors the bathysciines, but not in phyletic diversity. The basal stock seems to be close to Ptomaphagus, but the other derivative genera and other tribes will be discussed first. Adelopsis occurs in southeastern U.S. and Neotropical caves, but only troglophiles are known (Peck, 1978a, Szymczakowski, 1975). Proptomaphaginus is a relict in litter, soil, and caves in Mexico and the Greater Antilles (Peck, 1973a, Docou, 1973) but troglobites are not known. This genus seems ancestral to Ptomaphaginus of southeastern Asia, where some species occur as troglophiles (Peck, 1981b).

The tribe Nemadini contains no troglobites, but Dissochaetus occurs as troglophilic species in Mexico (Peck, 1973a, 1977c). Nemadus occurs occasionally as large populations in caves with large moist guano piles in the southeastern U.S. The species is near N. horni Hatch but is being reviewed.

The tribe Cholevini, when compared to Europe, is poorly represented in North America, where there are only facultative troglophiles. Catops and Sciodrepoides occasionally scavenge in caves. Prionochaeta opaca (Say) is a widespread forest inhabitant frequently using caves as climatic refugia at the southern edges of its range (Peck, 1977d).

Ptomaphagus

This genus, with 58 known New World species in the subgenus Adelops, is ecologically varied. Species live in forest litter and in various animal nests and burrows, while some montane forest species have reduced eyes and wings, and others are facultative and obligate troglophiles, or troglobites. The genus can be divided into subgenera and species groups based on various characters. The seemingly most-basal hirtus group in the basal subgenus Adelops contains most of the troglobites (19 restricted to the southeastern U.S.). This seems to be a case where troglobites survive as relicts of archaic lineages. However, the interpretation is questionable because the group is based on shared plesiomorphies, such as simple spermathecal morphology, rather than non-convergent synapomorphies.

Evolution in the Hirtus Species Group

Much on this subject has been published (e.g., Peck, 1973b, Peck and Lewis, 1978). I will summarize mostly new information and thoughts. The group seems a descendant of Tertiary forest edaphophiles. A remnant of the line is P. shapardi, an edaphobite of the Ozarks. Two ancestral lineages in the southeastern U.S. speciated during interglacial restriction to caves (or deep soil of cool forest refugia). The northern species formed the hirtus species cluster with three members, now in caves in Kentucky, Illinois, and Tennessee. A southern species formed the loedingi species cluster with 16 species in caves in Tennessee, Alabama, and Georgia. Unraveling species identities and characteristics has involved electrophoretic analysis of degree of genetic similarity (Laing, Carmody and Peck, 1976) in P. hirtus, and population hybridization studies for the species complex in Alabama (unpublished), as well as morphological study. These have found the limits of old taxa and the existence of new species. Taxa previously recognized as forms and subspecies merit species rank because they are reproductively isolated in hybridization studies, are electrophoretically differentiated to species levels, and they ecologically segregate themselves into distinct allopatric and monomorphic populations in regions where sympatry would be expected (Peck, 1975, and unpublished). A cladogram of species phylogeny is presented, but unfortunately space does not allow a discussion of the characters upon which it is based.

This picture of evolution is very different from an earlier one. There is now seen to be a more elaborate hierarchy of lineage splitting. P. shapardi in the Ozarks, the absence of montane edaphophilic ancestors in the Appalachians, and distribution patterns of other edaphobitic leiodids, indicates that the hirtus group ancestors may have been occupants of medium or low elevation mesic forests, and not necessarily montane forests as earlier stressed. The comparatively few descendant species of limited areal extent suggest that the ancestral edaphobitic species are few (two) and limited to a few areas of the western and southern margins of the Cumberland Plateau (explaining their absence from thousands of seemingly suitable caves, mostly in the Appalachian Valley). Comparatively low levels of troglobitic specialization may indicate cave occupation in only the later half of the Pleistocene. Life cycle studies (Peck, 1975a, and unpublished) do not show any of the remarkable specializations known for the bathysciines.

The consobrinus species group

This group, based on a more elaborate spermathecal shape, contains 13 species, mostly in the U.S., but with some in Latin America. Most are free living or nest and burrow inhabitants, but two are montane edaphobites of New Mexico, two are troglophiles in Mexico and Belize, and two are troglophiles in Arizona and Guatemala (Peck, 1973b, 1977c, 1978b, and 1980). Two separate cave restricted lineages occur, and montane preadaptation is questionable.

The cavernicola species group

This group is based on an even more elaborate spermatheca. The 25 species are all in Mexico and Central America, except for the widespread, winged (but seemingly obligately troglophilic) P. cavernicola. It ranges from Mexico, to Texas, the Ozarks, Iowa, and to Alabama and Florida. Four troglophiles occur in Mexico. The troglobites P. mckenziei and P. troglomexicanus of Mexico seem to have been derived from a P. cavernicola-like ancestor, and probably represent two cave occupations from one preadapted montane lineage (Peck, 1973b, 1977c).

Other Subgenera

The remaining three, seemingly more advanced, subgenera of Ptomaphagus (Tupania in tropical America, and Merodiscus and Ptomaphagus s. str. of Eurasia) do not have any cave-specialized species.

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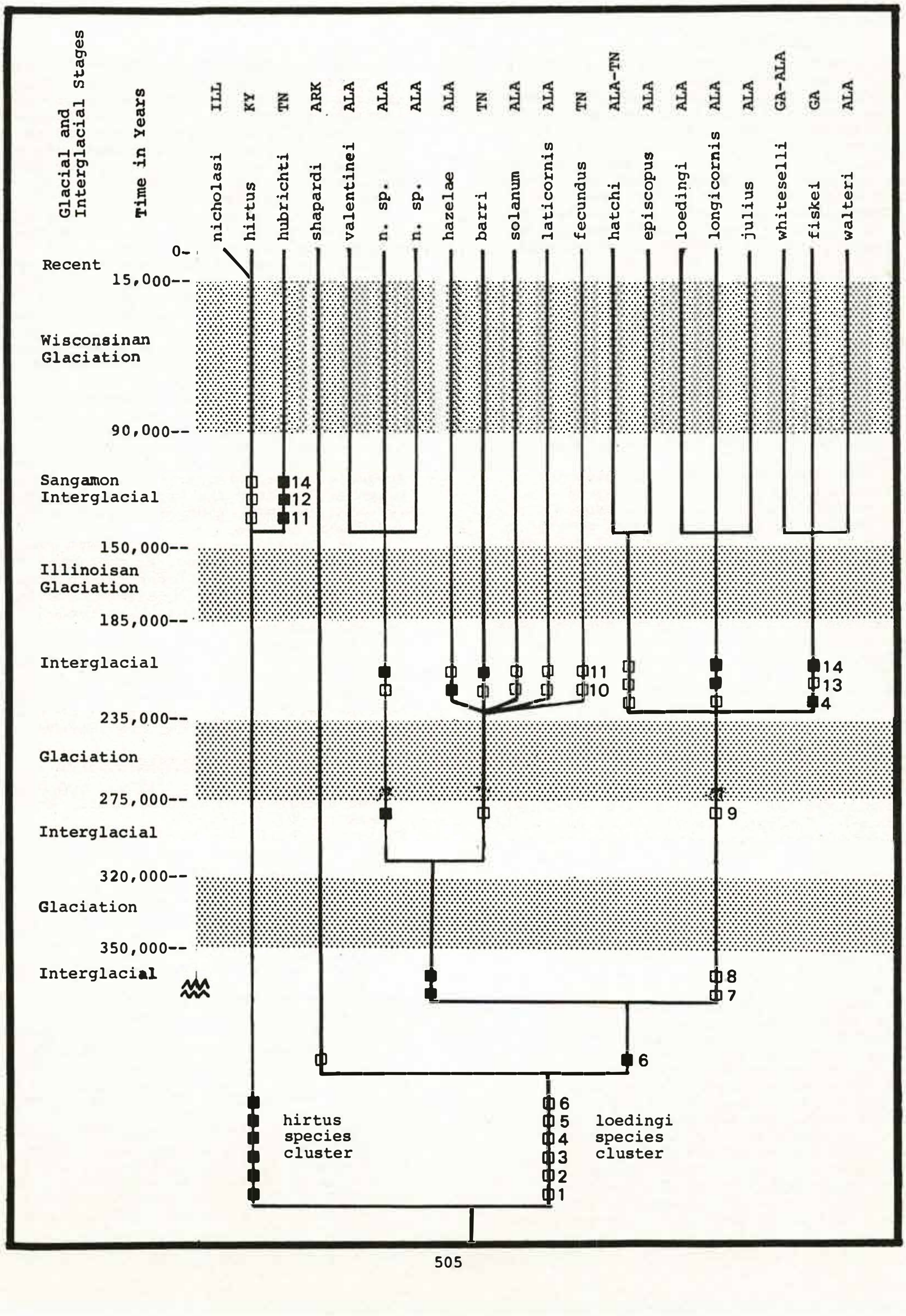
Table 1. Character state analysis for figure 1. To be discussed in detail elsewhere. Out group comparisons with non-cavernicolous Ptomaphagus and other Ptomaphagini. Potentially convergent (cave dependent) characters marked with asterisk.

Number	Character	Character State	
		ancestral	derived
1	spermathecal shaft	longer, thinner	shorter, thicker
2	spermathecal orifice	posteriorly oriented	laterally oriented
3	aedeagus	curved	straight
4	*mesosternal carina	lower	higher
5	pronotal strigae	present	reduced-absent
6	*eyes	cluster of facets	unpigmented spot
7	spermathecal shaft	thicher	thinner
8	posterior end of spermatheca	not or slightly expanded	greatly deflected
9	spermathecal crest	small	large
10	aedeagal tip	straight	upturned
11	hind pronotal sides	curved	straight
12	*body size	smaller	larger
13	*antennal segment III	subequal to II	longer than II
14	*antennae	shorter	longer

Figure 1. Phylogenetic hypothesis of evolution in the monophyletic, cavernicolous hirtus species group of Ptomaphagus (Adelops) of the southeastern United States. Numbers refer to characters in Table 1, transforming from ancestral (open squares) to derived (black squares) states. State abbreviations with species names indicate distribution. Lineage splits and character origin are shown for the latest likely times for the events (giving comparatively rapid evolution). If the events were earlier, diversification was slower. The model for differentiation is one of small allopatric populations isolated (virtually instantaneously) in caves during the beginnings of repeated interglacial cycles because of an inability to tolerate the initiation of epigean habitat warming and drying. Low level troglobites (or cave-limited troglophiles) formed in one interglacial were probably capable of overland dispersal as troglophiles in the next glacial. Increasing specialization incrementally limited the capacity for overland dispersal in glacials. The timing of cycles of glacials and interglacials is from Harmon et al. 1977, based on the use of geochemical isotope techniques to determine the time and temperature of deposition of cave stalagmites. However, there is still too much variation to give more than a rough framework upon which to hang biological events (see also Harmon et al. 1978a, 1978b). Interglacials are shown of greater duration than generally indicated by marine cores. The actual picture (including the effects of interstadial climate changes) may be more complex, suggesting greater difficulty in matching biotic and climatic events. If there was a "great interglacial" from 280,000 to 400,000 years BP (Harmon et al. 1977), it would have been a period of pronounced cave restriction and adaptation (or extinction).



Introduction to the Symposium on the Review and Synthesis of the Evolution and Zoogeography of North American Terrestrial Cave Faunas

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Abstract

The purpose of the symposium is to address questions of pattern and process in the evolution and distribution of major groups of cavernicolous terrestrial invertebrates in North America. Participants may review the number and distribution of cavernicolous taxa; the numbers of independent cave occupations by ancestral stocks; the relative importance of speciation before and after cave occupancy; the importance of pre-adaptation in montane and litter-dwelling ancestors and the site of development of regressive and progressive morphologies; if distributions show disjunctions and what caused them (plate tectonic or Pleistocene or other events); if levels of disjunction and specialization show taxon pulses or cycles of cave occupation and if these are related to Pleistocene events; whether cladistic phylogenies can be prepared and related to Pleistocene climatic (vicariance) events; if ecological factors like competition prevent sympatry and keep communities simple; if these above factors apply to temperate but not tropical faunas and where intermediate areas like Texas fit in; and where do we go from here in attempting to seek and synthesize an understanding of the dynamics of the origin of terrestrial cave faunas.

Introduction

Twenty-two years ago, in 1959 in Chicago (Barr, 1960), a symposium was held on speciation and raciation in cavernicoles. It was significant for bringing together for the first time students and studies of the invertebrate cave faunas of North America. Since that time many other studies and symposia on the evolution and distribution of our cave faunas have appeared, many involving people attending and participating in these meetings. Also, in the same time, significant advances have been made in a theoretical understanding of faunas in the fields of evolution, systematics, zoogeography, and ecology. These will be familiar to specialists, and topics of current interest or arguement are cladistic analysis of phylogeny, island biogeography, the evolution of community structure, and vicariant biogeography (Platnick and Nelson, 1978; Rosen, 1978).

Additionally, there has been another twenty years of field work in the biological exploration of North American caves. Another new vista has come within this time in allowing perspective on latitudinal gradients in cave faunas with the prolific collections that have came from caves in tropical America, especially in Mexico, Guatemala, and the Greater Antillean Islands.

It is the intended aim of this symposium to summarize advancements in our understanding of various groups of troglobites; in their toxonomic makeup, to see in what patterns these taxa occur, and to suggest what were the processes that produced the taxa and the patterns. It is unfortunate that we do not have specialists available to summarize significant invertebrate groups such as spiders, millipeds, and pselaphid beetles. Because of their inability to be with us, I would like to mention some sample work on these groups: on spiders by Gertsch (1973, 1974, and 1977) and on millipeds by Shear (1969, 1971, 1972, 1977) and the late Nell B. Causey (1977). There are groups that contain troglobites that are not considered here because they are exceptional and with two few species to establish good patterns for analysis. These are mostly tropical, and may be supportive of the evolutionary model of Howarth (1980). There are, in addition, many other groups that do not have a significant evolutionary association with North American caves, and these too have been excluded. Examples are annelids, chilopods, thysanurans, dermapterans, hemipterans, psocopterans, lepidopterans, dipterans, and staphylinid beetles (even though these may be very significant in an ecological role in cave communities).

The symposium will help to introduce our troglobite faunas in a wide perspective to our overseas visitors, and should do the same for North American specialists. It should be especially productive in helping to make comparisons and contrasts between the rich cave faunas of Europe and Japan with those of North America, especially in features that have been discovered since the synthesis of Vandel (1965). The information and idea interchange should be stimulating.

The study of the evolutionary biology of troglobites is concerned with two intertwining subjects; process (such as natural selection and the adaptation of organisms) and historical events (the development of phylogenies). I see a need for attempting Hennigian-cladistic analyses of morphological characters and of their transformations in proposing phylogenetic hypotheses of troglobites and their ancestors (Platnick, 1977, 1979). However, this is no easy task. We recognize that the problems of convergence and parallelism are exceptionally manifest in troglobitic lineages, as well as there being a paucity of character specializations (amorphies), which when shared (synapomorphies) give evidence of relatedness (Farris, 1979).

Not until we establish these can we propose hypotheses of evolutionary biogeography based on a sequence of phyletic branching, rather than upon an unsuited "classification".

The evolutionary biologist must as well be familiar with historical aspects of geology, geography, and climatology, because all taxa and their characteristics and patterns are the result of past events, patterns, and processes. Helpful steps in the sequence of forming biogeographic hypotheses may be: 1. based on the recency of common ancestry, hypothesize the recency of faunal connections (this may be crudely estimated by summing the distributions of extant faunal elements); 2. determine if other organisms share the same patterns of recency of faunal connection, suggesting a common causal agency; 3. attempt a correlation of the data with historical geology-geography-climatology, using either or both a vicariance and dispersal model, depending on the assumed vagility and other biological-ecological characteristics of the species; and 4. be prepared to alter the hypotheses in the light of new information about taxa, cladistic relationships, and distributions.

In summary, we should proceed from alpha level taxonomy of troglobites, to examining the phylogeny and distributional patterns of the troglobites and their non-troglobitic ancestors, and then to hypothesizing the processes that have produced the taxa and the patterns.

With this as a theoretical preamble, we should review some of the historical considerations that may have shaped the processes and patterns in developing the terrestrial invertebrate troglobite faunas of eastern North America, and those of the epigean ancestors from which they are decended.

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The Archanthropinae of the Petralonian Cave

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ΟΙ ΑΡΧΑΝΘΡΩΠΙΝΕΣ ΤΟΥ ΣΠΗΛΑΙΟΥ ΤΩΝ ΠΕΤΡΑΛΩΝΩΝ

Τοῦ Νίκου Α. Πουλιανοῦ
Σπηλαιολογικό Τμῆμα τῆς Ἀνθρωπολογικῆς Ἑταιρείας Ἑλλάδος:Δαφνομήλη 5,Ἀθήνα,706.

Στό Σπήλαιο τῶν Πετραλώνων-Χαλκιδικῆς,ἀποκαλύφθηκαν μέχρι σήμερα εἴκοσι ἑπτά στρώματα.
Τά πρῶτα δέκα στρώματα ἀνάγονται στήν ἀρχή τοῦ Μέσου Πλειστόκαινου, καί τά ὑπόλοιπα στό τέλος τοῦ Κατώτερου Πλειστόκαινου.
Σχεδόν σ'ὅλα τά στρώματα συναντῶνται τεμάχια ὀστῶν ζώων καί σπανιώτερα ἀνθρώπων ,ἴχνη φωτιᾶς,λίθινα καί ὀστέϊνα ἐργαλεῖα.
Τό εἶδος τοῦ ἀνθρώπου πού κατοικοῦσε στή σπηλιά εἶναι αὐτό τοῦ Ὄρθιου Ἀνθρώπου,ἤ ὅπως ὀνομάστηκε:Ἀρχάνθρωπος εὐρωπαῖος ὁ Πετραλώνειος.Αὐτός ἔζησε στό σπήλαιο ἀπό ἕνα ἑκατομμύριο χρόνια μέχρι 600.000 χρόνια πρίν κλείσει ἡ σπηλιά.
Εἶναι ὁ ἀρχαιότερος ἄνθρωπος στήν Εὐρώπη,καί ἡ λιθοτεχνία του ἐπίσης ἡ ἀρχαιότερη στήν ἤπειρό μας.Τά ἴχνη φωτιᾶς εἶναι τά ἀρχαιότερα πού βρέθηκαν μέχρι σήμερα στή γῆ μας.
Ὁ Πετραλώνειος Ἀρχάνθρωπος εἶναι αὐτόχθων,γι'αὐτό καί ὁ Ἑλλαδικός χῶρος περιλαμβάνεται στή ζώνη τῆς ἀνθρωποποίησης τῶν Πρωτευόντων.

The discovery of a Pleistocene fossil hominid from Greece in 1960 proved the existence of the Archanthropic stage in Europe during the Lower and Middle Pleistocene.

The ancestors of the Petralona cave-dwellers did not live in caves (A. N. Poulianos, 1980). Man first entered caves because of the ever-changing climatic conditions.

Systematic excavations of the Petralona cave, where Archanthropus europaeus petraloniensis died, were begun in 1968 under the directorship of Dr. Aris N. Poulianos, with the participation of this author, and are still under way.

Stratigraphy

The ancient climatic conditions are investigated with the stratigraphy which is revealed in the cave. The sequential deposition of strata corresponding to various geological periods depends on the climat of each period. The various strata which constitute the material in a section of the cave floor vary in color and texture of the earth and the find content (palaeoanthropological, palaeontological, archaeological, palaeobotanical etc.). The thickness of the layers uncovered in a section is greatest near the cave's original entrance and least in the interior of the cave. Thus the thickness ranges from 2 cm to approximately 2 m.

As the number of the layers increases, proceeding deeper into the earth, the age of a find within that layer also increases. At the present time 27 layers have been uncovered up to now. Layer 27 remains the deepest and thus the oldest. It is possible that future sections will disclose even older layers.

On the surface is layer No. 1, where the stalagmite seals the uppermost and most recent layer.

It is noted that no superficially located animal bone is more recent than approximately 500,000 years old (Kretén, B. and A. N. Poulianos, 1977).

The section located close to the original entrance to the cave was sealed off by nature. Here the two or three first layers are slightly enlarged in thickness. Large rocks and pebbles contribute to the thickening of these layers. A hard breccia layer formed from smaller rocks was deposited within these layers found near the mouth of the cave. Stalagmitic material cemented them, and later on a thicker stalagmitic layer settled over the breccia. The first stalagmitic layer and the breccia belong to an "interglacial" period, which is called Thermaecian in the Green context. This period probably corresponds to the Mindel-Riss (Holstenian) interglacial in the Alpine nomenclature.

The material of the layers formed under the stalagmitic breccia is indigenous and was not brought from anywhere else. The analysis done proved that the process of sediment deposition did not involve selectively water-borne deposition, but was somewhat random and constant (L. Kordos, 1978). Also, the deposition was indigenous, a product of very slow geological activity. More important in the deposition was soil erosion and the movement of different regional materials. Every layer was formed in situ, and almost always from the same material source. The difference between the layers and the percent change in the various constituent materials can be accounted for with two possible explanations: a) the different sequences of sediment deposition, and b) the difference in the material source of the sediment in each layer. The sediments also must have been formed with some redeposition of the preceding cave sediments, i.e. they were "worked" and changed with the passage of time.

The Alternations Between Layers

Layer No. 2 is dark brick-brown and within it many local pebbles. There are found many stone and bone tools, food refuse, various big and small mammals, and seeds from trees. The microfauna points to a humid and rather cold climate (M. Kretzoi, 1977; M. Kretzoi and N. A. Poulianos, 1981).

The following layer, 3, is narrow, yellowish-red and relatively hard. In this layer no microfauna or seeds are found. Also human activity is less noticed. Apparently we deal with a pretty warm and quite dry period, probably an "interglacial" one.

Layers No. 4, 6, and 8 look very much alike as the 2nd one, and No. 5, 7, and 9 like the 3rd one.

The 10th layer is a stalagmitic "tile" of about 5 cm thick, which divides the whole cave stratigraphy into two parts: the upper and the lower. Thus the tenth layer is an important landmark in the cave's stratigraphy, corresponding to another long interglacial. A. N. Poulianos (1981) named this period Thracian, probably corresponding to the Günz-Mindel interglacial of the alpine nomenclature. Thus layers of the upper part (2-9) are considered of belonging to the Mindel glacial, or Early Middle Pleistocene, while layers of the lower part (11-27) are considered of belonging to the Günz glacial period, or Lower Pleistocene. Because it is difficult to apply always in new areas the alpine nomenclature, A. N. Poulianos (1977) named the upper group of layers "The Petralonian" period, white the lower "The Crenian" period.

The Crenian period begins with the 11th layer, which the known skull and skeleton of Archanthropus europaeus petraloniensis was found in. The color of the soil is also dark brick-brown, and the evidence of human activity is very intense. the microfauna points to a humid and cold period, during which the archanthropinae prefered to live inside the cave (A. Poulianos and Kurtén, B., 1981, in press). The vertebrantes of this layer match those of the Biharian period and the Cromer-type vertebrates, which lived in the temporal vicinity of the Brunhes/Matuyama boundary.

The following layer No. 12 is narrow, yellowish-red and relatively hard. In this layer not even traces of microfauna or seeds are found. Apparently rodents remain outside during warm periods or hide elsewhere. This sequence of layers is, to a certain extent, going all the way down to the 27th layer, with some exceptions of definite character. It is important here to underline the fact that in most of the layers there are found stone and bone tools, remnants of food, traces of fire, and other signs of human activity. Besides the skeleton of the 11th layer, there were found in different layers parts from other skeletons of Archanthropinae.

The Dating

The relative dating done with the faunal and microfaunal material, as it was already mentioned, gives an age of Late Lower Pleistocene for the Crenian period (including the 11th layer of the "Mausoleum", where the Archanthropus was found), and Early Middle Pleistocene for the upper, the Petralonian period. The ablsolute dating is mainly tested on the stalagmitic material with different methods.

The top stalagmitic layer tested in different laboratories (Canada, England, Germany, Japan) with the U/Th series gives an average of 300,000 years (see extended bibliography). The same result is taken with the ESR (Electron-Sprin Resonance) method in Japan, and with TL in England and Germany.

The absolute date for the Mausoleum's 10th layer achieved by Ikeya (1980) using the ESR method is 670,000 years. The Uranium/Thorium method (Schwarcz et al., Hennig et al., Lyritzis, (1980) gives Lower Middle Pleistocene for this layer, that is ages of over 400,000 years, which is the upper limit for U/Th.

Recently the palaeomagnetic method was used on the stalagmite of the 10th layer from the Mausoleum by Alf Latham, which he tested in the magnetometer at Toronto. It was reversely magnitized. Thus the stalagmite is probably greater than 700 Ka, and it is of the Matuyama chronology in age (Letter to the Anthropological Association of Greece from 25-8-1980).

In conclusion, all dating, relative and absolute, point to an age greater than 700,000 years for the skeleton of Archanthropus from the Mausoleum. It is natural, that parts of skeletons, animal and human, found in deeper layers are much older in age. The Petralona cave, up to today, is the best dated cave in the best dated cave in the world. The Archanthropinae of this cave is the oldest people of the European continent, and its lithic technique the oldest "civilization" of Europe. The traces of fire are the oldest traces found up to today in the world.

All data of the excavations, which are still going on, prove that Archanthropus europaeus petraloniensis is autochthonous to the area.

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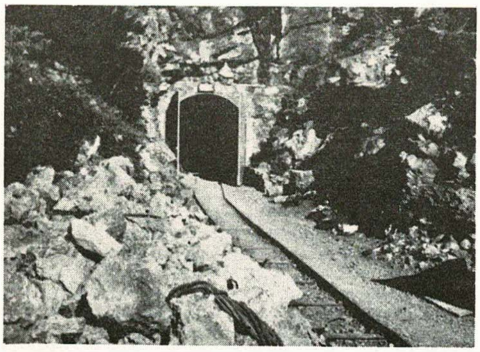

Photo 1: The entrance to the Petralona Cave, Greece.

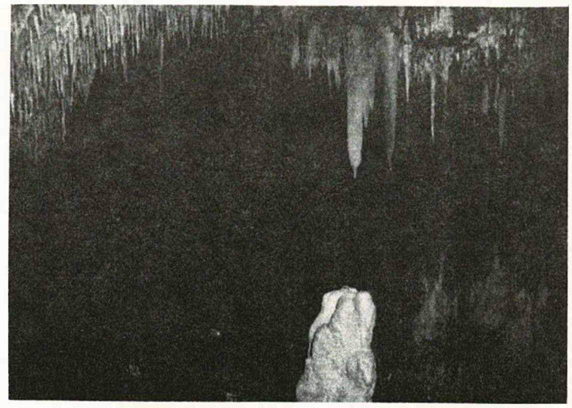

Photo 2: "Aristotle's Hall" at Petralona Cave, Greece.

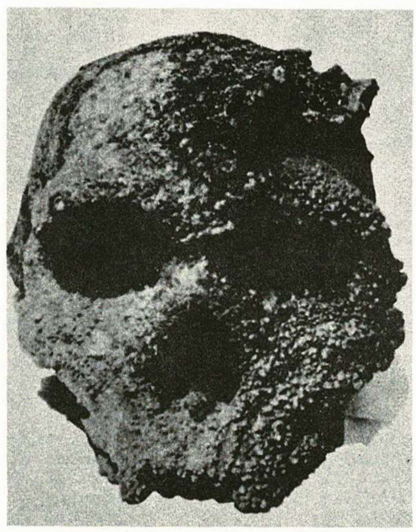

Photo 3: Archanthropus europaeus petraloniensis from Petralona Cave, Greece.

Karst Development in the Front Royal 7.5 Minute Quadrangle of Virginia

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Zusammenfassung

Das Front Royal Gebiet befindet sich im Shenandoah Tal der Tal und Kamm Provinz in Virginia (USA). Karst Landformen der Zwischenstuffe wurden mittels stereo pairs von Luftaufnahmen in niedrigen Höhen angefertigt und in die Front Royal topographische Karte (1:24,000) eingetragen. Modelle dieser Bodengestaltungen, hauptsächlich Bodensenken und Höhlen, stimmen mit dem lithologischen und strukturellen Streichrichtungen überein.

Die Entwicklung des Löslischkeit ist den sanftenbis steilen, aufgeworfenen Kambrium bis Ordovizium Karbonat Felsen angeslichen und faltet axiale spuren.

Bodensenk Modelle sind wenigstens durch zwei geomorphische Bodengestaltungen kompliziert. (1) Senken des Shenandoah Fluss Systemes sind fur lokale Steilheiten des Druckhöhengefalles verantworthlich. Das sich ergebene Modell gesteigerter Bodensenkenentwicklungen stimmt entweder mit der lithologischer und strukturellen Streichrichtung überein oder weicht davon ab. (2) Geröll und Schuttflächen bedecken Teile des Front Royal Gebietes. Diese Geröll decken beeinflussen direckt die Infiltration und Bodenentwichlung und können einen genügenden Ansdruck der Karstaktivität verhindern.

Introduction

The Front Royal 7.5 minute Quadrangle is situated primarily in the Shenandoah Valley of the Valley of the Valley and Ridge province of Virginia, U.S.A. (Figure 1). The North and South Forks of the Shenandoah River coverage along the western edge of the carbonate belt. The northeast-trending Cambrian and Ordovician carbonates range in attitude from gently dipping to steeply overturned. Along the south and southeast margins of the quadrangle, noncarbonate rocks of the Blue Ridge Complex, the Catoctin Formation and the Chilhowie Group are thrust over the carbonates.

Intermediate scale karst landforms were observed by stereo use of low altitude (6,100 m/ aerial photography and recorded on a 1:24,000 scale topographic map. Patterns of these features, sinkholes and caves, are observed to relate to lithologic and structural trends, as well as geomorphic features associated with the Shenandoah River.

Geologic Control of Karst Development

The karst-bearing carbonate units of Front Royal quadrangle are bordered to the west by the clastic Ordovician Oranda and Martinsburg formations (Figure 2). To the east, no solution features were observed on aerial photographs in the Waynesboro Formation, dominantly a clastic unit, although Rader and Biggs (1975) observed small sinkholes in the field. In the southern part of the quadrangle, noncarbonates of the Blue Ridge Complex, Catoctin Formation and Chilhowie Group are thrust over the karst-bearing units. Geologic units of the Front Royal quadrangle are summarized in Table 1.

The Rockdale Run Formation dominates the karst development of the area. Abundant sinkholes and numerous caves are found within this unit (Figure 2). North of the confluence of the Forks of the Shenandoah River, karst development in the Rockdale Run Formation extends along the axial trace of a south-southwest plunging anticline into the Lincolnshire, New Market and Edinburg units. A adjacent anticline, which is breached by the Shenandoah River to the east, also shows sinkholes development along its axial trace. In the southwest part of the quadrangle, aggressive surface runoff from the noncarbonates thrust over the Rockdale Run Formation has contributed to the solutional development of this carbonate unit. In addition to the numerous sinkholes observed, 45 of the 60 caves in the quadrangle are located in this approximately five square kilometer area of carbonate. However, much of this solutional development is also due to geomorphic influences of the Shenandoah River.

Geomorphic Control of Karst Development

Lithologic differences may be responsible for much of the karst development observed on the various carbonate units, however, geomorphic features complicate these patterns. Locally, entrenchment of the Shenandoah River has resulted in river bluffs and steepened hydraulic gradients. Sinkhole development is enhanced by these anomalous gradients. The resulting concentrations of sinkholes along the river bluffs extend into carbonates units otherwise containing only sparse solutional development (Figure 3). Hack (1963) observed such development of sinkholdes along the large streams of the Shenandoah Valley.

Terrace gravels are another geomorphic feature which complicates the pattern of sinkhole development in the Front Royal are (Figure 3). These gravel-covers diffuse infiltration and result in a deep soil development which appears to inhibit surficial expressions of karst activity (Hack, 1960).

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Table 1
Geologic Formations of Front Royal Quadrangel (adapted from Rader and Biggs, 1975)

Age	Rock Units	Thickness (meters)	Lithology	Karst Development	Symbol
QUATERNARY	Terrace deposits	0-8	pebbles and cobbles of sandstone and quartzite in matrix of clay, silt or sand	sparse, inhibits surficial expression	tb
ORDOVICIAN	Martinsburg Formation	914-	shale, some sandstone, minor limestone	rare	
	Oranda Formation	5	siltstone	none	
	Edinburg Formation	133±	shale, limestone	sparse except on anticline north of confluence of the Forks of the Shenandoah River	Ooelin
	Lincolnshire Formation	8-15	limestone with blocky chert		
	New Market Limestone	0-18±	limestone		
	Rockdale Run Formation	732	limestone, dolomitic limestone, dolomite and lenses of sandstone and chert	sinkholes abundant, contains 52 of the 60 caves of the quadrange	Orr
	Stonehenge	183-198	limestone	rare	Ost
CAMBRIAN	Conococheaque Formation	701	ribbon-banded limestone and dolomite and thin dolomitic sandstone	sparse, except north of Shenandoah River	Gco
	Elbrook Formation	610±	limestone, dolomitic limestone, dolomite and dolomitic shale	sparse, except blind valley along contact with Conococheaque Fm.	Ge
	Waynesboro	244±	shale with some sandstone, limestone and dolomite	none observed	Gub
PRECAMBRIAN-CAMBRIAN	Undivided		clastics volcanics and plutonics	none	GpGu

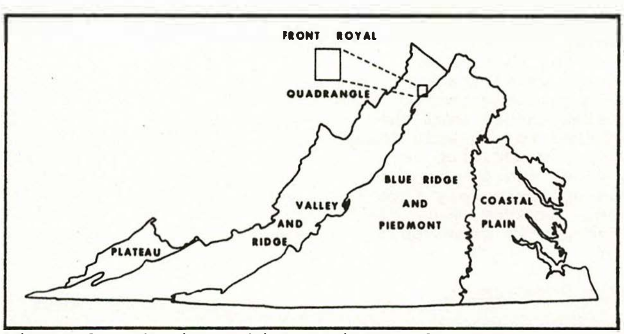

Figure 1: Physiographic Province and Location Map of Virginia

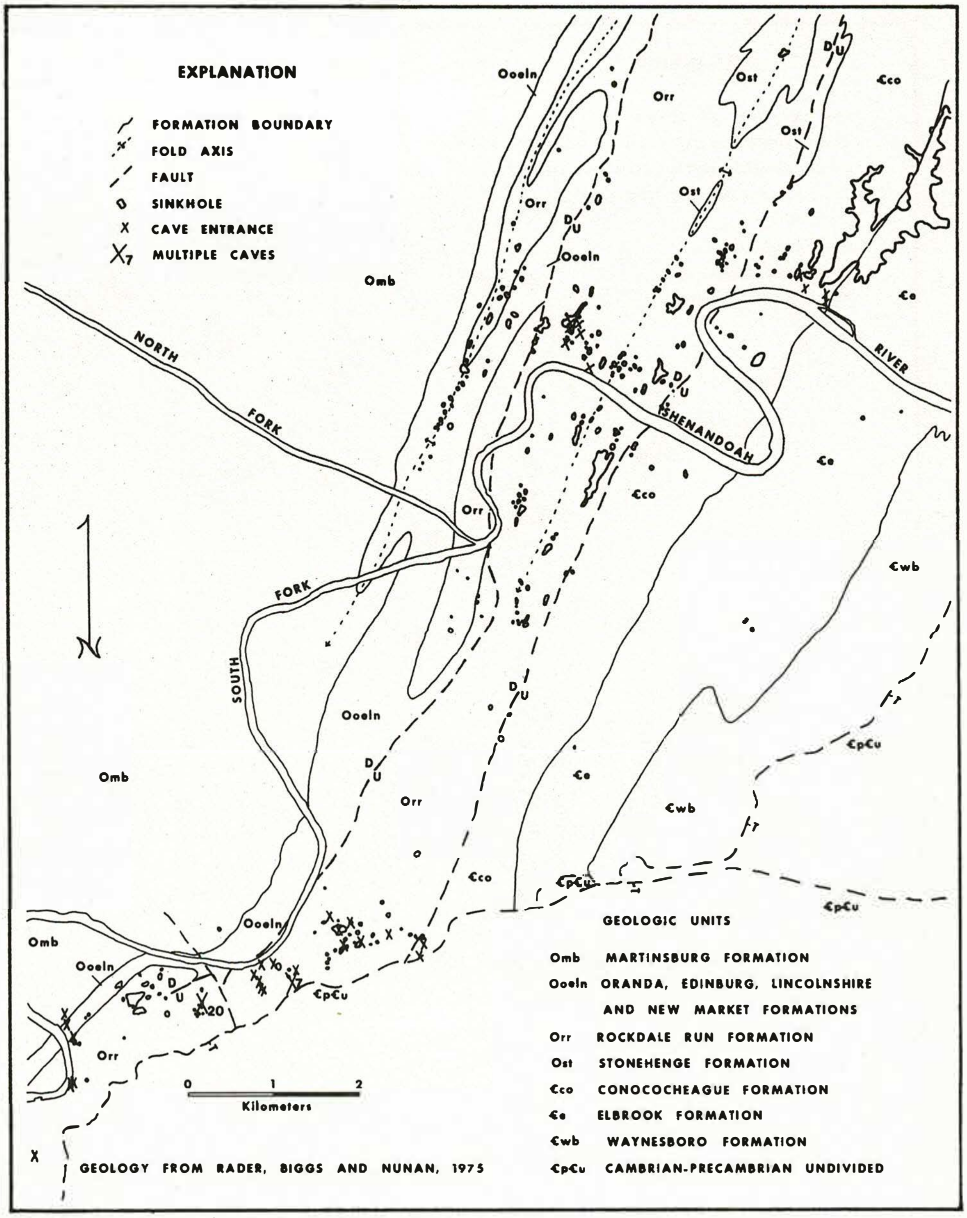

Figure 2: Geologic Control Of Karst Development Of The Front Royal Quadrangle

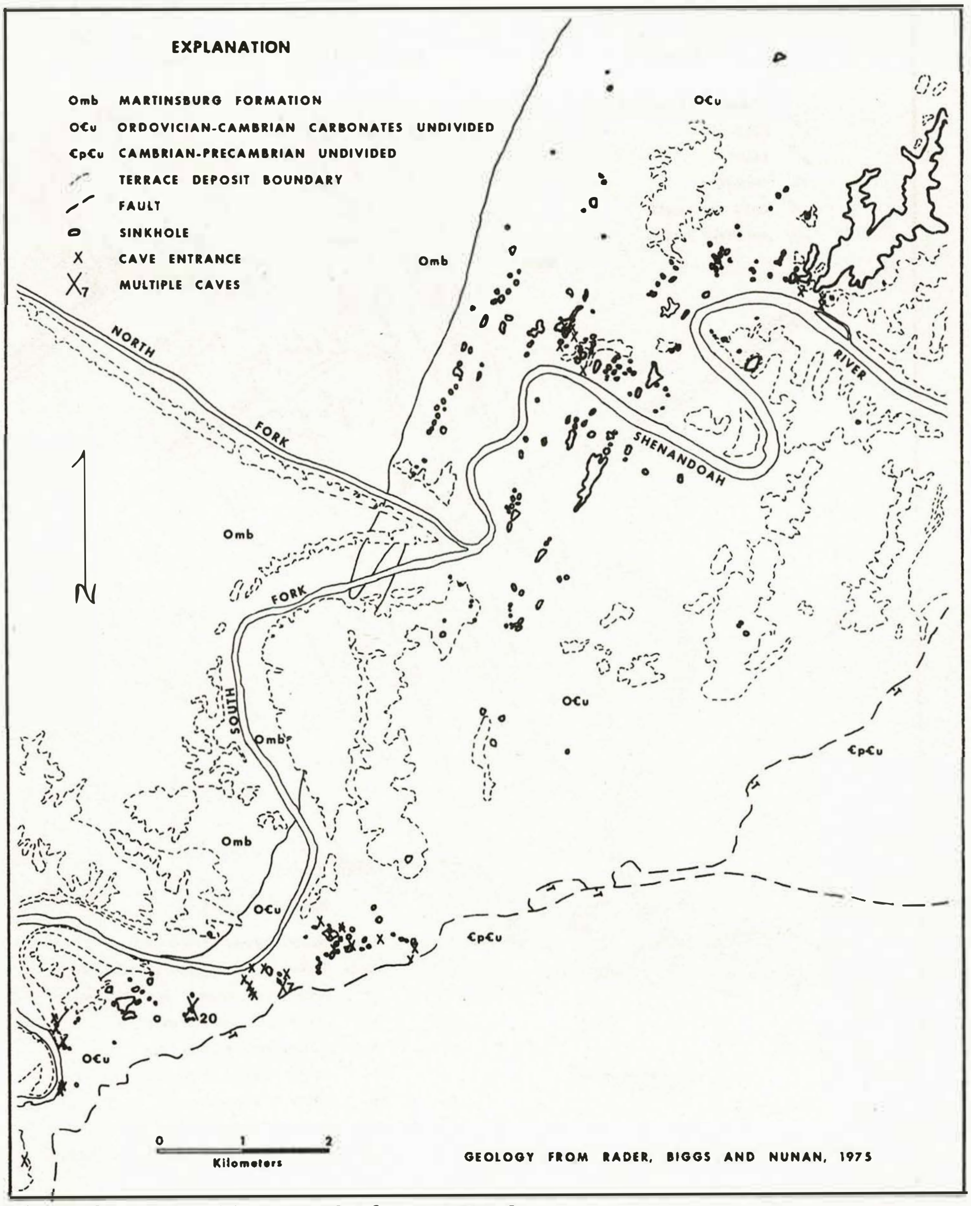

Figure 3: Geomorphic Control Of Karst Development Of The Front Royal Quadrangle

Karst Development in Rye Cove, Virginia

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Abstract

Rye Cove is a small karst plain located in the southwestern part of the Valley and Ridge province of Virginia, U.S.A. Intermediate-to large-scale landforms were located by low altitude aerial photography. Lineaments, observed from aerial photographs, correlate with karst features. Patterns of sinkholes, blind valleys and lineaments correspond to the structurally controlled trends of the area.

The dominant structure of the karst plain is the Rye Cove syncline. Karst features are observed to correspond to the resulting skewed parabolic trends of the Ordovician rocks. Blind valleys in the cove transect the Blackford Formation. The overlying Rye Cove Limestone contains the blind valley termini and major caves and is an area of uniformly high sinkhole density.

Karst is sparsely developed in the overlying Benbolt and Wardell Limestones. A notable exception is attributable to the subsurface drainage network of the Alley-Flannery-McDavids-Jackson cave system. This active drainage network is channeled betweenthe axes of the Rye Cove syncline and an adjacent subsidiary anticline located to the south.

The high solubility of some of the Ordovician carbonates, especially the Rye Cove Limestone, tends to obscure lineaments observed from low altitude photographs' however, lineaments observed from high altitude photographs correlate well with the blind valley.

Zusammenfassung

Die Rye Cove ist eine kleine Karstebene in dem südlichen Teil der Tal- und Hügelkette Virginias (USA). Mittelgrosse bis grosse Landformen wurden durch Luftaufnahem ermittelt. Die Züge die auf den Luftaufnahem zu sehen sind stimmen mit den Karstrukturen überein. Die Anordnung der Vertiefungen, Endtäler und Züge stimmen mit der strukturel kontrollierten Tendenz dieser Gegend überein.

Die vorherrschende Struktur der Karstebene ist die Synkline der Rye Cove. Es konnte beobachted werden das Eigenschaften des Karstes mit den schrägen parabolischen Tendenzen, die die folge ordoviciumer Felsblöcke sind, übereinstimmen. Endtäler in der Rye Cove durchschneiden die Blackford Ablagerungen. Der überlagernde Rye Cove Kalkstein enthält den Endpunkt der Endtäler und wichtige Höhlen und ist ein Gebiet von gleichmässig verteilten Dolinen.

In den überlagerten Schichten des Benbolt und Wardell Kalsteins ist der Karst nur wenig entwickelt. Eine bemerkenswerte Ausnahme kann das sub-oberflächen Abwässerungsnnetz des Alley-Flanner-McDavids-Jackson Höhlensystem zygeschrieben werden. Dieses aktive Entwässerungsnetz ist zwischen der Rye Cove synkliven Axe und der benachbarten Antikline, im Süden, eingeschlossen.

Die hohe Löslichkeit einiger Ordivicium Karbonate, insbesondere die des Rye Cove Kalksteins, neigen dazu die auf den Luftaufnahmen auftretenden Züge zu verwischen' trotzalledem stimmen Züge, die auf den Luftaufnahmen auftreten gut mit den Endtälern überein.

Introduction

Rye Cove is a small karst plain located in the Valley and Ridge province in Scott County, Virginia, U.S.A. (Figure 1/. The cove area is a thrust slice bordered by the Clinchport fault to the southeast and the Hunter Valley fault to the northwest. The Rye Cove syncline dominates the structure of the thrust slice (Brent, 1963/. Within the approximately 38.8 sq. km plain, a 365 m stratigraphpic section of Ordovician carbonates is exposed. These rocks contain intermediate-to large-scale karst landforms which were located using stereo low altitude aerial photography. The synclinal structure of this carbonate plain con tributes to the solutional development of Rye Cove. Hack (1965) has noted similar synclinal control of karst development in other areas of Virginia.

Geologic Control of Karst Development

The Rye Cove syncline plunges to the northeast. Surface expressions of the various carbonate units of the cove follow a skewed parabolic curve defined by the fold (Figure 2).

The Mascot Formation, a cherty dolomite containing some conglomerate near its top, is the oldest unit showing karst development in Rye Cove. The upper half of the unit represents the outer edge of the karst plain. A number of blind valleys extend into the unit as a result of headward erosion. Surface drainage is common over the Mascot (Figure 2).

The Rye Cove Limestone dominates the karst of the cove. This unit contains five of the six major caves (Holsinger, 1975) and the termini of most of the blind valleys in Rye Cove. The sinkhole density of this unit is the highest of any of the Ordovician carbonates represented. Subsurface drainage is the rule in the Rye Cove Limestone (Figure 2).

The Benbold and Wardell limestones are stratigraphically the highest units containing karst development in Rye Cove. These argillaceous limestones show marginal karst development except in the vicinity of Jackson Cave, where Holsinger and Whittemore (1971, Holsinger, 1975) traced the subterranean waters of the Alley-Flannery-McDavids-Jackson (AFMJ) cave system. The surficial karst development of this vicinity rivals that found on the Rye Cove Limestone. The deviation of the cave system from the Rye Cove Limestone into the less soluble Benbolt-Wardell limestones is due to the existence of a minor anticlinal fold in the Rye Cove Limestone, south of and adjacent to the Rye Cove synclinal axis. The anticlinal fold laterally channels the waters of the cave system into the Benbolt-Wardell limestones to the north (Figure 2).

The other major caves of Rye Cove, Cox Ram Pump and Franklins, are connected and their waters trend due south. These subsurface waters probably continue to the southeast to join the waters of the AFMJ system upstream from Jackson Cave.

The waters of the AFMJ system have been rraced to a series of springs along Mill Creek, just south of its junction with Taylortown Branch (Figure 2). These springs flow at a rate of 3.8 to 4.2 x 10^7 l/day (Holsinger, 1968, 1975).

Lineaments in Rye Cove

Lineaments observed from stereo pairs of low altitude (6,100 m) photographs yielded a low density pattern which closely resembles the surficial expression of the Rey Cove Limestone (Figure 3). This phenomenon suggests that the high solubility of this limestone tends to obscure such linear features.

The lineaments observed from oblique viewing of high altitude (12,200 m) photographs show a number of correlations with the blind valleys of Rye Cove. One array of three lineaments intersect at a blind valley in the Benbolt-Wardell limestones. A fourth lineament fades out a quarter of a mile short of intersecting the other three lineaments (Figure 3).

An important lineament intersects the edge of the south portal of Natural Tunnel, southeast of Rye Cove, and extends into Rye Cove where it fades out in the highly soluble Rye Cove Limestone. This lineament is also observed on LANDSAT imagery, where it can be seen to continue through an intersection with the resurgence springs on Mill Creek (Figure 3).

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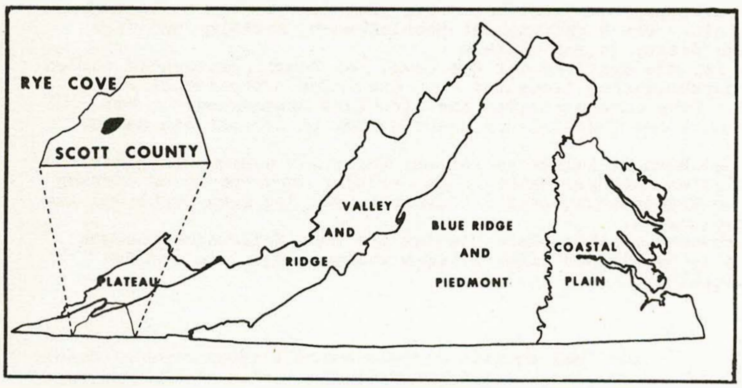

Figure 1: Physiographic Province and Location Map of Virginia

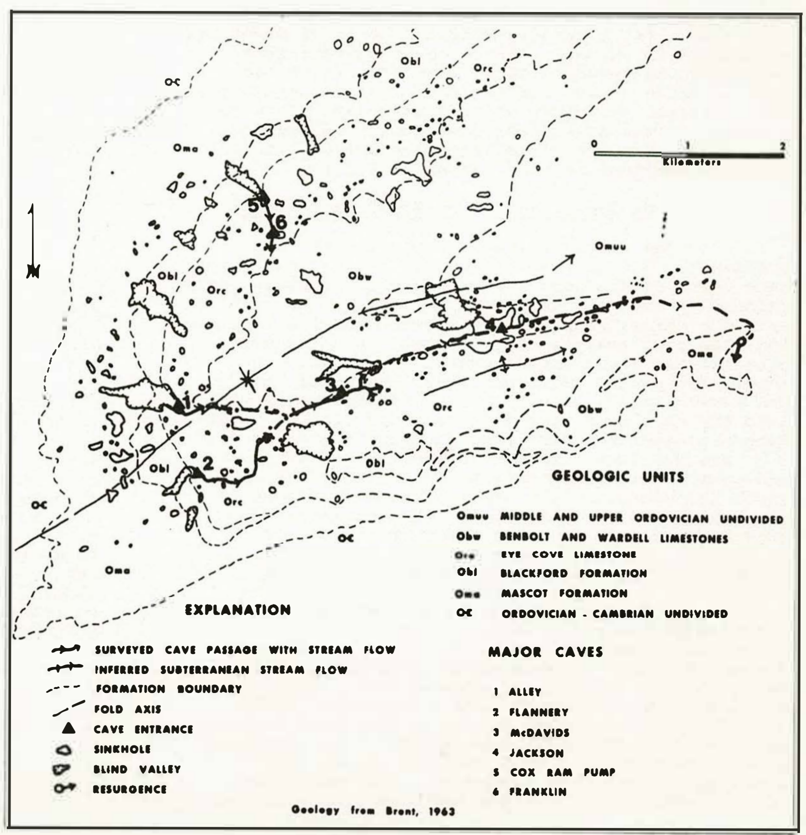

Figure 2: Geologic Control of Krast Development In Rye Cove

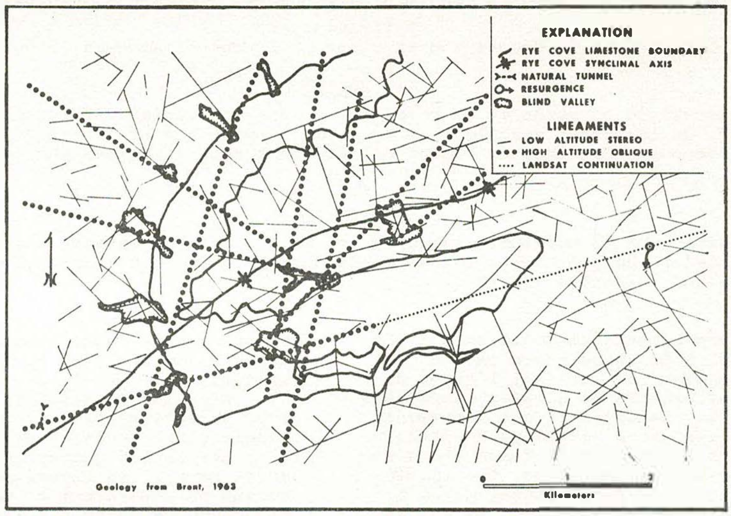

Figure 3: Lineaments In Rye Cove

Etude Comparee des Variations des Principales Caracteristiques Physico-Chimiques de Deux Sources Karstiques de Basse Provence en Fonction de la Nature Geologique de L'Aquifere

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Résumé

Cette étude a permis de comparer et de préciser le sens des variations saissonières des concentrations de Ca et de Mg, de la teneur globale Ca + Mg et du rapport R = Mg (mé/l) / Ca (mé/l) en fonction des débits de 2 émergences karstiques en région méditerranéenne, alimentées par des aquifères calcaire ou dolomitique.

Abstract

The seasonal variations of calcium, magnesium and Ca + Mg concentrations and of R = Mg (mé/l) / Ca (mé/l) are attempted to be related to the water discharge of two karst springs from mediterranean area, with limestone and dolomitic aquifers.

Les déterminations expérimentales de la solubilité de la dolomite dans l'eau, à la température ambiante et en présence de dioxyde de carbone, ont fait l'objet de plusieurs travaux (cf. par exemple le données rapportées par Muxart et Birot (1977). La dolomite est nettement moins soluble que la calcite et sa cinétique de dissolution est très lente. Dans le domaine de température et de P CO_2 recontré dans le milieu karstique, la dissolution du sel ne semble congruente qu'au dessus de 25°C. Pour des températures plus basses, Mg parait être plus soluble que Ca. Par ailleurs, la solubilité de chacun des deux sels (calcite ou dolomite) diminue en présence de l'autre, conformément à l'effet d'ion commun bien connu en chimie (Muxart, 1974).

Dans le milieu naturel, le problème est beaucoup plus complexe en raison de l'interaction d'un grand nombre de paramètres dont l'importance relative n'est pas toujours bien appréciée (données climatiques, pédoclimatiques, lithologiques, dimensions des cristaux et des vides, temps de séjour de l'eau dans les pores - micromilieux -, les fissures et plus généralement les conduits karstiques, nature du sol et de la couverture végétale, teneurs du CO_2 et des substances organiques acides, présence d'autres sels solubles dans les eaux, etc...). Ces différents paramètres peuvent agir à tour de rôle, ou conjointement, sur la cinétique de dissolution et la solubilité des deux carbonates.

En outre, dans les conditions du milieu karstique, la dissolution de la dolomite est un phénomène irréversible, puisque seul le carbonate de calcium précipite à partir des solutions sursaturées.

Il résulte de ces considérations que le rapport des concentrations des ions Mg et Ca dans les eaux naturelles karstiques (R = Mg (mé/l) / Ca (mé/l)) peut être très variable. Il dépend tout d'abord de la nature de la roche constituant le substrat et l'on peut considérer que la valeur de R est faible dans les calcaires, supérieure à 0,5 - 0,6 dans les calcaires dolomitiques et égale ou supérieure à 1, dans les dolomies. R est aussi fonction des conditions climatiques et tout particulièrement de la température des eaux (dissolution non congruente de $CaMg(CO_3)_2$). Enfin, dans le cas d'un système karstique donné, la solubilité des minéraux carbonatés dépend de l'interaction des divers facteurs cités précédemment et de leurs fluctuations. On peut en déduire que les valeurs de R des émergences de ce système seront variables au cours de l'année.

Plusieurs auteurs ont déterminé les valeurs de R des eaux de sources issues de karsts plus ou moins dolomitiques, en fonction des saisons.

Selon Marker (1973), qui a travaillé sur les karsts dolomitiques du N-E du Transvaal en Afrique du Sud, R est maximum pour les sources pendant la période des pluies du printemps et de l'été australs; l'inverse se produit pour les eaux de surface.

Pour Nicod (1966), qui a étudié de façon très détaillée le régime de quelques sources karstiques de Basse Provence, en France, R est maximum en saison sèche, c'est-à-dire en été ou au début de l'automne.

Il nous a paru intéressant de reprendre l'étude de Nicod, sur ce point précise, en comparant les variations du rapport Mg/Ca de deux émergences de Basse Provence dont l'une est alimentée par un aquifère à prédominace calcaire et l'autre par un karst essentiellement dolomitique.

Nature des aquifères et localisation des sources

Le Basse Provence calcaire, située dans le S-E de la France, comprend deux ensembles sédimentaires distincts soumis à la karstification : les unités du Jurassique et du Crétacé inférieur et la série du Trias.

Les travaux de Nicod et de ses collaborateurs (1966), (1967), (1973), (1976) et tout particulièrement son étude remarquable sur les régimes des sources karstiques de Basse Provence (1969) ont montré que la circulation de l'eau souterraine est différente selon les séries.

Dans les karsts triasiques, la circulation est du type phréatique et le régime des sources présente des fluctuations amorties et des débits de base soutenus.

Les unités jurassiques se trouvent en position de karst barré. La circulation de l'eau est vadose au dessus ou légèrement au dessous du niveau de l'émergence de type vauclusien. Elle est phréatique dans les zones plus profondes.

Le régime hydrologique de ces exurgences est variable et dépend de la nature de la roche, de sa porosité et des caractéristiques des conduits karstique. Ainsi, Nicod (1969) distingue - t - il les régimes:

- à pulsations brutales et à tarissement rapide et prolongé (exurgences de réseaux de conduits sans circulation fissurale)
- à fluctuations amorties et à débit de base soutenu (réseau de fentes, conditions structurales particulières ou présence de dolomies poreuses)
- à pulsations fortes - épisodiques ou en liaison avec des averses et à débit de base régulier. Ce régime mixte représente une combinaison des deux types précédents et se retrouve pour les réseaux complexes admettant à la fois une circulation rapide en période de crue et une circulation profonde plus lente assurant un stockage important.

Les deux sources étudiées font partie des exurgences des plateaux varois (altitude comprise entre 200 m dans la zone centrale et plus de 500 m dans la partie N-E).

La source d'Argens à Seillons est située à l'ouest, à 270 m d'altitude. Elle apparait au contact du karst barré du plateau de Selves et des argiles vindoboniennes du Bassin de Brue-Auriac. Elle draine les calcaires du Jurassique supérieur du plateau de Selves et des plateaux disposés à l'est et au nord de la Montagne Sainte Victoire. Nicod (1976) lui attribue un bassin d'alimentation s'étendant sur 135 Km^2. Le régime hydrologique est du type mixte (Nicod, 1969).

La source du St Rosaire à Tourtour, jaillit à l'est, à environ 660 m d'altitude, au contact des dolomies du Jurassique supérieur et des marnes du Keuper. Son bassin d'alimentation s'étend vers le nord et le nord-ouest (Montagne de l'Espiguières). Elle est caractérisée par des débits sensiblement constants tout au long de l' année (Nicod, 1969 et 1976), la circulation de l'eau s' effectuant lentement au travers des dolomies très poreuses.

Dans les deux cas, la zone en amont des sources est couverte par une maigre fôret comprenant des taillis de chênes pubescents associés aux buis sur l'ubac et des chênes verts adaptés à la sécheresse de l'été, sur l' adret.

Données climatiques

Le climat des plateaux varois est du type méditerranéen à tendance continentale. Les précipitations moyennes annuelles calculées sur une période de 25 ans (1951-1975) dans les trois stations de Barjols (256 m), Cotignac (380 m) et Aups (500 m) (transect SW-NE) sont respectivement égales à 790,4, 830,4 et 822,1 mm. Les valeurs des précipitations annuelles (P) et les courbes de répartition des précipitations mensuelles pendant la période d'étude des sources (1977-1980) sont représentées sur la figure 1. Le maximum du régime pluvial annuel est le plus souvent très marqué. Il se produit généralement en automne mais peut être décalé vers l'hiver (hiver 1977-1978). Le quantité d'eau tombée ainsi peut atteindre 40 % de la valeur de P (octobre 1979). Les mesures de températures se rapportent à la station de Cotignac. La température moyenne annuelle calculée sur 4 ans est de 12°C. Décembre (6,1°) et surtout janvier (4,5°) sont les mois les plus froids, juillet (20,4°) et août (19,4°) les mois les plus chauds.

De l'ensemble des données climatiques disponibles, on peut finalement conclure que le climat des plateaux varois est carctérisé par:

- l'aridité estivale (pénurie des précipitations et fortes chaleurs)
- l'âpreté relative des hivers (nombre de jours de gelée et alternance gel-dégel élevés, froid accentué par les vents violents)
- l'irrégularité du régime des précipitations aux plans spatial et temporel (nombre de jours de pluie faible, averses torrentielles déversant en 24 heures une quantité d'eau qui peut représenter 10 % du total annuel).

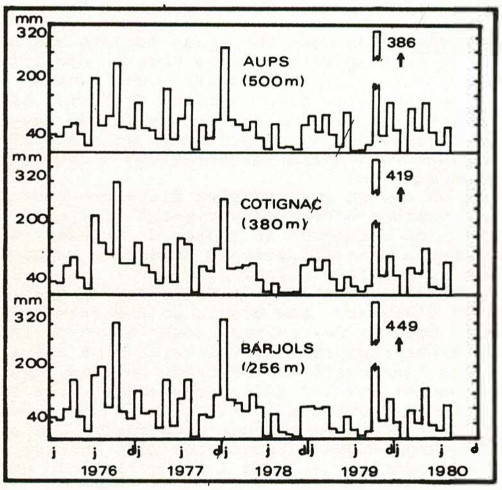

Figure 1. Variations des précipitations mensuelles dans les trois stations de Barjols, Cotignac et Aups, entre 1976 et 1980.

Données hydrologiques pendant la période d'observation 1977-1980

Les caractères du climat varois se répercutent sur le régime hydrologique des sources. Les fortes chaleurs de l'été produisent une intense évapotranspiration. Ainsi, Nicod (1967) a calculé que l'évapotranspiration potentielle peut dépasser 150 mm en juillet. La canicule, associée à l'indigence des pluies d'été provoquent une déficience hydrologique (entre 90 et 135 mm par mois entre juin et août, selon Nicod, 1967), qui se traduit dans le régime des sources par une période d'étiage prononcée.

L'étude du régime hydrologique de la source d'Argens est réalisé depuis 1975 par le S.R.A.E. du Ministère de l'Agriculture. Une ancienne série de mesures est également disponible et a été utilisée par Nicod (1969), pour montrer que la source présentait des débits d'étiages soutenus et des pulsations régulières, liées aux averses.

La comparaison des courbes des débits et des précipitations mensuelles durant la période étudiée permet de retrouver les conclusions de Nicod (fig. 1 et 2).

On peut remarquer ainsi:

- une très grande irrégularité dans le temps des variations de débits mensuels qui est à rattacher à l'inégalité du régime interannuel des précipitations en zone méditerranéenne,
- un fort contraste entre les débits moyens les plus élevés, compris entre 1 et 2 m^3/sec qui se produisent entre l'automne et le printemps et les débits mensuels d'étiage qui sont inférieurs à 0,1 - 0,2 m^3/sec selon les années.
- un décalage temporel entre les précipitations et les réponses enregistées à la source. Deux cas peuvent se présenter:
  - pendant la période sèche, où l'évapotranspiration est considérable, le régime d'étiage est bien établi et n'est pas influencé par les averses, même violentes. Cependant, dans les rares cas d'une année très pluvieuse (1976), suivie par un printemps humide (mai 1977), le débit de la source peut réagir aux fortes averse d'été, par suite de la saturation hydrique des réseaux souterrains profonds.
  - en période pluvieuse, l'augmentation du débit moyen n'est pas toujours fonction de l'intensité des précipitations mensuelles et varie selon que la réconstitution de la réserve hydrique du sol et de la nappe phréatique est plus ou moins complète.

L'étude des variations des débits moyens journaliers montre que celles ci peuvent être rapides. L'écoulement de l'eau étant différé de plusieurs jours par rapport aux précipitations, il faut admettre avec Nicod (1969), un stockage temporair dans les conduits karstiques de la zone vadose régulée par le fonctionnement de siphons. Le non tarissement de la source pendant la sécheresse estivale, indique quant à lui, l'existence de réserves profondes dans la zone phréatique.

Les variations de l'écoulement de la source du St Rosaire ne sont pas mesurées. Selon Nicod (1966) et (1969), les débits sont très réguliers, car le stockage de l'eau s'effectue dans les fissures et les pores de la dolomie qui joue un rôle régulateur fondamental. Le module (M), le débit à l'étiage (DE) et le pourcentage de l'étiage par rapport au module (p) sont respectivement estimés à 0,058 m^3/sec, 0,033 m^3/sec et à 57 %. Des calculs analogues effectués sur la source d'Argens montrent que M = 0,566 m^3/sec, DE = 0,030 m^3/sec et p = 5,3 % (Nicod, 1976).

Caractéristiques Physico-chimiques des sources d'Argens et du St Rosaire pendant la période 1977 - 1980

A. Fréquence des prélèvements et méthodes analytiques

Les caractéristiques physico-chimiques des deux sources ont été déterminées en prélevant les eaux environ une fois par mois, entre fin 1977 et 1980. Dans la mesure, où il ne nous a pas été possible de suivre l'évolution chimique des eaux avec un pas de temps plus court, nous ne prétendons pas que les échantillons analysés soient tous représentatifs du mois écoulé. Il n'en est certainement pas ainsi pour l'Argens durant les phases de hautes eaux. On peut néanmoins supposer que les échantillons dosé pendant les longues périodes d'étiage sont représentatifs des eaux de la saison sèche. Pour la source du St Rosaire, dont le débit est sensiblement constant tout au long de l'année, les concentrations mesurées chaque mois, reflètent assez bien celles des eaux écoulées durant cette période.

Pour chaque échantillon prélevé, nous avons mesuré:

- sur le terrain : la température, le pH et le T.A.C.
- au laboratoire : Ca et Mg par spectrométrie d'absorption atomique.

B. Source d'Argens

Les résultats obtenus sont rassemblés sur la figure 2.

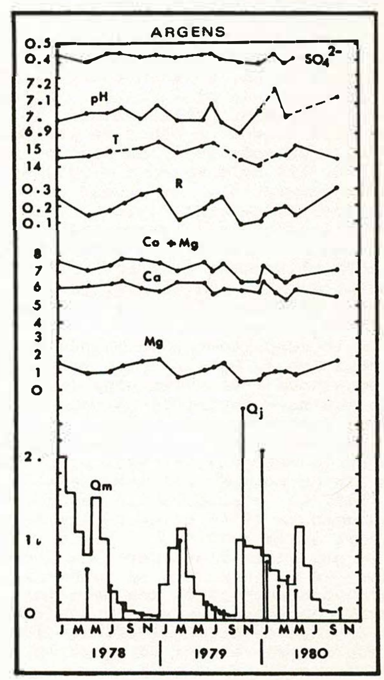

Figure 2. Variations des caractéristiques hydrologiques et physico-chimiques de la source d'Argens entre fin 1977 et 1980.
Q_m: débit moyen mensuel; Q_j: débit le jour du prélèvement; Mg, Ca, Ca + Mg, SO_4^{2-}: concentrations des ions exprimées en mé/l; T: température en degrés centigrades

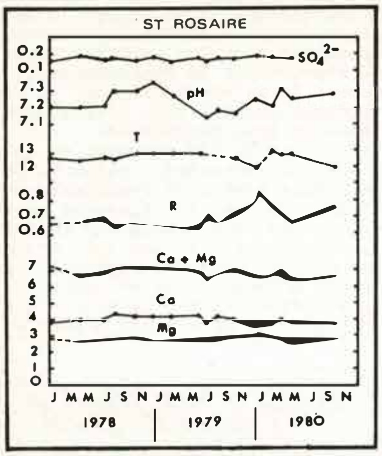

Figure 3. Variations des caractéristiques physico-chimiques de la source du St Rosaire entre fin 1977 et 1980.
Mg, Ca, Ca + Mg, SO_4^{2-}: concentrations des ions exprimées en mé/l; T: température en degrés centigrades.

- Température: En raison de l'importance du réservoir karstique profond, l'homothermie des eaux est de règle. Les eaux les plus tièdes correspondent aux débits d'étiage (séjour prolongé dans le karst) et les eaux les plus fraiches aux périodes de crues (transit rapide à travers le massif).

- pH: Les variations du pH avec le temps sont faibles. Elles sont le plus souvent comprises entre 7,0 et 7,1 et plus rarement entre 6,93 et 7,19.

- composition chimique: Elle traduit la nature géologique du bassin d'alimentation de la source, constitué surtout par des calcaires, et les eaux sont à nette prédominance calcique. Le magnésium est présent en faibles quantités (faciès dolomitique de la formation kimméridgienne), ainsi que les ions sulfates (recoupement par le réseau souterrain de la série triasique du Keuper, contenant du gypse).

- les teneurs en calcium sont toujours très fortes. Les variations saisonnières s'échelonnent entre 107 et 130 mg/l de Ca, soit un écart de 20,8 % par rapport à la teneur la plus faible. Elles ne sont pas une fonction simple du débit. Ainsi, la concentration de Ca peut être élevée en début de période d'étiage (ex: 129 mg/l en août 1978) ou bien en régime hydrologique élevé (128 mg/l en mars 1979), et la valeur est proche de la saturation. La teneur en calcium est plus faible en périodes de crues (118 mg/l en octobre 1979) par suite de l'effet de dilution lié à la montée brutale du débit, ou en fin de régime d'étiage, en raison d'un affaiblissement de l'activité microbienne due à la sécheresse, d'un abaissement de la P CO_2 et d'une diminution de la solubilité ou d'une légère reprécipitation de $CaCO_3$ au sein du karst.

- le comportement du magnésium est différent. Les concentration de Mg sont plus modérées et les variations saisonnières très accentuées ($5,3 \leq Mg \leq 20,5$ mg/l). Les écarts maxima enregistrés peuvent dépasser 286 % par rapport à la teneur la plus basse. Ces fluctuations se produisent en sens inverse des changements de débits et la teneur en Mg des eaux est systématiquement la plus élevée en fin de période d'étiage (ex: 21 mg/l en décembre 1978) et la plus faible pendant les crues (6 mg/l en octobre 1979) ou en régime de débits soutenus (9 mg/l en mars 1979).

- par suite d'une certaine complémentarité de comportement de Mg et de Ca, en fonction du temps, la somme des concentrations de ces deux ions varie le plus souvent, en sens inverse des débits. On retrouve ainsi le résultat de Nicod (1966) et (1973) qui avait souligné que les variations du T_H de la plupart des sources de Basse Provence étaient inversemment proportionnelles aux débits. Il faut souligner que cette règle doit être plutôt considérée comme une tendance et qu'elle souffre des exceptions dans la mesure où, pour des débits analogues, l'origine et l'âge des eaux peuvent être fort différents.

- les valeurs du rapport R = Mg (mé/l) / Ca (mé/l) sont dans l'ensemble plutôt faibles ($0,088 \leq R \leq 0,307$). L'étude de leurs fluctuations en fonction du temps montre que R est minimum pendant les phases de débits soutenus (R = 0,113 en mars 1979) et les crues (R = 0,088 en octobre 1979) et qu'il est systématiquement maximum en fin de saison sèche (ex: R = 0,292 en décembre 1978). Ces conclusions sont conformes à celles de Nicod (1973) qui note que R varie en Basse Provence dans le même sens que les T_H, donc en sens inverse des débits.

- le comportement des ions sulfates en fonction du temps est tout à fait analogue à celui du calcium. Dans la mesure où les concentrations de SO_4^{2-} sont relativement faibles et stables ($18 \leq SO_4^{2-} \leq 22,9$ mg/l), l'ordre de grandeur de R n'est pas modifié en adoptant pour le calcul de Ca, la valeur corriagée par rapport à la teneur en sulfates.

C. Source du St Rosaire

Les principales données sont rapportées sur la figure 3.

- Température: Les eaux sont plus froides que celles de l'Argens. Leur température varie dans un domaine très limité (11,9° $\leq T \leq$ 13°C). L'expulsion des eaux d'infiltration pouvant être plus ou moins différée, on observe au niveau des températures et selon les cas, des eaux tièdes (averses de fin de printemps et d'été 1978) ou des eaux fraiches (pluies torrentielles d'octobre 1979) évacuées en hiver.

- pH: Le pH est en moyenne plus élevé que pour l'Argens et les valeurs s'échelonnent entre 7,14 et 7,35.

- composition chimique: la source du St Rosaire présente une forte minéralisation à caractère magnésien, conséquence d'un aquifère dolomitique.

- les concentrations de Ca sont plus faibles qu'à la source d'Argens. Les écarts saisonniers compris entre 69 et 87 mg/l de Ca, correspondent à une variation d'environ 27 % par rapport à la valeur la plus faible. Les valeurs les plus basses s'observent pour les eaux fraiches de janvier-février 1980, résurgeant après les pluies diluviennes d'octobre 1979.

- les teneurs en Mg sont plus fortes que pour l'Argens. Les amplitudes saisonnières sont en revanche nettement plus modérées ($30 \leq Mg \leq 37$ mg/l) et ne dépassent pas 26 % par rapport à la valeur minimum. Mg semble varier à l'opposé de Ca, soit en sens inverse des débits (eaux fraiches de janvier-février 1980).

- toutefois, l'augmentation des concentrations du magnésium pour les débits élevés, ne compense pas la diminution de celles de Ca et la somme des teneurs de ces deux ions ne parait pas suivre - du moins si l'on se réfère à la courte série observée - une tendance précise.

- les valeurs du rapport R sont fortes et comprises entre 0,63 et 0,84. Ses fluctuations en fonction du temps sont plus irrégulières et moins rythmées que pour l'Argens. On observe que l'augmentation de R ne se produit plus en fin de saison sèche, mais que R est maximum (R = 0,84) pour les eaux les plus fraiches de janvier-février 1980, lors d'un accroissement de débit consécutif aux précipitations exceptionnelles d'octobre 1979.

- signalons pour terminer, que la teneur en ions sulfates de la source du St Rosaire est faible et constante ($7,6 \leq SO_4^{2-} \leq 9,2$ mg/l).

Conclusions

L'étude comparée de l'évolution du régime hydrologique et des caractéristiques physico-chimiques de deux émergences provençales : les sources d'Argens et du St Rosaire, associées à des aquifères à prédominance respectivement calcaire et dolomitique, permet de préciser le comportement géochimique des ions Ca et Mg en fonction du temps, c'est-à-dire des débits, pour chacun des deux systèmes considérés. Il apparait ainsi que:

- les changements saisonniers des teneurs en Ca sont relativement modérés ($\leq$ 27%) quel que soit l'aquifère; ils ne sont pas une fonction simple des débits mais dans tous les cas Ca diminue en période de crue.

- le comportement du magnésium est différent selon la nature de la roche - en milieu calcaire, l'amplitude des variations des teneurs en Mg est considérable ($\leq$ 285%) et Mg tend à augmenter systématiquement en phase d'étiage, - en terrains dolomitiques, les écarts de la concentration de Mg sont faibles ($\leq$ 26%) et Mg croit en période de crues (automne-hiver). Le même phénomène a été observé dans le Transvaal pendant les pluies de l'été austral (Marker, 1973). L'effet de dilution ne jouant pas pour le magnésium, il faut supposer que sa cinétique de dissolution à partir de la dolomite est plus grande que celle de Ca.

- les variations de la teneur globale Ca + Mg sont inversement proportionnelles aux débits en zone calcaire mais ne correspondent pas à une fonction simple de ceux-ci dans les dolomies.

- les fluctuations de R reflètent celles de Mg. Dans les calcaires, R est maximum en fin de période sèche et minimum en phases de crue ou de débits soutenus. Pour les dolomies, nos résultats indiquent que R croit avec le débit et sont conformes à ceux de Marker (1973). D'après les données de Nicod (1976), R apparait cependant indépendant de la température et du débit. Ces divergences dans les résultats concernant les dolomies, montrent que le problème est complexe et non encore résolu et qu'il n'est pas possible actuellement-avec les petites séries de mesures dont nous disposons - de définir une loi simple exprimant les variations de R avec celles des débits.

Remerciements

Nous remercions vivement M. Pinta pour les dosages des ions sulfates qui ont été réalisés dans son service de l'Orstom, par Mme Villette.

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Recent Flood Pulse and Hydrological Studies on the Russett Well/Peak Cavern System, Castleton, Derbyshire, England

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Abstract

A flood pulse study of Russett Well and the associated sink to resurgence system via Speedwell Cavern in the Castleton area of Derbyshire, England, was initially performed based on a classical Ashton type analysis of flow patterns supported by chemical variables. Subsequent work has involved continuous monitoring of flow pH and conductivity at the well supported by quantitative dye traces.

The results clearly show that different bodies of water of either vadose or phreatic type have differing chemical characteristics and can be identified by chemical variables and ionic ratios. Of particular value are potassium, magnesium and silica concentrations.

The overall results can be interpreted to show that Russett Well is a relatively recent and immature karst resurgence and that a complicated series of flow lines converge in Speedwell Cavern with some distributory flow via the nearby Peak Cavern system.

The results have revealed a hitherto unsuspected complexity in the hydrology of the Castleton area, in that the hydrological systems appear to be linked in a fractured rock aquifer rather than a series of separate conduits.

Résumé

On a fait une étude des pulsations en temps de crue du Russett Well (un puits) et du système contigu où les eaux tombent par une doline pour reparaître par la caverne Speedwell; ceux-ci se trouvant près de Castleton dans le Derbyshire, G. B. Cette étude a été fondée d'abord sur une analyse classique, type Ashton, au sujet des facons d'écoulement/de débit, supportée par des variables chimiques. Le travail subsequent a entraine un enregistrement continu de l'écoulement pH et de la conductibilité au puits, supporté par des traces quantitatives de colorant.

Les résultats montrent nettement que de différentes nappes d'eau, soit vadeuses, soit phréatiques, possèdent de différentes caractéristiques chimiques, et sont identifiables par des variables chimiques et par des rapports ioniques. De valeur spécial sont le potassiu, le magnesium et la concentration de silice.

Des résultats généraux, peut-on conclure que le puits, Russett Well, est une réapparition/resurgence Karst récente et jeune/non-mure et qu'une série de lignes d'écoulement/de débit converge sur la caverne Speedwell avec un écoulement distributeur par le proche systemè de Peak Cavern.

Les résultats révèlent une complexité insoupconnée jusqu'ici dans l'hydrologie de la région de Castleton. Castleton.

Introduction

The principal cave systems of the Castleton area of Derbyshire, England, are shown in Figure 1. They consist of a series of 12 allogenic sinks, at the limestone-shale margin, which engulf streams flowing southwards off the impervious shale catchment of Rushup Edge and feed water underground into a complex system of bedding plane caves, joints, faults, (some mineralised) and vein cavities. The general flow is for some 3-5 km eastwards, with a gentle stratal dip, under an apparent surface watershed to the all weather resurgences in Peak Cavern Gorge of Russett Well and Slop Moll with high flood overflow into the separate, adjacent, system of Peak Cavern. The drop in altitude from swallets to resurgences is 150-200 metres.

The swallet water is known to emerge at several points within the intermediate Speedwell Cavern, principally at Main Rising and Whirlpool Rising, before flowing down the Bung Hole series to within 500 m of the resurgences in Peak Cavern Gorge. Previous work (Ford 1966) suggested that the principal flow was from Main Rising with only secondary flow from Whirlpool Rising. However, recent exploration has thrown considerable doubt on this assumption and suggests that the situation is extremely complex, as both risings, independently or together, can discharge the principal flow depending on the amount of antecedent rainfall.

The hydrological arrangement in Peak Cavern Gorge is complex and has recently been changed. When the early work of February 1979 was carried out (Christopher 1980) Russett Well was the principal resurgence in low or medium flow. Slop Moll, thought to be an eighteenth century mine drainage level (=sough), becoming active at higher flows. At these stages of flow Peak Cavern discharges a modest flow of chemically different water. At very high flow stages Peak Cavern becomes another overflow route for the swallet water from Speedwell Cavern. However, during 1980 local cavers have excavated Slop Moll, lowering the bed of the stream by approximately one metre, with the result that it now flows at all times and in very dry weather Russett Well stops flowing. The system in other respects is unchanged. The existing knowledge on the Castleton caves has been summarised by Ford (1966, 1977) and flood pulse work limited to that of the author (Christopher 1980).

Early Flood Pulse Studies

The author found in his preliminary study (Christopher 1980) that flow and water chemistry at Russett Well showed marked changes over the 19 hour study period. Using criteria developed by Ashton (1966) it was possible to relate these changes to the hydrology and sink pattern postulated by Ford (1966).

Briefly, the twelve sinks were then thought to form three hydrological units, the most westerly sinks, P_1-P_4, flowing via Coalpit Rake to Main Rising Speedwell. The middle sinks (P_5-P_8) appeared to form a separate unit, also flowing to Main Rising, whilst the eastern sinks (P_9-P_{12}) flowed to Whirlpool Rising. All flows combine within Speedwell and emerge at the resurgences of Russett Well and Slop Moll.

A full range of chemical variables were studied and it was variability that could be interrelated with the flow and hardness data to give valuable clues as to the type of water emerging at a particular instant in time. Generally swallet water has a higher concentration of these ions than limestone percolation water and consequently peaks in concentration of these ionic species represent the arrival of swallet water as distinct from phreatic displacement water.

Subsequent Work

The work of February 1979 revealed the limitations of the "grab sampling" technique in studying a flood event and a move to continuous measurement was thought desirable. A preliminary study was performed in June 1980 when pH and conductivity recording was attempted. As a result of experience gained during this test a much more successful study was begun in mid-September and concluded in early October after three weeks of unbroken records. During this study a programme of quantitative dye tests was also undertaken in conjunction with Dr. S. Trudgill and a full report on this work is in preparation (Christopher and Trudgill 1981).

In outline, the whole programme involved continuous recording of flow, pH and conductivity at Russett Well. Automatic water samples were installed at Russett Well, Slop Moll and Peak Cavern. Three separate dyes were introduced into P_1, P_8 and P_{12} (P_{12} = Giants Hole) and three different chemical tracers into the intermediate sinks. Charcoal and cotton detectors were used and changed every two days. Detectors were also placed at all inlets in Speedwell Cavern, before dye was introduced to the sinks and removed two weeks later after the dye had reached the resurgences.

The results show a complex flow pattern with the principal resurgence in Speedwell being Whirlpool Rising for all sinks, except the eastern ones which are now thought to either flow via the Assault Course or by some as yet undiscovered route to Russett Well.

The first time of arrival of dyes from P_8 and P_{12} to Russett Well and Slop Moll are similar to the chemical flow times at 48 to 72 hours. The dye from P_1 took significantly longer, arriving at Russett Well and Slop Moll after 8 days. Contrary to expectations the results showed that Slop Moll behaved in a more "flashy" manner than Russett Well and that therefore Russett Well may be a more recent development.

It is also possible that a natural resurgence existed in the area of the present Slop Moll before eighteenth century mining modifications. This is to some extent supported by observations with Speedway Cavern.

Further, positive dye traces were obtained to Peak Cavern previously thought to be a completely separate system,fed solely by percolation water from the south. The flow times were, however, much longer at 10-14 days in each case. This suggests a more complex arrangement than was first thought and summarised in Figure 2.

Following the conclusion of the main programme of dye tests the weather, which had been settled, broke and a heavy flood followed. The conductivity trace at Russett Well was particularly interesting. There was an increase in flow 6 hours after rain began falling, accompanied by a sharp fall in conductivity. The flow was steady for the next 52 hours, but conductivity increased slowly for 27 hours then declined steadily. Thus, this event 33 hours after it began raining is thought to represent the arrival of the main swallet water, which took 36 hours to clear the system. However, further rainfall had occurred in the intervening period and the picture is complicated by multiple pulses.

The flood pulse results showing a very subdued response at Russett Well agree reasonably with the dye test results, but contrast with the more rapid responses recorded in the preliminary study. This may be a reflection of the alterations in the hydrology of Slop Moll since the early study. Overall the results suggest the Castleton acquifer behaves more like a fractured rock aquifer than a typical karst drainage system with piston flow.

This is in accordance with Ford's 1966 concept of the hydrology being controlled principally by mineralised faults and vein cavities. Any further study will have to involve full monitoring of all three resurgences.

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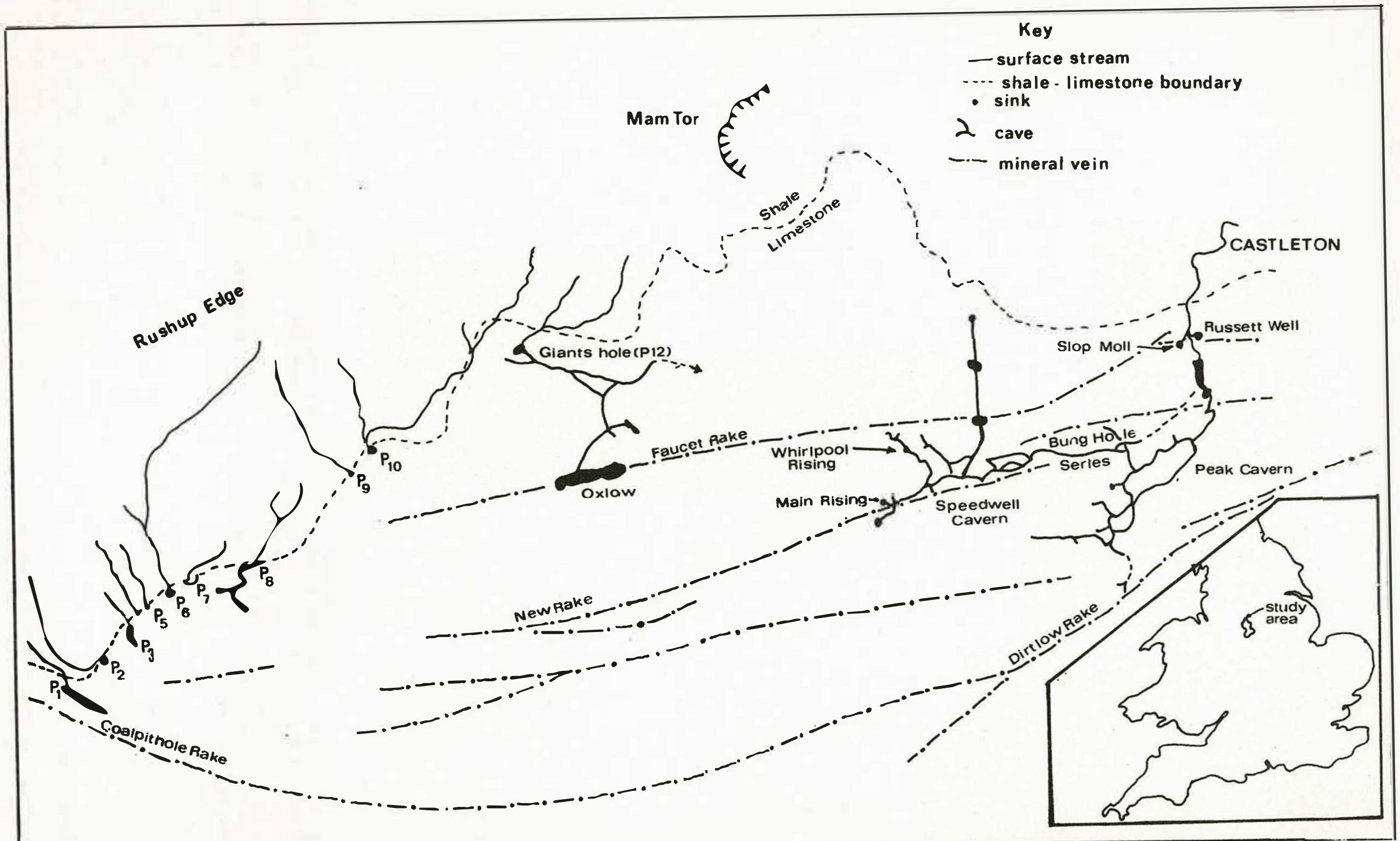

Figure 1. Geology and caves of Castleton area, Derbyshire.

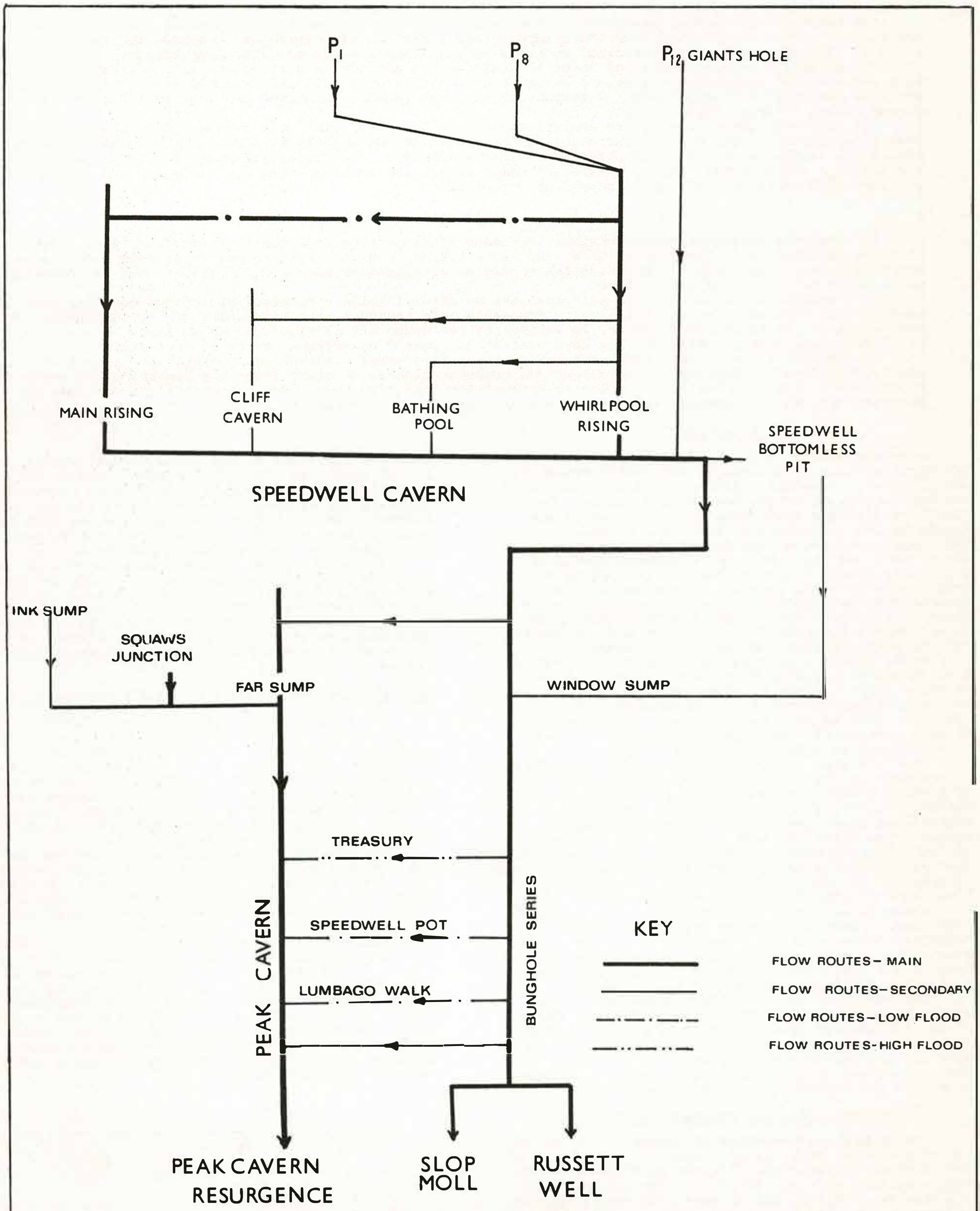

Figure 2. A representation of the hydrology of the Rushup sinks-speedwell-Russett Well system, Castleton, Derbyshire, England.

The Classification of Karst Waters by Chemical Analysis

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Abstract

The technique of cluster analysis has been applied to 107 representative chemical analyses of ground and surface waters originating from the Carboniferous Limestone of Derbyshire, England, and surrounding areas to identify the major geochemical controls on the limestone ground water composition.

The principal control was found to be biogenic carbon dioxide in conjunction with calcium carbonate. Less dominant but recognisable controls on water composition were soil and interbedded dolomite, shale and lava geochemical compositions. A further control was whether the water had evolved under open or closed system (vadose) conditions.

The limestone ground waters are characterized by a high and relatively stable concentration of calcium bicarbonate. Shale contact increases the concentration of magnesium, sodium and potassium. Extra magnesium, alone, is derived from dolomite or lava weathering. Low concentrations of calcium, high Pco_2 and low SI_c characterize surface waters. Thermal waters are enriched with magnesium, sodium and sulphate but impoverished in nitrate due to reduction processes.

Résumé

107 analyses chimiques representatives des eaux de nappe superficielle et de surface, d'origine du calcaire carbonifere du Derbyshire, G. B., et ses environs, ont ete traitees par la technique de l'analyse par groupes; ceci, afin d'identifier les controles geochimiques majeurs qui agissent sur la composition de la nappe superficielle carbonifere.

On a decouvert que le controle principal est en effet l'acide carbonique biologique conjoint avec le carbonate de calcium. Des controles moins dominants mais toujours reconnaissables sur la composition des eaux etaient: la terre, la dolomite, le schiste et des compositions geochimiques du lave. Ce qui avait de l'importance aussi, c'etait si les eaux etaient degagees d'un systeme ouvert ou souterrain.

Les grands traits perceptibles sont une concentration assez constante du bicarbonate de calcium (avec une augmentation du sulphate de sodium) et une concentration de chlorure (avec une concentration reduisante du nitrate): ces deux variations selon la penetration dans l'aquefer. Une concentration augmentee de magnesium provient de contact avec le schiste, le lave et la dolomite.

Introduction

Previous work on the ground waters of the Carboniferous Limestone of Derbyshire has, until recently, been limited. Stephens (1929) principally considered the suitability of waters for potable supply. Downing (1967) studied the subsurface ground waters of the deeply buried Carboniferous Limestone in the area of the Eakring oil-field down dip of the area considered here. He found that there was a gradual change in both ionic strength and dominant ionic species with penetration into the aquifer. The dominant species changed from calcium bicarbonate through calcium sulphate to sodium chloride type, and he proposed that these changes occurred as a result of calcite precipitation, sulphate reduction and ion exchange.

Back, (1966) developed the concept of hydrochemical facies when studying the ground waters of the Atlantic coastal plain of North America, where waters were classified according to the dominant ionic species. This broad classification is not applicable to this work as all the waters considered here would be classified as calcium bicarbonate type.

The only work to consider adequately the calcium bicarbonate waters of the Derbyshire limestone is that of Edmunds (1971). He subdivided the waters into five general groups: grit/shale, general limestone, mineralised areas, perched watertable and thermal waters. The first and last of these are chemically distinct but the remainder show more subtle variations than are suggested by the group headings and some of the analyses do not fit easily into the assigned group. Also, some of them overlapped as, for example, when grit/shale water flowed into swallets in mineralised limestone. There was also no attempt to assign "chemical fingerprints" to the various waters. However, being a very comprehensive published set of data it has been used as a basis for this study augmented by additional analyses of the authors.

Bertenshaw (1979) has also studied the ground waters of southeastern part of the Derbyshire limestone, but largely based his classification on that of Edmunds, and, apart from spatial analysis of his data and distinguishing the effects of dolomite, and open and closed system evolution, he made no attempt to refine the classification of Edmunds.

The Geological and Geographical Setting

The Derbyshire limestone is located in north central England and consists of a broadly anticlinal elevated block of limestone of lower Carboniferous age with a surface area of 325 sq km. The limestone is principally of S_2, D_1 and D_2 ages with reef complexes of P and B ages at the limestone margins. It has a patchy cover of a thin layer of deposits of Tertiary and Pleistocene age and heavily dissected with a network of dry valleys. The limestone is surrounded by shales and grits (coarse sandstones) of upper Carboniferous age. To the north and west the shales are of higher elevation, but to the east they are separated from the limestone by the broad Derwent Valley, whilst to the south the elevation of the limestone is similar to that of the surrounding grits. This geography results in low hardness allogenic water flowing into the limestone from the north and west and emerging principally at resurgences in the east and south, and along the principal river valleys of the Wye and Dove.

The principal structural controls on water movement are the topographical ones: the dry valley network and the geologic ones of interbedded volcanic rocks (dominantly olivine-basalt), a mineralised vein fault system and an extensive network of now disused mine drainage levels (soughs), whose effect can in some cases result in wholesale transfer of water from one catchment to another (Oakman 1979).

Data Sources, variables studied and Mathematical Analysis

The principal data sources were twofold, firstly the published analyses of Edmunds (1971) and original analyses of the authors. All of Edmunds' data is a single analysis at each locality, but most of the authors' data is based on multiple analyses at various flow stages. The resultant average analyses largely overcome the problems of temporal fluctuations known to occur in karst waters (Bertenshaw 1979); of the total of 107 analyses, 87 were from Edmunds.

The variables considered in the mathematical analysis were the concentration of the dominant cation species, namely calcium, magnesium, sodium, potassium. Additionally, two derived variables were also included; these were saturation index to calcite (SIc) and partial pressure of carbon dioxide (Pco_2).

Parameters were scaled by the medians of the parameters of the General Limestone Group (Ca 99.3, Mg 5.9, Na 6.6, K 1.3, Pco_2 2.03) to produce standardised values, while SIc was scaled on -1, producing an aggressivity value. This procedure circumvents the potential problem of the dominance of the analysis by one or more variables which happen to have the largest numerical values. The similarity algorithm used was Q-mode weighted pair-group average linkage using a form of inverse Euclidean distance

$$100\left(1-\frac{\sqrt{\sum_{m=1}^{p} w_m\left(x_{im}-x_{jm}\right)^2}}{\mathrm{MAX}\left(\sqrt{\sum_{m=1}^{p} w_m x_{im}^2},\ \sqrt{\sum_{m=1}^{p} w_m x_{jm}^2}\right)}\right)$$

where sites i and j are being compared in terms of p parameters x with weight w. The cations were assigned weights of 1, SI_c and Pco_2 0.5.

The results of the clustering are shown as a minimum spanning tree in Figure 1. Attention is particularly drawn to the "chemical fingerprinting" method originated by the authors, a data reduction method which clearly shows the anomalies in chemical properties. For convenience the programming language used was BASIC run on an RML 380Z microcomputer.

Influences on the Geochemistry of Derbyshire Karst Water

The dominant influences can be listed as follows: atmosphere, climate, catchment and soil (including boulder clay and loess) geochemistry, limestone geochemistry, geochemistry of lavas and their degradation products, mineral vein geochemistry.

Results

The results of the data analysis are presented in the form of a minimum spanning tree in Figure 1. This is similar in many ways to the more conventional dendrogram presentation, but in this case gives a more easily understood presentation.

The chemical fingerprint of the individual clusters are presented in Fig. 1 as a 6-figure mnemonic code where three symbols are used to represent the state of the six variables considered O represents low, X normal and 1 high values. For the cations values $\pm$ 50% of the mean analysis of Edmunds (1971) General Limestone Group were taken as normal. For SI_c the value was normalised on -1 to give an aggressivity figure, then supersaturated samples were coded O, and unsaturated samples coded 1. The normal limits for Pco_2 were taken as 90-110% of the mean standard analysis. In all cases the results are presented in the order Ca, Mg, Na, K, SIc, Pco_2.

Discussion

Figure 1 shows clearly that the principal geochemical controls outlined above can be picked out from the chemical composition of the ground water draining from particular rock types.

The principal groups identified in this analysis are grit/shale surface waters, general limestone waters, lava or dolomite affected waters and thermal waters. There are also intermediate types between surface waters and general limestone which come from karst resurgences, with a significant component of allogenic surface water in their discharge, and a mixed thermal and surface water group.

The dominating influence of the combination of biogenic carbon dioxide and limestone is seen in the contrast between the low calcium surface waters and the high relatively stable concentration of calcium bicarbonate in the limestone ground water of the General Limestone Group.

The mixed surface and limestone waters are characterized principally by low SIc, high Pco_2 (from vadose conditions in the aquifer) and high sodium (principally from road de-icing salt). The low magnesium of this group is a reflection of the purity of the limestone in the areas where these systems occur.

The dolomite and lava influence is similar in that it is characterized by high magnesium (Figure 1). The latter is what would be expected from the decomposition of olivine basalt by carbonate rich water.

Finally, we have the thermal waters principally characterized by both high magnesium and sodium concentration. This reflects the origins of these waters, as all these sites are at or near the limestone/shale boundary. They are both derived from clay mineral decomposition and also in the case of sodium by ion exchange for calcium. The elevated temperatures are explained both by the geothermal gradient with deep circulation over at least 15 years (Edmunds 1971) and possibly by exothermic oxidation of pyrite in the shale, as shown by the usually high concentration of sulphate present in Derbyshire thermal water, but not considered in this analysis.

Numerical values for the high and low states can be calculated from data given above.

The ultimate development of these waters is seen in the analysis of the Bradwell thermal spring water, which is high in magnesium, sodium potassium (but has a low K/Na ratio), sulphate and chloride, but has negligible nitrate concentration reflecting nitrate reduction processes deep in the aquifer.

A fuller discussion of all these points will be found in a later article (Christopher & Wilcock 1981).

Conclusions

Cluster analysis of 110 representative samples of Derbyshire ground water has revealed that they fall into four strong hierarchical groups: surface waters, general limestone waters, dolomite/lava waters and thermal waters; with two groups of intermediate composition and sub-groups differentiated principally by high Pco_2 reflecting open system (vadose) evolution.

This contrasts with Edmunds' subjective classification of which only his grit/shale and thermal groups are substantiated. His remaining groups are shown to be a mixture of more fundamental geochemical influences.

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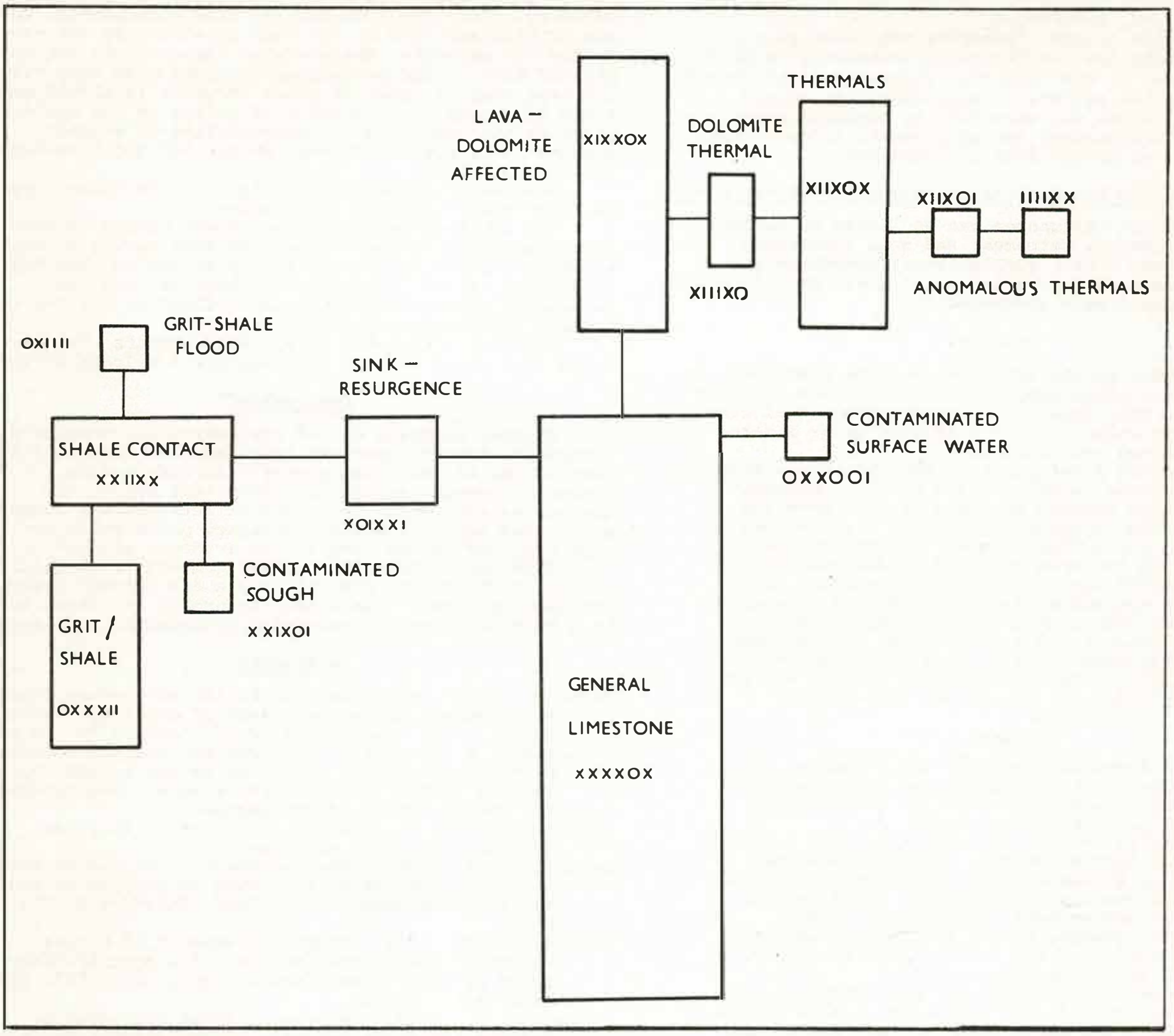

Figure 1. The minimum spanning tree of the 61% similarity level. The relative sizes of the 61% phenons are indicated by boxes of areas proportional to the number of sites in each group.

Cavernicolous Acari of North America

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Abstract

Acari have colonized nearly every terrestrial and aquatic habitat known, including caves. In North America 48 families of terrestrial mites have been reported from caves. A summary of these cavernicolous mites and their role in the cave community is presented. Most cavernicolous mites are troglophiles or guanophiles. Troglobitic species have evolved in several families. The evolution of cavernicolous mites from epigean forms is presented with examples from the family Rhagidiidae. The evolution of cavernicolous species from parasitic and phoretic forms is also presented with examples from several families.

Morphological and Mineralogical Features of Phreatic Speleothems Occurring in Coastal Caves of Majorca (Spain)

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Abstract

Large assemblages of subaqueous speleothems, reported from some coastal caves of the island of Majorca (Spain), emphasize the processes involved in underwater carbonate deposition in the phreatic zone. Geochemical implications, yet unknown, are discussed as a result of this find.

Floating crystallizations, wall coatings and ledge-like overgrowths are the most frequent types of phreatic speleothems in Majorca. Phreatic sea level pools, in caves partially drowned during the last Postglacial, are the specific physical environment in which these phenomena occur today. Furthermore, in several other caverns, over thirteen pleistocene paleolevels of the Mediterranean sea have been recorded above the present-day pool level.

These phreatic deposits are arranged radially around the tip of stalactites which penetrate the pool water surface or grow around any other suitable support. Both calcite and aragonite have been identified as their main constituent minerals. Optical microscopy, X-ray diffraction and scanning micrography of several samples collected in Cova de Sa Bassa Blanca seem to indicate that needle-like crystals of aragonite result in smooth-surfaced subaqueous overgrowths. On the other hand fibrous calcite and rhombohedral calcite crystals cause rougher and more wrinkled morphologies, very similar to some rimstone pool accretions.

We presume that the petrological, geochemical and mineralogical differences existing in the deposits left by the different Pleistocene epochs, will allow us to determine the Paleoclimatic conditions under which they were formed and also the evolution in time undergone by those.

Résumé

Les nombreux exemples de spéléothèmes subaquatiques actuels et fossiles rencontrés dans quelques grottes côtières de l'Ile de Majorque (Espagne) mettent en évidence l'importance des processus de précipitation des carbonates au niveau de la zone phréatique karstique.

Les cristallisations flottantes, les revêtements pariétaux et les concrétions sous forme de bandes de niveaux sont les spéléothèmes phréatiques les plus fréquents à Majorque. Ils se développent actuellement dans les lacs en équilibre avec le niveau de la mer, situés dans des grottes partiellement inondées depuis la dernière glaciation. Dans plusieurs autres grottes on a trouvé, au dessus du niveau actuel de la mer, treize paléoniveaux de la Méditerranée au Pléistocène.

Ces concrétions phréatiques se disposent radialement autour de l'extrémité des stalactites que restent immergées dans les lacs, mais croissent également sur tout autre support adéquat. La calcite et l'aragonite sont les constituants essentiels de ces dépôts. L'étude en microscopie optique, par diffraction aux rayons-X et par micrographie M.E.B., d'échantillons de la grotte Sa Bassa Blanca prouve, semble-t'il, que les cristallisations subaquatiques d'aragonite aciculaire donnent des concrétionnements lisses en surface. En revanche, les cristallisations rhomboédriques de calcite et celles de calcite fibreuse forment des concrétions rugueuses à aspérités, très semblables à celles trouvées dans les gours.

On peut penser que les différences pétrographiques géochimiques et minéralogiques des dépôts laissés en place au cours des diverses périodes du Pléistocène nous permettront de déterminer les conditions paléoclimatiques sous lesquelles ils se sont formés.

Resumen

Amplios conjuntos de espeleotemas subacuáticos, tanto actuales como fósiles, han sido citados en algunas cuevas costeras de la Isla de Mallorca (España). Este hecho apunta hacia una mayor importancia y generalización de los procesos implicados en la precipitación de carbonatos dentro de la zona freática del karst.

Cristalizaciones flotantes, revestimientos parietales y sobrecrecimientos a modo de bandas de nivel son los tipos de espeleotemas freáticos más frecuentes en Mallorca. El medio físico específico en el cual estos procesos actuan hoy en día lo constituyen los lagos freáticos, establecidos en equilibrio con el nivel del mar en cuevas parcialmente inundadas después de la última glaciación. Además, en varias otras cavernas, hasta trece paleoniveles marinos pleistocenos han quedado registrados por encima del actual nivel de los lagos.

Dichos sobrecrecimientos freáticos se disponen radialmente alrededor de los extremos de aquellas estalactitas que permanecen sumergidas en las aguas de estos lagos, crecienda también sobre cualquier otro tipo de soporte adecuado. La calcita y el aragonito han sido identificados como los principales constituyentes minerales de estos depósitos freaticos. El estudio mediante microscopía óptica, difracción de rayos-X y micrografía M.E.B. de varias muestras procedentes de la Cova de Sa Bassa Blanca parece indicar que los cristales aciculares de aragonito dan lugar a sobrecrecimientos subacuàticos de superficie lisa. Por otra parte, los revestimientos formados por cristales romboédricos de calcita, así como los de calcita fibrosa, originan morfologías más rugosas y ásperas; bastante similares a las cristalizaciones del interior de los gours.

Cabe esperar que la interpretación de las diferencias petrológicas y geoquímicas existentes entre los depósitos dejados por los distintos episodios pleistocénicos permita deducir datos paleoclimaticos muy estimables.

Introduction

An understanding of the forms and genetic factors of mineral deposits occurring in subterranean cavities requires a classification which takes into account their order and relationships. Among the most notable attempts at systematizing these deposits are the studies by HILL (1976), WHITE (1976) and SWEETING (1973). These authors indicate the existence of a limited group of speleothems that have developed in non-aerial conditions: termed "subaqueous speleothems" by WHITE (1976) and "underwater speleothems" by SWEETING (1973). Their classifications, however, fail to consider the hydrogeological zoning in which the speleothems were produced. In this respect it will be useful to remember that the concept of underwater speleothems does not necessarily imply their association with the phreatic zone, since subaqueous deposit environments frequently occur within the vadose zone of any karstic massif; such, for example, is the case of the rimstone pools (gours).

It is thus appropriate to distinguish a specific subgroup of underwater speleothems, which we shall call phreatic speleothems; this term, in addition to indicating the inherent physical milieu of the mineral deposits, serves to establish their genetic location within the hydrogeological zoning of karst. Having defined the concept of phreatic speleothems, it is necessary to take into account the nature of the base level that has determined the deposition of this type of subaquatic speleothems. It is thus useful to distinguish between phreatic speleothems belonging to a continental base level and those produced in direct association with the marine base level (see Table I).

This second division is especially necessary due to the fact that phreatic carbonated deposits occurring in coastal caves (marine base level) are found to be decisively controlled by the altimetric changes in sea level that took place during the Pleistocene, thus permitting interesting observations on chronology and geomorphology. On the other hand, these correlations become more problematic in the case of phreatic speleothems linked with a continental base level.

A few data concerning phreatic speleothems related to a marine base level is available in the literature on coastal caverns occurring in sites as Majorca, Spain

(GINÉS and GINÉS, 1974; POMAR et al., 1976; POMAR et al., 1979); Sardina, Italy (FURREDDU and MAXIA, 1964); Cuba (NUÑEZ-JIMENEZ, 1967; NUÑEZ-JIMENEZ, 1973); and Bermuda (HARMON, SCHWARCZ and FORD, 1978).

The Morphogenic Environment

Throughout the coastal karst of Majorca, the existence of caves whose lower portions are occupied by saltwater lakes is widespread. These flood levels constitute the upper limit of a karstic aquifer found in hydrostatic equilibrium with the present sea level of the Mediterranean.

While these caverns may possibly be attributed to remote speleogenetic processes that took place under phreatic conditions, they have undergone a significant subsequent evolution in vadose milieu (breakdown, aerial stalagmitization) during periods of marine level descent occurring in the course of glaciations. The caves were then partially inundated as a result of the relative rise in sea level connected with interglaciary events. In this context it is not uncommon to find aerial stalagmitic concretions which are submerged in the subterranean lakes so characteristic of the coastal karst of eastern Majorca.

Phreatic Speleothems in Majorcan Caves

In order to describe with greater precision the morphology, texture and mineralogy of phreatic speleothems occurring in Majorcan coastal caves, we shall make a distinction between present-day forming speleothems and fossil speleothems belonging to paleolevels of the karstic ground water table. The chronological implications of this second group of phreatic deposits is the topic of another paper presented at this Congress (GINÉS et al., m. s.). See Figure 1 for a schematic representation of the spatial distribution of these speleothems in Majorcan coastal caves.

Present Crystallizations

Among the phreatic speleothems that are being formed at the present time in littoral subterranean lakes corresponding to the current level of the Mediterranean, we shall mention the following:

a. Floating calcite. Formed by thin plates, white in color, suspended on the surface of the water by surface tensions. These flakes are composed of rhombohedral calcite crystals; the rhombohedrons are usually arranged with the C-axis oriented in a radial direction around the crystallization nucleus. The aerial face of the plates is completely flat due to the fact that precipitation occurs below the air-water interface.

Nucleation of the floating calcite occurs in two forms. In the first form, numerous tiny crystals having edges 5 microns in length occur, growing in conjunction with larger crystals, with edges varying between 10 and 20 microns. In the second form, one can observe abundant "rosettes" characterized by radial crystalline growth and joined to one another by the intergrowth of the rhombohedrons. These rosettes are notable for their considerably more rapid growth, surpassing the tiny initial crystalline generations in size (Figure 2); they reach lengths varying around 500 microns. It is important to emphasize the existence of rhombohedrons with curved edges; these indicate a rapid crystalline growth within the solution. The crystallization nucleus of the rosettes appears to be of mucilagenous organic matter, as identified by dissolving the calcite in diluted HCl. For additional data on the floating calcite, see POMAR et al, (1975) and POMAR et al. (1976).

The deposition of floating calcite would be controlled by such factors as: staticism of the water surface; saturation of carbonates in the water-air interface due to evaporation or to the lowering of partial CO_2 pressure; presence of organic material which is either manifested as a trigger of the precipitation rate or acts passively as a crystallization nucleus.

The floating calcite plates that are mechanically precipitated in the lake bottoms (as a result of dripping or surface movement) undergo significant neomorphic degrading processes-microsparitization-connected with the activity of mocroorganisms.

b. Epiaquatic speleothems. Coinciding with the present plane of phreatic waters in some coastal caves one finds bands of carbonated concretions encircling the lake perimeters. The bands have a constant width of approximately 50 cm.; this measurement corresponds to the extent of fluctuations (tides, waves of atmospheric pressure...) which affect the surface of the subterranean waters. In general, this belt of epiaquatic speleothems occurs as a thick bulge developing along the cavity walls as well as the tip of aerial concretions that are presently covered by water (Figure 3).

This band of crystallizations has a generally symmetrical profile with reference to a horizontal plane that would coincide with the thickest section of the concretion. The maximum thickness, which would correspond to the most frequent water level, shows a progressive decrease upwards as well as downwards; there are thus two definite zones (upper and lower) with an approximately 45-degree incline. The external morphology of these speleothems is rugose, similar to the "coralloidal speleothems" of HILL (1976). Upon closer examination a marked vertical micromorphological zoning is apparent, in contrast to the overall symmetry of the concretion: the surface of the upper zone is composed of small nodules which do not protrude greatly, while the farther down one goes the more evident the prominences become, until they eventually become delicate branchings several centimeters in length. The form and spatial position of the materials that serve to support the growth of the epiaquatic concretions have a decisive influence on the particular morphology adopted by these concretions, which display significant anomalies in their lower zone (POMAR et al., 1979).

The micromorphological zoning shown by the epiaquatic speleothems in a vertical direction results from the microscale arrangement of the crystals of which they are comprised. By means of scanning micrography it can be seen that the upper part of the speleothem is formed of calcite rhombohedrons, measuring 10 to 100 microns and generally having a radial arrangement around certain nuclei, that constitute protuberances of from 0.2 to 0.3 mm. These textural characteristics become gradually modified toward the middle zone of the speleothem, where one finds a greater perfection in terms of morphology and orientation of the crystals. The presence of unidentified organic filaments can be detected in all the crystallizations; these filaments are exceptionally profuse in the lower part of the concretion, paralleling the increase in the degree of degrading neomorphism that affects the crystals.

Epiaquatic speleothems are found genetically linked to the water-air interface of some coastal cavern lakes. Their development and morphology are seen to be dependent upon the periodic fluctuations of phreatic waters, which change is in turn determined by the periodic fluctuations of the sea level. These speleothems sometimes occur associated with the genesis of floating calcite; consequently the epiaquatic crystallizations often include floating calcite flakes deposited on their upper zone.

Ancient Crystallizations

The changes in sea level of the Mediterranean throughout the Pleistocene implied the consequent fluctuations of the ground water table of the karstic coastal aquifers. The alternate positive changes in sea level, linked with glacial-eustatic phenomena, have been recorded in some Majorcan coastal caves by means of the accumulation of ancient phreatic speleothems.

These carbonated deposits form extensive coatings which affect the cavity walls and any other suitable support (aerial speleothems...). The coatings to which they give rise adopt a more or less rounded morphology; such coverings mark level lines corresponding to the water plane under which every enlargement of phreatic speleothems has been produced (Figure 1). Up to thirteen level lines have been detected in Sa Bassa Blanca Cave (Alcudia, Majorca); each speleothem-lining corresponds to the level reached by the Mediterranean during the last interglacial events (GINES and GINES, 1974).

For study of phreatic speleothem samples from Sa Bassa Blanca Cave by means of optical microscopy, X-ray diffraction and scanning micrography has permitted the identification of two distinct mineralogies, each with its own specific external morphology (POMAR et al., 1976). Needle-shaped aragonite crystals growing perpendicular to their supporting surfaces create thick subaquatic coverings with smooth surface morphology. On these coatings, which frequently affect stalactites and other speleothems that have developed in an aerial milieu, aragnote-calcite inversions are observable; these inversions could be responsible for the autofracturing of many of the concretions. On the other hand, subaquatic deposits consisting of fibrous calcite as well as rhombohedral calcite crystals cause external rugose surfaces, quite similar to the concretions that cover the interior of the rimstone pools.

Phreatic calcite coverings are frequently superimposed on previous aragonite coatings (Figure 4).

Coupled with this circumstances is the fact that the various mineralogies determined for the phreatic speleothems of Sa Bassa Blanca Cave correspond specifically to distinct Pleistocene marine paleolevels. A study of the differences in petrology, geochemistry and mineralogy existing in phreatic deposits left by the respective Pleistocene periods will likely permit the substantiation of considerable data regarding the paleoenvironmental evolution of the karstic aquifer throughout the last interglacial episodes.

In studying calcite rafts and epiaquatic speleothems, we encountered processes of phreatic carbonate deposition which were taking place in the water-air interface. In ancient phreatic deposits, the mechanisms of chemical precipitation were not, it would seem, limited to the zone affected by the daily fluctuations of the water plane; on the contrary, they extensively influenced the entire cavity portion that was below the water plane in each period. Even so, in the phreatic coatings of Sa Bassa Blanca Cave, maximum precipitation occurs in the water-air interface, causing the phreatic coatings to have a marked jutting overgrowth comparable to that of epiaquatic speleothems described above.

Conclusions

The study of extensive assemblages of phreatic speleothems in Majorcan coastal caves allows a broader idea of the morphology and texture of carbonate deposits its originating in a subaquatic environment. At the same time it is perfectly clear that carbonate deposition in phreatic littoral conditions is a considerably important process, in terms of magnitude and geographical distribution.

The role of accumulation and cave filling played by phreatic speleothems contrasts with the primacy normally assigned to the processes of dissolution related to the chemical behavior of karstic phreatic waters. Geochemical implications, little recognized al present, are one of the most important conclusions to be drawn from these findings.

Important chronological data result from the altimetric correlation between ancient phreatic speleothems and the paleolevels of the sea occurring in the course of the last 300,000 years. By the same token, the mineralogical and textural differences among phreatic speleothems deposited throughout the Middle and Upper Pleistocene give rise to the expectation that important paleoclimatic and paleoenvironmental data may be obtained.

The existence of phreatic speleothems which are developing at the present time will considerable facilitate an adequate morphogenetic interpretation of ancient phreatic deposits related to marine paleolevels of the Pleistocene.

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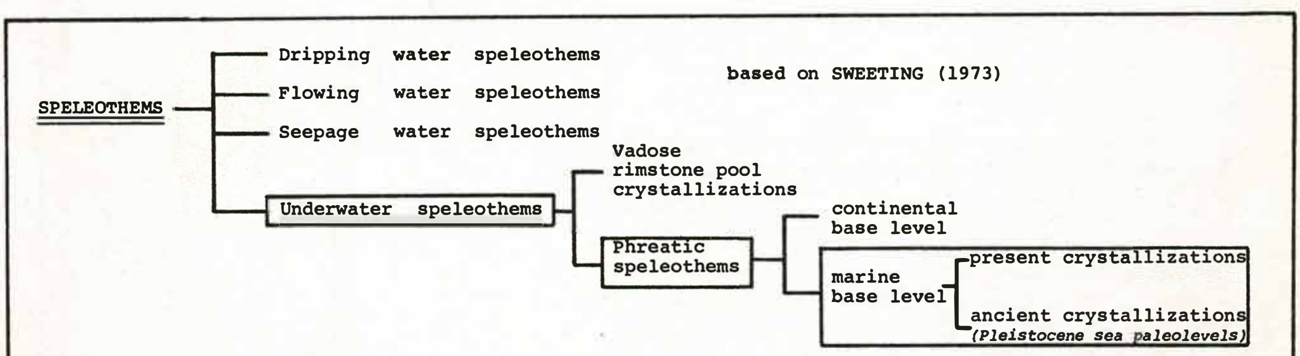

Table I

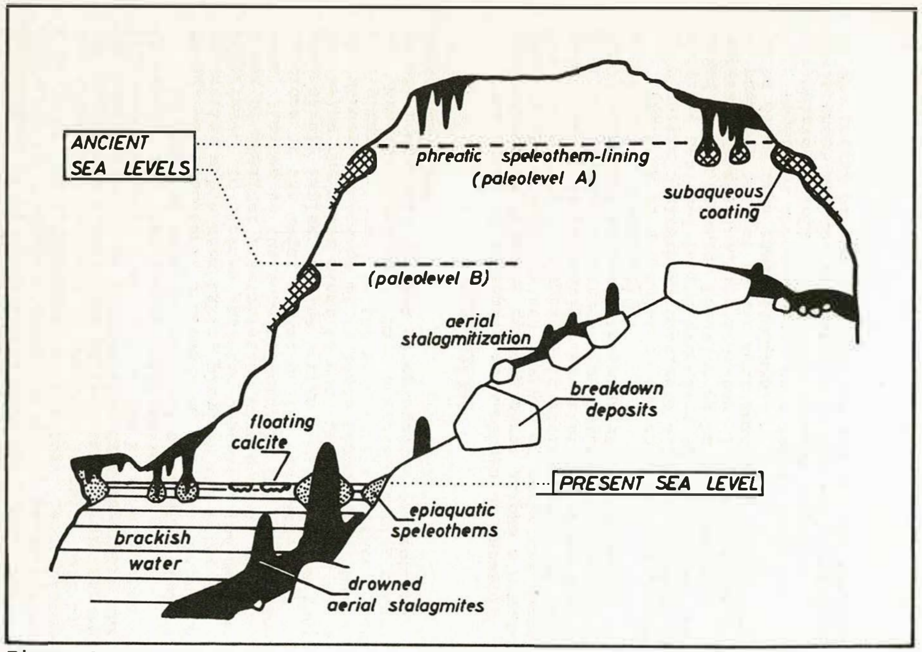

Figure 1

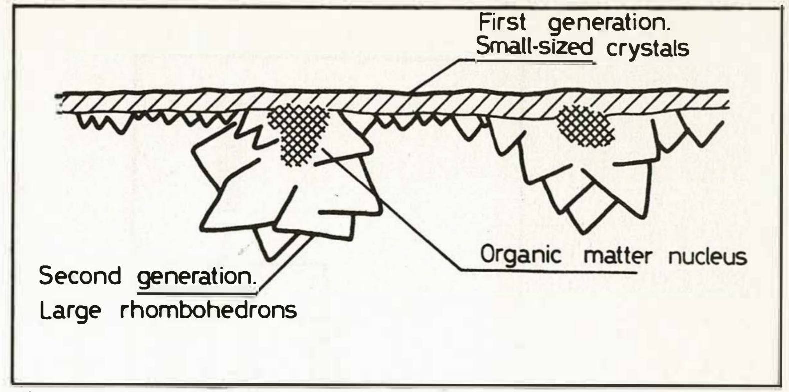

Figure 2 FLOATING CALCITE (Calcite Raft) lateral view

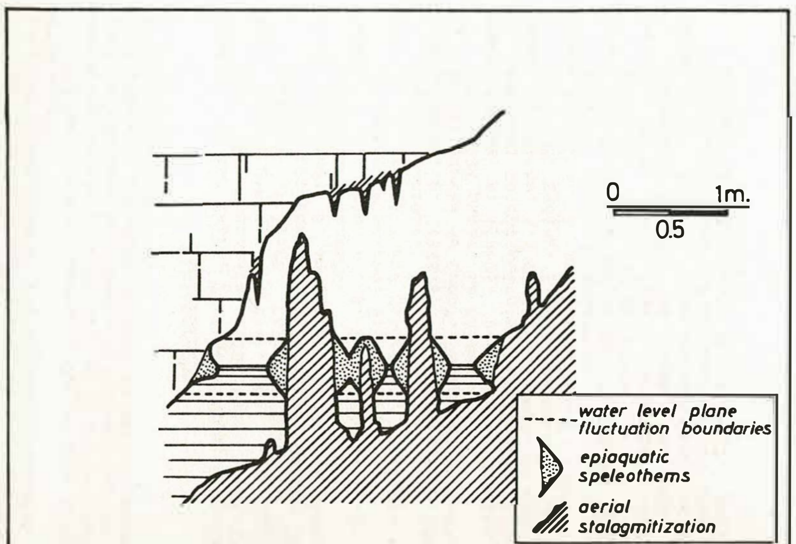

Figure 3 EPIAQUATIC SPELEOTHEMS

Cova de Cala Varques

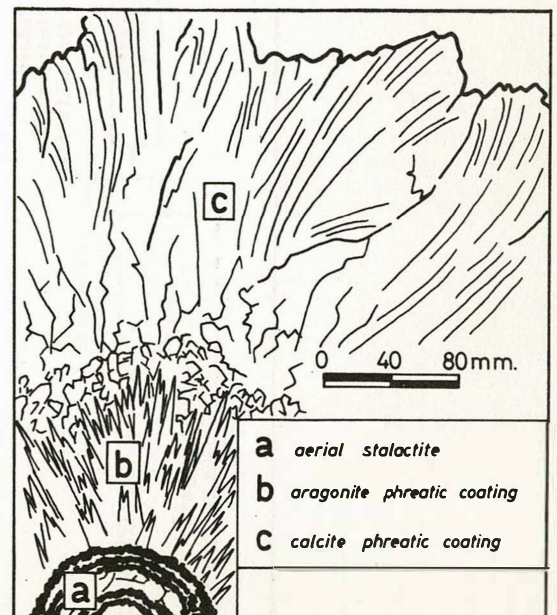

Figure 4 ANCIENT PHREATIC CRYSTALLIZATIONS
Cova de Sa Bassa Blanca

Phreatic Speleothems in Coastal Caves of Majorca (Spain) as Indicators of Mediterranean Pleistocene Paleolevels

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Abstract

Oscillations in the level of the Mediterranean sea during the Pleistocene produced corresponding oscillations of the ground water table in the coastal areas. These levels reached in the Middle and Upper Pleistocene have been recorded in some caves in the Majorcan karst by means of the phreatic crystallizations left by each epoch.

Significant data can be easily obtained regarding speleomorphology and chronology of some coastal caves and their sediments, on the basis of the altimetric correlation between Pleistocene beach deposits and these phreatic speleothem-linings. Furthermore it is possible to survey with great accuracy the sequences of paleolevels and minor oscillations of the sea during the last interglacials.

Research in the Cova de Sa Bassa Blanca has shown successive thick carbonate coatings on the cave wall, which define thirteen speleothem paleolevels ranging from +35 to +1.2 meters above the present sea level pools. Hence it appears that several high levels of the water table have controled the phreatic speleothem deposition during the interglacial events, leading to a sequence of extensive coatings and overgrowths of underwater speleothems on the cave walls. Good altimetric correlations with isotope - and faunal-dated beach deposits in the near coast of the cave suggest the presence in the Cova de Sa Bassa Blanca of several overgrowth levels pertaining to the Midel - Riss interglacial.

Stratigraphic criteria can aid in the interpretation of the complex history of this unusual speleothem infilling, taking into account that the low sea levels corresponding to the glaciations have been recorded in the cave by aerial stalagmitic processes.

Résumé

Les variations de niveau de la mer Méditerranée au Pléistocéne provoquérent des oscillations du niveau piézométrique dans les systémes karstiques littoraux. Les niveaux atteints au Pléistocéne moyen et supérieur peuvent être reconnus dans plusieurs grottes côtiéres de Majorque grâce aux cristallisations phréatiques déposées lors de chaque événement.

Des données significatives, relatives à la spéléomorphologie et à la chronologie de certaines grottes côtiéres et de leurs sédiments, peuvent être facilement obtenues en analysant les couches successives des dépôts marins pléistocénes d'une part et les emplacements des spéléothémes phréatiques d'autre part, afin d'établir des corrélations entre elles. On peut ainsi déterminer avec une bonne précision les variations de niveaux de la mer surveneues pendant les derniéres interglaciations, ainsi que d'autres variations de moindre amplitude.

Les recherches poursuivies dans la grotte de Sa Bassa Blanca ont permis de mettre en évidence des revêtements pariétaux successifs de carbonate calcique; ceux-ci traduisent l'existence de treize paléoniveaux s'étageant entre 1, 2 et 35 métres au dessus du niveau actuel de la mer. La bonne corrélation verticale observée avec les dépôts de plage aux environs immédiats de la grotte (dépôts datés par des méthodes isotopiques et faunistiques) nous a permis de constater la présence, dans la grotte de Sa Bassa Blanca, de plusieurs niveaux appartenant à l'interglaciation Mindel - Riss.

En premiére approximation, on peut attirbuer aux épisodes interglaciaires les périodes caractérisées par la formation de cristallisations subaquatiques, alors que les processus stalagmitiques au sens strict du terme se sont réalisés pendant l'abaissement du niveau de la mer pendant les glaciations.

Resumen

Las oscilaciones del nivel del Mar Mediterràneo durante el Pleistoceno implicaron la consiguiente oscilación del nivel piezométrico en los sistemas càrsticos litorales. Las cotas alcanzadas por dicho nivel freàtico han quedado registradas, en el interior de algunas cuevas costeras de Mallorca (España), por medio de cristalizaciones freàticas depositadas en el transcurso de los diversos episodios del Pleistoceno Medio y Superior.

Datos significativos concernientes a la espeleomorfología y cronología de ciertas cuevas costeras y sus sedimentos, pueden ser obtenidos facilmente en base a la correlación altimétrica existente entre estas alineaciones de espeleotemas freàticos y los depósitos marinos pleistocénicos. Ademàs es posible delimitar con gran precisión las secuencias de paleoniveles del mar, habidos durante los ùltimos interglaciares, así como otras oscilaciones menores.

Las investigaciones realizadas en la Cova de Sa Bassa Blanca han mostrado sucesivos revestimientos parietales de carbonato càlcico, los cuales definen hasta trece paleoniveles de espeleotemas subacuàticos abarcando desde 35 a 1,2 metros por encima del nivel marino actual. La buena correlación altimétrica observable con respecto a los depósitos de playa situados en las inmediaciones de la cueva, cuya edad ha sido establecida mediante estudios faunísticos e isotópicos, permite constatar la presencia en la Cova de Sa Bassa Blanca de varios niveles de concrecionamiento freàtico pertenecientes al interglacial Mindel-Riss.

En una primera aproximación, se pueden atribuir a los episodios interglaciales las etapas de fosilización ilevadas a cabo por cristalizaciones subacuaticas, mientras que los descensos del nivel del mar acaecidos durante las glaciaciones se caracterizarían por procesos de estalagmitización en sentido estricto.

Introduction

Since the end of the nineteenth century, when the speleological richness of the Manacor Marina (the south-eastern karstic region of Majorca, Spain) first became known, the subterranean lakes of this area have achieved considerable acclaim for their touristic interest. Almost all the caverns explored contain brackish lakes that undergo regular fluctuations of the water surface corresponding to the daily fluctuations of the sea level. It is evident that these are phreatic waters existing in hydrodynamic equilibrium with the sea surface, as has been shown by RODÉS (1925) in his tidegraph study of the minor changes in the lakes of the Coves del Dra.

Just as today we can verify the existence of a phreatic flood level that affects karstic caves near the coastline (which level is adjusted by means of hydrodynamic mechanisms with the zero point of the current sea level of the Mediterranean), by the same token in the past there obviously must have been some other varying flood levels corresponding to the various stable periods (of longer or shorter duration) occurring during interglacial Pleistocene transgressions.

Criteria for Interpretation

Recent studies (GINÉS and GINÉS, 1974; POMAR et al., 1979) have made evident the wide range of processes, current as well as fossil, of carbonate precipitation in a phreatic environment; processes which have taken or are taking place within the framework of the subterranean lakes in the littoral karst of Majorca (GINÉS et al., m.s., also presented at this Congress). Some of the phreatic deposits belong to the group of calcite and/or aragonite subaquatic speleothems (POMAR et al., 1976) whereas others appear to be closely controlled by minor fluctuations in the water table, as is the case for floating calcite and epiaquatic speleothems (POMAR et al., 1975; POMAR et al., 1979).

The most interesting aspect of phreatic speleothems found in the ~~caves of the~~ eastern karst of Majorca is probably that of the possibility of establishing altimetric correlations between the phreatic speleothem linings and fossil-beach levels belonging to interglacial stages of the Middle and Upper Pleistocene. In this respect it becomes quite easy to determine precisely the lines of carbonated enlargements, of phreatic origin, corresponding to the water table of each Pleistocene flood level that was experienced synchronicaly by the cave and the coastline.

There are fortunately a large number of studies on the fauna and geomorphology of the many Pleistocene beaches of Majorca; for a synthesis of this information, see BUTZER and CUERDA (1962), BUTZER (1975), CUERDA (1975), and POMAR and CUERDA (1980). There is thus available a wide range of data on sea levels reached during many of the episodes occurring throughout the interglacial events following the Mindel glaciation. This documentation has been corroborated and given greater chronological detail by means of the radioisotopic datings of STEARNS and THURBER (1967). Consequently, the flood levels recorded in many caves as a result of their alignments of phreatic crystallizations permit us to establish altimetric correlations relating to levels detected outside the cave by means of the study of the fauna and stratigraphy of beach deposits.

It is important to emphasize, at the same time, the fact that these alignments of speleothems only constitute the upper limit (corresponding to a paleolevel of the water table) of much more extensive coatings that affect the cave walls located below the speleothem overgrowth level. The various Pleistocene transgressions, with their consequent additions of subaquatic coatings, have caused the superimposition of phreatic crystallization layers, each of which was subsequently separated by intercalations of aerial concretions (dripstone and flowstone speleothems).

Phreatic Speleothems in Majorcan Caves

Just as the precipitation of floating calcite is a common occurrence at the present time in most of the lakes of Majorcan coastal caves, by the same token it is also possible to affirm that processes of epiaquatic overgrowth (POMAR et al., 1979) are particularly active in the present-day lakes of such caves as Cova de Cala Varques and Coves del Drac, among others. The greatest interest from a speleochronological point of view, however, resides in the alignments of ancient phreatic crystallizations located at the same height above the current water table (approximately two meters) in another series of caves; Coves del Pirata, Cova des Pont, Cova den Besso. And even more significant are the large groupings of subaquatic deposits which have developed in the famous Coves d'Artà, in Ses Coves Petites, and above all in Cova de Sa Bassa Blanca. In this last cave, GIÑES and GIÑES (1974) have observed up to thirteen paleolevels of phreatic crystallizations distributed between the datum level zero meters (corresponding to the present water table) and the highest datum measurement of +35 meters; this latter stabilization level of the phreatic surface could only have been reached during the Paleotyrrhenian interglacial stage (or Mindel-Riss, according to the European terminology).

All this leads to the supposition that criteria of altimetric correlation, coupled with a detailed study of the microstratigraphy of speleothem coatings on the walls of these caves, should provide a great deal of information about the complicated history of chemical sedimentation that has taken place, throughout the sequence of paleolevels reached by the ground water table during the last 300,000 years, simultaneously with the glacial-eustatic changes of the Mediterranean Sea (Figure 1). The stratigraphic interpretation which we suggest is broadened by the differences in mineralogy and texture as observed among the various phreatic deposit layers. These differences definitely constitute very valuable paleoclimatic data; by these means for example we were able to confirm, in our initial investigation, that paleolevels of the Eutyrrhenian (Riss-Würm) interglacial age, which are characterized in beach deposits by groupings of Senegalese warm-water fauna, bear a direct relationship to the large accumulations of aragonite subaquatic crystallizations found in the cave.

Another aspect to bear in mind for investigation of the microstratigraphy of these wall deposits is that of the alternate layering of subaquatic and aerial speleothems of calcium carbonate; this alternation is caused by the recurring rise and fall of the ground water table, which in turn is a result of major changes in climate and sea level during the Pleistocene. Thus the retreat of the flood level during glaciations would have been accompanied by intensive development of aerial stalagmitic formations (dripstone and flowstone speleothems), whereas the rises in sea level would have caused periods of subaquatic-concretion development in this type of subterranean lakes (Figure 2).

Chronology of Phreatic Crystallization Deposits

There are only a limited number of studies presenting a chronological interpretation of these processes of carbonate precipitation in the phreatic zone; the first data we have been able to find in the literature relate to levels of stalactites with enlargements existing in the Grotta de Nettuno (Alguer, Sardinia), attributed vaguely to the Tyrrhenian by BALDUCCHI et al. (1956). Cuban speleologists, on the other hand, have made datings, by means of isotopic techniques, of phreatic speleothems from the Cayo Caguanes caves (NUNEZ-JIMENEZ, 1973); they describe phreatic overgrowths to which they assign an approximate age of fifteen thousand years.

The initial aim of the speleological literature on the Balearic Islands was that of correlating Tyrrhenian levels with karstic phenomena (cf. the study on the caves of Formentera Island by MONTORIOL and TERMES, 1965). The chronological study of phreatic speleothems in Majorca and their relationships to Pleistocene beach deposits was launched in 1972 with a paper presented at the Second Spanish Congress of Speleology (GINÉS and GINÉS, 1974). This paper described the unusual assemblage of phreatic speleothems found in Sa Bassa Blanca Cave, assigning to these groupings ages ranging from the Paleotyrrhenian (Mindel-Riss) interglacial up to the post-Würmian warm fluctuations. Subsequent amplification of chronological data concerning phreatic speleothems in Majorcan caves is to be found in GINÉS (1973) and GINÉS et al. (1975). It is reasonable to expect that the detailed study of subaquatic crystallization groupings in Majorcan coastal caves, which study we are carrying out during the present year (1981), should considerably enlarge our knowledge in this area within the near future.

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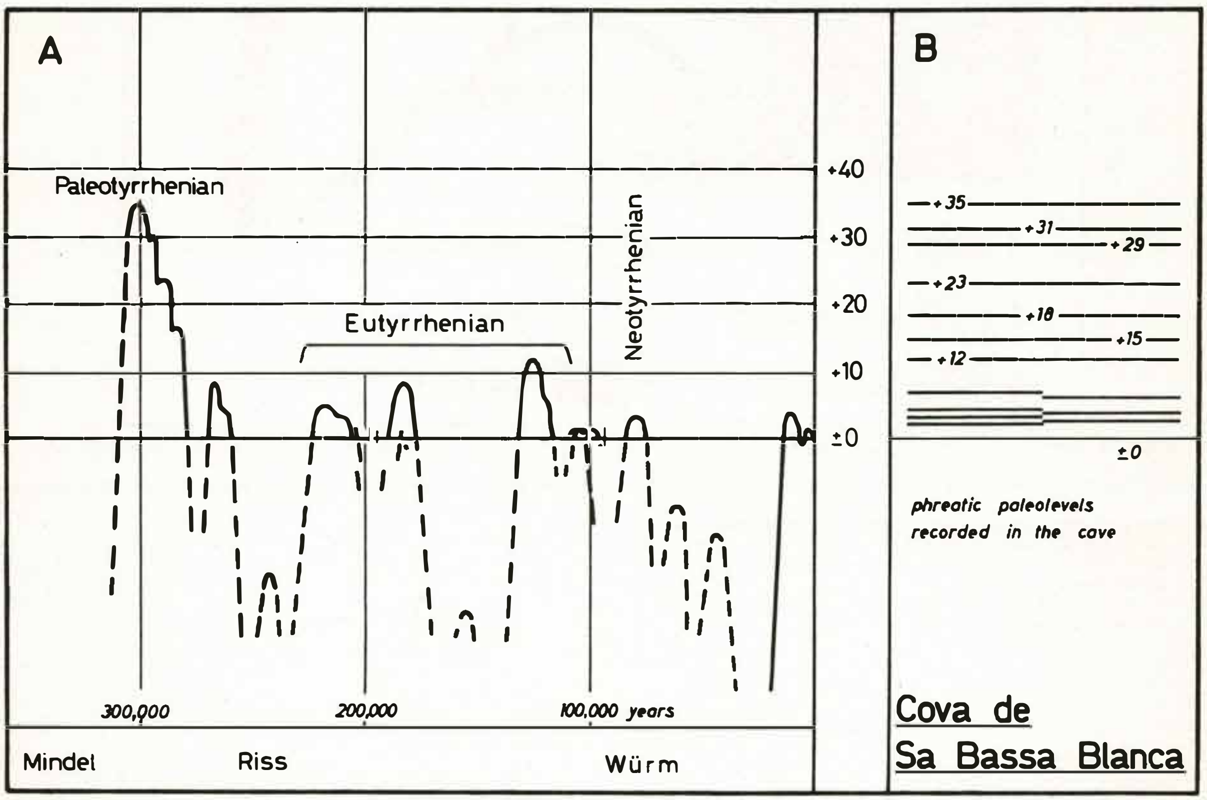

Figure 1

A. Mediterranean relative sea levels as recorded in Majorca. Based on BUTZER 1975 and CUERDA 1975.
B. Paleolevels of the ground water table found in Cova de Sa Bassa Blanca. After GINES and GINES 1974.

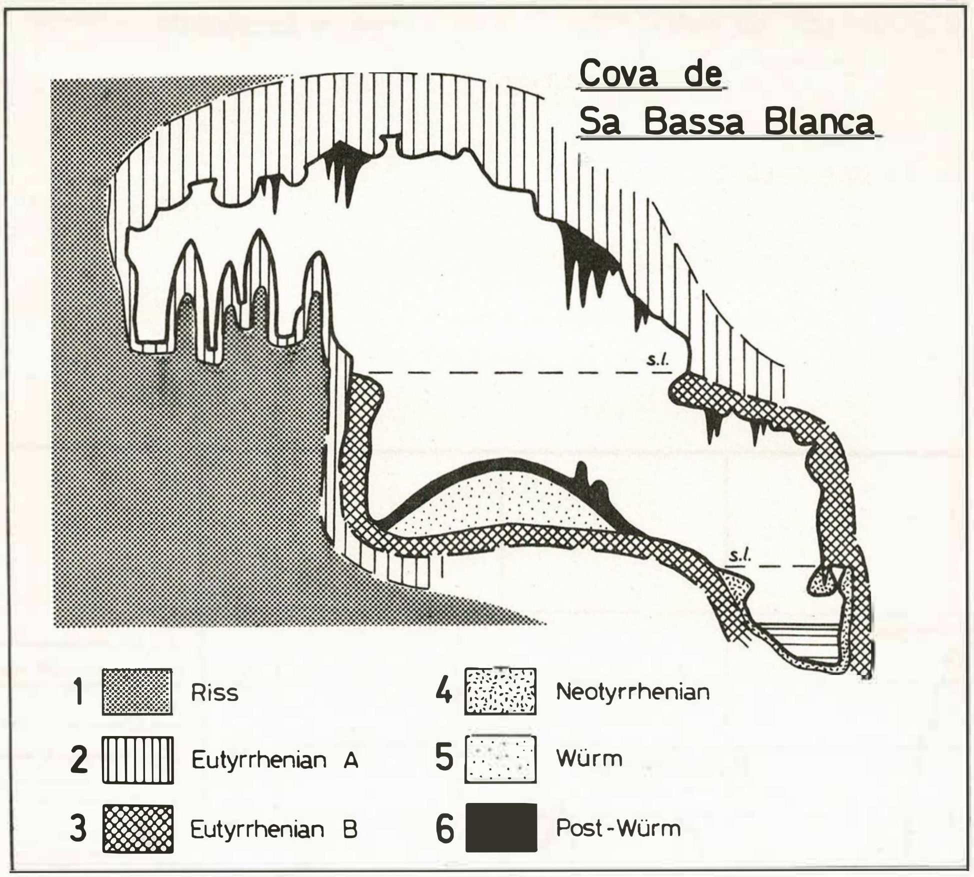

Figure 2

Schematic cross-section of a passage in Cova de Sa Bassa Blanca. A chronological explanation is suggested.

1. Aerial stalagmitization and block breakdown
2. Subaqueous speleothems
3. Subaqueous coating
4. Subaqueous coating
5. Gravity-cone of eolian sand
6. Aerial stalagmitization

s.l. Speleothem lining

The Karsts of the Oriental Part of Cuba

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Abstract

The fundamental characteristics of the karsts of the five oriental provinces of Cuba, deeply studied to prepare the Karstological Map of Cuba, are presented.

The largest karstic unities of this region are: the karstic Herradura of the Cauto, the Litoral karsts of the north, the karst of Gibara, the plane of Nipe, the litoral barriers between Gibara and Moa, the karstic ring of Nipe, the karst of Segundo Frente, the karst of Baire, the karst of Manzanillo, the karst of Cabo Cruz, the Central Valley, the karstic stripe of Guantanamo (sierra of Maria del Pilar, sierra Canasta, the plateau of Guaso, the "cuesta" of Jucaral, the plateau of Caridad de los Indios, the plateaus of Yateras, the sierra of Maquey, the sierra of Caujerí), the litoral karst of the SE, the karsts of Maisí, the karst of Gran Tierra and the karsts in serpentinitic rocks.

Many little isolated karsts are briefly mentioned and grouped by their common characteristics.

In the case of the largest unities are given data - about the rocks, the morphology, the drainage, the evolution, the genesis, etc., of each one of these karsts.

Résumé

Les caractéristiques des karsts des cinq provinces orientales de Cuba, qui furent études notamment pour la préparation de la Carte Karstological de Cuba, sont présentées.

Les plus grandes unités karstiques des provinces orientales sont: le Karstique Herradura du Cauto, les karsts littoraux du nord, le karst de Gibara, les barres littoraux entre Gibara et Moa, le anneau karstique de Nipe, le karst du Segundo Frente, le karst de Baire, le karst de Manzanillo, le karst de Cabo Cruz, le Vallée Centrale, le frange karstique de Guantanamo (Sierra de Maria del Pilar, Sierra Canasta, plateau du Guaso, "cuesta de Jucaral, plateau de Caridad de los Indios, plateaux de Yateras, Sierra de Maquey, Sierra de Caujeri), les karsts littoraux su SE, les karsts de Maisi, le karst de Gran Tierra et les karsts sur des roches vertes.

Beaucop de karsts petits et isolés, qui sont agrupées pour leurs caractéristiques communes sont seulement mentionnées.

Dans le cas des unités plus grandes sont données les notes des roches, de la morphologie, du drainage, de l'évolution et de la génesè de chacun d'elles.

The oriental part of Cuba formed by the provinces of Tunas, Holguin, Granma, Santiago de Cuba and Guantanamo covers an area of about 33,000 km^2 where the karsts sometimes form large and continuous zones, but in other cases are little isolated areas.

The biggest zone, which had not been mentioned in the literature until recently is the Karstic "Herradura" of the Cauto, which surrounds the plane occupied by the river of the same name and which is essentially a karstic surface of tabular type, developed on a continuous crest, always limited by strong slopes directed to the interior. It must be noticed that the limits are erosional and not tectonics. The surface is cut by blind karstic valleys, seasonally active.

This karst sinks, under the fluvio-marine accumalations of the Cauto's plane, in the central part of the "Herradura", where forms a large and continuous area of cryptokarst.

Some parts of the Karstic "Herradura" of the Cauto had been destroyed by radial tectonics movements and had originated raised blocks that can be considered as "mogotes" on account of their rounded tops.

Another karstic zone is related with the pleistocenic limestones that form the litoral margin of the northwestern part of the investigated area. It is a zone of intense karst, well known, by its characteristics of karst of mixed marine-subaereal origin and it is a marine surface recently emerged and dissected by valleys fossilized by the karstification. In its norwestern part there have been formed several lobulate "bolsa" bays, filling karstic depressions, of not too deep polie type, which are actually flooded by the sea. The ways of drainage and invasion of the sea are now the narrow entrances of these bays, in the form of karstic canyons half sank in the sea.

The karst of Gibara, represented by a block of limestones from the middle and upper Cretaceus, is one of the most developed in all the investigated area. It is an asimetric horst where the principal blocks sink gradually to the N and NE and actually form five principal crests. Between these crests there are, at several altitudes, large systems of lobulate complex polies of various types. In the bottom of these polies exist several "mogotes" and relics of the original interfluvial crests, where it had been developed gigant lapies of different types.

A type of individual karst which had been nominated "isolated karst" is dispersed all over the zone of the dome Camagüey-Tunas. Many of the isolated hills of this zone represent independent hills of "inselbergs" type, which means, monadnocks or hogbacks formed in limestones from the Upper Cretaceus, folded together with anothers vulcanosedimentary and instrusive rocks. More to the E. sometimes, the estructural crests of the Holguin anticlinorium are toped by metamorphic cretacic limestones which form clippes hills, related to broken blocks, isolated and submerged in the hot mass in the moment of its intrusion, folded together with it, and latter discovered by the erosion of the meteorized igneous rocks which surrounded them.

Independently of the clippes hills considered as isolated karst, exist too calcareous hills and plateaus, developed in oligo-miocenic limestones which are isolated parts, strongly karstified, of the surrounding "cuestas" remaining as relics. The biggest is the Yaguajay hill with 286 m.

An area with independent characteristics is over the miocenic calcareous marls which form the ancient barriers between Gibara and Moa, which are arc shaped in its horizontal plane, reflecting the form of the zone with domes of the eastern end of the Holguin anticlinoriun and the north part of the Nipe and Cristal domes. The barriers form massive crests with their fronts looking always inland, and their external slopes strongly karstified and divided in echelons by fossil marine cliffs.

One large area of karst is related to the limestones from the early and middle Miocene, forming the bottom of the Nipe plane, where there are not manifestations of positive forms of the karstic relief on the surface, but they are strongly karstified beneath the cover of deep soils.

A very interesting karstic area is related with the consolidated calcareous deposits which surround the Sierra of Nipe and are known as the Nipe Karstic Ring. Is useful to point, in first place, that this ring is not completely closed and in second place, that in the SE of the Nipe dome-block it is continuous with the calcareous rocks which surrounded the SW of the Cristal dome-block, forming a triangular lobe between these domes and the relief of the Central Valley. Geologically this is a complex ring. In its N part the most ancient stripes are not continuous and the eocenic limestones exist only, over gabbro, as isolated relics with well developed karst. This part of the ring is cut radially by several canyons.

The western arc of the ring is formed by a wide and continuous stripe of eocenic limestones, cut by deep and narrow canyons, until active, and by several complex hanging and blind valleys, some of which end in very deep depressions. The surface between these fossilized valleys forms a typical karst of cupolas and irregular depressions, with numerous caves.

The south part of the ring is prolonged forming a large lobule that penetrates between the Nipe and Cristal domes, which is known as karst of Segundo Frente. It is, in general, a tabular karst of plateaus and "cuestas", interrupted by parcial domes constituted by serpentinitic rocks and of its cover of tertiary and mesozoic piroclatic rocks, or by their blocks raised along the faults and denudated by the erosion. The south limit of this karst is formed by a continuous stripe of oligo-miocenic limestones which sank under a wide zone of marls of the same age.

The karst of Segundo Frente is developed in a deep sequence of limestones intercalated with marls of different ages. Its most western part is characterized by the existence of relics that form isolated hills. From here to the east is developed the external karstic "cuesta" of this karst, where the limestones surrounds in the south several partial domes constituted by insoluble rocks and are cut into deep canyons by the rivers that flow from the domes. The surface is divided by several semifossil vallleys, and the interfluvial crests are transformed in mogotes and karstic cupolas, existing too many irregular depressions, ponors and vertical caves.

Another unity of the karst of Segundo Frente is formed by plateaus, some horizontal and others ascendant to the domes of Nipe and Cristal. They are separated by wide and deep canyons with vertical and echeloned slopes. The largest of these plateaus had developed, by fossilization of a net of consecuent valleys, a system of polies with many ponors and descending caves, separated by karstic cupolas. Its highest part is transformed in an elongated group of asimetric mogotes and cupolas.

The karst of Baire, which forms part of the stripe of crests of the north side of the Sierra Maestra, can be considered between the most developed of Cuba. It is a combination of plateau type karst in the south part and "cuesta" type in the north part. From the geomorphological point of view, the relief has sings of "cuesta", with monoclinal crests cut by valleys and separated by longitudinal basins. In this karst, all the forms are of karstic or fluvio-karstic origin. The crests and the plateaus that remained between the basins and the valleys are transformed in a conical karst, with chains of mogotes separated by "hoyos". The distribution of the positive and negative forms had been determined by the existance of two systems of perpendicular faults. From the paleogeographic point of view, it represents the most ancient surface of all the territory of the Sierra Maestra, with age from upper Miocen to Pliocen.

To the W of the karst of Baire, in the western margin of the Bayamo river, there is a little karst formed by a line of mogotes, separated by fragments of dead valleys, and resting as relics over the insoluble base.

Between the NW slope of the Sierra Maestra and the cost of the Guacanayabo gulf was developed, on calcareous marls, the karst of Manzanillo which is similar by its morphology and hidrology to the Karstic Herradura of the Cauto. It has not surface karstic forms, but the subterranean forms of the karst are very developed beneath the pleistocenic fluvio-marine deposits of the plane, which constituted a SW elongation of the Cauto's plane. The karstified rocks crop out at both sides of this plane.

The karstic zone of the Cabo Cruz is a karstic plateau, cupola shaped, slightly inclined to the NW and the W and limited by vertical cliffs in the eastern and southern parts. The eastern margin is of denudative origin, but the southern is tectonic, and has been transformed by a long and intense marine erosion which formed the well known marine terraces of the zone and especially the famous terraces of Punta Escalereta, where it is possible to distinguish nine levels of emerged terraces. Under the surface the limestones are strongly karstified.

In the territory of the south of the Sierra Maestra there are, in many places, little isolated or separated karstic territories. They are develop in two types of forms. Some as relics of ancient covers and others as monadnocks of the calcareous bodies included in the vulcanosedimentary series of rocks of the Sierra Maestra.

Two little isolated karst are in the northern slope of the Sierra Maestra, one near to Cruce de los Baños and the other in the area of Hongolosongo.

In the north part of the Santiago basin there are chains of hills with calcareous relics and in the south slope of Sierra de la Gran Piedra there are calcareous lens discovered by the erosion of the deep valleys.

A wide development of karst could be found in the Central Valley where all the bottom of this intramontain depression is formed by limestones strongly karstified that only crop out in its margins forming the "cuestas" of the Sierra of Puerto Boniato, where the biggest forms are echaloned canyons that divided it in several isolate bodies. They crop out too along the Jarahueca river near the town of Seboruco forming a well developed conical karst.

In the Central Valley there are several domified structures where the limestones are karstified exactly in the contact with its vulcano sedimentary or intrusive base.

In the northern margin of the mountain chain of Gran Piedra there is a narrow stripe of karst isolated by the erosion, which in its western part forms a very narrow hogback and to the east is cut transversally several times, forming a chain of low mogotes.

The karstic stripe of Guantanamo include the larger territories of elevated karst, of Cuba. Begins in SW with the high monoclinal "cuestas" of the Sierra de Maria del Pilar, with echeloned slope and flat surface with mogotes. In its base there are karstic resurgences.

Non-Relictual Terrestrial Troglobites in the Tropical Hawaiian Caves

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Abstract

The Hawaiian Archipelago is the most isolated group of high oceanic islands. The native fauna reflects this isolation. Conspicuously poorly represented are the aquatic, soil, and cave arthropods of the continents. Nevertheless, highly specialized troglobitic arthropods live in Hawaii's relatively young lava tubes. Many caves species have preadapted close surface relatives still extant and are not relicts. They evolved from representatives of the speciating native fauna as a result of adaptive shifts much as other animals have adapted to exploit novel habitats. Their ancestors mostly either live in rainforests, e.g. Oliarus planthoppers, or scavenge on damp rocky substrates, e.g. Caconemobius crickets. I hypothesize that where there are extensive systems of interconnected subterranean voids, such as one finds in basaltic or karst areas, organic food energy is continually being carried into the deeper voids and out of the reach of surface animals, either because the resource is too diffuse to allow adequate harvestable energy to maintain their lifestyles, because of their inability to locate the scattered resources or reproduce in perpetual darkness, or because they cannot cope with the constantly hydrating atmosphere. Some preadapted species have made the adaptive shift to exploit this resource. These subterranean animals colonize larger cave passages only where their specialized environment is found, and it is here that they have been studied. Therefore, caves are windows through which we may view the fauna within the voids in the rock. But they are imperfect windows, for they are fragile and give the illusion of a food poor environment.

Résumé

L'archipel hawaïen est le groupe le plus isolé des hautes îles océaniques. La faune indigène reflète cet isolement. Les groupes taxonomiques d'arthropodes aquatique terrestres et cavernicoles continentaux s'y signalent par leur rareté. Des arthropodes troglobies qui sont remarquablement specialisés habitent des tuyaux de lave assez recemment formés à Hawaï. Beaucoup d'espèces cavernicoles ont de proches parents épigés préadaptés qui existent encore et qui ne sont pas rélictuels. Ils ont évolué de espèces représentatives de la faune indigéne par des procédés d'adaptation, tout comme d'autres animaux se sont adaptés pour exploiter de nouveaux habitats. Leurs ancêtres habitent en général soit les forêts humides, par exemple Oliarus (cixiides), soit ils fouillent dans le substrat humide et caillouteux, par exemple Caconemobius (grillon). J'admets comme nypothèse que là où il existe de vastes systèmes de réseaux souterrains, comme dans les régions karstiques ou basaltiques, l'énergie organique alimentaire se déplace continuellement jusqu'au zones les plus profondes et se trouve alors hors de la portée des animaux épigés, soit parce que les ressources sont trop diffuses pour que ces animaux rassemblent l'énergie suffisante pour perpetuer leur mode de vie, puisqu'ils ne sont pas capables de situer les ressources à l'état diffus ou de se reproduire dans un milieu toujours sombre, soit parce qu'ils ne peuvent pas supporter l'atmosphère toujours humide. Quelques espèces préadaptées ont évolué et se sont adaptées pour exploiter cette ressource. Ces animaux souterrains colonisent les grottes les plus grandes seulement où ils retrouvent leur milieu spécialisé et c'est là qu'on les a étudiés. Les grottes ne sont donc qu'une fenêtre pour observer la faune dans les espaces vides du rocher. Mais c'est une fenêtre défectueuse, car elle est fragile et elle créé l'illusion d'un environnement qui offre peu d'aliments.

The Hawaiian Islands extend over 2400 km across the northern tropical Pacific. They are the tops of mammoth submarine volcanoes and are separated from each other by deep straits, 50 km or more wide. The islands become older as one moves to the northwest, with the 8 main islands ranging in maximum age from ca. 6 million years for Kauai to less than 700,000 years for the youngest island, Hawaii (Dalrymple et al. 1973). Each island in turn was built by frequent fluid basaltic lava flows. Hawaii Island is still active volcanically. The native terrestrial fauna is represented by those few groups that were able to disperse across more than 3000 km of ocean and successfully colonize the islands. Some of those that won the dispersal sweepstakes adapted to new habitats and evolved into extensive species complexes giving Hawaii a bizarre and unique fauna.

In 1971 a diverse assemblage of terrestrial troglobitic arthropods was discovered in lava tubes on Hawaii Island. This discovery was quite surprising given the relative youth of Hawaii Island and particularly the extreme youth of the lava tubes. Furthermore, according to the then accepted paradigm explaining their evolution and distribution, troglobites were thought to be relicts and to have evolved from populations of troglophiles isolated in caves after their surface populations were extirpated by changing climatic conditions, such as during the Pleistocene glaciations (Barr, 1968; Poulson & White, 1969; Peck, 1974). Terrestrial troglobites were not expected in Hawaii since such extreme climatic changes did not occur and the preadapted moisture-loving groups that colonized caves on the continents are conspicuously poorly represented in Hawaii.

To dates more than 30 species of terrestrial troglobites have been discovered in Hawaiian lava tubes. Most of these are found on the youngest island of Hawaii, but others are known from Maui and Kauai. In fact, at least 8 groups have independently evolved troglobitic species on two islands. This indicates that cave adaptation is a general process and not an exceptional phenomenon.

On Hawaii Island the richest caves faunistically occur in high rainfall areas and in the younger (100 to a few thousand years old) flows of Mauna Loa and Kilauea Volcanoes. However, troglobite distribution is more strongly correlated with the presence of the stable saturated cave environment (Howarth, 1981) than with climatic zones. Most groups appear to have invaded caves only once on each island, although the cave moths, Schrankia spp. may be an exception.

Recently, (Howart, 1980) I proposed a bioclimatic model to explain the observed distribution of terrestrial troglobites. I believe that troglobites have evolved to exploit the organic resources washing or falling into the deeper small voids in fractured cavernous rock. In the deeper zones of this system the environment is a rigorous or harsh one for most terrestrial animals. It is perpetually dark, with a relatively constant temperature, with a constantly saturated atmosphere that is above the limits of many terrestrial arthropods, and without many of the enviromental cues used by surface species. The geological and biological evidence supports the view that these voids exist and that they are colonized by troglobites (Macdonald & Abbott, 1970; Howarth, 1981). Troglobites colonize cave passages only where their specialized environment is found. The occurrence of troglobites in lava tubes less than 100 years old indicates that subterranean disperal occurs. The important discovery by Ueno (1977) that fractured but non-cavernous rocks in Japan are also colonized by troglobites corroborates this thesis.

Significantly, close surface relatives are still extant for many of Hawaii's troglobites. These epigean relatives inhabit either of 2 very different habitats: rainforests and barren wet rocky substrates. Of the species that apparently invaded caves from the rainforest the cave cixiid, Oliarus polyphemus Fennah, the moths, Schrankia spp. and the threadlegged bug, Nesidolestes ana Gagné & Howarth, are the best examples.

The Caconemobius crickets are the best examples of species adapted to wet rock habitats. Their evolution encapsulates the phenomena of disperal, colonization, and adaptive radiation, and provides insight into cave adaptation in general. The genus Caconemobius (Gryllidae: Nemobiinae) is endemic, that is it is found nowhere else but in the Hawaiian Islands. All known species are apterous and apparently restricted to wet rock habitats, and different species are adapted to caves, cliff faces, rocky seacoasts, and young lava flows. There are at least 3 distinct species known from the Island of Hawaii. The presumed ancestral species, undescribed, lives in the splash zone along the rocky seacoast. The troglobitic species, Caconemobius varius Gurney & Rentz, lives in lava tubes from near sea level to over 2000 m elevation. The third species, C. fori Gurney & Rentz, lives on young unvegetated lava flows near Kilauea Volcano (Howarth, 1979).

The presumed ancestral habitat of Caconemobius is the wave splash zone of rocky beaches, and one or more species occupies this habitat on all of the main islands. This seacoast species lives in a moist saline environment and can probably survive oceanic dispersal. They are all strongly nocturnal and scavenge on the wave-tossed debris within the wet rock zone. They hide by day deep in cracks and voids and occur only where the boulder pile or sea cliff affords them suitable daytime retreats (Rice & Otte, in Pres.). This is a common habitat on the young island of Hawaii, where so many young lava flows have reached the sea. Undoubtably a marine littoral cricket was an early colonist along Hawaii's rocky shores.

This seacoast species was preadapted to colonize other wet rock habitats that meet the seacoast, such as sea caves and lava tubes. At some time, independently on Kauai, Maui, and Hawaii, populations of seacoast crickets made the physiological transition from salt to fresh water habitats and moved inland from the sea. On Hawaii Island, one group was able to find the required moisture deep within cracks, lava tube entrances, and other voids in young unvegetated lava flows, and instead of feeding on wave-tossed debris they fed on the organic material carried out onto the young lava by wind. This adaptive shift opened up a new habitat with a rich resource much larger than that along the seacoast. Thus the new population was able to expand and adapt rapidly to the new environment and evolved into C. fori. This cricket is so highly specialized that it lives only on unvegetated lava flows near Kilauea Volcano. It is strongly nocturnal and colonizes new flows within a month after an eruption, long before macroscopic plants appear. It disappears by the time the flow becomes vegetated (Howarth, 1979). The habitat is a rigorous one, but not so tenuous on the nearly continuously active Hawaiian volcanoes, since new flows cross older flows before the latter can become vegetated. Thus, the habitat has been available possibly as long as the island of Hawaii has been subaerial, i.e. ca 400,000 years (Epp, Personal communication).

Either the lava flow cricket or the coastal cricket found another wet rock habitat within the voids and caves of young lava flows on Hawaii Island. Basaltic lava, particularly pahoehoe, is so porous from gas vesicles, cracks, lava tubes, and other voids that there exists within the younger flows an extensive system of interconnected channels and air spaces. A distinct troglobitic species, C. varius has evolved to exploit this subterranean resource on Hawaii Island. Compared to its surface relatives, C. varius has vestigial eyes, thinner, paler translucent cuticles, longer thinner appendages, particularly the hind legs, and a lower metabolism with no indication of a circadian rhythm. Cave populations display great variability, and it is possible that there is more than one species (Gurney & Rentz, 1978; Rice, personal communication). The troglobitic species is an omnivore, feeding on tree roots and as a scavenger and opportunistic predator, especially on the animals which blunder into the caves from the surface.

From the morphology of their genitalia and the spination of the legs, the two inland species, C. fori and C. varius, are more closely related to each other than either is to the seacoast species, even though the ~~two epige~~an species superficially look alike while the troglobitic species appears quite distinct. There are two additional troglobitic species on the neighboring older island of Maui. These are allopatric but are closely related to each other. They appear to be more closely related to the group of seacoast species than they are to C. varius, even though they superficially resemble the latter. They certainly evolved independently and from a different ancestor than did the Hawaii Island troglobite. Furthermore, there is absolutely no geological or biological evidence of a land bridge between Maui and Hawaii.

Although one cannot deduce from the evidence the timing of the speciation events, the fact that, morphologically, C. fori and C. varius appear closely related indicates that they have an immediate common ancestor and suggests that there was one adaptive shift from salt to fresh water habitats and that the populations subsequently diverged into two inland species. This does not necessarily argue in favor of sympatric speciation as the three habitats (seacoast, lava flow and caves) are distinct from one another and have little overlap. Thus at most one could envision parapatric speciation. Perhaps isolating mechanisms developed at the overlap between the diverging populations since the heterozygotes might have been less adapted to either habitat. There is also the possiblity that the original seacoast species was replaced later by another immigrant species from Maui Island, thus isolating the inland populations.

These three troglobitic species of Caconemobius, one on Hawaii Island and two on Maui Island, clearly fit the same pattern of adaptive shifts and evolution to exploit a rigorous novel habitat also displayed by their congeners and indeed by many other native groups in Hawaii. Far from being ancient relicts in the sense of Vandel (1965), Poulson & White (1969) and Leleup (1967; 1976), these cave species are youthful and evolving specialized morphology, physiology, and behavior in order to exploit a rich but, at least for their surface relatives, a rigorous or harsh environment. The remarkable similarity of cave adaptations among such a diverse assemblage of troglobites worldwide strongly indicates that the animals are evolving through natural selection to adapt to the similar cave environment. This does not imply that troglobites have led many cave biologists to assume an ancient lineage and, therefore, not to look for the surface relatives. I suspect that if these three species of cave crickets were found allopatrically in neighboring karst areas in temperate regions, they would be described in a new genus with a prefix either "Speo-" or "Troglo-", and their relatives, also blind would be sought in some boreal forest rather than among the big-eyed crickets along neighboring wet rock habitats.

The evidence suggests that troglobites evolve from preadapted habitual visitors or accidentals in the cave rather than from well-adapted troglophiles. The former group requires an adaptive shift in order to fully exploit the cave resources. This adaptive shift may lead to the evolution of a troglobitic lifestyle. Well-adapted troglophiles on the other hand tend to remain opportunistic exploiters of the cave environment.

Some temperate troglobites may fit the scenario of isolation by changing climates (Barr, 1968). However, many species including those in the trophics probably do not. I postulate that adaptive shifts led to the colonization of caves and evolution of troglobites, including most of those in temperate caves, but that the complex geological history of the continents including glaciations has obscured the early history and obfuscated the earlier distribution and the evolution of troglobites there.

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Effects of Cyclones in the Karst of Cuba

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Abstract

During the days 10 and 11 of September 1979 the western part of Cuba suffered the effects of a Tropical Ciclon which according to the meteorological categories was only a depression. But this depression whose name was Frederic has not the strong winds that are necessary to be placed a hurricane but was followed by an enormous area of precipitations.

The amount of 500 mm of rain reached in the pluviometer of the international airport "José Martí" of Havana, constitute a new record in the ciclonological history of Cuba for a period of 24 hours. By this reason a great part of the mentioned airport and the surrounding part of the town, like others areas situated some kilometers to the west and to the south, were covered with several meters of water which could not drain by the surface because this mentioned flowded areas are situated in karstics depressions.

Résumé

Pendant les jours 10 et 11 de Septembre 1979 la partie occidentale de Cuba a souffert les effects d'un cyclone tropical lequel d'accord aux catégories météorologiques il a été seulement une dépression. Cette dépression, de nom Frederic, n'a pas eu les forts vents par etre cataloguée comme ouragan, mais elle fut suivée par une énorme aire des précipitations.

La quantité de 500 mm de pluie chute au pluviométre du aéroport international "José Martí" de La Havane, constitue un nouveau record dans l'histoire cyclonologique de Cuba pour un periode de 24 heures. Par cette raison, une grande partie du mentionné aéroport, autant que d'autres zones situées quelques kilométres au Ouest et au Sud, furent couvertes par quelques métres d'eau qui ne pouvaient pas drainer, puisque les mentionnées zones sont situées dans des dépressions karstiques.

During the days 10 and 11 of September 1979 the western part of Cuba suffered the effects of a Tropical Cyclone which according to the meteorological categories was only a depression. But this depression whose name was Frederic has not the strong winds that are necessary to be placed a hurricane but was followed by an enormous area of precipitation.

About the biggest amount of rain fall in Havana Province, which is a very flat low area, mainly in the central and south part with a narrow chain of elevations in the northern part.

The amount of 500 mm of rain reached in the pluviometer of the international airport "José Martí" of Havana, constitute a new record in the cyclonological history of Cuba for a period of 24 hours. By this reason a great part of the mentioned airport and the surrounding part of the town, like others areas situated some kilometers to the west and to the south, were covered with several meters of water which could not drain by the surface because this mentioned flooded areas are situated in karstics depressions.

Those depressions were sealed by the action of man over centuries by urbanization, agriculture, earth movement, airport construction and highway construction, among others things. This negative action had not been seen before, because it grew progressively and there were not rains of this proportion during the present century.

Western from Havana airport is the little lake called "Laguna de Ariguanabo", drained by San Antonio river which runs about 5 kilometers over the surface and reaches the town of the same name where it pass through a cave. This cave was not big enough to swallow the waters brought by the river, and on account of it the level went up to 10 meters over the normal height, and made possible the overflow of the natural dam represented by the limestones in the area of the ponor, covering a great part of the plain south of the town of San Antonio.

During an aerial exploration done just after the end of the strong rains, we could observe how the waters had taken the fossils valleys not normally used. The waters through this valley reach the town of "Güira de Melena", situated about 10 kilometers to the South the same as many thousands of years ago when in this area they reached the shore line.

We must say that the water spread all over the surface, for in this area do not exist any valley because it was under sea level when the river cut the valley that is now fossil. We must say too that Güira de Melena is only 16 meters over sea level.

This fact shows us that the fossil valley is really a semifossil one which could be used by the river under special conditions.

Another phenomena of great interest could be observed during the cyclone Frederic. It was the reopenning of fossil ponor which were filled with terrigeneous deposits of red soils. When this ponors were activated by the action of the pressure of the water accumulated over them and inside the subterranean cavities, the water suddenly dissappeared through them and finally new dry caves could be explored in places where they were not expected.

In the area of the town Ceiba del Agua the normal drillings made by the farmers for water supply became artesians, on account of the height level reached by the water table. Near to this town a cave which is normally used for champignon (mushroom) production, was transformed into a very active ponor and some of its galeries were completely flooded.

Although many other particular phenomena were observed, we believe it is unnecessary to mention all in this work.

Cuba, during the last two decades, has developed a very well equiped meteorological service, with a well distributed net of stations and five meteorological radars, which has, among its fundamental tasks, to protect the Cuban people from the destruction done by the hurricanes.

But in this case we see once more that the development of science must be simultaneous with the study of the karst phenomena by specialists who understand its differences from general laws for non-calcareous regions.

There were some of the damages caused by the tropical depression "Frederic" when it passed through the western part of Cuba on September 10 and 11. We shall present some of the karstic-geological elements which, jointly with the great rains, made possible the great flood we mention above.

Ariguanabo basin

The Ariguanabo basin has a total area of 185,6 km^2 and it is formed by the sub-basin of Gorea, 64,4 km^2, the sub-basin of the Ariguanabo lake, 108,9 km^2 and the sub-basin from San Antonio river, 12,3 km^2. This river, as we have already said, constitutes the superficial natural drain of the whole Ariguanabo basin.

The pluvial precipitation average is 1,600 mm, infiltration 0.30, which makes the average volume to be exploited almost 74,000 m^3 a year.

This basin is a complex one, for it does not have a geological nor structural uniformity, having also a great lithological variability. From a topographic point of view it is a well-defined basin.

The Ariguanabo lake is the largest of all its sub-basin, and its origins are due to the processes of denudation and flattening that have been shaping this area. All the superficial and subterranean flows converge in this area and at the same time carry putrid organic materials, as well as the products of erosion, lixiviation and decalcification, that have obstructed the subterranean conducts.

In the undersoil of the lake there is an abudance of limestone and marly limestone with some sandy layers of the Inferior Miocene to the Mid Miocene, with the presence of cavernous and typical limestone of the Güines Formation.

There are compact sediments of low porosity which act as retainers of water and belong to the Oligomiocene, as well as to the Superior Oligocene, mainly in its marly stages.

The presence of these low permeability rocks is what retains the water in the undersoil and does not let it go beyond it.

These geological elements favoured the storing of millions of cubic meters of water in the Ariguanabo lake in the days subsequent to the tropical depression.

Vento basin

Geological studies made in our country have demonstrated that there is no real and well-defined limit between Ariguanabo and Vento basins. In some plains such as the ones between the villages of Rincón and Murgas there is a contribution of the Ariguanabo basin to the Vento basin.

This circulation has taken place when the groundwater level has reached 60 meters of altitude, which can be achieved after intense and continuous rains, when the undersoil has become saturated.

This circulation takes place in the direction already mentioned, from Ariguanabo to Vento, through deep cracked rocks that are known to exist in the Northeast generally.

This circulation between the basins of Ariguanabo and Vento when the groundwater level has reached 60 meters of altitude, is what contributed partly to the rapid flood of Boyeros area, which belongs to Vento basin, as all the springs of the zone became artesian and most of the ponores became springs, as it happened in Aguada del Cura.

Talking with the neighbours of that area, they told us that the water had come from the Northwest just like the sea and in a few minutes all was flooded.

We must point out that because the force of the flow opened the fossilized ponores, many of these areas were immediately drained, probably because they run into other basins, as Vento basin was completely saturated and its level was several meters above the surface of the land.

Geological studies made by the engineer Jesús F. de Albear show that "the variations detected in the equipotential curve in water wells, during several years of observations, including those with great cones of influence such as the city aqueducts, have demonstrated that in natural, adequate and normal conditions, the subterranean waters should have overflowed from Ariguanabo lake to Vento basin.

San Antonio de los Baños river

This river feeds itself from the overflow of Ariguanabo lake from the south till it sinks its ponor and continues its course underground.

In serveral occasions gauging has been done in two places on the San Antonio river, one of them at the outlet of Ariguanabo lake and the other one some 200 meters before its submergence within San Antonio village. After comparing both measurements it is obviously deduced that the river receives subterranean contributions that have a great influence on its flow.

These contributions have been studied by the author. Many of them manifest themselves as potential springs in the bank of the river as well as in the form of minor subterranean currents that flow from small caves near the bank of the river.

Alpine Karst in the Sierra Nevada, California

Bruce W. Rogers

Abstract

Small areas of alpine karst have developed in the Sierra Nevada in calcitic to dopomitic marbles in roof pendant rocks from Ordovician to Triassic age as well as Recent travertines. The karst areas are located along the eastern uplands of the Sierra black from Yosemite National Park at an elevation of 2500 m southward past Mount Morrison - 3050 m, Kaiser Peak - 2700 m, Big Pine Creek - 3400 to 3600 m, to Sequoia National Park - 2600 to 3100 m. The caves present range from a few meters to nearly 2 km in length, commonly averaging about 250 m long. Major caves are generally developed in the calcitic marbles. Calcitic marbles weather to a solution cup-pitted surface while dolomitic marbles weather to an "elephant skin' texture or nivitation-induced granular disintergration sand. Most surface karren are subdued by glacial erosion and mantling by till. The caves are strongly controlled by the frequency of jointing with major passages parallel to the strike of the jointing. Hydraulic damming of groundwater on the updip side of intercalated insoluble rocks has also localized solution. Sulfuric acid solution derived from disseminated sulfides may have aided solution. Seasonally phreatic conditions are present during spring runoff and snowmelt. Scanty evidence suggests a pre-Wisconsin age for initial solution, filling with clastic sediments, and post-Wisconsin flushing and enlargement. Speleothem minerals consist of calcite and birnesite. Petromorph minerals include actinolite-richterite, diopside, grossularite, quartz, docrase, marcasite, and chlorite.

Introduction

Small areas of alpine karst occur along the crest of the Sierra Nevada in California. These areas are located in small lenses and pods of carbonate roof pendant rocks atop the Sierra Nevada Batholith. The rocks include calcitic to dolomiyic marbles which are remnants of a former metamorphic terrain. The roof pendants range in age from Pennsylvannian to Triassic with one small area of Holocene travertine. The marbles display a generally linear foliation striking about N. 30° W. with a near vertical dip. Joint sets with near vertical or horizontal dips trend parallel or at right angles to the regional foliation.

Yosemite National Park

The northernmost known karst area occurs along the Sierra crest in Yosemite National Park at an elevation of from 2300 to 3980 m. The roof pendant rocks here are composed of upper Paleozoic to Triassic age. The white, coarse-grained marble is locally mantled with till (Wahrhaftig, 1955-74). Forsythe Cave, the largest reported cave, is located in a small lens of marble near the northern tip of the Park at an elevation of 2683 m. The cave passage trends nearly east-west, against the strike (about N. 45° W. and N. 40° E.) of the primary joint sets that dip steeply. Foliation at the cave strikes nearly north-south and has a near vertical dip.

Most of Forsythe Cave consists of low, linear stoopway passage generally less than 2 m in height. One large room 14 m long is located near the center of the 155 m long cave. This room and scattered portions of the other passage reach a height of 8 to 10 m. An active stream flows the entire length of the cave. The cave appears to have largely developed during spring runoff. Minor development has taken place during summer and fall low flow conditions.

Somewhat farther south, small solution tubes up to 0.5 m in diameter have been reported in marble on the east side of Tioga Pass (at an elevation of about 2500 m) and near the summit of Mt. Dana (elevation 3980 m).

About 50 km to the southeast at Mt. Morrison and McGee Creeks lies a large Pennsylvanian to Permian age marble lens (Rhinehart and Ross, 1964). The grayish-white Mt. Baldwin marble strikes about N. 10° W. with a near vertical dip. There is a large cave on the north wall of Mt. Morrison, as well as many smaller openings on the east walls of Laurel and Bloody Mts. At elevations of from 2400 to 3740 m on Mt. Baldwin are many small solution pockets many of which are partially filled with optical grade calcite (Huber, 1981).

Kaiser Peak-Twin Lakes Wilderness

The Kaiser Peak-Twin Lakes karst area lies about 40 km farther southwest of Mt. Morrison. The karst area occurs in upper Paleozoic or Triassic-age marble. The marble ranges in composition from calcitic white, or gray-banded rock to a dolomitic buff rock (Bateman, Lockwood, and Lyndon, 1971). A foliation striking about N. 45° W. parallels the marble lens for its 3 km length. Major joints trent N. 30° E. and N. 40° W., with near vertical dips. A third set strikes N. 30° W. with a nearly horizontal dip. The caves are located in the calcitic marble portions of the roof pendant rocks. Karst features in the dolomitic portions are limited to minor, joint-controlled solution and nivitation-induced intergranular disintergration of the marble. Seven small caves are present in the marble lens. The northern-most is 1-2-3 Cave, a 262 m long complex that is 12 m in depth. Phreatic features are common in the passages; most of which are less than 2 m in diameter. Bedrock floors are common. A few calcite speleothems are present, as well as a large wall of actinolite-richterite mountain leather. Meander Cave is about 230 m long and 30 m deep. The upper portion consists of two parallel vadose stream canyons. The lower portion has formed along an inclined marble-hornblende quartz diorite contact. A zone of pink and green diopside, chlorite and marcasite-encrusted quartz crystals are exposed in the walls of the passage. Euhedral 8 cm in diameter grossularite crystals are present along the floor of the passage also. Minor amounts of tan calcite flowstone and stalactites and white calcite moon-milk are present. Swallet Hole, Black Lake, and Hidden Pond Caves have formed along a fault that bisects the center of the marble lens. All three caves have the irregular patterns of phreatic solution. Black Lake Cave has over 60 m of water-filled passage. The three caves have an aggregate of 190 m of passage. Only a few speleothems of white calcite stalactites and draperies occur in the lower portions of Hidden Pond Cave. In the southern portion of the marble lens is a small vadose cave (Spring Cave) which is about 30 m long. 200 m across the adjoining meadow is a series of small karst springs that emerge from blocky talus. About 75 m above the springs is a 2 m in diameter, partially blocked 10 m deep pit with a large inaccessable room at its bottom.

Pine Creek Area

Caves also occur in the Pine Creek Tungsten Mining District, located on the east slope of the Sierra about 30 km east of the Kaiser-Twin Lakes area. The caves occur in a tightly synclinally folded roof pendant of upper(?) Paleozoic age. The marble portion of the pendant is about 5.6 km long, up to 500 m wide, and at least 2 km deep with a N. 20° W. strike and vertical dip (Bateman, 1956). Most of the marble is calcitic. Although the marble occurs at elevations of between 2875 and 3630 m, most of the solution cavites thus far encountered have been located between 2875 and 3335 m in the upper workings of the Pine Creek Mine. When the Zero Adit of the mine was driven, large amounts of water were drained from the caves at rates of up to 7600 liters per minute, and at pressures of up to 11 kg per cm. The caves were found adjacent to the tactite ore bodies. The passages are up to 6 m in width and 60 m in length and parallel to the strike of the tactite and marble. Many are loosly filled with granitic sand and cobbles of marble, granite, and tactite. The bedding of the sands ranges from horizontal to nearly vertical with the latter being more common. Some of the sand fillings have undergone compaction as evidenced by small scale clickensiding along fractures. Sulfide minerals adjacent to the caves are highly oxidized; sulfuric acid may have assisted in the solution of the caves.

Mineral King Karst Area

74 km south of Pine Creek is the Mineral King karst area of Sequoia National Park. Located along the headwaters of the East Fork of the Kaweah River, the karst has developed in the middle of a 19 km

long roof pendant of Triassic-age metamorphic rocks (Christensen, 1963). Some karst is present in the middle of Mineral King Valley in Holocene age travertine. At the northern end of the valley, there is a 2 km long lens of marble containing an active sinkhole plain at an elevation of 2940 m. Large amounts of soil and vegetation are being washed into the 10 m deep sinkholes and cutters. A large spring 180 m below the sinkhole plain may be the resurgence of the karst water (Tinsley, Frantz, and Vele, 1979). Jordan Cave, a 90 m long, 43 m deep decorated cave, and Glacier Plug Cave, a 6 m deep firn-plugged pit, are located in this area. Empire Mine Cave is located 1.5 km to the east of the sinkhole area, at an elevation of 3100 m. The cave was blasted open during silver mine excavations in the late 1870's. Either of two 20 m drops lead to a 36 m long chamber. The chamber was mined from silver contained in galena and argentite(?) ores. Other ore minerals found in the cave include sphalerite, smithsonite, chalcopyrite, and "silver carbonates." Quartz crystals 70 cm in length are also present. The walls and ceiling of the room are coated with soot from a steam engine that was operated during mining operations. Except for a short side passage, the balance of the cave consists of a shaft that drops from the "Engine Room" to the water table about 70 m below the entrance. Several more small caves are located along the lower slopes of the valley as well as a major spring at elevations of from 2640 to 2875 m. All are shorter than 15 m for their accessable portions.

In the southeast corner of the valley is a large mass of marble about 2 km in diameter. Here there are about 14 small caves and springs and a nearly 1 km long system of 5 major caves. Snowmelt enters Alto Cave at an elevation of 3185 m, passes through Bathing, Sink, and Panorama Caves, and resurges at Onion Meadow Spring in the next cirque to the south at an elevation of 3024 m. Most of the cave system floods during the spring with discharges from the spring of near 1 m^3/sec. Sediments in the caves include peat, silt, sand, cobbles, and boulders up to 0.7 m in diameter. Speleothems include calcite stalactities, draperies, flowstone, stalamites, and moonmilk. Crystals of tremolite, grossularite and idocrase are present as petromorphs (Hutchins, 1978). Air temperatures of 7° C and water temperatures of 6° C have been made. Alto Cave consists of a single stream passage about 2 m in diameter that follows joints perpendicular to hornfels beds intercalated within the marble. The stream siphons at the bottom of the cave and emerges as a waterfall cascading over a hornfeld bed in the ceiling of Bathing Cave. That cave is a single passage about 5 m in height with one chamber just below the waterfall about 4 m in diameter. Below Bathing Cave, the stream is exposed for about 300 m where it enters Sink Cave. Sink Cave is a steeply decending vadose stream canyon passage about 4 m high. The cave is largely confined between two 0.3 m thick hornfels beds. The stream disappears into a narrow crack at the bottom of the cave and reappears in the upper end of Panorama Cave. Panorama Cave is the lowest portion of the cave system that can be entered, and is T-shaped in plan. During high discharge, water exits Panorama by either a meter in diameter streamtube passage or by a 3 m kigh stream canyon passage that eventually connects with Onion Meadow Spring. At low discharge, only the latter passage carries the water to the surface.

In the southwest courner of Mineral King Valley is a lens of calcite marble about 2 km in length. Another major cave system as well as 10 smaller caves are located in this lens. A stream from White Chief Cirque enters Cirque Cave at an altitude of 2990 m and traverses 1470 m of passage in Cirque, House, Batslab, and White Chief Caves, reappearing at Resurgence Slot at an elevation of 2970 m some 490 m further down the cirque. Like Panorama Cave system, much of the White Chief system floods during the spring runoff. Scallops indicate flows of as much as 2.5 m^3/sec. Sediments found in the caves range in size from fine sound to boulders 1 m in diameter. There are a few white, calcite speleothems including stalactites, draperies, coralloids, flowstine, and moonmilk. Quartz occurs as centimeter long crystals and birnessite-coated boxwork. Air temperatures of 1.6°C and water temperaturs of 1.5°C have been recorded. Cirque Cave consists of a linear maze of irregular chambers up to 16 m long and 4 m high. The upper portion of the cave is a maze of smaller tubes and canyons about 1 to 2 m in diameter or height. The stream disappears in the lower passage, travels underground about 90 m during summer, low flow conditions, and resurges on the opposite side of the marble lens about 90 m upstream from White Chief Cave. During high flow, the stream overflows Cirque Cave and travels a short distance on the surface and then enters Batslab Cave; resurging slightly upstream from the aforementioned spring. Batslab Cave is a single, 2 m wide, oval phreatic passage with a 2 m deep vadose trench in its bottom. White Chief Cave is a linear maze of large, 30 m long chambers and 3 m diameter tubes of phreatic origin. Many of these passages have shallow vadose trenches cut in their floors. A stream traverses the lower portions of the cave until it sinks within about 30 m of the final resurgence at Resurgence Slot Cave. During drought years a meter-thick ice floor covers the bottom of the main chamber due to the lack of warming water and entrained air normally brought in by the stream.

Located high on the western wall of Mineral King Valley is a 1.5 km long lens of calcite marble. Water flowing from Eagle Lake decends to the marble and sinks in a series of swallets at an elevation of about 2740 m. Several breakdown-choked vertical solution tubes are found along the walls of the blind karst valley that bisects the marble. At the northern, lower end of the marble lens, a large, 7°C spring resurges at 2610 m. It is thought that water from the swallets moves down the lens through solution passages along the strike and emerges at this spring. About halfway down the canyon below the spring is an 18 m high travertine mound with several very small caves. The stream is actively depositing calcite on the flanks of the mound and slowly filling these caves. Another travertine mound is located 1.6 km down the Kaweah River from Spring Creek. Several small caves are located in it. The travertine was deposited from goundwater derived from the sinkhole plain and the marble lens draining Eagle Lake. Subsequent undercutting by the Kaweah River has disrupted the travertine mound and scattered the blocks along the river channel.

Age of the Karst

There is some evidence, especially in the Kaiser Peak-Twin Lakes, Pine Creek, and Mineral King areas that the initial solution of these caves was started in late Wisconsin time; perhaps during the altithermal period between the Tahoe (70,000 ybp) and Tioga (10,000 ybp) glaciations. Surface karst features, and to some extent the caves themselves, were removed by Tioga glaciation. With the waning of the glaciers, sediments were deposited in the caves in some cases filling them. Subsequently moderate amounts of these sediments have been removed from the caves and passages near base level enlarged by seasonal streams (Rogers, 1980).

Conclusions

The karst features of the Sierra Nevada are located in Paleozoic to Mesozoic age roof pendant rocks. They are strongly controlled by jointing and insoluble rocks in the marble. Most caves occur in calcitic marble. Speleothems are scant, but sediments are common, especially the coarser fractions. Many caves are portions of active hydrologic systems usually flooding in spring and draining in the fall. Portions of the caves may be pre-late Wisconsin glacial in age; other portions are undergoing active enlargement.

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Soil Pipe Caves in the Death Valley Region, California

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Abstract

Under present climatic conditions, soil pipe caves are forming in the arid Death Valley Region of California. Two areas were studied: one in Pleistocene Lake sediments in the Lake Tecopa basin and one in Pliocene continental sediments in Cottonball Basin in Death Valley, In the Lake Tecopa locality, gradual upslope retreat of erosion surfaces first generate small, short 5 to 10 m long caves under a massive marl horizon after overlying alluvial fan deposits have been stripped. Breaching of the marl horizon and subsequent greater infiltration of thundershower waters has allowed larger caves to form in the underlying lake sediments. Caves up to 100 m long with rooms of 8 m diameter and 5 m heights have been located. Thin marls and borate-cemented hardpans support the roofs of these caves. Secondary crusts of tincalconite after borax decorate the walls and ceilings as well as actively spall breakdown blocks from the walls. Gypsum(?) crusts and coralloids are reported from some caves. Uric speleothems, amberat crusts and some secondary stream sediments are also present. Breaching of the supporting hardpans allows roof collapse and subsequent transformation of these caves into gulleys.

At the Cottonball Basin locality, stripping away of a desert pavement initiates soil pipe cave development. Most caves located are less than 20 m in length with under 1 m in diameter passages. Although cave passages developed in the mixed lacustrine and terrestrial sediments are of smaller size, the surface development of sinkholes approaches the density of tropical cockpit karst on a smaller scale. Secondary crusts of ulexite are seasonally common. Coallescing of aligned sinkholes gradually removes the roofs of these caves resulting in dendritic gulley complexes.

Introduction

Under present climatic conditions, suffosion caves are forming in the arid regions around Death Valley, California. These soil pipe caves occur in in the finer-grained sediments present in the playa basins. Both lacustrine and continental sediments show piping features. Most of the cave enlargement takes place during the short, violent summer thunder showers characteristic of this region.

Tecopa Lake Basin

At the southeastern margin of Death Valley is a group of suffosion caves located in lacustrine sediments of the Lake Tecopa basin at an elevation of 425 m. Lake Tecopa was one of the many pluvial lakes existent during the Pleistocene. Deposits of this fine-grained sediment accumulated in the lake basin during most of this time (Noble, 1931). The sediments are buff to grayish tan siltstone with minor pale green bentonitic clay, white tuff, and tan to orange marl. Detailed sedimentological study of these beds has shown that they consist of very fine sand and silt. The silt to clay sized fraction is composed of about 60% illite, 30% koalinite, 9% smectite - mostly montmorillonite - and a trace of chlorite. Heavy mineral analysis has shown that the sediments are derived from areas of very varied lithology including Paleozoic sedimentary, Mesozoic intrusive, and Cenozoic sedimentary rocks. Although about 122 m of sediments are assigned to the Lake Tecopa beds Noble, 1931), perhaps as much as the upper 45 m may be alluvial fan material (Snyder, et. al., 1964). A Pleistocene age is assigned to the lake beds based on the occurrence of camel bones within the deposits (Chesterman, 1973).

Cave development is initiated when the overlying sediments are stripped from a 0.6 m thick calcite marl bed. Surface drainage crosses the sediments until it reaches the marl horizon where it sinks along enlarged joints and then pipes out 3 to 5 m long caves up to 1 m in diameter. Most of these initial caves are located along edges of gullies that radiate from the main Amargosa River channel. At several locations, however, collapse of the marl horizon has taken place hundreds of meters from the gullies. Cave development proceeds raidly along vertical joints striking N. S., N. 30° E., and E. W. once the marl is breached. Piping of silts from the underlying sediments enlarges the diameter of the cave passages until lower marl beds are reached. Most of the lower marl beds are thin, 3 to 6 cm, and are easily breached, forming small waterfalls in the cave passages. Vadose corrosion by washed-in sediments, pipping of bedrock silts and spalling of peds and blocks by secondary sulfate and borate mineralization all act to enlarge the caves. Eventually the roofs collapse and the caves become new gullies. Many gullies have relic soil pipe features along their lengths and are usually headed by active soil pipe caves, thus inferring that suffosion cave development may be an important process in slope retreat in this area.

A typical soil pipe cave in this area is Tincal Cave. About 85 m long, it reaches a depth of 10 m. Most passages are about 1 to 2 m deep vadose stream canyons. Meander nitches, floor slots, and potholes are present. About halfway through the cave is a 10 m long breakdown determined chamber. Along its north wall are flowers and coralloids of tincalconite, $Na_2B_4O_7 \cdot 5H_2O$. Crystals of borax have formed in crevices in the walls and, following breakdown of the wallrock, have dehydrated to tincalconite when exposed to circulating air. Temperatures of 20°C and relative humidities of 20% have been observed in the cave. Nearby Adit Cave has stalactites and flowstone composed uric acid derived from bird guano. "White puffy gypsum(?)" has been reported from the back of another low 25 m long cave to the south (Deane, W., 1970). Small deposits of amberat are present in Tincal Cave, Adit Cave, and nearby Tin Pan Cave.

Cottonball Basin

Cottonball Basin is located 85 km to the northeast of Tecopa Lake in approximately the center of Death Valley. At this locality, Pleistocene and Holocene age transported gravels form a desert pavement over Pliocene to Pleistocene (?) age gravelly mudstone and sandstone of the Funeral Formation (McAllister, 1970). Soil pipe caves are locally abundant in both Mustard Canyon and Harmony Borax Works Hill at elevations of about -67 to -73 m. Other suffosion caves have been reported in the nearby Gnomes Workshop area at an elevation of about -49 m (Kastings, 1979). To the southeast in the East Coleman Hills, piping and minor solution have developed pseudokarst features (Hunt, Robinson, Bowles, and Washburn, 1966). Cave development here is initiated when the overlying gravel is stripped from the Funeral Formation. Infiltration of torrential rainwater and subsequent piping remove the silt-sized fraction of the sediments. Capillary action deposits halite and ulexite at the surface of the siltstones causing polygonal ground patterning. Subsequent rainfall is channeled into the cracks seperating the polygons and localizes piping and minor solution at the intersections of the cracks. The spacing of the sinkholes closely approximates that of the polygon intersections. The sinks enlarge at the expense of the polygonal pans until a surface very similar to tropical cockpit karst is formed. Small caves, less than 1 m in diameter and 20 m long, form under this surface (Hutchins, 1979). Relief on the pan surface is limited to the local base level which is located about 7 m below the polygonal pan surface. The polygonal ground pattern is aided in spreading by the formation of low ramparts along the gravel-siltstone contact. Sheetwash is ponded at this rampart and increased sapping of the gravel allows piping to develop in the newly-exposed siltstone. In the interior of the pseudokarst field, swallet divide degredation and cave roof collapse allow debdritic gulley complexes to form.

Conclusion

Suffosion caves are forming in the Death Valley region under present climatic conditions. Stripping of overlying desert pavements allows rainwater to initiate piping in lacustrine and continental fine-grained sediments. In addition, secondary deposition of salts assit in cave formation. Eventual coallescing of swallets and cave roof failure results in the formation of dendritic gulley complexes.

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Karst Development in Siliceous Rocks, Venezuelan Guiana Shield

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Abstract

In the Precambrian shield area of southern Venezuela, there are extensive outcrops of non-calcareous quartz sandstones, siltstones, shales and conglomerates, all slightly metamorphosed and belonging to the Roraima Group. Those rocks are exposed as table mountains in which exceptionally large sinkholes (up to -314 m) and long caves (up to 1350 m) have been discovered. The area is covered by a thick jungle with rainfalls of as much as 4 m per year.

Several hypotheses have been proposed to explain the development of the different cave types:

I) Hydrothermal alteration of the quartzite, softening the rock and loosening the quartz grains and subsequent enlargement of caves by piping. Examples: Simas mayor and Menor de Sarissariñama.

II) Chemical weathering of quartzite, especially along highly fractured zones near the edges of the scarps, and mechanical removal of the grains. Examples: Cuevas de Urutany.

III) Chemical weathering of originally softer rocks, as shales (mainly kaolinite), finely stratified siltstone and conglomerates. Examples: Cueva del Conglomerado and Cuevas de Guaiquinima.

IV) Open fractures near the edges of scarps, with possible enlargement by weathering and grain removal. Example: Cueva del Abismo.

Cave Mineralogy shows very rare assemblages as opal, chalcedony, lithiophorite, iron and manganese and organic materials, pigotite, evansite and a new mineral: Sveite.

All of the above mentioned phenomena are not rare but rather widespread and form one of the most unusual karst types of the world.

Resumen

En el escudo Precámbrico del sur de Venezuela, existen extensas zonas cubiertas de rocas no calcáreas, como areniscas cuarzosas, limolitas, lutitas y conglomerados, todas ligeramente metamorfizadas y pertenecientes al Grupo Roraima. Estas rocas están expuestas formando extensas mesetas, en las cuales se han descubierto simas excepcionalmente profundas (hasta -314 m), asi como largas cuevas (hasta 1350 m). El área en general, está cubierta por una espesa selva con alta precititación de hasta 4 m al año con pH de 3,5 a 4,5.

Varios mecanismos se han propuesto para explicar el desarrollo de los diferentes tipos de cuavas, a saber:

I) Alteración hidrotermal de la cuarcita, ablandando la roca y soltando los granos de cuarzo, con posterior formación de cuevas por "piping". Ejemplos: Sima Mayor y Menor de Sarisariñama.

II) Meteorización química de la cuarcita, especialmente a lo largo de zonas muy fracturadas cerca de los bordes de los acantilados, posterior remoción mecánica de los granos. Ejemplo: Cuevas de Urutany.

III) Meteorización química de rocas originalmente blandas, como lutitas formadas esencialmente de caolinita, limolitas finamente estratificadas y conglomerados. Ejemplos: Cueva del Conglomerado y cuevas de Guaiquinima.

IV) Fracturas abiertas cerca de los bordes de los acantilados, con ensanchamiento por meteorización y remoción de granos. Ejemplo: Cueva del Abismo.

La mineralogía de espeleotemas muestra asociaciones muy raras, como ópalo, calcedonia, litioforita, oxidróxidos de hierro y manganeso, materiales orgánicos, pigotita, evansita y un mineral nuevo: sveita.

Los fenómenos mencionados no son raros, sino mas bien extendidos y frecuentes en el área de Guayana, formando uno de los tipos de carso mas apartados de lo normal.

Vertebrate fossils in lava tubes in the Galápagos Islands

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Abstract

Collections of fossil vertebrates have been made recently in the Galápagos Islands. Lava tubes on the large islands of Santa Cruz, Floreana, and Isabela have yeilded rich fossil deposits, while a reconnaissance of three smaller islands (Genovesa, Plaza, Santa Fé) has been unproductive. Fossils in Galápagos are deposited in lava tubes via roof collapses, through the feeding activities of barn owls (Tyto alba punctatissima), and the capacity of the roof collapse to serve as a natural trap. Many of the fossils are still unstudied, so definitive statements regarding certain aspects of the fossil fauna are not pssible at present. Highlights of the very rich deposit in Cueva de Kubler, Isla Santa Cruz, include three extinct cricetine rodents (Megaoryzomys curioi, Nesoryzomys indefusses, N. darwini) and three species of Darwin's finches that apparently are extinct today on Santa Cruz (Geospiza difficilis and two undescribed forms). In addition, the cucoo Coccyzus melacoryphus, warbler Dendroica petechia, and medium ground finch Geospiza fortis all appear to be absent from the Cueva de Kubler site. When a radiocarbon chronology becomes available shortly, a maximum date can be placed on the colonization of Santa Cruz by these species. Deposits on Isla Isabela are significant mainly for documenting the former existence there of Megoaryzomys and Nesoryzomys. Fossil sites on Isla Floreana are dominated by remains of tortoise (Geochelone), mockingbirds (Mimus trifasciatus), and ground finches (Geospiza magnirostris), each of which is now presumed to be extinct on Floreana.

The terrestrial vertebrates of the Galápagos Islands have been very important in the development of evolutionary concepts. Thus it is ironic that essentially no fossil record has ever been recovered for these renowned insular animals. During three trips to Galápagos (3-17 January 1978, 30 May - 8 August 1978, 1 October 1980 - 6 January 1981), I collected fossils of reptiles, birds, and mammals from lava tubes on Islas Santa Cruz (Indefatigable), Floreana (Charles), and Isabela (Albemarle), three of the larger islands in the archipelango. Thorough searches of the smaller islands of Genovesa (Tower), Plaza, and Santa Fé (Barrington) have produced nothing of paleontological interest. The collected fossils, most of which will be deposited in the United States National Museum of Natural History, Smithsonian Institution, represent the first serious paleontological attempt to document the evolution and past distribution of vertebrates in Galápagos. The fossils gathered during the first two trips are largely identified, although in the reptiles and in certain avian groups such as Darwin's finches, the identifications are still somewhat tentative. Fossils from the most recent trip are presently being cleaned and sorted. Thus this report is but a preliminary summary of my findings as of March 1981.

The Galápagos are characterized by a general lack of alluvial deposits, there being only one functional fresh water stream in the entire archipelago. Most of the fossil sites located thus far are in lava tubes with roof collapses, while one is in a large earthquake fissure. The fossils in each deposit are derived from one or both of two causes: ancient roosts of barn owls, or the action of natural traps. Ancient barn owl roosts are almost entirely responsible for two sites on Isla Santa Cruz (Cueva de Kubler and Cueva de Iguana), while natural trap sites include André's Cave on Santa Cruz and all of the localities on Islas Floreana and Isabela.

That the barn owl, Tyto alba punctatissima, was responsible for the deposition of fossils in Cuevas de Kubler and Iguana is ascertained by the following characters: 1. The sediments lack laminations or any sort of distinct stratigraphic units. This, in combination with the random orientation of the fossils themselves, argues against a fluvial or aeolian orgin. 2. Large vertebrates, such as adults of tortoises (Geochelone) and land iguanas (Conolophus), are either absent or are extremely rare. The fossil fauna almost entirely comprises animals of a size well suited for prey itmes of Tyto. Especially noteworthy in this regard is the overwhelming dominance of the rodent Nesoryzomys indefessus, as Tyto today is known to be very mammalophagous. Also important is the age distribution of the very large, extinct rodent Megaoryzomys curioi. Most fossils of M. curior in Cuevas de Kubler and Iguana are of small, immature individuals; the relative scarcity of fully grown adults suggests that such animals were too large to be taken as prey by Tyto. In contrast, André's Cave, a proposed natural trap site, has abundant remains of adults of M. curior, while immature specimens are rare. 3. Tyto commonly lives in lava tubes on Isla Santa Cruz today, and occurs as a fossil in Cueva de Kubler. The only other owl in Galápagos, living or extinct, is the short-eared owl (Asio flammeus), which is not known to use lava tubes.

Natural trap localities are generally characterized by the presence of large animals, especially tortoises, that apparently fell unintentionally into roof collapses which do not permit exit by non-volant animals. Boney accumulations in natural traps are not as rich, neither in number of species nor in number of individuals, as in barn owl sites. Vertebrate remains in natural trap sites tend to be concentrated near the entrance (roof collapse) of the lava tube in either situation, but in natural traps the fossils cluster rather randomly about the entrance, thinning as one goes farther from the entrance. In ancient barn owls roosts, the fossils are distinctly accumulated below wall ledges that served as the roost.

Certain fossils may represent animals that voluntarily entered the lava tube and died there. In many instances these fossils are difficult or impossible to distinguish from natural trap occurrences or isolated prey remains. However, adults of land iguanas and Megaoryzomys in sites on Islas Santa Cruz and Isabela that are not effective natural traps, and various birds in sites on Isla Floreana (an island where Tyto has never been recorded), may have been deposited in this manner.

Cueva de Kubler

The richest known fossil site in Galápagos is in Cueva de Kubler, Isla Santa Cruz, a large lava tube near the southern coast, 2 km northwest of the Charles Darwin Research Station. Because of the importance of this site, it will be treated in greater detail than other localities. Cueva de Kubler, at an evelation of 80 m, has been described and mapped by Balasz (1972), Montoriol-Pous and de Mier (1977), and Stoops (1967). In 1978, I dug a small test pit (Excavation IIB - 1,0x0.7x0.36 m deep) in unconsolidated, poorly sorted, fine sediment of a talus slope in Cueva de Kubler that yielded thousands of fossils of reptiles, birds, and mammals. Among the reptiles are very small tortoises (Geochelone), lizards (Tropidurus, Conolophus, and Phyllodactylus), and snakes (Dromicus). The birds include the black rail (Laterallus spilonotus), dove (Zenaida galapageonsis), barn owl (Tyto alba punctatissima), vermilion flycatcher (Pyrocephalus rubinus), large-billed flycatcher (Myiarchus magnirostris), mockingbird (Mimus parvulus), and at least ten species of Darwin's finches. The mammals recovered are bats (Lasiurus), two extinct rice rats (Nesoryzomys indefessus, N. darwini), and the huge extinct thomasomyine rodent Megaoryzomys curioi. Nesoryzomys dominates the fauna of Exc. IIB, being known from more than 600 individuals and more than 6000 actual specimens. The only other abundant taxa are the small iguanid lizard Tropidurus and the dove Zenaida galapagoensis, each of which is known from over 100 individuals.

Also occurring in Exc. IIB are bones of two species of introduced rodents, the black rat (Rattus Rattus) and the house mouse (Mus Musculus). Unlike the fossils of native animals, the bones of Rattus and Mus are light in color and are completely unmineralized. Although all five species of rodents occur in all levels of Exc. IIB, the consistant and distinct difference in preservation strongly suggests the non-contemporaneity of native versus introduced species. The apparent mixing of bones is confirmed by the fact that the deposit has accreted vertically from the overflow of the thick sediment accumulation above Exc. IIB. This accretion therefore occurred since the arrival of introduced rodents, probably no more than 60 years ago.

Unfortunately, Exc. IIB yielded nearly no plant material, but instead consists mainly of bones, land snails, and fine inorganic sediment, none of which is very well suited for radiocarbon dating. Two new excavations (IIA, IIC) were carried out in Cueva de Kubler in 1980, from which fossils are now being cleaned and sorted. Based on field identifications, Exc. IIC (4 m downslope from IIB) appears to be very similar to Exc. IIB in faunal and sedimentary features. Exc. IIA, however, contains carbonized plant fragments that are well suited for radiocarbon dating. In addition, Exc. IIA is located above Excs. IIB and IIC in a horizontal section of fine-grained but boulder-ridden sediment that is nestled against the north wall of Cueva de Kubler and is separated laterally from the talus slope by a longitudinal series of boulders. The sediment of Exc. IIA has suppled the sediment of Excs. IIB and IIC through simple gravitational slumping. Thus it appears that the fossils of Exc. IIa are in situ, and have not been subjected to re-deposition like those of Excs. IIB and IIC. Exc. IIA (1.0x3.0x0.8 m deep) was conducted in vertical increments of 0.2 m and horizontal increments of 0.5 m. Most units contain plant fragments associated with hundreds of land snails and hundreds to thousands of vertebrate fossils. A preliminary scan of the thousands of specimens of rodents reveals the presence of Rattus and Mus only in the surficial portion of the deposit. As in Excs. IIB and IIC, these remains are fresh and unmineralized, unlike the dark, mineralized fossils of Nesoryzomys and Megoaryzomys.

Two aspects of the fossil birds of Cueva de Kubler are particularly interesting. Firstly, no fossils of the cuckoo Coccyzus melacoryphus, yellow warbler Dendroica petechia, or medium ground finch Geospiza fortis have been identified in Exc. IIB, nor have these species been found in a brief perusal of Exc. IIA. Each of these birds is a conspicuous member of today's avifauna near Cueva de Kubler. As revealed by a collection of prey remains of living Tyto in this area, these species are preyed upon today by Tyto. Therefore, if C. melacoryphus, D. petechia, and G. fortis also prove to be absent from the fauna of Exc. IIA (which contains several thousands of avian fossils), I believe that these three species did not occur on Isla Santa Cruz at the time of deposition of fossils in Cueva de Kubler. Through radiocarbon dating, it will be possible to state a maximum date for the colonization of Santa Cruz by these species. No radiocarbon ages have yet been determined for Cueva de Kubler, but they should be available late in 1981, thus providing the vital temporal control in my zoogeographic and evolutionary study of Galapagos birds.

Secondly, Darwin's finches from Exc. IIB include the following taxa that occur in the area today: Geospiza fuliginosa, G. magnirostris, G. scandens, G. (Platyspiza) crassirostris, G. (Camarhynchus) parvulus, G. (Camarhynchus) pallidus, G. (Certhidea) olivacea. More exciting is the discovery of three Darwin's finches that apparently no longer live on Santa Cruz, namely G. difficilis (extinct on Santa Cruz since the 1930's) and two undescribed forms, one of which is related to G. difficilis while the other is intermediate between G. fortis and G. (Platyspiza) crassirostris. Cranial elements of Darwin's finches are very diagnostic, unlike the post-cranial elements. Exc. IIA contains hundreds of fossil rostra and mandibles of Darwin's finches that are now beining studied to see how and if they differ from those of Exc. IIB.

Other sites on Isla Santa Cruz

Cueva de Iguana is an earthquake fissure, 12 m deep and 0.5 - 3 m wide, that is 200 m north of the Charles Darwin Research Station. Twelve different small accumulations of bones (varying greatly in degree of mineralization) have been collected from ledges along a 150 m section of Cueva de Iguana. The fauna appears to be very similar to that of Cueva de Kubler. André's Cave. Seven additional minor fossil-bearing sited, most of which mainly contain remains of M. curioi, are discussed by Steadman and Ray (ms).

Isa Isabela

No fossiliferous sediments were located on Isla Isabela, although two lava tubes (Cueva de Sucre, Cueva de Macas) on the southern flank of Volcán Sierra Negra yielded surficial specimens of reptiles, birds, and mammals. Among the latter are remains of Megaoryzomys sp. and an apparently undescribed form of Nesoryzomys.

Isla Floreana

Work on Floreana was confined to two regions, Bahia de las Cuevas and Bahía Post Office. No fossils were recovered from the former area, whose shallow caves are only weathering features in the exposed strata of two scoria cones. Well preserved surficial remains of vertebrates were collected from four lava tubes near Bahía Post Office: Cueva de Post Office (Inferior), Cueva de Post Office (Superior), and two unnamed caves. Few fossils were found in any sort of sedimentary context. The fossil fauna comprised tortoised, lizards, snakes, bats, and a variety of birds. Most significant are the abundant occurrences of large ground finches (Geospiza magnirostris) and mockingbirds (Mimus trifasciatus), two species collected on Floreana in 1835 by Charles Darwin, but apparently extinct there today. Tortoises also occur in high numbers at these sites. Historical records show that tortoises became extinct on Floreana around 1850 (Broom 1929). Three radiocarbon ages on surificial material from Cueva de Post Office (Inferior) have been determined at University of Arizona. They are A-2088 (wood, Bursera cf. graveolens) 990 + 120 yrs. BP; A-2089 (wood, Prosopis cf. juliflora) 80 $\pm$ 110 yrs. BP (modern); A-2090 (horny scute, not bone, of shell of tortoise (Geochelone) 310 $\pm$ 80 yrs. BP. All ages are corrected for ^{13}C as reported. Thus it appears that organic material has been accumulating in this cave for at least 1000 years.

Acknowledments

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Isopods (Oniscoidea) from Caves in North America and Northern South America

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Abstract

Probably all species of Oniscoidea except some from very dry regions can live in caves. Soil inhabiting species which normally live in dark, damp, highly organic places are able to get food in caves. They are usually lightly pigmented and with few or no eyes. Some examples from North America are in the genera Scleropactes and Trichorhina. Some races, subspecies or even species have become locally adapted to life in caves and they have little or no body pigment and less developed or no eyes when compared to their soil dwelling relatives. They are in genera such as Ligidium and Miktoniscus.

Most species in some genera (e.g.; Brackenridgia and Cylindroniscus) are truly adapted to cave life. The species always are without body pigment or eyes and spend their whole life in caves. In the New World they are in the families Trichoniscidea and Philosciidae. Species of Trichoniscidae are from temperate and tropical regions. All species of Philosciidae from caves in the New World are from the tropics.

Most subgroups of oniscoids are distributed worldwide which suggests that they evolved early, perhaps in the Paleozoic Era just before continental drift took place. There has been some indication that the closest relative of a trichoniscid from a cave in Spain is a trichoniscid from a cave in Mexico. The original land mass split and species of many genera of trichoniscids evolved independently in the New and Old Worlds. Species of Philosciidae probably evolved locally.

Introduction

Probably all species of oniscoidea except some such as species of Armadillidae which normally live in relatively dry places can adapt to humid cave habitats. In all probability most species could be found at the entrance and sometimes deep within suitable caves. In general oniscoids need constant moisture in their habitats and they are able to adapt to places with a suitable moisture and temperature regime. Oniscoids for the most part eat decayed vegetation and fungi so they should find food in caves. Many soil inhabiting isopods are lightly pigmented with few or no ocelli. Some species from dense leaf litter and loose soil are completely without body pigment and ocelli. The true troglobitic species are always without body pigment and without ocelli, because they live exclusively in deep, dark caves. Two species even live in water in pools in the caves--T. aquaticus and M. laevis. The terrestrial isopods then are frequently present in caves and species and genera whose sole habitats are caves have evolved among them.

Of the two major families with cave adapted members, the Trichoniscidae is the best represented worldwide and in North America. There are 19 described species in five genera in North America and they are found in many caves in the eastern and southwestern part of the United States through Mexico south to near Central America. Species of Philosciidae, the second major family with species from caves, has only three species in two genera from caves in North America. Two species from monotypic genera are from lava tubes in Hawaii. They are present in southern North America (Yucatan), Cuba and southern South America. The genera of the two families are listed in Table 1.

Table 1

Genera of Oniscoidea whose members are almost exclusively from caves in North America, northern South America and Hawaii. The number of species from caves in each genus is in parentheses.

Trichoniscidae	Philosciidae
Amerigoniscus Vandel (7)	Troglophiloscia Brian (2)
Cylindroniscus Arcangeli (4)	Colombophiloscia Vandel (1)
Mexiconiscus Schultz (1)	Hawaiioscia Schultz (1)
Brackenridgia Ulrich (6)	Halophiloscia Schultz (1)
Typhlotrichligiodes Rioja (1)	

Some Genera from Caves in North America

Species of many families which live in dense, highly organic soil in the tropics frequently have body pigment reduced or absent and have few or no ocelli when compared to their relatives from habitats which are more open and more lighted. Many times when they are collected in or very near to caves they are confused with species whose pigment or ocelli number reduction came about by living exclusively in caves. When the habitats have little or no light as in soils and caves the body modifications are similar. Species in the genera Trichorhina, Scleropactes and Eubelum, among others, are modified to live in soil, and frequently recorded from shallow caves. At first glance they might seem to be adapted to live in caves, but they are not.

Ligidium and Miktoniscus--The species of the two genera are frequently present in caves and in some instances appear to be isolated enough to form races, subspecies or occasionally even species in the caves. One species in each genus in North America is present exclusively in caves and have lost most or all body pigment ald all ocelli. Local populations from caves of other species have become modified in less radical ways (Maloney, 1939; Vandel, 1965a; Schultz, 1965, 1970b, 1976).

Brackenridgia--Species of the genus are the most widely ranging of all with cave living species in North America. They are present from caves in California, New Mexico, Arizona, Texas, south through Mexico to caves near the border of Mexico and Guatemala (Vandel, 1965a).

Amerigoniscus--Although the genus is defined on a pigmentless blind species from about the ground, A. rothi, from Oregon, all eight others are from caves in eastern, central and central western United States. They were at one time thought to be in a genus which was described on a specied from Georgia, S. S. R. (Vandel, 1977).

Cylindroniscus--The genus is defined on a species from humus, C. seurati, from Cuba. Other species have been described from caves in northern, central and Yucatan, Mexico (Shultz, 1970a).

Mexiconiscus--Only one species has been described so far, but the genus from San Luis Potosi, Mexico, probably contains more species. They live in the water of pools and streams in caves (Schultz, 1964, 1968; Vandel, 1970).

Typhlotrichligiodes--Although only one species has been described in the genus, it is important in that the species can be shown to be related to a species from caves in Spain. The evolution of the two species (each in a different genus) can be shown to be related to the breaking apart of North America and Eurasia by continental drift. Both species live in the water of cave pools (Vandel, 1965c).

Troglophiloscia--Two species of this genus of Philosciidae have been described from caves. One is from Yucatan, the other from Cuba. The species appear to be well adapted to cave life. They also have more spindly appendages when compared to other members from non-cave locations (Brian, 1929; Schultz, 1977).

Colombophiloscia--Non member of the poorly defined genus have been recorded from Colombia, but one species is from a cave in Venezuela (Vandel, 1968).

Hawaiioscia and Halophiloscia--Each genus has only one species. They are pigmentless and without ocelli and live in lava tube caves in Hawaii (Schultz, 1973).

All genera in the family Trichoniscidae are located in temperate and tropical regions of North America from generally south of the continental glaciation line to southern Mexico. Genera in the family Philosciidae are located only in the tropics in Cuba, Guatemala and northern South America. The ranges of the genera of each family apparently are distinct, but the region of possible overlap. Yucatan, Guatemala and Cuba, has not been throughly explored. According to Vandel (1965b:130) isopods are not commonly present in caves in the Old World tropics. However, species from caves in the tropics in the New World are common. Indeed, most of the species are from Mexico, Cuba, Central America and northern South America all of which are tropical. Those from the

United States are from temperate regions and many are from caves in the dry southwestern part of the country.

Discussion

Vandel (1965b:128) stated, conservatively I think, that there are about 2000 species of oniscoids. Of the 2000 species, 230 are cavernicolous or live exclusively in caves. He further stated that of the 230 cavernicolous species, 152 or about 70% were trichoniscids in the broad sense. The trichoniscids (family Trichoniscidae) are also the most common species in caves in North America. Vandel also stated that of the 230 species of cavernicolous oniscoids only 22 have been found in caves in the tropics which he considered to be truly troglobitic. They were Troglophiloscia silvestrii (Cuba), Setaphora caeca (Burma), Setaphora kempi (Assam, India) (all Philosciidae) and Trogleubelum tenebrarum (Zaire) and Neosanfilippia venezuelana (Venezuela) (both Eubellidae, broad sense). It is my opinion that N. venezuelana is a soil inhabiting form which is just casually present in the cave. Trogleubelum tenebrarum is unknown to me, and since it is from Africa it will not be considered here. Except for T. silvestrii which is a truly troglobitic species, the two other species of Philosciidae are not known to me. However, species of oniscoids which I have recently described from caves in Sarawak, Borneo, which include species of Setaphora were not adapted to the caves since they were not different from specimens collected outside of the caves. Species from caves in the tropics many times have probably been confused with those from the thick organic matter near the caves. From this dense organic matter habitat they easily can move into the caves.

In terms of the time of speciation of forms which live in caves, the two species of Philosciidae each in a separate genus from lava tube caves in Hawaii (not more than 6 million years the age of the Hawaiian Islands) might be cited (Schultz, 1973). The species apparently evolved from some now extinct epigean ancestor and have become pigmentless and without ocelli all within the course of 6 million years. Whether pigment and eyes can be lost in this short time in other species of Philosciidae from caves in the tropics or anywhere must be subjected to further research.

Evolution

The oniscoids (suborder Oniscoidea) are first encountered in the fossil record in the Eocene part of the Paleogene Period about 60 million years ago. Since the earliest fossils are not much different from species living today, their evolution must go back many, many years. Vandel (1945) stated that because most subgroups of oniscoids are worldwide in distribution their differentiation from the parent stock of more primitive isopods was sometime in the Paleozoic Era or more than 185 million years ago. This was before the beginning of continental drift so most subgroups got transported from the early contiguous land mass to what now are the continents.

The Trichoniscidae are one of the most primitive subgroups of oniscoids being only less primitive than the Ligiidae. Since most of the commonly present species of isopods in caves are trichoniscids, it is probable that they evolved on the early continental land mass which separated into North America and Eurasia. When the land mass split the members of the family were separated. Vandel (1965c) showed that one of the nearest relatives of Cantabroniscus primitivus from a cave in Spain is Typhlotrichligiodes aquaticus from a cave in Mexico. Both species are very primitive trichoniscids. This has been interpreted to indicate that the division was early or near the beginning of the separation of the continents. Another genus Miktoniscus has species in the temperate regions of both North America and Europe. Most members of Miktoniscus from North America have an ocellus and live in leaf litter. Some species have an ocellus and live in caves. Only one species, M. racovitazai, is blind and lives exclusively in caves in Virginia and Kentucky (M. r. racovitzai) and Oklahoma (M. r. oklahomensis) (VAndel, 1965a). Apparently no species of Miktoniscus is exclusively adapted to cave life in Europe.

The species of other genera of Trichoniscidae from North America are exclusively present on that continent. Species of many other genera are exclusive to Europe. The two groups of genera demonstrate how the primitive members of the family were isolated early in their phylogenetic history and have evolved into two different groups of genera since the continents split.

The species of Philosciidae from caves apparently are more tropical and local in distribution and their higher category evolution, if it occurred, is not at all clear. Species from caves of the other families of oniscoids are even less known and their evolution, except for a few species, are not known.

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Hydrogeology of Northern Fayette County and Southern Scott County; Kentucky, USA

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Abstract

The study area includes about 300 km^2 in the Inner Bluegrass Karst Region of Central Kentucky, USA. It is underlain by nearly horizontal Middle Ordovician limestones with minor amounts of shale and other lithologies. The principal investigative tool has been water tracing using optical brightener and direct yellow dyes with cotton fabric detectors. The following results are based mainly on 40 original dye introductions which resulted in 30 underground flow connections ranging in length from 0.4 to 12.1 km.

Groundwater flow in this area is in more than 10 groundwater basins, of which at least 3 (Lindsey Spring, Silver Springs, and Slacks Spring) have areas in excess of 10 km^2 and base flow discharges at about 20 l/s; and 2 (Royal Spring and Russell Cave) have areas in excess of 20 km^2 and base flow discharges of about 50 l/s. Flow patterns appear to be dendritic and the development of both surface karst features and the size of conduits appears to be related to position in the basin, being greatest in the central and downstream portions and least near divides, which may or may not underlie surface divides. The major conduits in the Royal Springs and Slacks Spring Basins are apparently related to master joints or unmapped faults which trend down the regional dip to the north-northwest, but the structural, stratigraphic, or other controls of solutional development elsewhere are less obvious. The low water table is generally at a depth of less than 25 m beneath the land surface.

Résumé

L'etude de ce secteur comprend environ 300 km^2 de la région intérieure du Bluegrass Karst qui se trouve au centre de l'Etat du Kentucky, aux Etats-Unis. Au-dessous se trouve une base horizontale de calcaire qui date de la période Ordovician Moyenne, et une certaine quantite d'argile schisteuse et d'autres lithologies. La methode de recherche principale était d'employé des calques d'eau avec des appareils optiques lumineux, et des teintures jaunes directes avec détecteur en tissue de cotton. Les resultats suivants sont basés en principe sur 50 teinures originaux qui ont été es introduites et par de suite s'ont abouties dans 39 courants d'eaux souterrains mesurant de 0.4 à 15.0 km de longueur.

Les courants d'eaux souterrains de ce secteur se trouve aussi dans plus de 10 bassins d'eaux souterrains, desquels au moins trois (Lindsay Spring, Silver Springs, and Vaughns Spring) ont une étendue de plus de 10 km^2 et un debit de décharge d'environ 20 l/s; aussi, 3 (Royal Spring, Slacks Spring, and Russell Cave) ont une étendue de plus de 20 km^2 et un débit de décharge d'environ 50 l/s. La décharge semble être dendritique et le developpement de la surface Karst et la grandeur des conduits semble avoir des rapports a la position du bassin qui est plus grand a la partie centrale et descendante de la rivière, et moins grand près de la ligne de partage des eaux, ce qui peut on ne peut pas indiquer des partages d'eaux a la surface. Les conduits mageurs de la source Royal Springs et de certains autres bassins d'eaux souterrains sont, en apparence, apparentés aux correspondances principaux ou aux failles inexplorés qui se dirigent vers la dépression régionale. Mais, la structure, la stratigraphique et les autres controls du développement des solutions sont moins évidents. La surface phréatique est généralement d'une profondeur de moins de 25 m de la surface terrestre.

The study area includes about 300 km^2 in the Inner Bluegrass Karst Region of Central Kentucky in Northern Fayette and Southern Scott Counties and covers portions of the cities of Lexington and Georgetown (Fig. 1). The area is underlain by Middle Ordovician limestones and shales of the Lexington Limestone Formation (Black et al., 1965). The Tanglewood and underlying Grier Limestone Members of this formation contain only minor ~~amounts~~ of shale, while the overlying Millersburg Member and a few thin units within the Tanglewood and Grier contain appreciably more. Although thicknesses vary considerably within the study area, the stratigraphy shown in Fig. 2 is representative.

The objectives of this study were: 1) to establish the flow paths and drainage basins of the major springs through dye tracing; 2) to obtain as much semi-quantitative information as possible from these traces; and 3) to learn what factors influence the movement of groundwater throughout this area.

Optical brightener, direct yellow, and fluorescein dyes were employed in dye tracing. Optical brighteners were originally used in Europe (Crabtree, 1970; Glover, 1972; Smart, 1976), and later adopted in this country by Quinlan for use in the Mammoth Cave Region (Quinlan and Rowe, 1977). Direct Yellow dye was initially used by Quinlan (1976). Direct yellow is used in place of optical brightener when the background (usually from detergents) prohibits use of the latter. Both dyes are water soluble and virtually colorless in dilution, non-toxic, detectable in very low concentrations over long distances, have high photochemical decay rates and are capable of absorption onto untreated cotton (Smart, 1976; Quiland, 1976). Cotton fabric detectors were used for the absorption of these dyes and fluorescein was detected by absorption on activated charcoal (Dunn, 1957). Positive traces have generally been identified as weak, medium, and strong by visual inspection of detectors or elutriants under ultraviolet light, but detectors and elutriants in later phases of the investigation have also been evaluated spectrophotometrically (Thrailkill, et al., this volume).

More than 50 dye introductions have been made in establishing the flow paths to the major springs in the area. Traces range in length from .4 km to 15.0 km, and all but one have been detected less than a week after dye was introduced (detectors are collected on a weekly basis).

Flow to the springs appears to be dendritic, with many input points leading to one output point. In no case has a dye introduction appeared at more than one spring, although at high flows numerous overflow routes may appear near the spring.

Groudnwater flow in this area is in at least 11 groundwater basins (Fig. 1). Three of these (Royal Spring, Russell Cave, and Slacks Spring) have areas in excess of 20 km^2, while 3 others (Lindsay Spring, Silver Springs, and Vaughns Spring) have areas between 10 km^2 and 20 km^2. The larger springs have base flows of about 50 l/s and peak flows in excess of 2000 l/s. The others have base flows of about 20 l/s, with peak flows in excess of 500 l/s.

Groundwater basins may or may not correlate with surface basins. Three of the major springs (Spring Lake, Santen, and Gano) have drainage basins which underlie surface valleys. The divides of the other basins, however, show little correlation with surface drainage basins. Where surface streams exist, groundwater flow is often at an angle to surface flow direction. This is characteristic of much of the drainage to Lindsay and Silver Springs (Fig. 1 and 2).

Solution development is concentrated in the central and downstream parts of groundwater basins, as indicated by dye traces; greater development of surface karst features, especially sinkholes; and greater conduit development, where accessible. Near groundwater divides, solution development is shallow or nonexistent and surface streams may exist. Depth of sinkholes (especially karst windows) and vertical relief along assumed flow paths indicates most solution development occurs within 25 m of the surface.

Both stratigraphy and structure exert variable influence on the movement of groundwater throughout the area. Spring Lake Spring appears to be the only major high level spring in the region. It is apparently perched on a less soluble unit (Cane Run Bed) and the stream issuing from the spring eventually sinks below the unit, and later resurges at Lindsay Spring (Fig. 1). All other major springs are near and at about the same elevation as the major streams of the area (Fig. 1).

The major structural elements in the north-central portion of the area are diaclases (master joints or small faults). The major flow to Royal Spring follows such a diaclase in both its lower (Thrailkill, et al., in press) and upper parts, as does flow in a small groundwater basin to the east (Thrailkill, et al., in press).

Still farther to the east, the downstream portions of the Vaughns Spring basin follows a third diaclase which is well-defined by aligned sinkholes. This basin is unusual in that its flow passes beneath a major surface stream. Initially, North Elkhorn Creek, South Elkhorn Creek and Town Branch, the major surface drainages of the area, were assumed to form the boundaries of groundwater basins. Although this is probably the case in most of the area, a trace from McGee Sink to Vaughns Spring crossed under North Elkhorn Creek (Fig. 3), which must, therefore, overlie the Vaughns Spring groundwater basin. The mechanism controlling the crossing is not known, but may be related to a local impermeable bed. It does not appear to be due to alluviation. Elsewhere, groundwater flow has been found to cross beneath smaller surface streams (Fig. 2). A fourth example of flow along a diaclase is the Slacks Spring Basin to the west of the Royal Spring basin. Flow along such diaclases is in accordance with the suggestions of earlier workers (Hamilton, 1950; Mull, 1968; and Faust, 1977).

Elsewhere in the study area, however, the relationship of subsurface flow to diaclases, mapped faults, and linear sinkhole trends is not obvious, and in the Silver Springs basin, flow from a swallet on a fault flows away from the fault at nearly right angles (Fig. 2). Furthermore, a substantial segment of the Slacks Cave basin flow conduit can be examined in Slacks Cave, whose passage morphology shows little joint control.

The four diaclases discussed above are approximately parallel to regional dip, and the flow in these basins is approximately down the dip, but in both the Lindsay and Silver Springs basins, flow crosses anticlinal and synclinal axes at nearly right angles (Fig. 2). Although such mapped anticlines may not actually exist (W. C. MacQuown, pers. comm., 1980), the lack of correspondence between groundwater flow and mapped structures suggests the latter cannot be used to predict the former. Except for Spring Lake Spring (discussed earlier), all 11 of the springs discharging groundwater basins emerge from nearly the same stratigraphic interval in the Grier Limestone Member from 6 to 18 meters below its top, and it appears that the major conduit development in the area is in the upper Grier Limestone Member.

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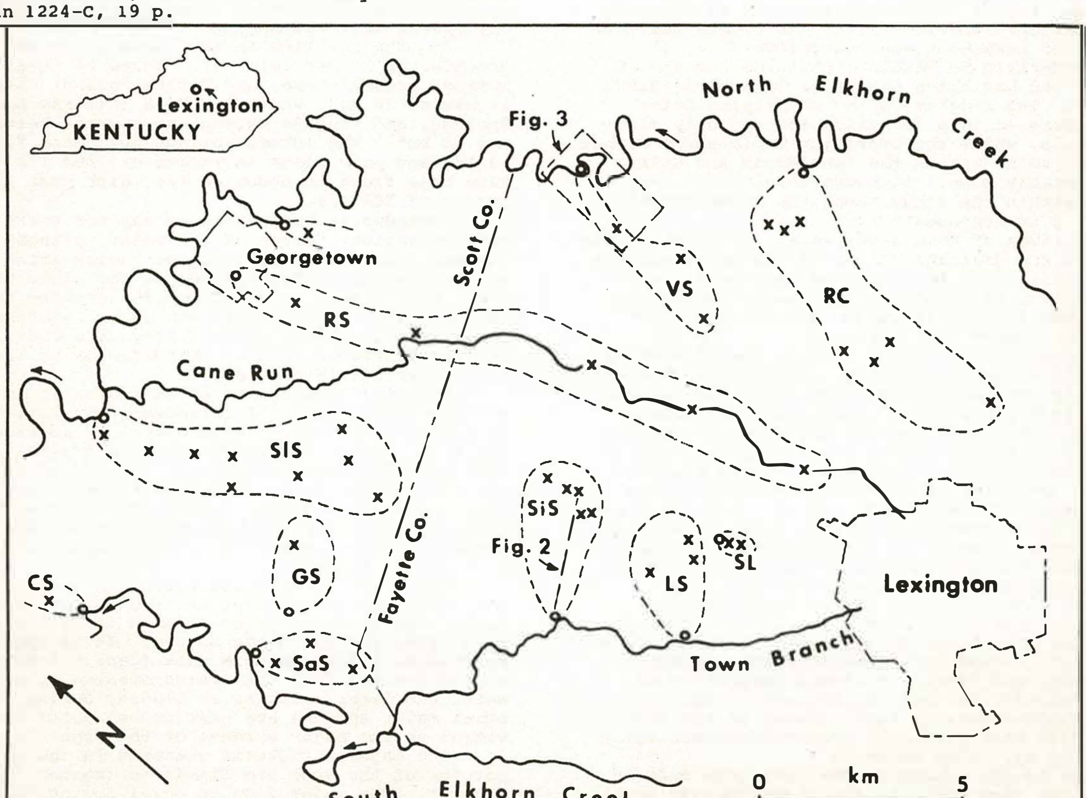

Figure 1. Map of study area. Dashed lines outline swallets (crosses) traced to springs (open circles). Groundwater basins (generally somewhat larger than area outlined) are: CS, Cornett Spring; GS, Gano Spring; LS, Lindsay Spring; RC, Russell Cave; RS, Royal Spring; SL, Spring Lake; SaS, Santen Spring; SiS, Silver Springs; SlS, Slacks Spring; and VS, Vaughns Spring. Only major surface streams shown. Not index mpa in upper left and location of Fig. 2 and 3.

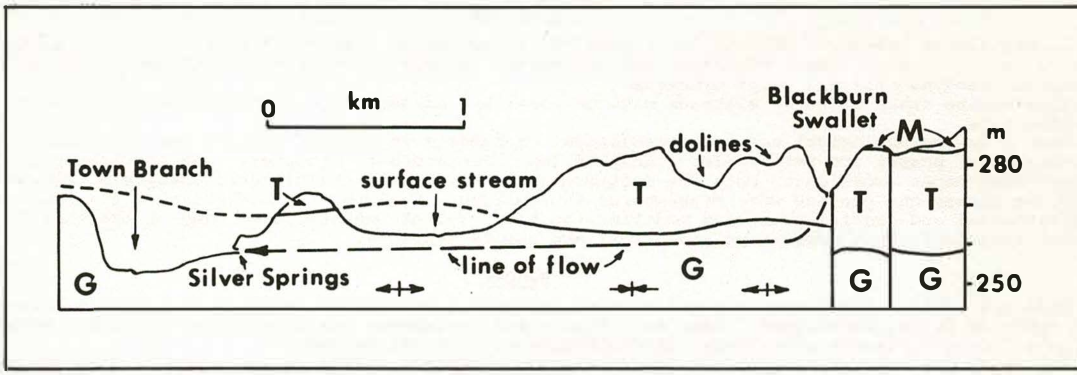

Figure 2. Cross-section from Blackburn Swallet to Silver Springs (see Fig. 1 for location). Geology from Miller (1967); stratigraphic units are members of Lexington Limestone: M, Millersburg; T, Tanglewood; and G, Grier. Anticlines and syncline indicated with appropriate symbols. Note 20:1 vertical exaggeration.

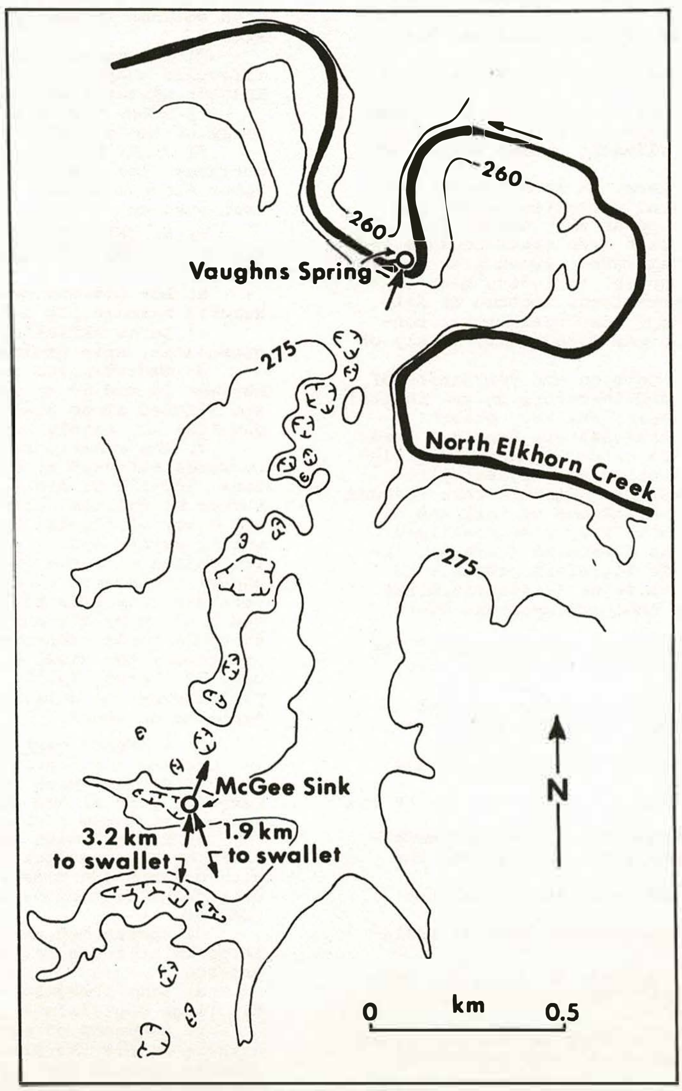

Figure 3. Map of lower part of Vaughns Spring ground-water basin (see Fig. 1 for location). Topographic contours in meters.

Morphogenetical and Chronological Aspects of Some Karst Areas in the Italian Alps

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Abstract

In the alpine limestone regions it is possible to recognize a great variety of Karst landscapes and types of karstic forms. Their evolution was controlled by multiple factors: morphometrical, lithological, structural, geodynamical and morphodynamical.

Some alpine areas of karst plateaus with dolines, and of summits with glaciokarstic features are described here.

From a few morphological and paleopedological characters it can be inferred that the main karstic morphogenetical phases are rather old, likely of lower Pleistocene, or older. The successive evolution of karst landscapes experienced both the neotectonical uplift, and the climatic changes of Pleistocene. During the rising the plateau were dismembered by faulting. Besides, in the course of the cold periods, the periglacial and glacial processes modified the karst relief, obliterating many of the karst dolinas. The resulting landscapes present polygenetical and complex aspects.

Résumé

Dans les régions karstiques alpines on peut reconnêtre une grande variétée de paysages karstiques et de types de formes karstiques. Leur evolution à été influrncée par plousieurs facteurs: morphométriques, lithologiques-structureaux, géodinamiques et morphodinamiques.

Ici on décrie brièvement quelques zones karstiques alpines ayants le caractère de plateaux avec dolines, ou de sommets avec cuvettes glacio-karstiques. Les aspects morphologiques et paléopedologiques permettent de reconnêtre que les principales phases morphogenetiques karstiques de ceux reliefs sont plutot anoiennes, pour la plupart du Pléistocène inférieur ou du Néogène. L'évolution suivante du relief karstique à ressentie soit des évènements néotectoniques, soit des variations climatiques du Pléistocène. Pendant le soulévement les plateaux karstiques ont étés démémbrés par l'activation de failles. En outre pendant les périods froides s'est vérifié un démantélement des formes karstiques par des processus périglaciairs et glaciairs. Les paysages qui en résultent sont de type complexe et polygénetique.

In the calcareous areas of the Italian Alps there is a great variety of karstic landscapes and morphological types whose evolution was controlled by the following factors:

- morphometric features of the relief (slopes, height, etc.);
- local lithological and structural situations;
- neotectonic events;
- interference with other, non-karstic processes of fluvial, glacial and periglacial type, related to the alternation of various climatic phases during the Pleistocene.

For purposes of comparison, it seems useful here to summarize the morphological situations regarding some areas of the Italian Alps as they emerge from preliminary studies, together with more specific data and examples taken from the literature. Areas with evolved karstic morphologies were chosen, including many dolinas or large closed depressions, located at different heights and in distinct morphostructural contexts, mostly in thick limestone formations, mainly of the Mesozoic (Fig. 1).

Data on the moment of emersion and denudation of these limestone formations and therefore on the initial phases of karstic morphogenesis, are very scarce. Within the ambit of the central-eastern Prealps, Lower Miocene marine sediments were raised to more than 1300 m above sea level (Monte Cavallo, Western Friuli). Lower and Middle Pliocene marine sediments were instead raised to 500 m (Monte San Bartolomeo of Salò and in the region around Lake Garda). They were sometimes verticalized corresponding to flextures (Cornuda, in the Venetian Prealps). It is therefore possible to identify an important Late Pliocene (Villafranchian) tectonic phase, preceded by another important Upper Miocene phase.

For the sake of uniformity of description of the karstic areas considered here, we will follow this order:

a) denomination, geographic location, number of the Foglio of the Map of Italy 1:100.000 IGM, references in the literature;

b) morphographic definition and heights of the karstified surfaces;

c) tectonic and neotectonic context and age of the formations examined;

d) type of karstic surface depression and underground cavities, and possible relationship with the hydrographic network;

e) characteristic reliefs between the karstic depressions;

f) considerations on the geomorphological evolution of the area.

1) a) Massif of Cansiglio-Cavallo (Venetian Prealps, Fogli 23-24) (H. Lehmann, 1959; G.B. Castiglioni, 1964; F. Fuchs, 1970).

b) Plateau with dolinas located at various heights between 900 and 1600 m enclosing a large structural polje.

c) Plateau with faulted blocks, defined towards the Venetian plain by a large flexure scarp passing northwards to a large syncline in which the polje lies, and thus to a faulted anticline. The karstic relief with dolinas is mostly modelled in Cretaceous reef limestones.

d) Innumerable dolinas, including large types of irregular shape, funnel- and shaft-shaped types. Many karstic shafts also open on the surface.

e) Dome- and cone-shaped hillocks occur in certain areas of the plateau between the dolinas.

f) Fuchs has identified three main erosional flat surfaces, the highest of which was modelled after the Upper Miocene uplift. The largest dolinas are found on this surface.

2) a) Colle del Montello (Venetian Prealps, Foglio 38) (G. Abrami & F. Massari, 1968; S. Venzo, 1977). See Figure 2.

b) Low plateau with a very great number of dolinas; heights between 150 and 300 m.

c) Large anticline of mainly Miocene limestone conglomerates, axis prolonged approx. E-W.

d) Medium-sized and shallow dolinas (diameters between 30 and 50 m, some metres deep). Some of these are aligned along shallow valleys. The subterranean cavities are mainly horizontal.

f) The western sector contains four karstified terraces situated at different heights (1st: 140-150 m; 2nd: 180-190 m; 3rd: 250 m; 4th: 275-300 m); the number of dolinas increases with height. These terraces are forms of fluvial erosion modelled by the River Piave which, during uplift of the anticline, alternated deepening phases of a pre-existing valley (Biadene furrow) with phases of lateral erosion. The surfaces of the upper terraces have also been deformed as a result of uplift and bending by the anticline. The state of alteration of the paleosoils occurring on the terraces indicates respectively the Riss, Mindel, Günz and Middle/Upper Pliocene (S. Venzo, 1977). During the cold periods of the Pleistocene the dolinas were partially filled by thick deposits of loess.

3) a) Monte Grappa (Venetian Prealps, Foglio 37) (F. Carraro & U. Sauro, 1979). See Figure 3.

b) Plateau with forms mainly of fluvial, fluviokarstic, glacial and periglacial type, heights ranging between 1000 and 1700 m.

c) Plateau with faulted blocks defined towards the plain by a large flexure scarp. The karstic landscapes with dolinas are modelled in Jurassic limestone. The Cretaceous formations instead make up large rounded ridges.

d) Sparse medium-sized dolinas; some large dolinas; large karstic depressions partially demolised by fluvial erosion.

e) Some irregular cone-shaped hillocks rise among the large depressions.

f) Segments of some old valley bottoms are recognizable within the plateau, dissected by the deep canyons running towards the large southern tectonic scarp. Karstic dolinas and depressions are found on these relics of the wide old valley bottoms. A neotectonic fault scarp defines the main karstic area to the south. Thick tectonized concretional deposits corresponding to the fault plane are correlated to an important phase of karstic erosion.

4) a) Lessini Mountains (Venetian Prealps, Fogli 36-48) (A. Pasa, 1954; U. Sauro, 1973, 1974). See Figure 4.

As regards points b), c), d) and e), see above bibliography. We will limit ourselves here to describing a dolina located on a large slope dislocated by neotectonic faults at 600 m. The stratigraphy of the deposits of this dolina has been studied from the points of view of sedimentology, paleopedology and prehistorical archeology (D. Magaldi, C. Peretto & U. Sauro, 1981). The dolina had already trapped loess deposits during the Mindel; during the Mindel-Riss a type of subtropical soil (a "paleoudalf") developed in these loess deposits. It may be deduced from this that some of the current dolinas, although not very large or deep, are of considerable age, since they were already well defined in the Lower or Middle Pleistocene.

5) a) Southern Monte Baldo (Venetian Prealps, Fogli 35, 48) (A. Pasa, 1954; G. Benvenuti & U. Sauro, 1977).

b) Plateaus with dolinas and landforms of periglacial and fluvio-karstic type, at heights between 600 and 1600 m.

c) Plateau with faulted blocks inclined towards the west. Neotectonic scarps and fault bluffs. The karstic landscapes are modelled in Jurassic limestone.

d) Many dolinas and some large depressions with thick periglacial deposits of loess and cryoclastic fragments. Many dolinas are filled to the rim.

e) Some irregular cone-shaped hillocks are to be found among the dolinas.

f) Around the dolinas, both polygonal pattern and alignments along hydrographic furrows may be recognized. The intense weathering of the karstic relief by cryoclastic processes during cold phases of the Pleistocene and the fossilization of many of the depressions by the loess cover are evident. The deflation areas of the loess corresponded to the nearby large morainic and fluvio-glacial amphitheatres of the River Adige and Lake Garda.

6) a) Serle Plateau (Lombard Prealps, Foglio 47) (L. Laureti, 1969; M. Chardon, 1977).

b), c), d), e) and f) Plateau with dolinas and some cone-shaped hillocks some very accentuated, between 600 and 1000 m. The various cone-shaped hillocks are interpreted by Chardon as relics of an old relief of the "Kegelkarst" type which evolved in subtropical climatic conditions towards the end of the Tertiary. The "terra rossa" present in some of the karstic cavities is mainly composed of kaolinite and illite, and may be correlated with these old morphogenetic phases.

7) a) Circo di Moncodeno - Grigna Group (Lombard Prealps, Foglio 32) (A. Bini, G. Cappa & A. Pellegrini, 1976 and relative bibliography). See Figure 5.

b) The glacial crique of Moncodeno is deeply karstified, at heights between 1700 and 2400 m.

c) The cirque is arranged in a faulted syncline with sides accentuated by fault scarps and, on its bottom, a step-like arrangement formed of small fault bluffs.

d) In the area of the cirque bottom at heights of less than 1950 m large irregular dolinas prevail. Instead, the higher zone is dominated by pit-dolinas, shafts and grikes. The density of the pit-dolinas and shafts is locally extremely high (up to dozens per hectare).

e) Some small dome-shaped hillocks rise between the largest dolinas.

f) A preliminary morphological analysis shows the intensity of glacial erosion within the ambit of a deeply karstified tectonic relief. Glacial modelling was also favoured by Pleistocene neotectonic evolution, which accentuated the irregularities.

8) a) Conca delle Carsene - Marguareis (Ligurian Alps, Foglio 91) (G. Dematteis, 1963; M. Julian, J. Nicod & Cl. Orengo, 1972). See Figure 6.

b) Plateau in which a large glacial trough between 1800 and 2500 m is dissected.

c) Faulted syncline with many evident scarps and fault bluffs, partly neotectonic. The limestones are of the Jurassic and Cretaceous.

d) Some large glacio-karstic depressions are to be found both along the main axis of the Conca delle Carsene, and near the edge of the large northern scarp. Dolina fields cover the flat northern ridge between 1900 and 2100 m. The bottoms of the glacio-karstic depressions are areas of very high density of shafts, although these are also found in other positions.

e) Some dome-shaped hillocks are located in the dolina areas.

f) This territory shows the pre-existence of a plateau of karstic erosion which cut off the main tectonic structures. Glacial erosion later operated efficiently in the more faulted areas, near the axial zone of the syncline which shows many glacio-karstic depressions corresponding to very numerous absorbing cavities.

This short review produces elements indicating the evolution of some of the most characteristic karstic landscapes of the Italian Alps. In particular, we may deduce that many of the now-existing karstic or glacio-karstic landscapes of the Southern Alps are the result of a somewhat long and complex evolutional history which began in the Neogene. The most efficient phases of karstic morphogenesis presumably correspond to relatively warm wet periods, both during the Upper Tertiary and Pleistocene, in which subtropical types of paleosoil developed. During the Lower Pleistocene the areas in question must have been in the form of large plateaus by numerous large, deep dolinas, some with polygonal contours, with cone- or dome-shaped hillocks rising among them.

Today, in effect, in those areas where fluvial and glacial erosion and/or periglacial processes acted with less intensity, we can recognize the relics of this old karstic relief and filling deposits derived from old paleosoils in some cavities. However, most of the karstic depressions have instead been almost completely demolished by erosive processes or filled with loess deposits. Perimetral parts of many large dolinas, partially demolished or completely filled, are easily recognizable on Monte Grappa and Monte Baldo.

In the high karstic areas, subjected more intensely to glacial erosion, the dolina karstic relief is almost completely eroded. The very numerous shafts which open in these areas do not always show evident relationships with the current surface forms. Many of them derive from the evolution - in subglacial and/or periglacial conditions - of absorbing conduits of old dolinas destroyed by erosion.

The role played by neotectonics, which contributed towards the accentuation of the reliefs and thereby favoured the erosional demolition of the karstic relief, is evident everywhere.

These elements agree with those already reported on the Trieste and Slovenian Karst (P. Habic, 1968; C. D'Ambrosi, 1971; I. Gams, 1972; R. Gospodaric, 1976; P. Ambrosetti et al., 1973).

Deeper studies on these questions by research teams and specialists in karstic geomorphology, including paleontologists, pedologists and prehistoric archeologists, represents a stimulating field for investigations in the near future.

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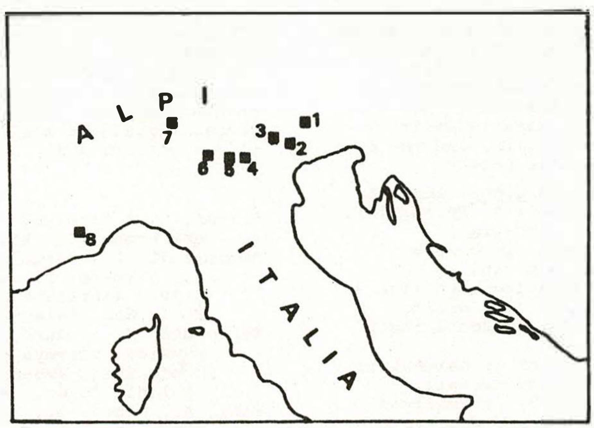

Figure 1. Geographical locations of the described karst areas.

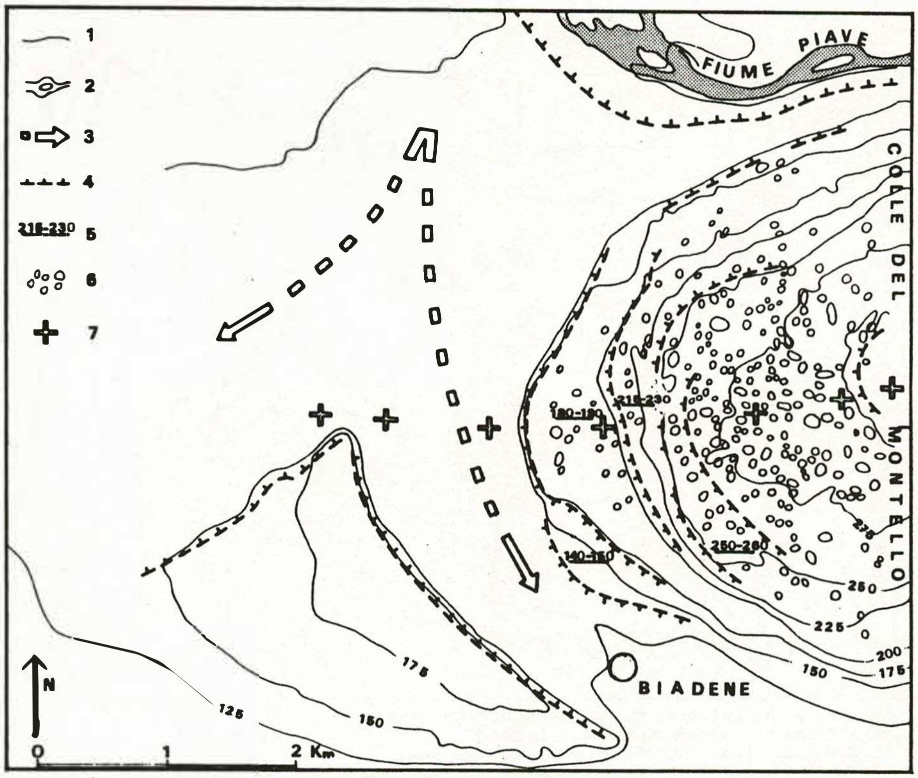

Figure 2. Geomorphological sketch of the western area of the Colle del Montello. Legend: 1) contour lines, 2) Piave river bed, 3) old river beds of Piave, 4) main scarps, 5) heights of the main erosional terraces, 6) dolines, 7) anticline axis.

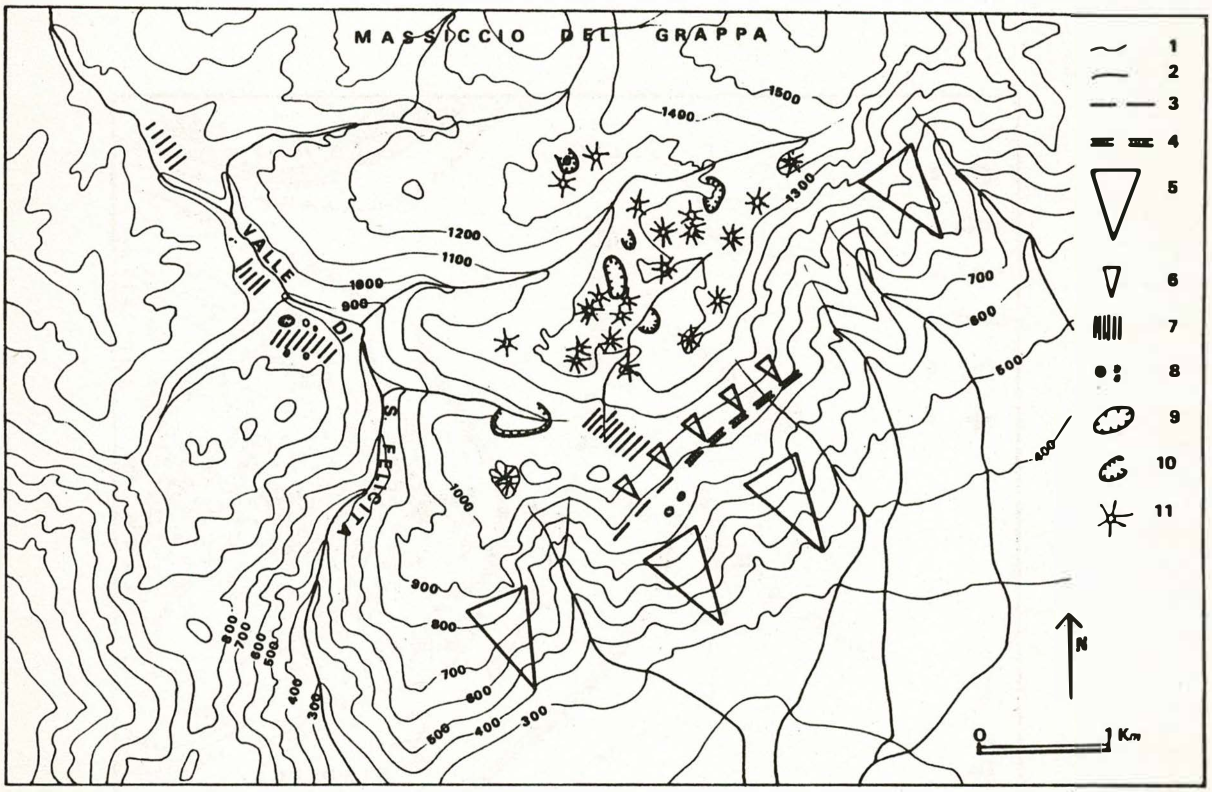

Figure 3. Geomorphological sketch of the southern area of the Monte Grappa plateau. Legend: 1) contour lines, 2) main hydrographic net, 3) fault line, 4) thick calcite concretions along a fault plane, 5) large tectonic scarp, 6) neotectonic fault scarp, 7) old karstified dead valley bottom, 8) dolines, 9) wide karstic depressions, 10) karstic depressions demolished by fluvial and periglacial erosion, 11) irregular cone- and pyramid-shaped hillocks.

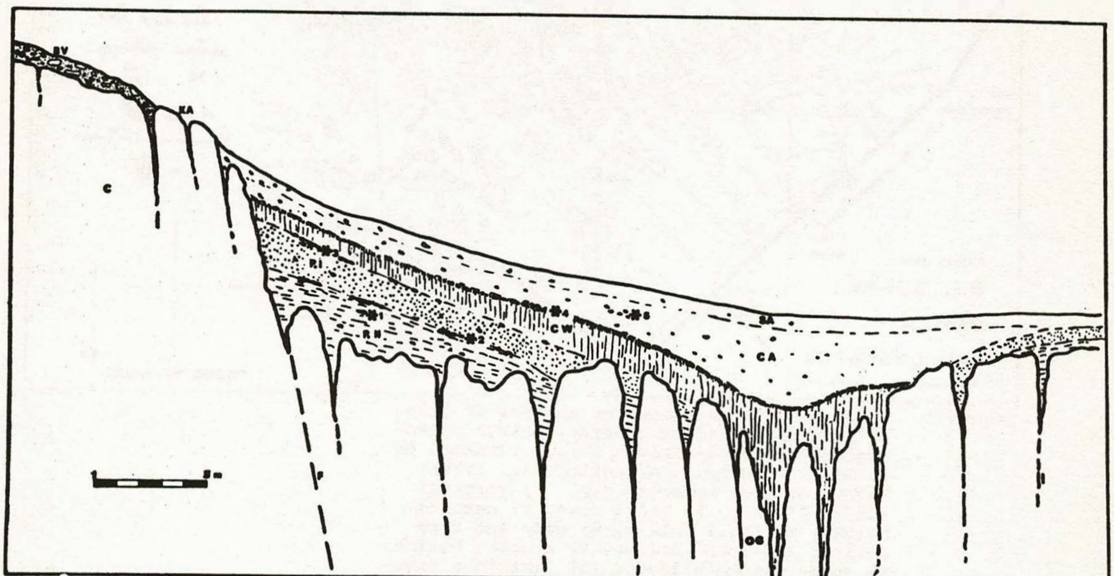

Figure 4. Schematic profile of a doline in the Monti Lessini. Legend: C) limestone, B.V.) slope breccia, K.A.) Fundkarren, F) Fault and relative neotectonic scarp, O.G.) solution pipes, S.A.) agricultural soil, C.A.) anthropogenic colluvial silts, C.W.) wurmian colluvial silts (with loess structure), P.I.) upper paleosoil (Hapludalf), P.II.) lower paleosoil (Paleoudalf), 1) biface of lower Paleolithic, 2), 3) lens of colluvial flint fragments, 4) postwurmian soil with neolithic stone implements, 5) lens of colluvial flints fragments.

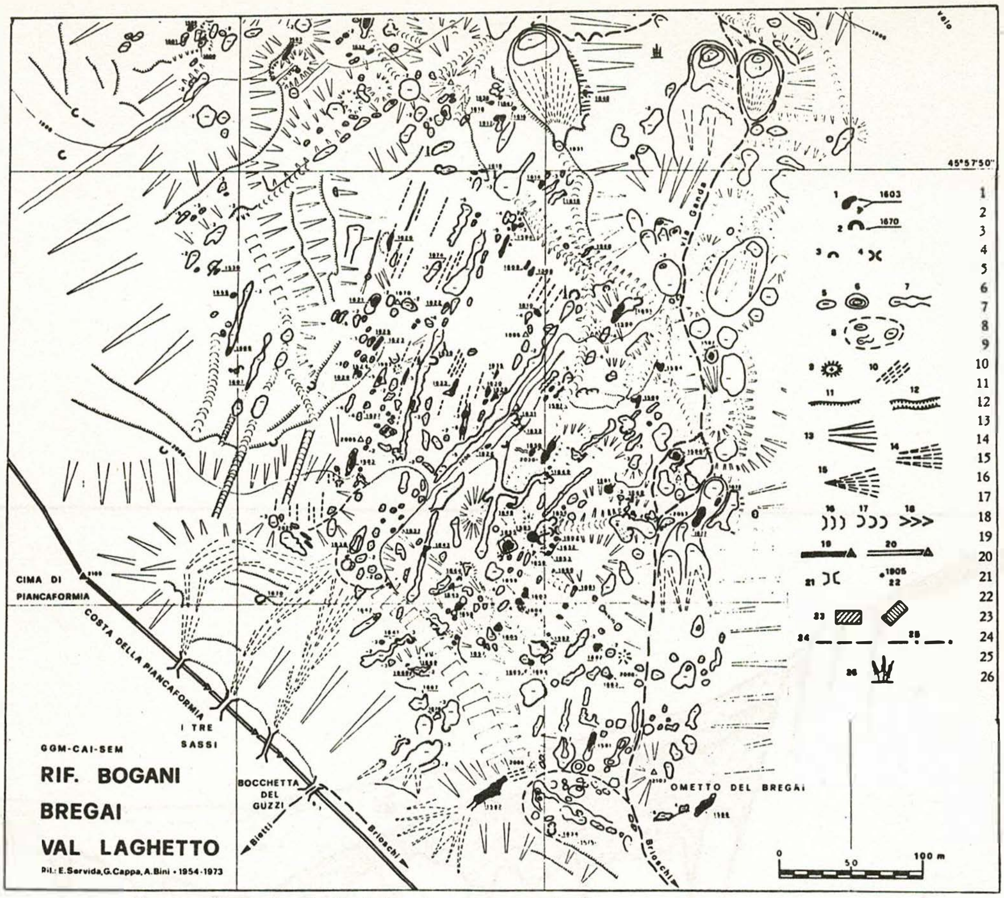

Figure 5. Geomorphological sketch of an area of Circo di Moncodeno -Grigna (Source: Carta morfologica del Bregai-Grigna Settentrionale, in A. Bini, G. Cappa & A. Pellegrini, 1976). Legend of some symbols only: 1) vertical shaft, 2) cave, 3) small cave, 4) natural bridge, 5) small doline, 6) wide and deep doline, 7) "open" doline, 8) complex doline, 9) cone- shaped hillock, 10) limestone pavements, 11) rock walls.

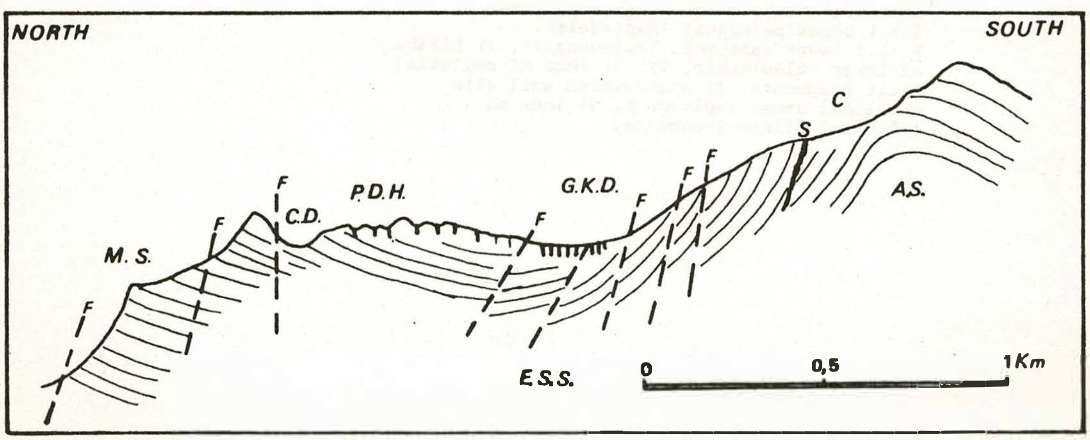

Figure 6. Schematic north-south cross profile of the Conca delle Carsene-Marguareis. Legend: F) fault, M.S.) main scarp, C.D.) wide closed depression, P.D.H.) plateau with dolines, cone shaped hillocks, and shafts, S) shaft, G.K.D.) glacio-karstic depression, C) cirque, F.S.S.) faulted syncline structure, A.S.) anticlinal structure.

Reflections on Karst Geomorphology Research in Italy: 1960-1980

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Abstract

A brief review of a few of the most significant papers on karst geomorphology of Italy, issued in the last two decades, is presented here. Some reflections on the state of Italian karstological research are made.

Résumé

Dans cette communication on présente une brève aperçu des pubblications le plus significatives sur la géomorphologie karstique en Italie apparues dans le période 1960-1980. On développe quelques considérations sur l'état de la recherche karstologique italienne.

The following short review deals only with some of the most significant research on karst morphology in Italy carried out in the last twenty years (excluding research undertaken by foreigners). This review supplies a schematic although representative picture of the state of karst research in Italy between 1960 and 1980.

Research on Chemico-physical Processes of Erosion and Deposition

An important international symposium on the chemico-physical processes occurring in speleogenesis and classification of subterranean forms was organized in 1972 by the Italian Speleological Society (various authors, A.A.V.V., 1975). On the basis of research carried out in the Grotte di Castellana, a graphic method for the study of natural solutions was perfected (C.F. Nobile, 1975). The role played by carbon dioxide in solution processes of gypsum was shown (P. Forti & E. Rabbi, 1979). In relation to the characteristics of soluble rocks and the dynamics of chemical processes, the concepts of hyperkarst, karst, parakarst, hypokarst, and pseudokarst were discussed and perfected (F. Anelli, 1973; A.A. Cigna, 1978) and the speleogenetic role of the "diffusion effect" in laminar flow was shown (A.A. Cigna, 1975).

Superficial Karst Forms

Studies on regional morphology were carried out in some areas of the Prealps and Appennines (G. Nangeroni, 1971; G.B. Castiglioni, 1974; L. Laureti, 1969; U. Sauro, 1973; E. Lupia Palmieri & G.M. Zuppi, 1977; G. Abrami & F. Massari, 1968; L. Brancaccio, S. Di Nocera & A. Rodriguez, 1980). Many aspects of karstic reliefs appear to be strongly influenced by the lithological and tectonic conditions of the constituent rocks (F. Forti & T. Tommasini, 1966; F. Forti, 1968; P.R. Federici, 1970; F. Cucchi, F. Forti & F. Ulcigrai, 1975; G. Corrà, 1974). In the high-mountain karstic areas, however, we find polygenic typical forms, resulting from a combination of glacial, periglacial and karstic processes (D. Croce, 1965; G. Dematteis, 1968; C. Balbiano D'Aramengo, V. Bergerone & F. Cossutta, 1977). Many studies have been devoted to the karstic microforms, their morphometric aspects (S. Belloni & G. Orombelli, 1970), relationships with lithology (F. Forti, 1972), biological processes occurring in the genesis of some types (A. De Fanti, 1971; G. Perna, 1974), and the environmental significance of the various limestone-pavement landscapes (G. Perna & U. Sauro, 1978).

Cave Morphology

Thanks to intensified exploration, speleological documentation has grown greatly, and the terminology and methods of collecting data have been perfected (G. Cappa, 1974; A. Bini & G. Cappa, 1974; A.A. Cigna & C. Lewis Railton, 1978). Many studies devoted to caves are important for their scientific rigour and interdisciplinary widening of knowledge on various aspects of subterranean environments. Among the most important we mention here: notes on the Piaggiabella system (Piedmont) and the Michele Gortani Cave (Emilia-Romagna) which are among the largest Italian cavities as regards respectively limestones and gypsum (G. Dematteis, 1966; M. Bertolani & A. Rossi, 1972). Some research was particularly oriented towards the relations between subterranean karst morphology and lithological and tectonic conditions (G. Cancian, 1976; F. Zezza, 1975; A. Casale & F. Vaia, 1972; F. Cucchi, F. Forti & R. Semeraro, 1975). In the Abisso di Monte Cucco (Umbria) the relations between subterranean canalization and rock porosity were analysed (L. Passeri, 1972). In the Lessini Mountains (Venetian Prealps) the karstic cavities show very well-defined structural-morphological locations (U. Sauro, 1974) and occur typically (G. Rossi & U. Sauro, 1977). The analysis of cavities in gypsum allowed the development of the concept of antigravity erosion (G. Pasini, in various authors, 1975). In the Lombard Prealps some karstic systems developed even before the Messinian event of "dissection" of the Mediterranean, bringing about the excavation of large valleys (A. Bini & G. Cappa, 1977). In the central-southern Appennines, a study of the subterranean karst systems, many of which are of the "crossing" type, showed several active events separated by filling episodes related to neotectonics, climatic oscillations, variations in sea level, and external morphogenesis (L. Laureti, 1965; F. Anelli, 1967; M.A. Bocchini Varani, 1971; C. Cattuto, 1976; A. Bocchini & M. Coltorti, 1978; M. Bertuccioli, G. Reichenbach & F. Salvatori, 1978; P. Forti & D. Postpischl, 1979). A study of the sediments of some caves, aimed primarily at research on prehistorical archeology, allowed paleo-ecological reconstructions at various moments of the Italian Pleistocene (E. Borzatti von Löwenstern & D. Magaldi, 1969; F. Fedele, 1972; D. Magaldi & A. Raspi, 1976; F. Martini, B. Sala, G. Bartolomei, M. Tonon & L. Cattani, 1974; G. Bartolomei & A. Broglio, 1975). Only a few caves have been equipped as experimental laboratories for biospeleological and speleologico-physical research (S. Polli, 1969; T. Tommasini, 1978). As regards hydrogeological aspects, thanks to many experiments made using tracers, we have more data on the conditions of water circulation in karstic aquifers (A. Moretti, L. Pannuzzi, G. Stampononi & N. Zattini, 1965; A. Dal Pra & L. Stevan, 1969; D. Grassi, 1974).

Considerations

This brief review shows how geographic karstology has not everywhere always been able to keep up with progress made in this field in many other European countries, although it has been traditionally established over the last twenty years in Italy. In effect studies on regional morphology in karstic areas are not numerous, even though they have been used to advantage with appropriate maps. The reasons for this are due to a crisis in Italian geographico-physical research. On the other hand, "scientific speleology" has undergone rapid development, as shown by the production of much interesting documentation and scientific data, not only by professional researchers, but also by many amateurs.

Today, research on karst morphology seems to be influenced by various weaknesses and defects which may be summarized as follows:

- absence of research coordination, due primarily to the lack of interest on the part of official research organizations in Italy;
- scarcity of initiative of interdisciplinary research, aimed at complete knowledge on the various environmental aspects of the karstic regions;
- poor connection of research with the problems of planning of the karstic areas.

Considering the extent, variety and interest of the Italian karstic regions, they may be said to represent an ideal field for geographico-naturalistic investigation by research teams composed of both professionals and amateurs, for our better knowledge and utilization of this environmental heritage.

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Subterranean Phreatic Biocoenoses of North Western Iran

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Abstract

Results of the phreatobiological researches carried out in Iran by the Zoological Institute of the University of L'Aquila (Italy), during the years 1977-78 are reported.

Numerous stygobiontes species among amphipods, cyclopid and harpacticoid copepods, asellid and microparasellid isopods, oligochaetes, etc. are pointed out.

Introduction

According to some Authors, for what concerns the aquatic fauna, Iran may be divided in three different faunistical provinces, one going from the coasts of the Caspian sea to the central highlands, the others respectively limited to the south-western and to the southeastern parts of the country.

In these provinces may be found subterranean elements of different origin and relationships, which are of considerable biogeographical interest. The "caspian" forms include some thalassoid elements of marine origin and of recent immigration in the underground systems, which are generally limited to the coastal interstitial systems. In the inner highlands there are mainly more ancient, palaeartic elements with different degree of specialization to the underground conditions. In the southern provinces, at last, both eastern and palaeartic elements of different age can be found together.

Nevertheless, as far as we know, with the exception of the papers of Löffler (1959, 1960) and Lindberg (1941, 1942), in which a few, sporadic records of aquatic subterranean species are listed, until now practically nothing was known about the phreatic hypogean fauna of this country.

This fact prompted us to carry out, in summer 1977 and in autumn 1978, a series of field investigations in the phreatic subterranean systems of the north-western part of Iran, viz. along the coasts of the Caspian sea (Kelar-Abad, Kargash, Noreshar, Chalus) and in the inner highlands around Isfahan (Shar-e-Kord, Farrochá, Cialestore) and Teheran (Karaj).

In the course of these researches, 41 collecting stations (man-made fresh and brackish-water wells and some cisterns) were sampled using the technique of Cvetkov (1968) modified by Danielopol and Dancau (in Bou, 1974). For each of them, the main geographical, topographical and chemico-physical data, together with the biological samples, were obtained.

The biological collections are noteworthy for the presence of a considerable number of stygobiont or eustygophil species, of great systematic and biogeographical value. Mainly among the crustaceans, the majority of which revealed themselves to be undescribed or new for the Iranian fauna.

The following animal groups were identified: hydrozoa, rotifers, turbellarians, cyclopid and harpacticoid copepods, cladocerans, ostracods, asellid and microparasellid isopods, amphipods, nematods, oligochaetes, gastropods, bivalvia, water mites, collembols and insect larvae. The copepods, the ostracods and the oligochaetes are the most abundant groups, in some samples the cyclopid copepods or the ostracods being the dominant group.

Among the copepods, numerous species of interstitial cyclopids and harpacticoids were pointed out: some of these were already known both from epigean and underground waters (wells) of Iran (Chappuis, 1954; Lindberg, 1942; Löffler, 1959, 1960; Rylov, 1928), other ones are new for the Iranian fauna or for the science. In particular, the cyclopids are represented by a few stygophil or stygobiont species, as Diacyclops iranicus Pesce & Maggi, Diacyclops languidoides (Lilljeborg), Diacyclops languidus (Sars), Acanthocyclops (Acanthocyclops) cf. cephallenus Pesce, Bryocyclops (Haplocyclops) cf. neuter Kiefer (Dussart, in litt.), and by more numerous stygoxen species, which live both in subterranean and epigean waters, as Paracyclops fimbriatus (Fischer), Tropocyclops prasinus (Fischer), Eucyclops serrulatus (Fischer), Acanthocyclops (Megacyclops) viridis (Jurine), Acanthocyclops (Megacyclops) viridis deserticola Lindberg, Acanthocyclops robustus (Sars), Acanthocyclops vernalis (Fischer), Diacyclops crassicaudis s.l. (Sars), Diacyclops bisetosus (Rehberg).

The harpacticoids are represented by true stygobiont species as Nitocrella petkovski Pesce and Nitocrella paceae Pesce, which are at present endemic for Iran, and by other stygophil or eustigophil species as Attheyella crassa (Sars) and Canthocamptus staphylinus (Jurine) which show a wide geographical distribution.

Among the isopods, remarkable and of a great biogeographical interest is the discovery in Iran of the family Microparasellidae since, until now, no representatives of this family had been reported from this country. All the material of this group belongs to the species Microcharon raffaellae Pesce which was collected in a freshwater well in the highland of Isfahan and which is at present to be considered endemic from Iran.

From a systematic point of view, the above species fits in the group of the fresh-water species of the genus Microcharan (after Pesce, in press), being close to M. kirghisicus Jankowskaya from central Asia and to M. phreaticus Coineau & Botosaneanu from Cuba.

As regard the genus Microcharon, it shows a wide, cosmopolitan, distribution (Europe, Asia, Africa, WEst Indies, New Caledonie, etc.): several species and subspecies are reported from inland subterranean waters, other ones from interstitial marine habitat. According to some authors (Coineau, 1968; Pesce, in press; Danielopol, 1980) the fresh-water species of Microcharon have a marine origin: they penetrated and got adapted to the inland groundwaters during the Miocene regressions of the "Tethys sea" in the same way of many other subterranean groups as cirolanids, stenasellids, thermosbenaceans, amphipods (Bogidiella, Ingolfiella) and mysids. All of this was according to a model that Stock (1977) called "Regression Model".

The other isopods which were collected belong to the family Asellidae and to the widespread species Asellus aquaticus (L) Racovitza which is well represented in our samples, both from the Caspian area and the inner highlands.

At the present time, the genus Asellus Dudich is divided in three different phyletic lines which, according to some authors, represent three distinct subgenus: Asellus s. str., Mesoasellus Birstein and Phreatoasellus Matsumoto.

From a biogeographical point of view, it is to be considered an euroasiatic group, with a wide geographical distribution. The species A. aquaticus recently penetrated deeply in western Europe, both in epigean and subterranean waters.

The material of Amphipods belongs to a new genus, Phreatomelita Ruffo with the species P. paceae recently described by Ruffo (1979). According to the authors, the new genus is close to some indopacific genera living in subterranean freshwaters: Psammoniphargus Ruffo, from interstitial waters of the island of Reunion, Paraniphargus Tattersall, from fresh-waters of the Andamane Islands and from Giava, Galapsiellus Barnard, from the Galapagos, as well as to the amphipods of the "Hadziid-group" sensu Stock (1977).

Besides its great systematic and biogeographical interest, the discovery of P. paceae in the underground waters of Iran is remarkable. As far as we know, it represents the only and the first amphipod which is reported from the phreatic subterranean waters of this country.

As regards the oligochaetes, which are well represented in the groundwaters, are very abundant in our collections. Most of the species belong to the families Lumbriculidae, Naididae, Enchytraeidae and Tubificidae (mostly cocoons), being generally distributed in the superficial layers of the sampled sediments. The following species were identified: Peloscolex velutinus (Grube); Nais eliguis Müller; Tubifex tubifex (Müller) Nais sp.; Peloscolex sp. and Lycodrilus phreodriloides Malevich.

The majority of these show a wide geographical distribution and live both in epigean and subterranean waters, offering a little biogeographical value. On the contrary, the species Lycodrilus phreodriloides is very interesting since, until now, it occurred only in the Lake Baikal. The other related species living together in the connected rivers Jenisej and Angara: L. phreodriloides lives on stony bottom or on sponges, the other species of the same genus prefer muddy or sandy sediments.

According to E. Dumnika, who kindly determined these materials, the specimens from Iran differ from the original description by some details, which could assure the identity of the Iranian populations of this species.

In association with the oligochaetes, insect larvae as Chironomids, Ephemerids, etc., occur abundantly in the same wells, being very numerous in the superficial layers of the groundwater.

All the other material which was collected are still in course of study by specialists who will publish their results as soon as possible.

At the end, this first, preliminary approach to the phreatic subterranean systems of Iran already revealed their remarkable interest from a biological point of view, as well as pointed out a rich and diversified fauna living in the underground waters of this country. However, still much has to be done in this field, since the species that we reported above most probably represent only a small portion of the subterranean aquatic fauna of Iran. Therefore, it is likely that the study of the remaining samples, as well as the continuation of the biological researches in the underground systems of Iran, will lead to additional discoveries and to a better knowledge of the Iranian fauna.

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Soil Biology in the Southeastern Italian Alpine Area: General Problems of Biospeleology

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Its History in Brief:

Running through the biospeleology history again, we realized that biological data concerning caves of the alpine southern region are available only in the second middle of the XIX century thanks to the work of geographers and geologists. Entomologists came much later on. Little or nothing is known about endogeous fauna, which has been however, studied by famous entomologists such as Berbese, Silvestri, Agostino Dodero, or from time to time by Andrea Fiori.

The ecological classification of cave-dwellers is based on their morphology and it is a very old and experienced acquisition, even if it evolved and changed in the long run.

The beginning of the XX century offers a great quantity of new research works, which reached their highest point in important monographies, particularly those on Coleopters as well as on Myriapods and Isopods.

Method of Work and Terminology:

In the wake of important works, as those on the Coleopters written by Jeannel and G. Müller, the unsurpassed masters, a more specific type of research has developed-that in caves. There are a great many naturalists who collect particularly in caves and send their material to important specialists who carefully describe it.

Along with these researchs and systematics, an ecological classification of the organisms has been developed with the purpose of synthetizing their morphological characters and their adaptation capacity to life in caves.

Limits of Traditional Models:

Thanks to the setting-up of, on one side, laboratory researchs (Moulis, France) in the second middle of the XX century and, on the other, a more careful study of soils, the habitat of the so-called "troglobionts" seems to be in these later years much wider, not only in caves but also outside in the soil. However, soil researchs are still at the beginning!

According to the most recent results, there are two categories of specialized hypogeous organisms: 1) the edaphobiants, very little and flat, who colonize soil pores; 2) the troglobionts, with a greater size and extended legs, who colonize the microsplits of the same soils and, from time to time, caves.

It is possible that, because of serious pedological instability due to climatic or human cause, troglobionts disappear from the superficial soil-stratum and are found only exclusively in caves. This fact is visible in a cline-environment such as the Prealps and the high plain in Northeast Italy.

The Present Situation of the Research and a Possible Approach for an Environmental Utilization

The more flexible understanding of soil populations offers greater possibilities for further studies and experimental researches.

It is possible to forget as axiom, the model "cave-isle". New approaches on the soil are practicable, at least for the following three points:

1) The period, in which Invertebrates populations began to be endemic, must be considered shorter. There is evidence that it took place in post-glacial area.
2) The population dimension must be brought up-to-date, taking into acount not only caves, but also endogeous sides.
3) The above information seems to be very useful and convenient for environmental researches, as well as naturalistic interventions as for biogeography and genetics, as for agriculture and forestry use.

Soil Biology: Activity and Prospects of the Research Carried Out by the "Centro di Ecologia del Cansiglio", Venitian Prealps, Italy

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The "Centro di Ecologia del Cansiglio"

The "Centro di Ecologia del Cansiglio" is a public association among scholars, including University professors, with the purpose of increasing ecological information of one of the most interesting areas from the naturalistic point of view, and more respected in the southern Italian Alps-the Cansiglio forest and its neighboring areas.

Cansiglio, set in the Northeast of Italy, is in particular a karsic plateau with the form of a wide "polje" at an average altitude of 1,000-1.200 m all surrounded by mountains. It is covered mainly by a beech (Fagus salvatica) and tar-tree (Picea excolsa), white fir tree (Albies alba) forest. It is a vast and unique remnant of a much wider wood extension. Today it represents the greater wood of the Venitian Prealps as well as of the Italian Alps.

Activity:

The "Centro di Ecologia del Cansiglio" is carrying out many different projects on the following subjects: the study of local karsic phenomenon, speleology, glaciology and pedology, general soil biology and biospeleology, and many different aspects of ecology.

Soil Biology and Invertebrates Biospeleology:

These two items are of great interest, because they help to know better life strategy in a Karstic soil (calcareaous Mesozoic) covered by a luxuriant and mixed forest.

A great deal of research work has been done both in deep caves (also 600 m deep) and on the superficial soil, and consequently a great deal of information is now available.

Underground climatology, speleology and glaciology observations are now much more precise and systematic, thanks to the setting-up in the last few years of some underground stations (little labs).

Projects to be Concluded:

1) A detailed list of soil invertebrates, which are the most important voice of terrestrial bio-mass;

2) A survey on the invertebrates food chain in order to point out: the ecological role of the different species including those similar; the importance of the different species on the "soil turnover" (Terrestrial Isopods, Diplopods, Oligochets); and because Proteus anguinus is a very rare amphibian in Italy, our Center is carrying on a study on its food chain. In the hipogean Italian stations, where Proteus anguinus has been found, water crustacea seem to be its prefered food. For this reason, these organisms are under observation from the quantitative point of view.

Publications:

The Center has issued, until now, a great deal of articles and still more are in the press.

Carbonaceous Sediments in a Gypsum Karst (Hainholz/South Harz, Federal Republic of Germany)

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Abstract

Gypsum karst sediments from surface "Schlotten" and a solution cave (Jettenhöhle) were analysed for element (EDAX) and mineral composition (X-ray diffraction) and investigated by electron microscopy. Calcite content varies greatly among samples, reflecting different climatic conditions during their formation. Residual organic and inorganic authigenic forms of a calcite grains can be discerned and part of the cave sediment is formed by accumulating calcite floats.

Zusammenfassung

Gipskarstsedimente aus Schlotten und einer Laughöhle (Jettenhöhle/ wurden auf ihre Element- (EDAX) und Mineralzusammensetzung (Röntgenbeugung) analysiert und unter dem Elektronenmikroskop untersucht. Der Calcitgehalt variiert zwischen den Proben erheblich, verschiedene klimatische Bildungsbedingungen reflektierend. Residuale organische und anorganische authigene Calcitkristalle könne unterschieden werden. Ein Teil der Höhlensedimente wurde durch akkumulierende Calcithäute gebildet.

Introduction

Karstification processes in gypsum not only create caves by underground dissolution, but also sculpture the surface. Insoluables of gypsum rock or water- and windborne material will fill the solution cavities above and below ground. To assess the mineralogy and genesis of these sediments, the gypsum karst area "Hainholz" (Hauptanhydrite formation, Zechstein 3, Upper Permian) in the South Harz region of Germany was investigated. The former anhydrite is entirely gypsified and the original thickness of this formation of 35-60 m has been reduced to 10-40 m by karstification. The area, a nature preserve, is wooded and has an annual mean precipitation of 800 mm (Brandt et al., 1976).

Sampling and Methods

Typical karst surface features of the Hainholz are the so called "Schlotten", which are cylindrical pits up to 15 m deep and 1 m wide, forming at intersections of clefts by solution.

Eleven sediment samples were taken from one filling, representing a profile 6 m deep (Kempe and Emeis, 1979).

Underground 26 caves with together 1.4 km passages are known. The caves have developed in non-turbulent water bodies and are flooded by several meters of sediments. Thirty samples of various sediment types were taken from the floor and from wall pockets of one of these caves, the Jettenhole, being the longest and most advanced in development (Figure 1).

The mineralogy of selected samples was established by X-ray diffraction. Morphology of the grains was studied with electron microscopy and crushed samples were analyzed for their elemental composition by EDAX (=energy dispersive analysis of X-rays).

EDAX was conducted at 20 kV, so that elements at the grain surfaces are overrepresented. By EDAX, only elements heavier than sodium can be analyzed; by assuming the presence of certain anions, however, the analysis can be converted from element weight percentages to oxides or mineral percentages.

Discussion of Results, Schlotten Sediments

The process of Schlotten formation is depicted in Figure 2, the x-axis representing time. Theoretically four sediment types of different origin may be trapped in these pits:

At the bottom, ongoing dissolution of gypsum leaves irregular, porous sediments, residualia, comprised of magnesite, dolomite, and calcite, which are accessories present in the Hauptanhydrite (Kosmahl, 1969; Brandt et al., 1976) (Figure 2, layer 1). On top, residues of the former Hauptanhydrite caprock may accumulate (Figure 2, layer 2). In glacial times, loess could have entered the Schlotten (layer 3). Finally, residuals from the surface dissolution may be washed into the deepening trap (layer 4). These sediments should be fine grained and more tightly packed than the leftovers in layer 1. Also, organic debris from the surface is to be expected.

The minerals found within the actual sediment are calcite, dolomite, magnesite, quartz, feldspar, illite, kaolinite and chlorite. Also poorly crystalized iron oxides (limonite) occurs. Element distribution with the profiles was recalculated for most likely oxides and mineral species and is shown in Figure 3. The profile is characterized by three carbonate poor layers (30-60% $CaCO_3$) interrupted by two very carbonate rich strata (80-90% $CaCO_3$). Within the carbonate poor layers, charcoal flitters and gastropod shells were found.

Morphologically, three different calcite species were found.

1) longitudinal, about 50 to 20 my large crystals with corroded surfaces (Plate 1, 1) possibly residuals from the bedrock;
2) steep rhombohedrons (0221), about 20 my large and uncorroded; they are of inorganic, authigenic origin and have formed in interstital waters (Plate 1, 2);
3) 20 my long and 1 my wide rods with longitudianl notches (Plate 1, 3); calcite rods like these were reported from moonmilk by Roger and Moore (1976). In our case, these rods comprise up to 20% of the total sediment.

All of these carbonate crystals are imbedded in a very find matrix of clay minerals, iron oxide and quartz, individual grains not being larger than 1 my. The whole profile seems to be composed of residual material of the theoretical layer 4.

Indications of loess or former caprock (red clay and siltstone) have not been found. The caprock obviously had been removed, when the Schlotten began to develop.

The layers of poor carbonate content with their organic particles probably have been washed into the Schlotten during times of warmer climate when high soil CO_2 partial pressure allowed an extended dissolution also of residual calcite.

Thus, carbonate rich layers originate from glacial time, when soil activity was considerably lower, if not totally absent because of permafrost.

Tentatively correlating the two carbonate rich layers with the last two ice ages, the Schlotten could have started to develop in the Holstein interglacial, some 250 000 years ago. This date fits into the terrace development of that area and marks the time the last major erosion event has occurred (Brandt et al., 1976).

From hydrochemical investigations, an overall lowering of the gypsum karst of 4 m in 10 000 years of humid climate has been estimated. Taking into consideration that the depth of a Schlotte is just a differential parameter, this rate also fits into the general estimate of karst denudation velocity.

Cave Sediments

Table 1 lists EDAX-composition of 30 samples recalculated for likely minerals of oxides and normalized to 100%.

The sediment composition varies considerably and minerals recognized by X-ray diffraction include calcite, dolomite, magnesite, quartz, kaolinite, illite, and gypsum. The high copper contents may be explained by the high copper contents of teh Zechstein formation or by instrumental artefact. Gypsum is present mainly in samples near the entrance, where in winter cold and dry air is drawn into the cave and evaporation causes gypsum. In addition, calcite is precipitated when seepage drips to the floor. The calcite crystals thus formed are 10 my long steep rhombohedrons and are recognized throughout most of the samples.

Sample 25 is powdery gypsum, possibly formed by frost desintegration at a former entrance to the cave. Further inside the cave sediments have very high calcite contents, generally above 80%. Those samples with more than 10% $MgCO_3$ (magnesite and/or dolomite) are gypsum residuals as mg-carbonates cannot be formed under present hydrochemical conditions (FISCHBEK, 1974). Morphologically, these carbonates show corroded surfaces lacking idiomorphic shapes. Under the electron microscope, another group of carbonates is striking:

lancet like, with stepped surface, often bundled into radial groups (Plate 1,4). Single crystals are around between 50 and 300 my long and around 30 my wide. They are the residues of calcite floates (e.g. sample 29) precipitated at the surface of the cave pools. Already in 1930, Biese has described the origin, though the hydrochemical background was revealed only recently. The Jettenhohle is underlain by the karstified Stabfurt dolomite (Figure 4). Along clefts or small faults, the carbonate rich karst waters rise through the T3 clay into the lower part of the Hauptanhydrite (Y3), creating the solution caves there by dissolving additional $CaSO_4$ and returning by gravitational convection into the lower aquifer. Hydrochemical monitoring of the cave pools in the Jettenhohle in 1975 has shown that all year round pools do not reach gypsum saturation, but are supersaturated with respect to calcite. CO_2 pressure in these water bodies is high in contrary to low PCO_2 of seepage water. Consequently cave pools are degassing CO_2 and calcite will precipitate at the water surface. Throughout the millenia, these calcite floats have accumulated to several meters of deposits in the cave.

Following the model calculations of Dreybrodt (1980) on the kinetics of calcite deposition from water films, a calcite float of the depth of 100 my and the area of 1 cm^2 would roughly need one to two years for its formation. The assumption in these estimations is that the water is exchanged after it had lost all calcite possible. The limiting rate in this deposition is the CO_2 diffusion to the water surface. One solid meter of these sediments could thus have formed within roughly 10,000 years, placing the cave sediments into Holocene times.

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Table 1
EDAX Elemental Analysis of 8 Elements Totalling 100% Recalculated for Minerals or Oxide Likely to Occur in the Sediments

Sample No.	$MgCO_3$	Al_2O_3	SiO_2	$CaSO_4$	K_2O	$CaCO_3$	Fe_2O_3	CuO
1	2.3	2.0	7.5	64.4	0.5	21.2	1.4	0.6
2	4.6	5.0	18.0	18.9	0.9	47.2	3.5	1.8
3	3.8	6.1	5.4	44.8	0.4	36.4	0.9	2.1
5	1.3	11.2	1.1	32.0	0.1	52.5	0.1	1.7
6	7.0	7.1	24.0	25.0	1.7	27.8	4.5	2.3
7	9.8	2.4	8.4	3.6	0.4	72.0	1.9	1.7
8	12.8	1.5	6.1	5.1	0.1	70.2	1.2	2.9
9	6.5	1.5	5.0	2.4	0.3	81.2	2.4	0.7
10	6.1	0.9	3.8	2.1	0.3	84.0	2.0	0.9
11	24.2	2.5	8.8	1.2	0.2	60.3	1.5	1.2
12	3.1	1.0	3.3	2.6	0.2	88.4	0.7	0.7
13	8.5	1.9	5.0	2.3	0.3	80.2	1.0	0.8
14	4.5	0.7	2.5	2.4	0.1	86.5	1.4	1.8
15	5.4	1.7	5.8	2.1	0.4	81.8	1.8	1.1
16	7.6	1.6	4.9	1.4	0.3	82.1	1.2	0.8
17	18.5	0.9	3.7	0.9	0.2	73.6	1.1	1.1
18	6.7	1.0	3.8	1.4	0.3	84.5	1.6	0.8
19	1.6	0.8	2.6	1.4	0.2	91.3	1.3	0.8
20	2.6	1.4	5.0	1.3	0.3	85.9	2.6	0.8
21	11.2	5.7	17.3	1.1	1.2	57.9	5.1	0.5
22	4.4	4.1	12.3	3.6	0.7	70.9	3.1	0.8
23	6.3	7.8	31.4	1.6	1.3	44.5	6.4	0.7
24	2.9	21.3	6.9	1.4	0.5	64.0	2.4	0.6
25	0.3	0.1	0.7	84.1	0.1	13.9	0.1	0.7
26	5.7	10.3	50.9	1.8	2.9	21.0	6.7	0.7
27	36.0	3.0	12.8	1.5	0.5	42.2	3.3	0.7
28	7.6	3.6	12.6	1.3	0.9	70.5	3.0	0.6
29	2.9	6.8	3.2	2.6	0.3	82.5	0.8	0.7
30	6.8	12.7	50.1	1.0	3.3	18.3	7.2	0.7

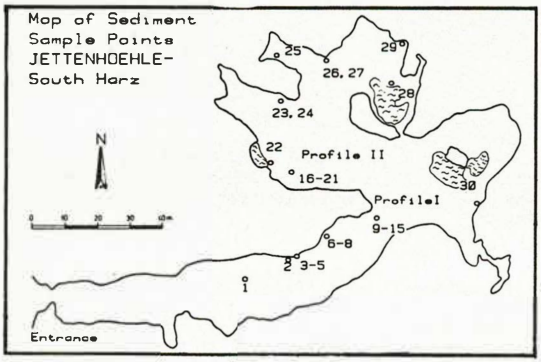
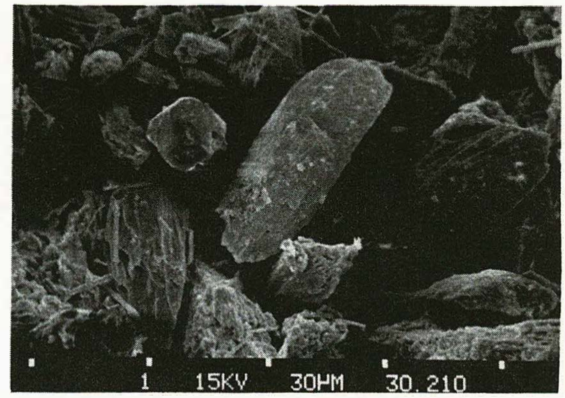


Figure 1: Map of Sediment Sample Points JETTENHOEHLE - South Harz



Picture 1

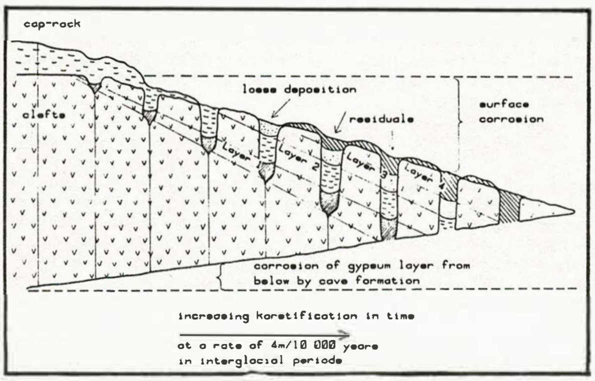
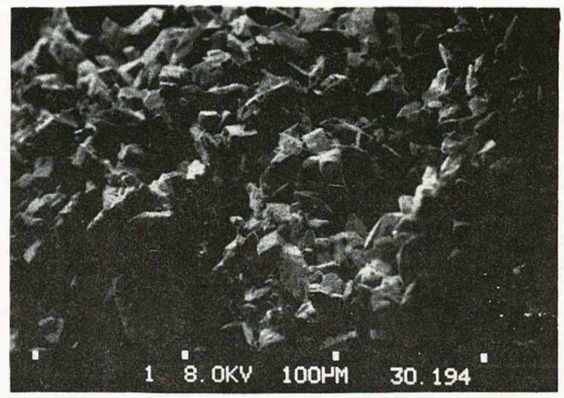


Figure 2: Model of Schlotten Devel- opment in South Horz Gysum Karst



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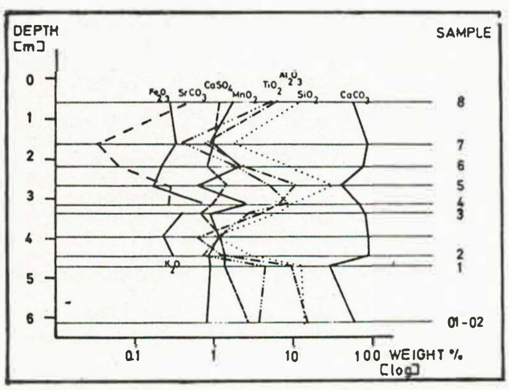
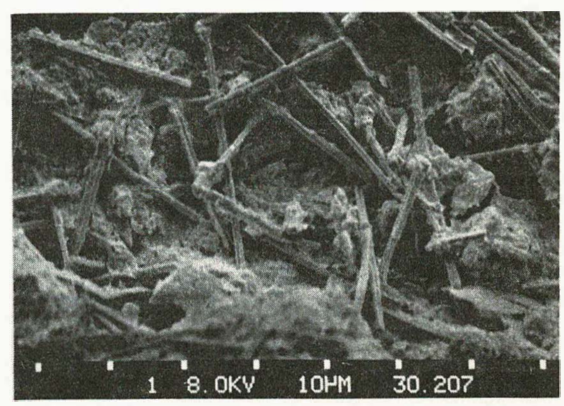


Figure 3: Mineral cencentration in Schlotten



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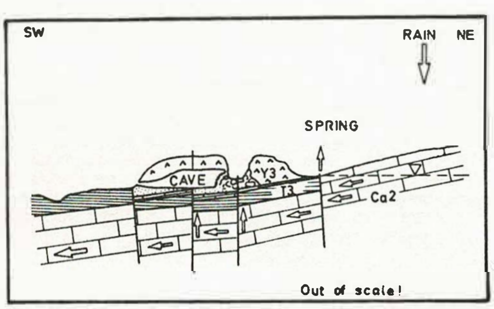
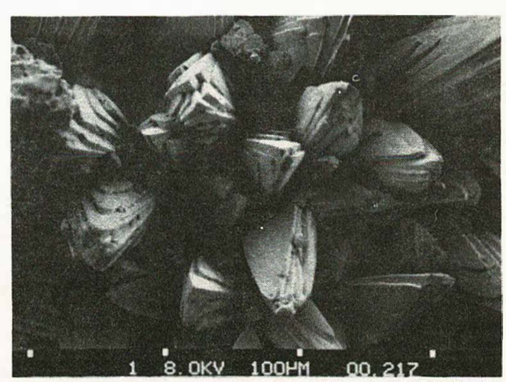


Figure 4: Sketch of geological pro- file through Hainholz



Picture 4

Techniques de Progression en Riviere Souterraine a Gros Debit

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Résumé

Avec la découverte récente de rivières souterraines aux débits exceptionnels (5 à 20 m^3/s), notamment au Mexique et surtout en Papouasie Nouvelle-Buinée, de nouvelles techniques de progression ont dues être mises au point afin de vaincre des difficultés jamais rencontrées sous terre à ce jour. Les remarques qui suivent constituent la première approche de ces problèmes. Les techniques décrites ont été utilisées avec succés par l'expédition nationale de la Fédération Française de spéléologie en Nouvelle-Bretagne et notamment lors de l'exploration des rivières de KAVAKUNA/MATALI et NARE.

Abstract

With the recent discovery of large river caves in Mexico and Papua-New Guinea (flow: 5 to 20 m^3/s), new technics had to be developed in order to compete with difficulties never encountered underground. This paper is a first approach to the problem. The technics described have proven to be successful in the exploration of the KAVAKUNA/MATALI system (flow: 10 m^3/s; depth: 459 m; length: 3500 m) and the NARE river (flow: 15 m^3/s; depth: 400 m; length: 4500 m). This explorations were made by the 1980 French national expedition to New Britain (PNG) led by the author.

Avec la découverte récente de rivières souterraines aux débits exceptionnels (5 à 30 m^3/s), notamment au Mexique et surtout en Papouasie Nouvelle-Guinée, de nouvelles techniques de progression ont dues être mises au point afin de vaincre des difficultées jamais rencontrées sous terre à ce jour. Les remarques qui suivent constituent la première approche de ces problèmes. Les techniques décrites ont été utilisées avec succès lors de l'exploration des rivières de KAVAKUNA/MATALI (débit 15 m^3/s), NARE (débit 10 m^3/s) et MYNIE (débit 20 m^3/s).

Avec davantage de pratique et d'entraînement, on peut espérer vaincre des rivières encore plus importantes.

Equipement Particulier

L'exploration de rivières à fort débit suppose un matériel spécifique qui s'ajoutera à l'équipement habituel.

A. Matériel personnel:

- le port du gilet flotteur est obligatoire à tout moment; celui-ci devra être porté par dessus la combinaison, mais sous le baudrier (et les longes). Ses attaches devront être bien serrées et escamotées
- le casque doit être équipé d'un éclairage mixte avec une lampe électrique étanche et surtout très fiable, qui doit être allumée avant toute tentative exposée
- des chaussures légères à semelle souple permettant de nager facilement sont indispensables. Les bottes de caoutchouc montantes qui se remplissent d'eau sont à proscrire
- les genouillères et coudières peuvent être utiles contre les chocs. Les combinaisons de plongée ne sont pas indispensables dans une eau dont la température est supérieure à 20°C.

B. Matériel collectif:

Plusieurs accessoires se sont révélés très utiles.

- bateau pneumatique: le modèle idéal semble être celui en forme de fer à cheval, très relevé à l'avant et sans boudin à l'arrière, pour permettre de palmer. Trois points d'ancrage sont nécessaires pour les manoeuvres d'assurage et deux poignées pour se maintenir dans les remous. Le fond doit être gonflable séparément et le tout doit supporter largement le poids d'un homme.
(voir schéma suivant)
- grappin: il doit être solide, suffisamment léger pour y ajouter un flotteur (fabrication peu évidente) et suffisamment lourd pour être lancé efficacement. Les pointes des dents doivent être arrondies, le modèle idéal reste à définir (trident, ancre, flèche...) Il doit être utilisé avec une corde en double, sans neoud, très solide (10 mm minimum) et flottante si possible. La corde sera uniquement passée dans l'anneau du grappin sans y être attachée de manière à pouvoir la récupérer.
- des chambres à air ou des sacs étanches gonflés peuvent être utiles comme flotteurs supplémentaires ou, plus simplement, pour tester l'importance des remous.
- l'équipement sera complété par des palmes et un assortiment de cordes statiques et dynamiques, des cordelettes flottantes et des anneaux de sangle.

Techniques de Progression

A. Dans la rivière:

Il est rarement possible de progresser directement dans les rivières à fort débit, mis à part dans certains passages à fort courant mais sans remous, ou lors d'évasements en forme de lacs. Le premier se laisse dériver au gré du courant, soit à la nage, soit en canot et installe un relais 30 à 40 m plus loin. De là, il assure la progression du second sur 40 m supplémentaires et ainsi de suite. Si le courant n'est pas remontable, il faut laisser une cordelette tout le long afin de se tracter au retour.

B. Les traversées de rivières:

La plupart du temps, la progression pourra se faire sur l'une ou l'autre berge. Mais à chaque méandre de la rivière, il faut gagner l'autre berge pour poursuivre.

- à gué: lorsque cela est possible, c'est le moyen le plus rapide. Assuré par l'aval (cf. techniques d'assurage), le premier utilise les blocs qui émergent de l'eau pour progresser (saut, escalade plus ou moins immergée, passage en force...); il doit éviter au maximum l'immersion afin de ne pas être déséquilibré, voire emporté.
- à la nage: un bon nageur, après entraînement à l'air libre et une certaine habitude de l'eau vive, peut franchir un passage sans remous en utilisant les effets du contre-courant. En aval de chaque bloc, une zone de contre-courant peut permettre de se stabiliser avant la zone de courant suivante qui sera franchie soit en plongeon, soit en nageant... vite! Dans tous les cas, le passage se fait en force.
- à l'aide d'un grappin, on peut également traverser à la nage selon le principe du bac à traille.

Disposant d'un point fixe, en amont, sur l'autre rive, le nageur se laisse aller dans le courant qui le ramène automatiquement sur l'autre berge.

- en bateau pneumatique: le premier, à plat ventre dans le canot, utilise des palmes ou des rames pour traverser, en utilisant les mêmes principes qu'à la nage (contre-courant, bac à traille); il pourra franchir des courants plus violents, voire même des remous peu importants. Il devra cependant prendre la précaution de bien ranger les cordes de traction et d'assurage pour éviter de s'emmêler. Il ne devra en aucun cas être relié au canot (risque de coincement sous le bateau ou plaquage contre un bloc ou une paroi).
-escalade artificielle: si les conditions le permettent (taille raisonnable, roche saine, temps...), une progression au plafond peut permettre de traverser en pendule.
- au grappin: le grappin est un moyen pratique mais peu fiable d'installer une corde en travers de la rivière pour faciliter la traversée. L'idéal serait bien entendu un lance grappin qui autorise la précision et la force de lancer.

Cependant, le grappin peut être dangereux car il impossible de choisir l'emplacement idéal et surtout d'être sûr de la solidité de l'amarrage ainsi constitué. En outre, comme sa fonction l'implique, le grappin peut s'accrocher n'importe où et...définitivement!

La méthode la plus sûre consiste à utiliser un bloc de l'autre berge lorsque cela est possible. Le grappin doit être équipé d'une corde en double (sans noeud de manière à pouvoir la récupérer en cas de coincement du grappin) et lancé derrière le bloc en son milieu. Il suffit ensuite de jouer sur chaque corde de manière à ceinturer le bloc. Les deux extrémités de la corde sont ensuite tendues selon des angles choisis. La traversée se fait sur la corde la plus pratique. Le système peut également être utilisé avec un objet lourd si le bloc s'y prête.

C. Les tyroliennes:

Dès lors qu'une personne a atteint l'autre berge, il est facile de tendre une corde pour aider, ou même supporter le passage des autres. Je ne reviendrai pas sur les problèmes de tension au niveau des amarrages qui ont déjà fait l'objet de publications. Cependant, dans le cas qui nous interresse, certaines précautions particulières doivent être abservées:

- ne jamais porter de sacs sur le dos ou être relié à un sac
- ne jamais se mousquetonner sur une tyrolienne ou pire, sur un bloqueur: il vaut mieux tomber à l'eau et être récupéré par la corde d'assurage que de risquer d'être bloqué sur la corde dans l'eau
- si un bloqueur doit être utilisé pour faciliter la progression, il ne devra pas être relié à l'utilisateur (cf. accident équipe Suisse en Nouvelle-Guinée)
- en règle générale, il faut éviter des excès de corde, de boucles et de sangles qui risquent de se transformer en collet sous l'eau et essayer de progresser au maximum hors de l'eau.

Techniques D'Assurage

Ces techniques sont valables pour toute chute dans une rivière à fort débit et doivent tendre à utiliser la force de l'eau plutôt que de la combattre.

A. Par l'amont:

C'est la première idée qui vient à l'esprit puisqu'elle tend à raccourcir au maximum la chute possible. En fait, elle est à proscrire totalement pour plusieurs raisons:

- le nageur tracté par l'amont risque de plonger sous l'eau par l'effet du courant
- la vague créée par le corps inerte recouvre la tête
- la pression de l'eau sur la cage thoracique plaque le baudrier et entraîne un risque d'étouffement
- il faut déployer une force considérable pour lutter contre le courant
- une chute courte peut être plus dangereuse (chocs, coincements).

B. Par l'aval:

C'est un assurage dynamique qui utilise le courant sans ~~le co~~mbattre. La chute est plus spectaculaire mais plus sûre avec un minimum de sang froid. Il permet une grande mobilité, rapide de surcroît et un amortissement non négligeable de la chute. Il convient de choisir des emplacements propices pour un maximum d'efficacité. Le point d'assurage doit se trouver entre la zone de récupération et le point où il y a risque de chute (et en aval de ce dernier). La distance entre le point d'assurage et la zone de récupération ne doit pas être inférieure à la largeur de la rivière.

En cas de chute, le nageur se laisse emporter par le courant. Il doit, grâce au gilet, flotter même par gros remous. Dès qu'il atteint la zone de récupération (par exemple une zone de contre-courant ou plus calme), il peut nager vers la berge. La personne qui l'assure doit l'assister sans le tracter. Cette manoeuvre ne nécissite aucun effort particulier.

C. Cas particulier de l'assurage par le haut:

Lorsque la berge est très abrupte, voire verticale, l'assurage devra se faire ~~dep~~uis le haut. Le principe reste le même, mais l'assurage par l'aval n'est pas indispensable puisque la traction sortira le nageur hors de l'eau. La hauteur depuis le point d'assurage jusqu'au niveau de la rivière devra cependant êtra supérieure à la largeur de la rivière.

Conclusion

Ces techniques sont le premier résultat d'expériences face à des situations particulières. Elles restent néarmoins très risquées et supposent une grande habitude de l'eau vive et beaucoup de sang froid.

Ce type d'exploration constitue certainement un premier pas vers une spéléologie différente de celle pratiquée jusqu'alors. Outre les nouveaux problèmes techniques qu'elle engendre, son aproche suppose un engagement certain. Mais en poussant à l'extrême, on peut se demander ce qu'il adviendrait du plaisir, de l'intérêt et de la finalité d'une progression entièrement en artificielle au plafond d'une galerie pour les deux simples raisons qu'il n'y a pas d'autre moyen connu et que la caverne elle, continue...?

En toe cas, il est certain que nous sommes confrontés à des problèmes nouveau qui dépassent le cadre de la spéléologie classique. Nul doute que dans un futur que j'espère très proche, cet article fera sourire...

Le Gouffre B.U. 56 = -1,192 Mètres (Massif De La Pierre Saint-Martin)

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Résumé

La découverte au cours de l'été 1980 d'un nouveau gouffre important sur le varsant espagnol du massif de la Pierre St Martin relance l'intérêt pour la recherche de la rivière souterraine Saint Georges. Cette exploration (non terminée) jusqu'à la cote - 1200 m constitue déjà la plus profonde jamais réalisée à partir d'une seule entrée. Elle relance également dans certains esprits l'idée de record du monde de profondeur...

Cet article fait le point sur l'état actuel des recherches de la rivière Saint Georges, et décrit ce nouveau gouffre qui devient (au 30 aout 80) le 4éme plus profond du monde.

Abstract

During the summer of 1980, an entirely new system of caves was explored to the depth of - 1200 m in the spanish side of the Pierre Saint Martin Karst. This exploration (uncompleted) is actually the deepest ever made starting from a single entrance. This new discovery gives the opportunity to talk again about the Saint Georges underground river as well as the possibility of a new world record...

This paper takes stock of the actual state of the St Georges searches and describes this new system that becomes (as of Aug 20th, 1980) the 4th Deepest in the world.

Introduction

Les nombreuses années passées à la recherche de la rivière Saint-Georges viennent de porter une partie de leurs fruits, et ceci de manière quelque peu spectaculaire, puisqu'en quelques semaines un nouveau gouffre a confirmé l'existence de circulations d'eau importantes en Espagne, à l'extrémité sud du massif de la Pierre Saint Martin.

Le BU 56 a donc permis 20 ans après la Pierre et 10 ans après le Lonnet-peyret, de suivre à nouveau le cours d'un collecteur sur une grande longueur (7500 m) et jusqu'à la profondeur provisoire de 1192 m. Cette nouvelle cavité qui n'a pas encore reçu de nom devient donc la plus profonde d'Espagne et la quatrième du monde. Elle constitue en outre pour les amateurs d' intégrales en tous ghres l'exploration la plus profonde jamais réalisée. Ajoutons que la connaissance que nous avons actuellement de cette rivière ne permettent pas de trancher entre les diverses théories concernant le réseau Saint-Georges, dont ce collecteur est certainement tributaire.

Alores? Découverte de la Décade à la Pierre Saint-Martin? Coup de chance? Exploration la plus profonde du monde? Et j'allais l'oublier, Futur record du monde? Chacun jugera en fonction des raisons qui le poussent à descendre sous terre...

Pour nous, c'est surtout un pas de géant sur le chemin de la connaissance du bassin et de l'hydrogéologie générale de la Pierre. C'est aussi la preuve des possibilités humains et matérielles de la spéléologie d'aujourd'hui et, pourquoi pas? d'une certaine déontologie.

C'est enfin la récompense d'une obstination, d'un travail de recherche et d'exploration que nous sommes heureux de pouvoir offrir aujourd'hui à Isaac SANTESTEBAN, en hommage à Félix RUIZ DE ARCAUTE et Francis ZAMORA.

Contexte Geologique

Située à l'extrême sud du karst de la Pierre St Martin, dont elle fait partie intégrante, la zone de BUDOGUIA possède une géologie similaire à l'ensembel du massif. Les cavités s'ouvrent dans la couverture crétacée des "calcaires des canyons". Cette puissante série carbonatée du Campanien-Turonien mesure près de 400 m d'épaisseur et recouvre en discordance la zone axiale primaire constituée par les schistes et grès psammitiques du Namuro-Westphalien épais de 500 m. Ces fameux "calcaires des canyons" forment la majeure partie des immenses étendues lapiazées des bassins traditionnels de la Pierre St Martin et du St Georges.

Des calcschistes ± gréseux du Maestrichtien-Campanien affleurent en plusieurs points, aussi bien sur la ligne frontière (Pic d'Arlas, Soum de Lèche) que sur le rebord méridional du bassin du BU 56 (Paquiza Linzota, Hoya del Solano, Hoya del Portillo de Larra). Ces terrains brunâtres typiques sont tout de même moins bien karstifiés que les calcaires massifs du Campanien-Turonien.

Si le dispositif tectonique est assez simpledans son ensemble, la partie espagnole possède néanmoins une certaine complexité de détail. La zone axiale paléozoïque affleure à plus de 2000 m à la base des hautes parois dominant Lescun (Pic d'Ansabère, Table des Trois Rois, Pic d'Ani On retrouve ces mêmes roches primaires sous la forme de minuscules affleurements au fond des canions de Kakouéta et d'Fhujarre vers 500-700 m d'altitude, prouvant à quel point le noyau axial imperméable plonge nettement vers l'Ouest et le Nord-Ouest.

Les terrains crétacés qui intéressent directement le spéléologue forment une vaste coupole (anticlinorium) ondulée selon un train de plis d'axe Est-Ouest. Depuis la frontière, on voit ainsi se succéder au Sud le puissant anticlinal de la Sierra d'Anabarcardia, lequel va s'ennoyer à l'Ouest sous l'épais complexe calcschisteux du Maestrichtien, puis la partie synclinale de la Paquiza Linzota-Linza Maz et enfin le remarquable pli en genou culminant au Chinebral de Gamueta (2358 m).

Cet ensemble structural possède de multiples particularités. En premier lieu, on remarque en ennoyage général vers l'Ouest sous la couverture du Maestrichtien et du Nummulitique dont il reste un témoin attardé au sommet du Linza Maz (1945 m).

En second lieu, toute la carapace des "calcaires des canions" est intensément tectonisée. La forte fracturation fait ainsi apparaître deux directions préférentielles, l'une grossièrement Est-Ouest dans la direction des plis, l'autre beaucoup plus cisaillante de types Sud-Ouest/Nord-Est. De plus, le train de plis assez serrés qui affecte cette couverture crétacée montre de multiples replis à déversement sud. Le flanc méridional du pli Budoguia-Table des Trois Rois illustre parfaitement ce phénomène de replissement intense où l'ossature des calcaires des canions renferme dans ses plis synclinaux des remplissages de calcschistes maestrichtiens.

LE BU 56

Situation

L'entrée du gouffre s'ouvre sur une terrasse du flanc Nord de la Sierra de Budoguia, à environ une heure de marche de la Hoya del Portillo.
coordonnées: X:74,35 Y:347,55 Z:1980 m.

Historique

La découverte du BU 56 fin août 79 par Jean-François PERNETTE est arrivée au terme d'une prospection systématique d'est en ouest de la Sierra de Budoguia. Une première exploration solitaire permet d'atteindre la cote - 92 après désobstruction du méandre "N". Un puits arrosé fait suite.

En juillet 1980, l'exploration est poursuivie par Jean'François PERNETTE, Richard MAIRE, Gérard BOUSQUET et Serge FULCRAND. Bientôt rejoints par J.P. BLANC, G. BOUTEILLER, D. MARTINEZ et Y. PASCAL qui regroupés sous le nom d'"AMALGAME 80", explorent et topographient avec l'INSTITUCION PRINCIPE DE VIANA le réseau sur 7500 mètres jusqu'à la cote - 1192 m.

Description

A. LES PUITS (de 0 à - 433)

Le site de l'entrée du BU 56 est très beau; une table de lapiaz ~~entre deux~~ falaises, forme un belvédère de 150 m^2 en face duquel s'étend toute la faille d' Ukerdi, d'Ania Larra jusqu'à Bellagua ... Le puits d' entrée, de plusieurs mètres de diamètre, est profond de 20 m et encombré d'un névé important, qui gêne la descente. A sa base, un large méandre très pentu, mène après un soupirail à un premier ressaut de 6 m, et à un puits de 18 m. Ensuite, un P 12, entièrement colmaté par des blocs, absorbe le filet d'eau du névé. A quelques mètres du fond cependant, le courant d'air descendant d'engage dans une fissure où coule un ruisselet issu d'un autre réseau. Après désobstruction, le méandre "N" se tortille sur une soixantaine de mètres assez sévères (dénivellation : 15 m) et débouche enfin à - 92 sur un nouveau puits dans lequel s'écoulent les deux ruisselets réunis.

Nous poursuivons la descente dans une série de puits plus ou moins arrosés jusqu'à la cote - 220 où le réseau actif devient très étroit, et donc dangeureux en cas de crue. Au cours de la remontée, nous remarquons une petite lucarne vers - 125 que nous décidons d' explorer en priorité. C'est ainsi qu'après une courte désobstruction, nous abandonnons les puits actifs au profit d'une série de puits fossiles : après deux ressauts de 5 et 7 m, un puits de 65 m se dédouble en son milieu en 2 puits de dimensions semblables. L'un d'eux nous mène à - 220 dans un calcaire très dur, où une nouvelle circulation d'eau cascade dans des petits puits étroits (P8, P9, P5, P30).

Nous resterons d'ailleurs bloqués 5 heures au pied du P 30, envahi par une cascade après l'orage du 14 août 80 ...

Une nouvelle étroiture agrandie nous permet heureusement de cout-circuiter la suite des puits arrosés d'atteindre (P10, _78 dans une faille très longue) la cote - 387 où nous avons encore le choix entre deux suites possibles. La première que nous empruntons constitue l'aval le plus évident. Après un ressaut de méandre de 3 m, nous descendons un P25 arrosé qui n'est autre que le prolongement du P78 sus-jacent (en réalité, il s'agit d'un puits unique de 110 m). Le ruisseau dévale deux autres ressauts (P4, P3) et se jette au bout de quelques dizaines de mètres dans un joli petit collecteur de 5m x 7m environà la cote - 433.

B. L'AMONT-AVAL SUPERIEUR (de - 433 à - 475 et de - 433 à - 363)

Le ruisseau débite à peine 20 l/s et s'écoule dans une galerie de taille moyenne, très concrétionnée. Le puissant courant d'air descendant nous donne l'espoir de déboucher incessamment dans l'immense galerie que l'on suppose à la verticale du vallon d'Ukerdi ... Après 300 mètres d'une progression très aisée, nous butons sur une voûte mouillante. Celle-ci est heureusement court-circuitée, mais 150 mètres plus loin, nous nous heurtons à un nouveau siphon, à - 475. Le courant d'air prometteur s'échappe vers - 460 dans des affluents. Tout espoir de trouver un collecteur important grâce au BU 56 semble s'être envolé. En remontant, il restera à voir par acquit de conscience le départ présumé du méandre de - 387.

Quant au réseau amont proprement dit du "Rio de Budoguia", nous le remontons à partir de - 433 sur près de 900 m de développement. Après un parcours de 250 m, un fort grondement nous fait immédiatement penser à une diffluence et peut-être par bonheur au recoupement d'un aval différent. En fait, il s'agit du même "Rio de Budoguia" qui réapparaît 350 m en aval vers - 445. Nous avançons encore de 150 m dans une galerie bien surcreusée au départ, puis nous rencontrons une confluence. A droite, un méandre confortable est remonté sur plus de 120 m (la suite ne présente aucune difficulté). A gauche, la galerie principale (5-7 m) aboutit à la cote - 363 au pied d'une vaste galerie-galle très déclive de 20 m de large. Après plusieurs ressauts terreux et des amoncellements de blocs, nous atteignons un passage bas vers - 300 d'où proviennent le ruisseau et le courant d'air ...

C. LE "MEANDRO OPRIMIDO" (de - 387 à - 452)

Du balcon de la cote - 387 qui surplmobe l'amont-aval supérieur, le courant d'air s'insinue dans un méandre à faible pente. Le shiste y apparait de temps à autre sous la forme d'éboulements très instables. Malgré son étroitesse, le cheminement n'est pas du tout évident dans le Méandro Oprimido : il faut sans cesse chercher son chemin sous et sur les blocs coincés entre deux parois pourries, dont l'écartement n'autorise parfois le passage qu'à un seul niveau. Au bout de 150 m environ, le shiste disparait complètement, pour laisser la place au calcaire des canions. Le méandre devient alors plus étroit et à plusieurs niveaux, se divisant même en 2 branches. Dans le réseau inactif, un R4 et un P15 mènent à la cote - 440 où le méandre se poursuit encore sur 100 m avant de déboucher (enfin!) dans une petite galerie ébouleuse à - 452.

D. LE RIO AVAL (de - 452 à - 815)

La petite galerie ébouleuse s'élargit très vite jusqu'à 15 mètres. Nous ~~dévalons à toute~~ allure une pente d'éboulis au bas de laquelle un petit collecteur apparait sous les blocs. Nous le suivons sur 300 m dans une galerie toujours assez vaste qui s'amenuise soudain tandis que le rio commence à cascader sur le socle primaire. Sur 500 mètres ensuite, la progression rappelle celle dans des extrèmes amonts des autres rivières du massif : AN3, FR3, SC3 ..... Plusieurs siphons sont évités grâce à des galeries latérales, pas toujours commodes.

Quelques cascades nécessitent des mains courantes de sécurité (R4, P10, MC10) A - 575, nous débouchons dans une première petite salle.

Une corde sera obligatoire pour descendre entre deux blocs (P19)! Au bas de la salle, la galerie se poursuit, plus étroite mais très pentue. Il nous faut à nouveau équiper des passages délicats (2 MC12) où la rivière cascade sur le socle primaire en escalier, 300 mètres plus loin, nous sommes déjà à - 700 !

Après un léger virage vers le Sud, la galerie s' agrandit et la pente devient plus faible : il semble que l'on arrive à un confluent. Dans une sorte de salle compliquée, une galerie arrive effectivement rive gauche, du Sud donc. Serait-ce la rivière de l'A 60? L'actif en tous cas, doit passer sous les blocs. Nous jetons un coup d'oeil sur une centaine de mètres, face à un vent violent qui descend sans doute de quelque gouffre de la Hoya...

Mais l'aval continue aussi! La rivière s'écoule lentement dans un canion large de 7 à 8 mètres. Un bief encore plus profond que les autres nous oblige à utiliser les pontaonnières, et, 150 m plus loin, nous débouchons dans une salle circulaire. La rivière s'engoufre entre les blocs tandis que nous remontons, avec un soupçon de crainte, l'éboulis abrupt. L'endroit ressemble trop à la salle terminale de l'AN 3...

Un laminoir entre la voûté et les blocs, et ça passe!

C'est le début de la salle RONCAL, mais nous ne le savons pas encore. Nous poursuivons la montée de l' éboulis, dans un silence impressionnant, sur 80 mètres de dénivellation. Parvenu au sommet, nous redescendons de 110 m! En tout, 500 mètres en distance horizontale, rectiligne de surcroit. Quant à la largeur, nous ne l' avons pas mesurée ...

Nous approchons maintenant de la cote - 800 tandis qu'un grondement s'amplifie. Nous parvenons enfin sur une vire concrétionnée tandis que 25 mètres plus bas, une vraie rivière cette fois se déchaine entre les deux parois encaissées du Canyon RONCAL.

E. LE "RIO DEL RINCON DE BELLAGUA" (de - 815 à - 1192)

Au bas de la verticale de 25 mètres, la rivière coule au fond d'une haute fissure. Des bassins profonds peuvent être évités sur les cinquante premiers mètres, puis un P5 nous conduit au coeur du problème. Là, une crue serait mortelle. Des bassins écumant sont passés pkus ou moins en opposition ou en nous immergeant au 3/4. Un vide brumeux accompagné d'un bruit d'enfer s'offre brutalement à nos yeux après 250 m de progression depuis le P25 : nous frisons alors les - 900! Immédiatement, l'ambiance et la cadre du puits de l'Ouragan au Berger viennent à notre esprit. Nous sommes à peu près à la même profondeur, dans du "gros" et sur une vire surplombant la cascade. Mais cette fois la différence est de taille : nous ne sommes pas des amateurs de classiques pensant avec envie aux illustres prédécesseurs, nous sommes bien les premiers...

En réalité, une verticale d'une dizaine de mètres nous conduit sur un énorme bloc dans la Sala Paquiza. Cette dernière est richement concrétionnée en fistuleuses au-dessus de la rive droite. Nous continuons en nous insinuant entre les blocs, là où passe la rivière. Pendant près de 400 m, le parcours s'effectue principalement sous les ammoncellements de rochers effondrés qui encombrent toute la galerie, mais à - 940 nous débouchons à nouveau sur du "gros" (40m X 30m). L'altimètre au cou, nous dévalons le vaste couloir chaotique et passons la cote - 1000 sans le savoir. Au bout de 300 m, nous nous heurtons à un rétrécissement et à un abaissement de la voûte se terminant sur siphon. L'altimètre indique - 995 et nous n'arrivons pas à croire que nous ne passerons pas cette fameuse cote fatidique de - 1000, compte tenu de l'ampleur générale du trou (en fait, nous sommes à - 1041). Aucune continuation ne paraît évidente et nous nous restaurons en faisant triste mine. Il faut trouver la suite! Une équipe va explorer les parties hautes de l'immense galerie-salle précédente et escalader des coulées de calcite impressionnantes. L'autre équipe découvre un passage minuscule un mètre au-dessus de l'eau. Après un dédale de couloirs et de blocs coincés, une large strate décollée remontante (h = 60 cm) est suivie sur 20 m. La chance est décidément avec nous : nous débouchons sur le côté d'une vaste galerie large de 30 m.

Nous sommes maintenant persuadés de dépasser les - 1000, d'autant plus que nous percevons bien le grondement lointain de la rivière. Les dimensions de la grande galerie de Belagua sont colossales sans pour autant être inhumaines. De plus, les blocs paraissent débonnaires avec cette couche de calcite blanche et ces cascades de gours qui éclairent littéralement notre progression. Véritablement, ce spectacle tranche avec les amoncellements lugubres et noirs de la SALA RONCAL, semblable à la Pierre St Martin.

Vers - 1060/ - 1080, la rivière coule dans des passages bas surcreusés sur les bords de la galerie principale. Après une tentative dans le cours même du rio, nous nous rabattons sur le vaste conduit sec situé en rive gauche, lequel finit par se rétrécir à 7-10 m vers - 1100. Aux alentours de - 1140, dans un autre "shunt" inactif, une petite escalade délicate (qui sera évitée au retour) est réussie juste à gauche d'un petit affluent. Puis nous poursuivons dans une superbe galerie de 20 m de large et à voûte arrondie : ici, la rivière s'écoule tranquillement sur toute la largeur dans un grand lit de galets pour se perdre finalement à travers les cailloutis au pied de la sala Linza que nous gravissons sur plusieurs dizaines de mètres. Par chance, la continuation est rapidement découverte sur le côté gauche où un passage bas de plafond conduit à une salle déclive en forme d'amande (120 m X 50 m). A l'extrémité aval de celle-ci, la rivière réapparaît (-1189) pour se jeter 15 m plus loin avec fracas dans le premier ressaut de 10 m d'un canyon sinistre à peine large de 2 m à sa base.

Le grondement assourdissant, l'eau écumante, le débit (1/2 m 3/s) les parois hautes et lisses constituent les éléments indissociables d'une ambiance que nous connaissons bien, nous qui revenons de Nouvelle Guinée. Mais cette fois, nous sommes à 1200 m de profondeur! Un équipement en vire est installée grossièrement sur la gauche pour pousser une reconnaissance avec les quelques bouts de corde qui nous restent. Nous progressons zvec précaution sur les flancs concrétionnés et déversants du canion, pour descendre finalement une verticale de 8 m entre la paroi et une coulée de calcite. Nous nous arrêtons là, à - 1192, faute de matériel et de temps, au sommet d'une profonde fissure dans laquelle se déverse avec furie le "Rio del Rincon de Belagua".

Conclusion

Si l'on tient compte des trois points fondamentaux suivants:

1. Coloration positive entre Belagua et l' émergence d'Illamina (Cf. I. Santesban, 1980)
2. Module annuel d'9llamina = 5,64 m^3/s (Cf. E.D.F.)
3. Superficie approximative de l'impluvium = 70 à 85 km^2 (Cf. précipitations et débit d'Illamina).

Il est possible d'affirmer aujourd'hui que le système du BU 56 constitue, la branche méridionale la plus importante du Saint Georges souterrain. Cette rivière du BU 56 (ou Rio del Rincon de Belagua) est formée par la confluence du Rio de Budoguia et du Rio dela Hoya vers - 710. Ce Rio de la Hoya correspond très vraisemblablement au collecteur important découvert à - 410 dans l'A 60. Le diagramme des directions de galeries du BU 56 (Cf. Fig.) illustre bien l'utilisation préférentielle de certaines fractures et met effectivement en évidence une direction générale E-O et une direction secondaire NE-SO. L'ensemble du réseau se développe ainsi à l'aplomb du vallon Sud d'Ukerdi et se dirige sous la vallée de Belagua selon un azimut de 263° par rapport au Nord géographique. Il semble donc de plus en plus évident que le puissant complexe souterrain du Saint Georges soit constitué par la réunion du BU 56, du système d'Ukerdi-Ania Larra, du dydtème de Zampori et d' autres réseaux secondaires. En fin de compte, un ou Plusieurs écoulements parallèles au BU 56 paraîtraient tout à fait conformes à la direction générale E60 des fractures, soit dans le pendage axial des plis. De plus, une réorientation de ces écoulements vers l'aval en direction du NW doit intervenir à la faveur de failles perpendiculaires aux précédentes et en fonction du pendage des couches vers le Nord.

L'organisation du système du BU 56 met magnifiquement en lumière l'adaptation d'un grand réseau souterrain à la structure interne d'un massif calcaire. La zone de transfert verticales s'effectue traditionnellement par une "cascade" de puits entrecoupés de méandres étroits jusqu'à - 430 (calcaires des canyons), puis la rivière collectrice s'écoule sur le niveau imperméable des grès et shistes primaries en utilisant le grand système de fractures E60°. Le plafond très incliné de certaines galeries entre - 300 (rio de budoguia amont) et - 500 (à l'aval du Méandro Oprimido) correspond au pendage accentué des couches vers le nord du pli de Budoguia. L'affouillemnt aisé du plancher paléozoique a facilité les phénomènes de décompression (effondrements massifs, en plaques ...). La génèse du réseau est bien conforme à celle des autres grands gouffres du massif.

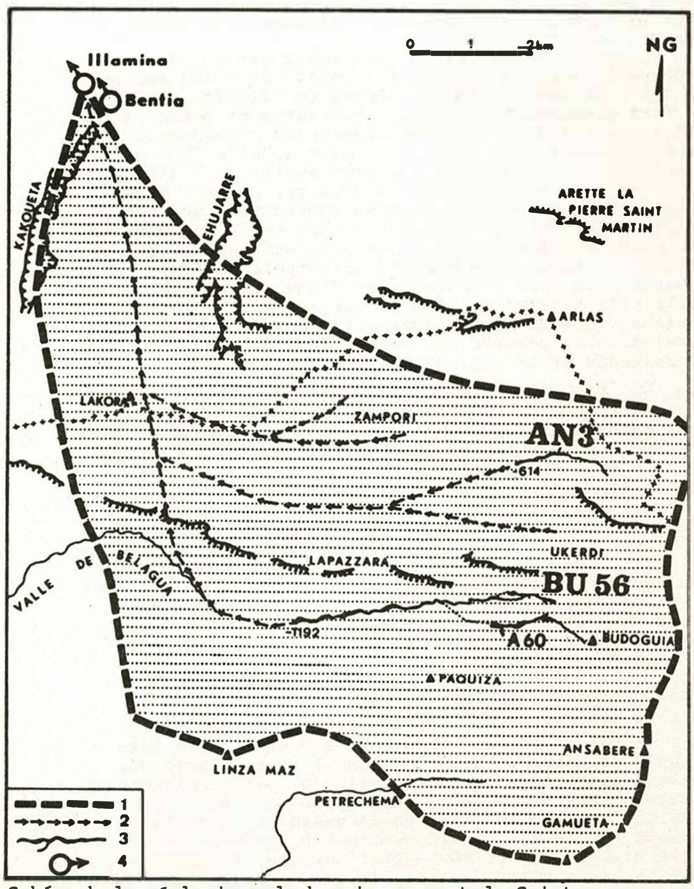

Schéma hydrogéologique du bassin-versant du Saint Georges souterrain (légende: 1, limite approximative du bassin-versant. 2, principaux écoulements souterrains supposés. 3, principaux réseaux connus. 4, émergences.)

Enseignement de la Speleologie au Quebec

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Résumé

Fondée en 1971, l'Ecole québécoise de spéléologie, commission de l'enseignement de la Société québécoise de spéléologie, propose aux personnes intéressées à l'exploration souterraine, novices ou adeptes, un programme d'éducation en spéléologie. Ce programme vise la sensibilisation de la population à l'existence des phénomènes cavernicoles ainsi qu'à la préservation de ceux-ci. Il permet la mise en place de projets éducatifs permettant d'accroître la qualité de la pratique spéléologique au Québec.

Cependant, ce qui distingue l'enseignement de la spéléologie québécoise c'est son intégration dans un concept de plein air global. Elle s'y définie comme un ensemble de moyens permettant de vivre temporairement dans le milieu naturel et débouchant sur une manière d'être et d'agir conditionnée par l'environnement et caractérisée par une utilisation intelligente et respectueuse du milieu cavernicole afin de s'y récréer, de la découvrir et de se connaître.

Abstract

Founded in 1971, the Ecole québécoise de spéléologie is the education commission of the Société québécoise de spéléologie and, as a school, has elaborated on education programs in speleology for people interested in cave exploration, beginners as well as experienced cavers. This program aims at introducing quebecers to caves, caving and related topics like cave preservation. It also permits the S.Q.S. to put forward education projects which have had an overall beneficial effect on the quality of caving activities and, hence on the effectiveness of our cave preservation program.

The uniqueness of this education program is most probably its close relationship with an integrated concept of outdoor activities. Hence, these activities are visualized as a set of means used for oneself to live in harmony with a natural environment and develop, as a consequence, a way of being and living closely related to the rules of this environment. This way of living is characterised by a comprehensive and respectful attitude towards its caving environment, and ultimately ends in a better knowledge of man and its intricated relations with its surroundings.

Introduction

L'année '81 constitué pour l'Ecole québécoise de spéléologie une dixième (10) année d'existence. Elle marque le sommet d'une progression qualitative et quantitative de services visant à satisfaire les besoins d'un nombre croissant d'amateurs et d'intervenants en spéléologie. A ce jour, son intervention dans le développement de la spéléologie québécoise constitue un des facteurs dominants de la réussite de l'expansion de l'activité en accord avec la préservation du milieu.

Cheminement Pedagogique

Le cheminement pédagogique mis de l'avant par l'Ecole québécoise de spéléologie tente de répondre aux aspirations de deux catégories d'individus. (fig. 1) Il offre en première partie une formation individuelle commune. Les niveaux concernés sont identifiés en ordre chronologique par les noms suivants: information, découverte, sensibilisation et initiation.

A ce dernier niveau, l'individu se voit offrir la possibilité de poursuivre une progression axée sur sa formation personnelle ou celle de s'acheminer à travers les étapes de la formation de cadre.

Les spéléologues optant pour l'enseignement ont accès à la totalité des niveaux de formation individuelle alors que l'inverse n'est pas possible. Au-delà du niveau initiation, le cheminement individuel comporte les niveaux du perfectionnement et de la spécialisation alors que celui de la formation de cadre offre la succession des niveaux d'initiateur, de moniteur et d'instructeur en spéléologie. Le niveau équipier est destiné à parfaire la formation de personnes ne répondant pas aux pré-requis du brevet d'initiateur.

Niveaux de Formation

Chacun des niveaux de formation est défini selon des objectifs spécifiques. Le détenteur d'un brevet cadre peut assumer l'encadrement des stages des niveaux inférieurs selon la chronologie établie. C'est ainsi que l'instructeur pourra encadrer les stages à tous les niveaux alors que l'initiateur ne pourra encadrer qu'à partir de celui de l'initiation. La définition de l'initiateur, du moniteur et de l'instructeur en spéléologie se lit comme suit:

L'initiateur est la personne reconnue comme possédant des connaissances la rendant apte à diriger un groupe à la découverte, à la sensibilisation ou à l'initiation au milieu cavernicole.

Le moniteur est la personne reconnue comme possédant les connaissances techniques, scientifiques et pédagogiques nécessaires à l'enseignement et à l'animation d'activités spéléologiques.

L'instructeur est la personne reconnue comme possédant à fond les connaissances techniques, scientifiques ~~et pédagogi~~ques la rendant apte à l'enseignement et à l'animation d'activités spéléologiques.

Pré-Requis au Stage et au Brevet

Les pré-requis d'admission aux stages sont fixés selon les niveaux de formation. Ainsi, il ne faudra que manifester son intérêt et fournir un équipement minimal pour être admis au niveau de la découverte, alors que les éventuels participants à un stage de moniteur devront avoir réussi un stage de niveau initiateur 3 ans auparavant, pouvoir démontrer leur implication en spélélogie et particulièrement en enseignement ainsi que fournir un matériel perfectionné. Au niveau de la formation individuelle, les participants aux stages sont éligibles à une attestation de participation alors qu'à celui de la formation de cadre, ils reçoivent un brevet reconnu à l'échelle provinciale. Les pré-requis au brevet sont généralement constitués par des résultats à obtenir dans les évaluations du stage, ainsi que par des résultats à obtenir dans les évaluations du stage, ainsi que par des périodes d'encadrement obligatoires à effectuer après celui-ci.

Durée des Stages et Validité des Brevets

La durée spécifique de chaque stage est déterminée en heures d'activités spéléologiques. Les durées adoptées par l'E.Q.S. sont les suivantes:

Découverte	5 heures
Sensibilisation	15 heures
Initiation	45 heures
Perfectionnement	Variable
Spécialisation	Variable
Initiateur	90 heures
Moniteur	270 heures +
Instructeur	540 heures +

\+ Incluant les heures d'implication obligatoires dans le milieu selon des modalités définies.

En ce qui concerne la validité des brevets de formation de cadre, ils sont valables pour une durée de 3 ans. Après cette période, déterminée à partir de la fin du stage, le cadre est tenu de participer à une session de requalification. Celle-ci lui permettra d'obtenir une nouvelle carte d'enseignant, indiquant la validité de son brevet pour 3 nouvelles années. A ce jour, les divers stages québécois de formation de cadre ont permis l'émission de 189 brevets.

Sujets de Formation

Les sujets de formation sont évidemment propres à chacun des niveaux. Pour illustrer la variété des thèmes abordés, nous présentons ici la liste des sujets du niveau sensibilisation et celle du niveau initiateur:

Sensibilisation (formation des amateurs) 15 heures	Exploration souterraine
	Karst et cavernes
	Biospéléologie et microclimatologie
	Matériel et techniques d'exploration souterraine

	Histoire et développement de la spéléologie Spéléologie et plein air.
Initiateur (formation des cadres) 90 heures	Karst et cavernes Microclimats des cavernes Vie en cavernes Caverne, habitat humain Ethique du spéléologie Adaptation psychologique et physiologique au milieu souterrain Matériel d'exploration Prospection: instruments et méthodes Exploration du milieu souterrain (techniques de progression) Alimentation spéléologique Topographie souterraine Sécurité sous terre Secourisme élémentaire Sauvetage Historique de la spéléologie Organisation spéléologique québécoise Sites cavernicoles québécois Enseignement de la spéléologie

Contenu Pedagogique

Tous les niveaux de cheminement pédagogique possèdent non seulement une identification concrète des sujets de formation mais également un contenu pédagogique spécifique. C'est ainsi que chaque cadre peut lors de l'organisation d'un stage, utiliser un "guide pédagogique". Ce document contient pour chacun des sujets de formation la description de divers éléments dont:

l'objectif du cours
le contenu, le champs d'action
les actions à réaliser
les moyens de réalisation
les moyens d'évaluation
une bibliographie ainsi que
des données horaire (fig. 2)

Speleologie et Education au Milieu Naturel

La spéléologie au Québec fait partie de ce que l'on appelle le loisir de plein air et plus spécifiquement l'exploration du milieu naturel. Elle se définie, dans ce contexte, comme une activité constituée d'un ensemble de moyens qui choisit l'individu pour vivre temporairement dans le milieu naturel plus spécifiquement le milieu cavernicole. Ses principales composantes deviennent alors la connaissance et la compréhension du milieu cavernicole, la locomotion, l'habitation, l'alimentation et l'énergie. Ces composantes entrânent une manière d'être et d'agir conditionnée par l'environnement et caractérisée par une utilisation intelligente et respectueuse du milieu cavernicole afin de se récréer, de la découvrir et de se découvrir. C'est probablement cette façon de percevoir et de développer la spéléologie qui constitue l'apanage de l'exploration souterraine au Québec.

Conclusion

L'implantation d'une structure d'enseignement apparamment complexe mais très efficace a permis à la spéléologie de s'intégrer dans le développement du plein air au Québec. Elle conserve ainsi à la Société québécoise de spéléologie le privilège d'orienter les intervenants selon les intérêts des spéléologues et de la spéléologie en général. Elle permet, puisqu'en fonction depuis le début de l'exploration souterraine organisée au Québec, d'assurer un développement simultané et cohérent de l'activité et du potentiel cavernicole de notre pays, tout en s'intégrant dans une démarche conceptuelle d'éducation au milieu naturel.

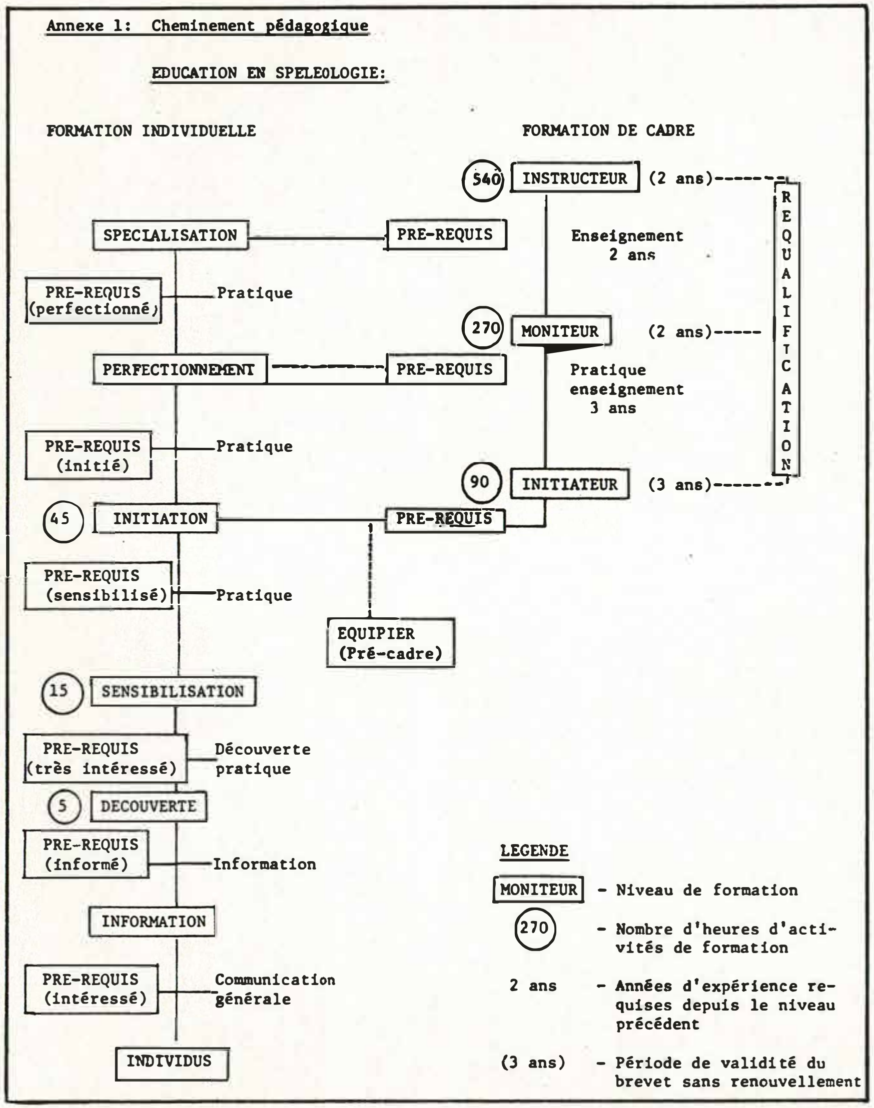

Figure 1.

SUJETS DE FORMATION

I N T R O D U C T I O N

(Disposition de l'information)

U.3.C.2.81 — 3.1 **TITRE DU COURS** — (X-Y-Z)

- Année de rédaction
- Niveau
- Cadre
- Stages de formation
- Sujet de classement: éducation et formation

- Durée pratique
- Durée théorique
- Nombre d'heures total (suggestions)

OBJECTIF:	But à atteindre.
CONTENU:	Description sommaire du contenu de cours.
CHAMPS D'ACTION:	Relations du contenu de cours avec les composantes fondamentales et les éléments généraux du concept plein air (voir 2.1).
SUJETS D'ENSEIGNEMENT:	Matières d'enseignement.
ACTIONS A REALISER:	Les actions susceptibles d'être accomplies par le stagiaire afin de faciliter l'acquisition des connaissances.
MOYENS DE REALISATION:	Les méthodes et les moyens utilisables par l'enseignant pour faciliter l'acquisition des connaissances.
MOYENS D'EVALUATION:	L'objectif terminal. La maîtrise des connaissances théoriques et pratiques acquises. Evaluation généralement continue.
BIBLIOGRAPHIE:	Quelques ouvrages de référence.*

* Référence très importante (lecture)

Figure 2.

Le Protection du Karst en France

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Résumé

Problème majeur aujourd'hui, la protection du karst revêt, en France, plusieurs aspects: la lutte contre les pollutions, qu'il s'agisse de la pollution des eaux résultant des rejets liquides dans le sous-sol calcaire (égoûts de villages, rejets résiduaires de porcheries ou d'"usines à veaux", pollutions chimiques par des entrerpises industrielles) ou des rejets solides (dolines et gouffres, dépotoirs, transformés en charniers, en décharges publiques ou clandestines) et la lutte contre le pillage des grottes, qu'il s'agisse de la destruction des cristallisations (qui se vendent très cher dans des "bourses" aux minéraux) des gisements paléontologiques et archéologiques.

Dans l'un et l'autre cas, les spéléologues sont les témoins privilégiés et atérrés de ce qui se fait. Ils ont un rôle multiple: ils doivent dénouncer avec vigueur toutes les atteintes au milieu souterrain dont ils sont les témoins et, pour cela, alerter les autorités, les administrations, le public. Ils doivent aussi essayer de protéger les grottes sans pour cela en réglementer et restreindre l'accès, ce qui n'est pas facile. Ils essaient enfin de faire appliquer la législation fort complète et fort complexe qui existe en ce domaine ou de la faire modifier quand elle est insuffisante.

Abstract

In France karst protection includes many aspects: the struggle against pollution, that is to say the subterranean water pollution from liquid injections into the calcareous underground (sewers from villages, waste from swine or real industrial breedings, chemical pollution by factories) as well as solid waste (many holes have been transformed in charnel-houses or unofficial or clandestine rubbish-holes) and the fight against cave plundering, that is to say speleothems (which are sold at very expensive prices in the mineralogical fairs) and paleontological or archeological areas of destruction.

In every case, speleologists are the first witnesses of this situation. Their list is multiple: it is incumbent upon them to educate against all the blows to the subterranean environment; therefore, they must alert the appropriate administration and the public. They also must try to protect the caves without making regulations or limiting the access to them, which is not easy. As a last resort they try to make the legislation (very complete and complicated) to be enforced or to be modified when insufficient.

That is one of the urgent tasks of the French Federation of Speleology, because more and more land is being degraded.

La France comprend plusieurs régions karstiques plus ou moins vulnérables. A cet égard, il convient de distinguer la vulnérabilité d'un bassin ou massif karstique (problèmes de pollution) et la vulnérabilité d'une cavité particulière (qui peut se rattacher au cas précédent ou présenter un aspect original et même spécifique). Cela nous conduit à examiner successivement deux domaines:

- la protection du karst proprement dit
- la protection de certaines cavités.

La Protection du Karst:

La notion du karst recouvre des réalités fort diverses. Si l'on admet qu'elle englobe tous les terrains calcaires ou assimilés susceptibles d'être transformés par l'eau, on constate, pour notre pays, qu'il existe une grande diversité de reliefs, de structures géologiques, de climates, qui ont déterminé des conditions humaines bien précises. Par exemple, une structure tabulaire en marches d'escalier comme celle du Jura a favorisé un habitat relativement dense et groupé, propice à une pollution des eaux souterraines et des cavités, alors que les zones plissées et les karsts d'altitude sont des secteurs moins sensibles à cet égard, sauf en certains points où la construction massive d'installations d'accueil pour les sports d'hiver amène ou risque d'amener des effets comparables à ceux des "plateaux".

La lutte contre les pollutions est difficile: en effet, s'il est souvent aisé à un certain stade de reconnaître qu'une rivière souterraine ou une resurgence est polluée, il l'est moins de définir la nature et l'origine de cette pollution. Pour cela, des prélèvements et analyses sont nécessaires, des colorations aussi pour prouver le bien-fondé d'une hypothèse quant aux causes.

En ravanche, il est fréquent de constater que de nombreux gouffres ou dolines-pertes, sont transformés en dépotoirs, en décharges clandestines, ce qui est, bien sûr, un facteur de pollution important. La loi française interdit tout rejet résiduaire liquide ou solide dans le sous-sol, mais elle est bien mal appliquée. D'ailleurs les stations d'épuration lorsqu'elles existent, sont insuffisamment efficaces (par exemple, et c'est la règle générale, s'il n'existe pas en amont un réseau d'égout séparatif: eaux pluviales - eaux usées, et si, en aval, il n'a pas été prévu de traitement tertiaire, par exemple par lagunage ou épandage). Tout cela fait que nous connaissons peu de rivières souterraines qui ne soient plus ou moins gravement polluées. Une vaste campagne d'information est actuellement en cours qui se concrétise par des conférences - animations, doublées d'une exposition itinérante, de films et de diaporamas. En avril 1980, un colloque national sur la protection des eaux souterraines en pays calcaire a été organisé par la F.F.S. à Besançon.

A cette campagne d'information s'ajoute un travail de terrain qui consiste à recenser, sur place, les causes de pollution: égoûts et décharges, rejets industriels, effluents de porcheries ou d'étables industrielles, rejets de fromageries etc... Une carte des pollutions est en cours de réalisation. Dés qu'un cas grave est décelé, un dossier est établi et remis aux administrations et à la presse. Responsables et opinion publique sont ainsi informés du danger. Le rôle des spéléologues s'arrête là mais c'est, on le voit, un rôle essentiel. Les exemples récents d'épidémies d'hépatite virale dues à la pollution des eaux de consommation montrent la réalité du mal et l'urgence d'une thérapeutique. Il ne s'agit pas, en effet, de protéger uniquement "nos" cavités, celles qui sont pénétrables mais l'ensemble du domaine karstique, d'est à dire du massif et des bassins naturels dont il se compose.

La Protection des Grottes:

Outre ces agressions de la vie moderne, le milieu naturel souterrain est aussi victime, dans ses parties pénétrables par l'homme, d'autres déprédations qui exigent là aussi, des mesures de protection. On peut, à cet égard, distinguer deux catégories: la destruction des paysages ou des biotopes souterrains et le pillage des gisements archéologiques et paléontologiques.

La destruction des paysages ou biotopes souterrains est parfois plus ou moins involontaire: elle est due, par exemple, à une trop grande fréquentation par les spéléologues chevronnés ou occasionnels. Il en résulte des altérations graves: salissure ou bris de concrétions, souillures diverses (dépôts de carbure, boites de conserves etc..) Par ailleurs, une fréquentation excessive peut perturber gravement le biotope de certains animaux; il en va ainsi de l'hibernation des chauves-souris.

Ces déprédations sont plus préoccupantes encore lorsqu'elles sont volontaires: il s'agit des briseurs de concrétions qui se constituent des collections privées ou qui en font le négoce dans les bourses aux cristaux et minéraux (la vente des concrétions de grottes n'est pas expressément interdite en France !). Ils rejoignent les pilleurs de gisements archéologiques et paléontologiques parmi lesquels on distingue également deux catégories: les fouilleurs clandestins qui garnissent leurs vitrines privées... et ceux qui commercialisent leur butin, même si la loi condamne ces pratiques.

Face à cette situation préoccupante, plusieurs solutions sont envisageables. L'une consisterait à règlementer sévèrement l'accès aux cavités (dont les entrées seraient fermées). Cette règlementation supposerait un contrôle strict des allées et venues des visiteurs, l'octroi d'autorisations etc... et la limitation du nombre de visiteurs.

La Fédération Française de Spéléologie est hostile à toute idée de règlementation, qui restreindrait la liberté de pratique de la spéléologie. Elle estime que ce genre de mesure doit demeurer tour à fait exceptionnel et que l'on ne doit y recourir que pour des cas, eux aussi exceptionnels (par exemple, la Grotte de Lascaux).

Les spéléologues français ont délibérément opté pour une autre politique qui repose sur l'éducation des spéléologues habituels ou occasionnels afin que leur comportement sous terre respecte à la fois les impératifs de la sécurité et du respect de l'environnement.

A l'égard des pilleurs de concrétions, de sites archéologiques et paléontologiques, notre position est celle de la vigilance: surveillance rapprochée des cavités les plus menacées, poursuites judiciaires contre les contrevenants pris en flagrant délit, campagnes de presse. Enfin, la Fédération Française de Spéléologie est en pourparlers avec les responsables du Ministère de l'Environnement et du Cadre de Vie pour étudier des projets de loi et de décrets destinés à compléter ou améliorer la législation en vigueur (notamment en ce qui concerne le problème des bourses aux minéraux et cristaux et la vente des concrétions.) On devrait aboutir très prochainement à la promulgation de nouveaux textes en ce sens.

C'est donc une série très complète et multiforme d'actions que la Fédération a entreprise. Il était grand temps car le mal progressait très rapidement. Il reste à espérer que ces initiatives ne demeureront pas sans effet.

The Foraging Behavior Of The Cave Cricket

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Abstract

Temperate zone caves have a limited amouht of energy input especially the deep cave areas occupied by the cave cricket, Hadenoecus subterraneus. This cricket is an obligate trogloxene as it must reproduce in the caves but must forage outside. Crop contents indicate that H. subterraneus is a scavenger, relying on rare and unpredictable food items such as carrion and fermenting fruits. It is hypothesized that a scavenger will forage more efficiently than a strict predator or herbivore which exploits a more common and predictable food source.

To test this hypothesis, baited and unbaited pitfall traps were set both inside and outside the cave to ascertain food preferences. H. subterraneus exhibited definite preferences among alternative bait types under a variety of experimental situations (natural and manipulative). These preferences were measured in terms of numbers of crickets attracted to each of seven baited traps and the control. The alternative food types were quantitatively ranked on the basis of several parameters: 1) nutritional value (calories per gram dry weight, calories per gram wet weight, % fat, % protein, % carbohydrate, % water) and 2) odor character (intensity, threshold, persistence). Preference was correlated most strongly with odor intensity and caloric content, especially the latter, for crickets of all sizes. Crickets selected baits high in available calories and therefore maximized energy gain per unit time. Ontogenetic differences in preferences were pbserved/

Zusammenfassung

Höhlen der gemässigten Klimazone haben einen geringen Energiezufluss, besonders in den Tiefhöhlengengenden die von Hadenoecus subterraneus bewoh t werden. Diese Grille ist zwangsläufig ein Trogloxen, den sie kann sich nur in Höhlen fort pflanzen, muss sich aber im Freien Nahrung beschaffen.. Kropfinhalt deutet an, dass H. subterraneus ein Aasfresser ist, der sich auf Gelegenheitsnahrung wie zum Beispiel Aas und gegorene Früchte verlässt. Die Hypothese wird aufgestelt dass ein Aasfresser tüchtiger in der Nahrungbeschaffung ist als ein Raubtier oder Pflanzenfresser.

Zur Prüfung dieser Hypothese wurden geköderte und ungeküderte Fallen in -und auserhalb der Höhle aufgestellt um die bevorzuget Nahrung der Grille festzustellen. Unter natürlichen und manipulierten Versuchsbedingungen bevorzugte H. subterraneus bestimmt Ködeten. Diese Vorlieben wurden gemessen durch die Zahl der Grillen die von jeder von sieben geköderten Fallen und einer Kontrollefalle angezogen wurden. Die verschiedenen Nahrungsarten wurden quantitativ aufgrund der folgenden Parameter geordnet: 1) Ernährungsarten (Kalorien pro Gramm Trockengewicht, Kalorien pro Gramm Feuchtgewicht,% Fett, % Protein, % Kohlenhydrat, %Wasser) und 2) Geruchscharakter (Intensität, Schwelle, Dauerhaftigkeit). Köderbevorzugung für Grillen aller Grössen hing am meisten von Geruchsintensität und besounders von Kaloriengehalt ab. Grillen bevorzugten Köder mit hohem Kalorien-gehalt und maximierten demgemäss den Energiegewinn pro Zeiteinheit. Ontogenetische Unterschiede in der Bevorzugung verschiedener Nahrung wurden beobachtet.

Interpretation as a Primary Tool in Cave Conservation and Management

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Abstract

Effective interpretation can be a valuable tool to aid speleologists in the presentation and perpetuation of cave resources. Since a majority of people are only occasional visitors to caves and they confine their visits to commercial or show caves, the burden of demonstrating the value of the underground realm lies almost entirely with the interpretive presentations available at show caves. A concerted effort must be maintained by the managers of show caves to demonstrate a high level of concern for conservation of their resource as well as in caves in general. From the instant a visitor arrives at a cave, he is influenced by every aspect of the operation -- the grounds, the facilities, the interpretive staff and the resource itself.

To be effective, interpretation must progress beyond the hypothesized speleogenesis of formations and include entertaining elements as well. Spontaneity, enthusiasm and expertise of interpreters becomes paramount. A review of some techniques in use at show caves in the United States demonstrates that creativity does not have to be sacrificed in achieving the conservation theme.

Only by fostering a genuine appreciation throughout the general population, of the complexity of the forces effecting caves, can speleologists expect to be able to rally support for cave conservation. When caves become important resources to everyone, the job of conserving them will become easier.

Zusammenfassung

Eine eindrucksvolle Darstellung über den Höhlenreichtum kann als wertvolles Werkzeug zur Präsentation der Höhlen angewandt werden. Da die Mehrheit der Bevölkerung nur gelegentlich Höhlen besucht, und diese Besuche sich meistens auf öffentliche Höhlen beschränken, liegt die Verantwortung der Interpretation über das unterirdische Reich fast vollständig in der Händen des Personals von öffentlichen Höhlen. Deshalb sollte von den Verwaltungen dieser Höhlen eine gemeinsame Anstrengung erstrebt werden, um das Interesse der Bevölkerung zum Schutz und Erhaltung des Reichtums der Höhlen zu erwecken und zu pflegen. Besucher konnen angenehm beeinflusst werden beim Anblick der Anlagen und der Betriebe öffentlicher Höhlen und des Reichtums derselben.

Um wirkungsvoll zu sein, eine Auslegung über die Entstehung der Höhlen sollte weitergreifen als bloss Theorie der Formation, sie sollte auch unterhaltende Bestandteile enthalten. Ungezwungene natürliche Begeisterung und fachmännische Darstellung sind ausschlaggebend. Eine Untersuchung über die Methoden die in öffentlichen amerikanischen Höhlen gebraucht werden zeigt, dass mit schöpferischer Gestaltung das Thema Schutz und ERhaltung der Höhlen nicht vernachlässight wird.

Nur wenn ein echtes Verständnis über die Wichtigkeit der Höhlen in der Bevölkerung gefördert wird, können Höhlenforscher Unterstützung durch das Publikum erwarten.

Cave conservation is a concern of only a small segment of the world's population. In fact, a majority of people have never experienced "wild caves"-- these are left to the adventurers. How does one answer the common question: Why go caving? For a speleologist, caves are natural laboratories providing conditions not found elsewhere and for the recreational caver they are new frontiers or challenges. But, what do they offer the general public? Until those of us who feel that caves should be conserved can realistically answer these questions in terms that are acceptable to people who know nothing about speleology, caves will succumb to other desires of mankind. They will be lost to mineral interests, energy projects, developers, rock hounds and other groups who do not or will not consider caves in their planning.

In the dawn of human history, caves provided a much more meaningful resource than they do today. Early civilizations found caves to offer a multitude of uses: shelter from hostile weather conditions, protection from predators, cold storage for supplies and even a place to express themselves through drawings on the walls. As people became more inventive, they began to construct their own shelters that extended from the cave entrance and finally, entirely on the surface. Caves began to be ignored and an element of mystery and intrigue became attached to discussions of caves. The strange, different world of the subterranean realms became the subject of folklore and exaggeration. Gradually, apprehension developed into fear and most people today find little of value, short of novelty to make caves and cave resources worth conserving.

The fact that cave resources are fragile and dependent on surface forces makes their preservation a difficult battle, especially without strong support of the population. As speleologists, we can scream about cave destruction all we want, but without public support, our energy is wasted as we lose battle after battle. The answer lies in an alternate offensive: the cultivation of a conservation ethic and cave appreciation in the general public. We must exercise great care however, in attempting to reach our goal. We can not, nor should we, expect to convert every man, woman and child into an avid caver. To do so, would jeopardize the resources from another angle -- over use. We must proceed with a moderated outlook and try to convey to the public that caves are important non-renewable resources and should be preserved for the future generations.

Unfortunately, bringing caves to the surface through lectures, publications and photographs will not have much effect on people's thinking. It is only through personal experience that we seem to gain significant insight. Thus, we need to take the world's population caving! Of course such a feat is impossible, but it does pose a challenge. Probably the best way for the general public to experience a cave is in a commercial or show cave. The hardships and hazards are reduced and the route is generally tailored to make it an easy trip for everyone. Show caves are not threatening to most people and represent a novel form of entertainment to many. If we manage to get a person to take a cave tour, we have a captive audience -- this may be our only chance to convince him of the value of cave resources. I am not suggesting a "hard sell" but rather a subtle indoctrination. Only an expert interpreter can convey our message in such a manner that it is absorbed and implanted. When a cave visitor comes out bubbling with enthusiasm and excitement over the resource, we have made another convert. They can hardly wait to see another cave -- sometimes they want to go back through again! It is very rewarding to guides to know that they have accomplished such a feat.

One thing must be kept in mind throughout this discussion and that is: a visitor can be just as rapidly turned off to caves by a poor guide. In fact, it is probably easier to influence people negatively than develop their enthusiasm. We may only get one chance to convert a would be cave enthusiast and we must be sure that we put our best people (interpreters) where they can converse with the most visitors. This is a heavy responsibility, but good interpreters rally to the challenge. Actually, the effectiveness of any interpretive program lies ultimately with the individual interpreter's attitude, training and desire.

As important as cave interpretation is, all show caves in the United States do not operate with the same emphasis placed on interpretation. Different parameters cause interpretive presentations to vary a great deal. True commercial caves are businesses and their owners must make a profit to continue their operation. Overhead and expenses must be kept to a minimum to enable these caves to keep their admissions price to a level that the visitor will pay. Some caves find the easiest way to reduce expenditures is to pay low wages to the guides. Such practices tend to recruit less than qualified individuals to fill the interpretive positions and the entire program suffers, and so does the conservation cause. I am not implying that all commercial caves operate in this manner but rather, where a profit or bust situation exists, it is more prevalent.

Government or publically-owned caves tend to operate at or below a break-even level. Thus, while the admissions price is usually lower, the subsidizing of operations by public funds enables these caves to put more funds into the interpretive program. This has a marked effect on both the philosophy and the techniques employed in interpretation.

Interpretation geared to a strong conservation theme is deemed inappropriate by many commercial operators and too often any conservation conveyed to visitors is more by accident than by design. Most caves have realized that in order to protect their investment, they must curtail some practices that have historically been profitable. Such practices as the selling of speleothems in their gift shops have been contrary to the perpetuation of their own caves. This is true even if the sales items are imported from a calcite mine (a cave mined for its saleable speleothems) because it encourages visitors to steal formations during tours because these rocks are marketable.

Interpretation of a cave is not totally limited to the tour of the underground. Well kept grounds, informative exhibits and friendly staff members set the mood and increase the visitors' responsiveness to the interpretive presentation. Long waits and large crowds should be avoided whenever possible as these factors tend to negatively effect visitors. A cave manager should place a strong emphasis on pleasing the "customer" if he wants to succeed. This is true whether there is a profit incentive or not. I have heard heated discussions between commercial cave owners and public cave managers as to the virtues of treating visitors well. Such arguments are totally ridiculous, because both groups can only survive by serving the public.

In order for an interpretive program to meet our goal of implanting a cave conservation ethic in every visitor, it must address the needs of that visitor as well. Many people find science and scientific explanations to be boring and even threatening, so scientific theory must be tempered with entertainment as well. While different types of entertainment appeal to different groups of people, one technique is universal -- enthusiasm. Enthusiasm is infectious and an interpreter who can foster enthusiasm in several members of a tour will soon have the attention of the whole group. The enthusiasm of a guide is not something that can be taught, but is a result of a combination of training, understanding, polish (self-confidence) and most of all, love of people and the cave. Some guides may never reach this level but it should be the goal of every cave manager to kindle this trait in all interpreters.

As I have stated previously, interpretive theory varies greatly from cave to cave and what may be very effective at one cave may be totally wrong at another. Through my observations at a number of caves throughout the United States, I have observed two distinct approaches emerging as controlling factors. I classify them as the <u>commonplace</u> approach and the <u>unique</u> approach.

The commonplace approach attempts to relate the cave to experiences visitors have had in other situations in their lives. Practices that fall into this category include what I term "fantasy tours". This is a tour that describes speleothems as looking like another object; e.g. a stalagmite that looks like a babies bottle, a stalactite that looks like a pencil or a rock that assumes the shape of a famous person's profile, etc. Also in this category, I include the colored light shows, was museum figurines and piped music. All these techniques attempt to entertain the visitor by presenting the cave trip as an extension of every day occurances. Unfortunately, this approach has a tendency to negate the value of the cave as a resource because people tend to group it with other "sideshows."

The unique approach is on the other end of the scale. Caves are treated as unique and mysterious works of nature. These tours are mose sensual experiences -- the stillness, the dampness and the fragility are all emphasized. Often the great age and the lack of adequate explanations are presented to encourage the visitor to acquire a questioning attitude and an intellectual curiousity about the experience. Some interpreters attempt to have their groups imagine how the first explorers must have felt -- their uncertainty, their fears and reservations. In this category, I would also include the organized spelunking tours, historical tours and candlelight tours. As an approach to cave conservation, this group of techniques have a strong positive emphasis because if we can get visitors to treat caves as unique realms, they will tend to view each cave as a separate, valuable resource.

In practice, each tour will have elements of both approaches but will tend strongly toward one or the other. As an additional measure, we must consider the visitors' attitude toward the tour as well. If we can agree that enthusiasm is a worthwhile goal, then we can extend the classification into a grid and define one end of an axis as "enjoyable" (including enthusiasm) and the other end as distracting or not enjoyable. Various factors will effect the placement of a tour on this grid. For example, a visitor who has waited a long time for a tour is already hovering toward the non-enjoyment end of the axis. In contrast, a visitor who finds the receptionist friendly and the exhibits pleasing may be well on the way toward the enjoyable end. Generally, the interpreter who leads the tour will be faced with a group that has already been conditioned before the tour begins. The guide can move the group along the grid only by overpowering the previous influences.

As far as conservation themes are concerned, the better tours are up and to the right (see Fig. 1). There are no numerical values assigned because the placement on the grid is subjective rather than objective. Philosophically, there is no measure of enjoyment only obvious enthusiasm or disinterest. Also, there is nothing to keep a commonplace experience from being enjoyable, I have simply made a personal value judgement that the commonplace does not permit the conservation theme as well as a unique experience.

Conservation themes can also be demonstrated in other ways. For example, the touching of cave formations discolors them and reduces their growth. At Lehman Caves, we employ a box of pieces of broken speleothems at the entrance and pass them among the members of the tour group with the understanding that they have been given the chance to feel "real" formations and they should not touch any in the cave. The practice seems to work quite well although there are still some individuals who find it necessary to touch a "wet one". Other caves have touch stones along the tour route and these are utilized in much the same manner.

Effective lighting is another way show caves can make their tours more enjoyable: the more indirect lighting used, the more intriguing the cave appears. Providing the visitor a map of the cave helps most people understand where they have been and the understanding that often the surface gives little sign of the cave resource below. Any technique that makes a visitor think, will aid the conservation cause. But the most important of all is the guide.

In summary, the most effective way to foster the conservation of cave resources is by presenting every cave visitor with an enjoyable and meaningful experience, thereby spreading the burden of the preservation ethic to everyone. Only by fostering a genuine appreciation throughout the general population, of the complexity anduniqueness of the forces effecting caves, can speleologists expect to be able to rally support for cave conservation. When caves become important resources to everyone, the job of conserving them will become easier.

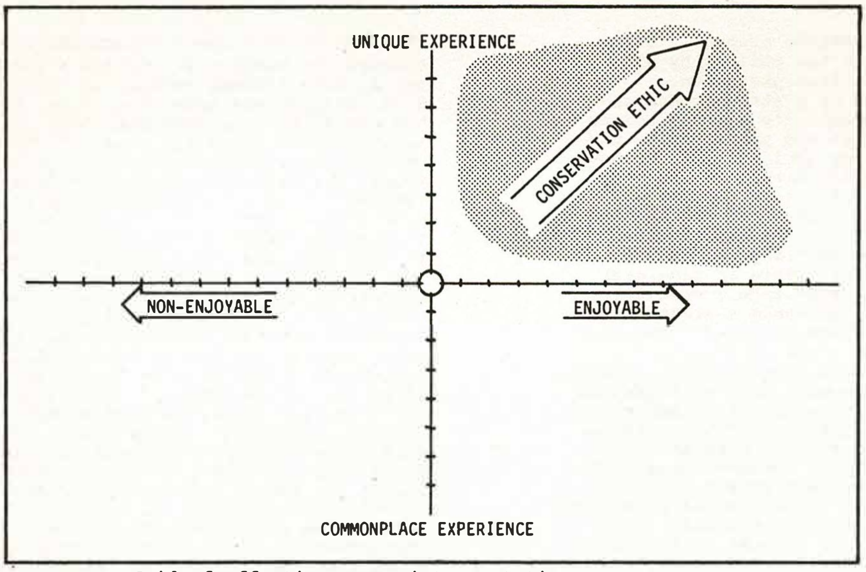

Figure 1. Grid of effective cave interpretation as it relates to the presentation of a strong cave conservation ethic.

Morphological And Behavioral Adaptations Of The Cave Cricket For Exploitation Of Unpredictable Food Resources

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Abstract

The cave cricket, Hadenoecus subterraneus, shows morphological and behavioral adaptations for reacting to and exploiting rare and unpredicatble foods. Adult Hadenoecus have long slender legs which enable them to travel long distances quickly compared to younger instars which have shorter legs relative to their body size. Adults also possess extremely long antennae which get the sensory receptors further off the ground and into the air containing odors. Chemoreception is further enhanced by various waving patterns executed by the crickets as they triangulate in on odors which may be relatively far away. Behavioral observations and pitfall trap data show adult crickets are able to detect and get to food over greater distances than little crickets who are restricted to local food patches. Mean Free Path (an index of rectilinear motion) data add further support ot these observations as adults travel rectilinearly (which is adaptive in getting them out of the cave to their natural food source) while juvenile instars show a high degree of turning which functions to keep them in the area in which they have been foraging successfully.

It is hypothesized that a scavenger like Hadenoecus should be a more efficient forager than an herbivore which exploits a more common and predictable food source. Ceuthophilus stygius, the camel cricket was studied for this purpose. Crop analyses indicate this species is more herbivorous in diet than Hadenoecus. The legs and antennae of Ceuthophilus are short and rather stout. The antennae are used as mechanoreceptors and observations indicate little or no chemoreceptive function. Ceuthophilus locates food by contact chemoreception using its maxillary and labial palps.

Zusammenfassung

Morphologische und Verhaltensanpassungen erlauben der Höhlengrille, Hadenoecus subterraneus auf seltene und unverlässliche Nahrungsquellen zu reagieren und dieselben auszunützen. Erwachsene Hadenoecus haben verglichen mit jungen, deren Beine im Vergleich zur Körpergrösse relative kurz sind, lange, schlanke Gleder mit denen sie grosse Strecken im kurzer Zeit zurücklegen können. Die extrem langen Fürler der erwaschenen Grille heben die Sinnersrezeptoren hoch über den Boden in die Geruck tragende Luft. Chemoreception wird weiter gesteigert durch verschiedene Wellenbewegungen, welche die Grille ausführen, während sie sich Gerüchen nähern, die ziemlich weit entfernt sein können.

Verhaltensbeobachtung und Fallendaten zeigen an das erwaschene Grillen Nahrung über grössere Entfernungen wahrnehmen und finden können als junge, die auf lokale Nahrungsquellen angewiesen sind. "Mean Free Path" Daten (i.e., ein Index geradliniger Bewegung) erhärten diese Beobachtunge, da Erwaschene sich geradlinig fortbewegen (was als Anpassung angesehen werden kann, weil sie dadurch aus der Höhle und zu ihren natürlichen Nahrungsquellen geführt werden) während jugendliche zwischen den Häutungsstadien (= instars) sich in Kreisen bewegen, was den Zweck hat, sie in dem Gebiet zu halten, wo sie mit Erfolg auf Narungssuche gehen können.

Es wird angenommen das ein Aasfresser wie Hadenoecus ein tüchtigerer Futtersucher sein sollte als ein Pflanzenfresser der eine allgemein vorkommende und voraussehbare Nahrungsquelle benützt. Ceuthophilus stygius, die Kamelgrille, wurde zu diesem Zwecke studiert. Kropf Analysen zeigen das diese Art eine pflanzenreichere Diät hat als Hadenoecus. Beine und Antennen von Ceuthophilus sind kurz und eher gedrungen. Die Antennen dienen als Tastorgange und scheinen wenig oder keine chemoreceptive function zu haben. Ceuthophilus findet Nahrung durch Berührungs chemoreception mit seinen maxillaren und labialen Fühlern.

The Evolution of the Virginia Cave Commission

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Abstract

The Virginia Commission on the Conservation and Use of Caves was established by the Virginia General Assembly in 1978. It published a report to the Governor and the General Assembly in less than a year with no direct appropriation and then ceased to exist.

This Study Commission recommended that a permanent Cave Commission be established and this came about in a two step process. After much negotiating with the leadership of the General Assembly, that body approved a one year Commission with $8,000.00 in funds. This budget made it possible for accomplishing many things on a scale never before done in the Cave comminity.

One recommendation, The Cave Protection Act, contained several major improvements over the old law, including the banning of Speleothem sales and limitation of cave owner liability. Some of the recommendations of this Commission are described in this paper. The Cave Protection Act was approved overwhelmingly by the General Assembly in 1980 with little opposition, but several amendments, that protect the right of the cave owner to use his or her cave as he or she sees fit, were added.

In 1980 the Cave Commission was made a permanent State Agency as part of the Department of Conservation and Economic Development. However, no additional funding was provided. Since no operating funds are now available for the Commission, interested cavers formed the Virginia Cave Conservancy to provide a means of funding, not only the Commision but also for encouraging the ownership and management of caves. This Cave Conservancy will seek to raise funds from public solicitation and fund-raising projects such as bingo and dues. The funds will go to support cave acquisition and management as well as to assist organizations such as the Virginia Cave Commission.

Zusammenfassung

Der Virginia Commission on the Conservation and Use of Caves (Ausschuss für Höhlenschutz und-gebrauch) wurde im Jahre 1978 von dem Unterhaus in Virginia gegründet. Innerhalb eines Jahres hat er dem Gouveneur und dem Unterhaus ohne direkte Gelbdewilligung einen Bericht eingereicht und wurde dann aufgelöst.

Dieser spezielle Ausschuss empfahl, dass ein ständiger Höhlenausschuss begründet werden sollte, was in einem zweitteiligen Vorgan zustandegekommen ist. Nach langen Verhandlungen mit der Führerschaft des Unterhauses wurde ein einjähriger Ausschuss mit öffentlichen Geldern von $8000 gebilligt. Dieses Budget ermöglichte die Ausführung von vielen Sachen, die in solcher Weise nie vorher unter Höhlenforschern gemacht werden konnten.

Ein Vorschlag, das Cave Protection Act (Höhlenschutzgesetz), enthielt einige grössere Verbesserungen des alten Gesetzes, u.a. die Verbannung des Verkaufs von Höhlenformungen (Speleothem) und die Begrenzung der Haftpflicht für Höhlenbesitzer. Einige dieser Empfehlungen des Ausschusses werden in diesem Vortrag beschrieben.

Das Höhlenschutzgesetz wurde 1980 von dem Unterhaus überwältigend gebilligt, aber einige Zusatzartikel, die das Recht des Höhlenbesitzers bewahren, seine Höhle nach seiner Weise zu gebrauchen, wurden hinzugefügt.

Im Jahre 1980 wurde der Höhlenausschuss auf ständiger Basis ein Teil der Department of Conservation and Economic Development (Abteilung für Schutz und Wirtschaftsentwicklung). Jedoch, keine zusätzlichen Gelder wurden bereitgestellt. Weil keine Betreibskosten zu dieser Zeit für den Ausschuss bereitstehen, haben interessierte Höhlenforscher die Virginia Cave Conservancy (Höhlenbehörde) gegründet, um den Ausschuss und auch die Förderung des Besitzes und der Verwaltung von Höhlen zu fundieren.

Diese Höhlenbehörde wird versuchen, Gelder durch öffentliche Werbung und Fundierungsprojeckte wie Bingo und Beiträge zu beschaffen. Die Gelder werden Höhlenerwerbung und-verwaltung sowohl als Organisationen wie der Virginia Cave Commission unterstützen.

I first suggested the idea of a cave commission in 1970 to a caver in Richmond. He did not agree that getting the state involved with caves and caving would be a good idea. However, within several years, I did find a few cavers who agreed that a cave commission would be a desirable thing and by 1975, I had set the wheels in motion through Virginia State Delegate Bill Axselle. Together we set up a committee to study the problems of cave conservation and the role of the state in dealing with cave conservation.

The new committee was composed of cavers, a legislator, representatives of several appropriate state agencies and representatives of commercial caves in Virginia. After two meetings, it became apparent that the state agencies were not in favor of adding additional duties to their agencies. This, apparently because they felt that the General Assembly would not fund anything of this nature, and they did not wish to have any additional work without additional fundings.

So, the cavers were told by the representative of the agency that before their agency could support any on-going state activity to protect caves, we would have to thoroughly document almost everything about caves in Virginia. This request was beyond our resources to accomplish in any reasonable length of time. They were informed of our limitations but said they could not help, other than to supply us with a copy of John Holsinger's book, Descriptions of Caves in Virginia. Up to that point, the commercial cave representatives had not, in any signifying way, opposed what the cavers were trying to do.

Since the current route appeared to be unproductive, I made the decision to go straight to the General Assembly with our ideas. I asked Delegate Axselle to draft a preliminary resolution, Joint House Resolution 10. I sent draft copy to everyone on this committee: commercial cave owners, agency heads, etc., plus all the NSS chapters in Virginia, and asked for their support and suggestions. No suggestions came in. As a result, Axselle set up a public meeting with the Rulse Committee prior to the start of the 1977 session of the General Assembly in order to get any input from the rulse committee and other interested people. Several changes were suggested at this meeting including the deletion of the word "overcommercialization" from the whereases. We agreed to that, and after that hearing, representative of commercial caves never again spoke publicly against any of our resolutions at any hearing over the next three years.

The one commercial cave representative who spoke against the resolution at that hearing in 1975 opposed the concept of commissions in general. He was opposed to any cave commission because he believed that it would lead to government regulation of commercial cave operations, even though this was prohibited by the resolutions. This individual continued to oppose the commission to the end and tried unsuccessfully to get the Virginia Chamber of Commerce to oppose the resolution I do not think that early opposition of the one commercial cave representative had any eventual effect on how long it took to get the resolution passed.

In Virginia, many legislators believe that bad laws and bad resolutions are worse than no laws at all. So, when there is a new concept proposed, the General Assembly tends to take its time while considering all aspects of the proposed law. Three or four years is typical for bills and resolutions of this type to be passed in Virginia. This was particularly true for this commission since it was not only a new concept for Virginia, but to the best of my knowledge, it is the first commission ever established in the United States to study overall use and conservation of caves.

The cave resolution was carried over in 1977 and then passed in 1978. The vote in the House was 76 to 7. It was amended by the Senate (funds deleted) and passed 40 to 0; the House then passed the Senate version. Resolutions do not require the governor's signature so the committee was approved as of the final day of the General Assembly in March, 1978.

I found that many cavers did not understand the concept of commissions in general, even though the vast majority of laws in Virginia go the route of either Legislative Study Committee or Commissions. I had to convince cavers that ultimately the goal of protecting caves would be better served not solely by cave protection laws, but by ongoing structure, commission, agencies whose purpose is to protect caves, educate people, and even manage some caves. It is unlikely that punitive laws alone can adequately protect caves.

It is desirable to have people within state government who will come up with positive solutions to problems and be able to react quickly when threats to caves become apparant. This process of working for the support of cavers began to get results in late 1977, when numerous cavers began to contact their delegates. But, ultimately the commission was passed because Delegate Axselle was able to convince John Warren Cook, Speaker of the House and chairman of the Rules Committee to give the commission a try. I believe that 1978 was the first year that the commission could have established under the circumstances.

Work and Recommendations of the Virginia Commission on the Use and Conservation of Caves

The Virginia Commission on the Conservation and Use of Caves was to make a report to the governor and the General Assembly; do this in less than a year with no direct appropriation and then cease to exist. That is what happened; its 43 page report was published and went to the Governor and the General Assembly with three major recommendations and extensive background material.

The Cave Protection Act contained several major improvements over the old law, including the banning of Speleothem sales and limitation of cave owner liability. Some of the recommendations of this commission are described on the next few pages.

Sale of Speleothems

A major recommendation of the commission was that Virginia join West Virginia and Maryland in banning the sale of speleothems or their export from the Commonwealth for sale elsewhere (see proposed Virginia Cave Protection Act, Appendix III). By eliminating this incentive for removing these mineral formations from caves, much vandalism should be stopped. Information on the provisions of the State cave protection law should be widely disseminated, perhaps by signs posted in cave entrances, to warm vandals that their activities are unlawful.

Limitation of Cave Owner Liability

The Commission recommended that cave owners be absolved from liability in the event of an accident in their cave. Persons entering a cave would then have to do so at their own risk except at commercial caves where an admission fee is paid. The provisions of the proposed Cave Protection Act (See Appendix III) will permit the use of caves for recreational and scientific purposes without imposing unwarranted liabilities upon the cave owner.

Proposed Permanent Cave Commission

The Commission recommended establishing a permanent Virginia Cave Commission composed of eleven members, serving three-year staggered terms (See proposed legislation creating Commission). Most of the members should be persons active and knowledgeable in the management, exploration, study and conservation of caves. Expertise in the fields of cave biology, geology, archeology, palentology, history, and recreation may be represented.

Virginia's caves represent a unique, limited, and non-renewable natural resource of great scientific, historic, educational, economic and recreational value. Vandalism and pollution are rapidly destroying this resource. In order to prevent Virginia's spelean wilderness from being destroyed within our lifetime, immediate steps need to be taken to protect Virginia's significant caves. The Commission recommends that a permanent Cave Commission be created to assist State agencies dealing with cave-related problems, that a new, more comprehensive Cave Protection Act be enacted, and that the Virginia Research Center for Archeology be granted a special appropriation for the 1980-82 biennium to conduct a two-year archeologic survey of Virginia caves.

Establishment of a Temporary Cave Commission and Passage of the Cave Protection Act

The Study Commission recommended that a permanent Cave Commission be established. This came about in a two step process. After much negotiating with the leadership of the Virginia General Assembly, that body approved a one year Commission with $8,000.00 in funds. This budget made it possible for accomplishing many things on a scale never before done in the community.

The Cave Protection Act was approved overwhelmingly by the General Assembly with little opposition but several amendments that protect the right of the cave owner to use his or her cave as he or she sees fit.

As public interest in outdoor recreation continues to grow and land development accelerates in the intermontane valleys west of the Blue Ridge, increased pressure will be put on Virginia's limited and fragile cave resources. In order to preserve the unique educational, recreational, scientific, historic and economic value of Virginia's caves and karst areas, the Commonwealth needs to make a continuing commitment to safeguard this spelean wilderness. A permanent Cave Commission, composed of concerned citizens, working in conjunction with other agencies of the Commonwealth, appears to be the most effective vehicle for focusing the attention of both government and the public on this goal.

It is anticipated that future efforts of the Cave Commission to conserve Virginia's cave resources will fall primarily into four broad areas - collecting and maintaining a complete data file on cave resources within the Commonwealth, providing information to the public about caves, their value and the laws protecting them, advising and assisting public agencies and private landowners making cave management and land use decisions, and studying those aspects of cave ownership and management that are directly affected by public policy.

The Commission has already made great progress in collecting and maintaining a cave data file. The establishment of the Virginia Significant Cave List and the inventory of publicly owned caves were great milestones in the assessment of Virginia's cave resources. The development of a computer data storage and retrieval system in cooperation with the Division of Mineral Resources has put a wealth of easily accessible cave data at the disposal of engineers and planners throughout the Commonwealth. A list of Virginia cave owners is currently being compiled. As more data becomes available, the Commission will add to and update these data files on a continuous basis.

In its ongoing role as a source of information about caves and their protection, the Commission has published several articles and brochures as noted above. In the coming year, the Commission plans to erect signs at significant caves stating the provisions of the Cave Protection Act and place displays at several of Virginia's commercial caverns. A continuing program of publishing articles and brochures on caves, their value and their protection is also envisioned. The Commission's speakers bureau on cave related subjects is expected to become a fully functioning entity. Cooperative efforts with other public agencies which provide information on caves to the public are anticipated as well.

The study functions of the Cave Commission will diminish significantly with the publication of this report. While some aspects of cave conservation such as cave ownership law and the effectiveness and enforcement of the Cave Protection Act will require further study, the basic studies establishing the value and extent of Virginia's cave resources and the threats to these resources have been completed. The principal focus of future annual reports by the Commission will be on the changes in the state of the Commonwealth's cave resources and on the Commission's ongoing efforts to conserve them.

In its advisory capacity, the Commission has been actively developing its ability to assist public agencies and private landowners engaged in making cave management and land use decisions. For example, data on the location and significance of caves along the proposed route of US #58 in Lee County was provided to the Department of Highways so that destruction of significant caves could be avoided. In another instance, the

Commission notified the Virginia Research Center for Archeology about an important find of Indian inscriptions in a Bath County cave and arranged permission for a James Madison University archeologist to visit the cave to evaluate the significance of the find. With the new computerized data base developed by the Commission and the unusual speleologic expertise of the Commission's members, an expanding role is foreseen for the Commission in the development of cave management plans, the protection of significant caves, and the study of land use in karst areas. It is hoped that the Commission can continue to provide the focus for cave conservation efforts in the Commonwealth and to serve as the source of authoritative information on all aspects of cave use from recreation to civil defense.

Establishment of the Permanent Cave Commission

In 1980 the Cave Commission was made a permanent State Agency as part of the Department of Conservation and Economic Development. However, no additional funding was provided. Since no operating funds are now available for the Commission, the interested cavers formed the Virginia Cave Conservancy to provide a means of funding not only the Commission but also for encouraging the ownership and management of caves. The purposes of a Conservancy are listed in the Appendix.

This Cave Conservancy would seek to raise funds from public solicitation, fund-raising projects such as bingo and dues, etc. The funds would go to support cave acquistion and management as well as to assist organications such as the Virginia Cave Commission.

Quantitative Dye Tracing in an Alpine Karst Environment

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Abstract

The karst of the Mount Castleguard area exhibits numerous (>100) springs, relatively few accessible sinks and high seasonal and diurnal variations in flow. In 1979 and 1980 a quantitative tracer program was undertaken, mostly using the fluorescent dye Rhodamine WT. Analysis was made with a Turner Designs Model 10 Series Flurometer capable of continuous flow or discrete sample fluoremetry. Twelve-volt snowmobile batteries provided power and resolution was better than one part per 10^{11} Rhodamine. Grab sampling was by automatic water samplers at frequencies of one to six samples per hour.

Basic flow routes were first established. Then repeated tests from selected sinks under different flow conditions were made to test for the presence of underground drainage divides.

All tests were distributary to numerous springs and no true divides found. However, characteristic time-concentration curves allowed functional classes of springs to be identified. Varying multiple peaks in dye output under different flow conditions represent the changing importance of parallel conduits. Some pulses may represent the flushing by the diurnal flood of trapped tye. The tracing results plus a deep recession of the karst aquifer in summer 1980 allowed functional spring clusters to be identified. A simple model for the 4-dimensional network is envisaged.

Résumé

La karst de la région du Mont Castleguard possède plusieurs (>100) sources karstiques, relativement peu de gouffres accessibles, et de fortes variations saisonnières et quotidiennes de débit. En 1979 et 1980, un projet de traçage quantitatif fut entrepris, utilisant principalement le colorant fluorescent Rhodomine WT. Les analyses furent menées à l'aide d'un fluoromètre Turner Designs Model 10 capable d'accomoder des échantillons individuels ou un flux continu. Des piles de motoneige (12 volts) constituaient la source d'énergie et la résolution dépassait une partie par 10^{11} Rhodamine. L'échantillonnage fut mené automatiquement, à une fréquence de un à six échantillons par heure.

On a établi d'abord les trajectoires de flux. A partir de gouffres choisis, des tests furent répétés sous différentes conditions de flux, afin de vérifier la présence de lignes souterraines de partage des eaux.

Dans tous les cas, le traceur fut distribué à de nombreuses sources et aucune véritable ligne de partage des equx ne fut identifée. Cependant, des classes fonctionnelles de sources purent être distinguées à l'aide des courbes temps/concentration caractéristiques. Des crêtes multiples variables dans le débit du colorant sous différentes conditions de flux reflètent l'importance changeante des conduits parallels. Quelques pouls peuvent témoigner du rinçage par la crue quotidienne de colorant emprisonné. Les résultats des traçages et une récession profonde de l'aquifère karstique au cours de l'été 1980 ont permis l'identification de groupments fonctionnels de sources karstiques. Un modèle simple pour le réseau en quatre dimensions est envisagé.

Signaturen Für Höhlenpläne

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Das vorliegende Signaturenverzeichnis basiert auf einem ausführlichen Studium der bisher erschienenen nationalen und internationalen Veröffentlichungen über Höhlenplansignaturen. Von 1977 bis 1980 wurde intensiv an der Signaturensammlung gearbeitet, geändert undumgeschrieben bzw. gezeichnet. Die jetzige Fassung gibt bestimmt Anlaß zur weiteren Diskussion und wird sicher nicht kritiklos hingenommen werden.

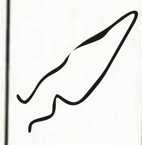
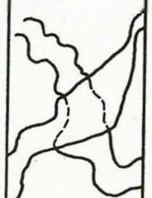
Zusammengestellt wurde diese Signaturensammlung für Speläologen, die Höhlenpläne anfertigen, die aber keine spezielle Ausbildung in einer der Geowissenschaften haben. Es wurde bewußt darauf verzichtet, verschiedene Signaturen getrennt, für große oder kleine Höhlen aufzuführen. Eine solche Unterscheidung ist sinnlos, da in großräumigen Höhlensystemen auch "Kleinstgänge" vorkommen. Die Auswahl der Signaturen wurde so getroffen, daß die bisher international gültigen erhalten blieben bzw. ergänzt wurden, eine weitere Entwicklung der Zeichen ist so jederzeit möglich. Es ist hiermit also eine Grundlage erstellt, die die beste Voraussetzung für eine gute internationale Verständigung schafft.

Für die Tuschedarstellungen wurden Schablonen und Schreibgeräte entsprechend der ISONORM ISO 3098/1 verwendet. Drei wesentliche Merkmale zeichnen die Anwendung der ISONORM aus:

1. gute Lesbarkeit
2. internationale Vereinheitlichung
3. speziell zur Mikroverfilmung bestens geeignet.

Allen, die durch Diskussionen und anderweitige Mitarbeit zum Gelingen dieser Sammlung beigetragen haben, möchte ich meinen Dank aussprechen.

Die Übersetzung des Textes in die Kongreßsprachen erfolgte durch die Mitarbeit von Reno BERNASCONI, Michael FIELD, Jean Ch. GRUNENWALD, Irene SCHELLHAMMER, Roland WINKELHÖFER.

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
1	0,25	0,25		Vermessungspunkt erster Ordnung, markiert, z.B. Haken, Gewindebolzen, o.ä.
2	0,25	0,25		Vermessungspunkt zweiter Ordung, markiert, Befestigungspunkt natürlich oder künstlich
3	0,25	0,25		Visierlinien (von Messpunkt zu Messpunkt!)
4	0,7	0,5		Gang, Raumbegrenzung
5	0,5	0,35		Gang, unter anderem verlaufend (bei normaler Darstellung des Grundrisses gibt es nur diese Signatur!)
6	0,5	0,35		Gang, über anderem verlaufend (wird bei niveaugebundener Darstellung benötigt)

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No. 1
engl. Survey point, marked, 1st grade (artificial i. e. piton or bolt etc.)
es. Estación topográfica principal, marcada, por ejemblo clavo, taco de expansión, etc.
fr. Repère ou marquage topographique principal (par exemple artificiel, piton, clou, spit etc.)
ital. Caposaldo principale
рус. Тригонометрический пункт, маркирован, первого порядка, /искуственно как крюк, винт и т.п./

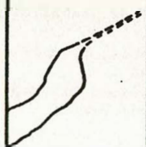
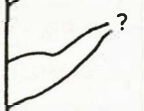
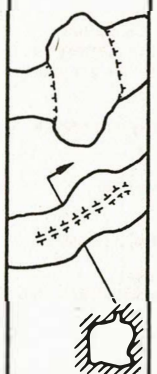
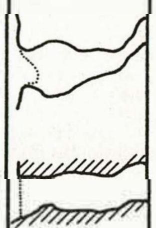
No. 2
engl. Survey point, marked 2nd grade (artificial and natural belay points)
es. Estación topográfica secundaria, marcada, punto de sujeción natural o artificial
fr. Repère ou marquage topografique secondaire (par exemple artificiel: piton, clou, spit etc.; ou naturel: stalactite, grosses pierres ... ou tout autre repère remarquable)
ital. Caposaldo secondario
рус. Тригонометрический пункт, маркирован, второго порядка/искуственные или естественные пункты, закрепления/

No. 3
engl. Line of sight (from point to point)
es. Linea de mira (de estación a estación)
fr. Ligne die visée (resultante de l'azimut et de l'angle de pente)
ital. Poligonale
рус. Линия визирования, измерительная база

No. 4
engl. Passage limits
es. Galeria, contorno de la cavidad
fr. Contours de la cavité
ital. Galleria
рус. Проход, ограничение пространства

No. 5
engl. Passage running under another
es. Galeria que pasa por debajo de otra (en la representación gráfica usual sólo existe este signo!)
fr. Galeries ou boyaux se croisant à deux niveaux différents (ci contre passant au dessous)
ital. Galleria passante sotto un' altra galleria
рус. Проход, проходящий под другим проходом

No. 6
engl. Passage running over another
es. Galeria que pasa por encima de otra (se emplea para representación relacionada al nivel)
fr. Galeries ou boyaux se croisant à deux niveaux différents (ci contre passant au dessus)
ital. Galleria passante sopra un'altra galleria
рус. Проход, проходящий над другим проходом

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
7	0,7	0,5		Gangfortsetzung, ohne Möglichkeit des Weiterkommens
8	0,5	0,35		Gangfortsetzung, mit Möglichkeit des Weiterkommens
9	0,35	0,25		angenommene, geschätzte Raumform
10	0,35	0,25		Deckenform
11	0,5	0,35		Trauflinie (hier beginnt die Höhle!)

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
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рус. Сигнатуры для чертежи пущеры

No. 7 engl. Unpassable continuation of passage
es. Continuación de galeria intransitable
fr. Continuité de réseau non pénétrable
ital. Prosecuzione inesplorata, intransitabile
рус. Продолжение прохода без возможности дальнейшего прохождения

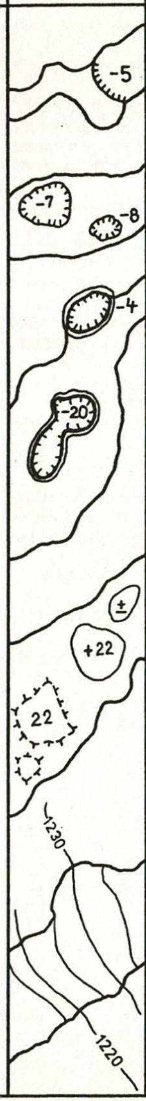
No. 8 engl. Possibility of continuation of passage
es. Continuación de galeria transitable
fr. Continuité de réseau éventuellement explorable
ital. Prosecuzione inesplorata, transitabile
рус. Продолженние прохода с возможностью дальнейшего прохождения

No. 9 engl. Estimated room shape
es. Contorno supuesto o estimado
fr. Contours et dimensions de cavité évalués
ital. Rilievo incerto o eseguito senza adeguati strumenti
рус. Предполагаемая, оцениваемая форма пространства

No. 10 engl. Roof shape
es. Forma de la bóveda
fr. Contours des voutes ou plafond
ital. Rilievo della volta
рус. Фдрмы кровли

No. 11 engl. Drip line (the beginning of the cave)
es. Linea marcando la entrada de la cavidad
fr. Ligne marquant le seuil de la cavité (cette ligne est observable de façon naturelle au sol, par la trace des goutees d'eau tombat du haut du porche)
ital. Linea marcante l'ingresso di cavitá
рус. Линия каплепадения

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
12	0,5	0,35		Stufe (Steilabbruch, Wandstufe)
13	0,5	0,35		Abgrund in der Höhle (Innenschacht) Angabe der Tiefe in Meter
14	0,7 0,5	0,5 0,35		Schachteingang (Tageslicht) Angabe der Tiefe in Meter
15	0,35	0,25		Kamin und Schacht
16	0,35	0,25		Kamin (diese Darstellung ergibt sich aus der Signatur für Deckenformen)
17	0,35	0,25		Isohypsen (Höhenmeterangabe wie auf den int. Kartenwerken)



engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
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ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No. 12 engl. Step or vertical drop (depth in metres)
es. Escalòn, escarpa
fr. Dècrochement apic ou ressaut vire corniche
ital. Salto
рус. Уступ /крутой обрыв, уступ в скальной стене/

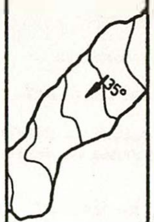
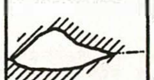
No. 13 engl. Interior shaft or pitch (depth, height in metres)
es. Pozo dentro de la cavidad (profundidad en metros)
fr. Puit en cavitè
ital. Pozzo
рус. Пропасть в пещере /внутренняя шахта/

No. 14 engl. Surface shaft or pitch (daylight , depth in metres)
es. Boca de una sima (al aire libre), profundidad en metros
fr. Gouffre
ital. Ingresso di cavità verticale
рус. Устье щахты на поверхности

No. 15 engl. Chimney and shaft or aven
es. Chimenea y pozo
fr. Puit et cheminèe
ital. Pozzo e camino
рус. Узкая крутая расщелина и шахта

No. 16 engl. Chimney (see no. 10)
es. Chimenea (representaciòn deducida de la representaciòn de la bòveda, vèase 10.)
fr. Cheminèe (no. 10)
ital. Camino (no. 10)
рус. Узкая крутая расщелина

No. 17 engl. Contour line, height in metres above sea level, written as on international maps
es. Curvas de nivel (isohipsas); indicaciòn de los metros de altura como en los mapas topogràficos
fr. Isohypse, altitude en metres
ital. Isoipse , altezza in metri
рус. Изогипсы /стрелка указывает на направление наклона/данные м отнесены к нормальному уровню

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
18	0,35	0,25		Formenlinien, mit Gefällepfeil und Neigungsangabe
19	0,35	0,25		Gefällepfeil (in der Höhle) Gefällepfeil (vor der Höhle)
20	0,35	0,25	⌖1234,5	Höhe über NN in Meter
21	0,35	0,25	(6,4)	Ganghöhe, Raumhöhe (Boden bis Decke) Angabe in Meter
22	0,35	0,25	± 0 -12 +34	Höhendifferenz bezogen auf den Eingang, Angabe in Meter
23	0,35	0,35	—·—·—	Kluft, Spalte
24	0,35	0,35	═·═·═	Störung,Verwerfung
25	0,35	0,35	—··—··—	Schichtfuge
				

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No.18 engl. Floor contour, arrow in direction of fall, with degree of slope
es. Forma del suelo; flecha indicando el sentido de la pendiente, inclinación en grados
fr. Les lignes reproduisent le nivellement du sol (la pente est orientée selon la flêche et indiquée en degree)
ital. Pendenza (la freccia indica il punto più basso)
рус. Линии формы дна со стрелкой наклона и с указанием наклона

No.19 engl. Arrows in direction of slope (solid in cave, outlined outside cave)
es. Flecha de pendiente (dentro de la cavidad) flecha de pendiente (fuera de la cavidad)
fr. Accident de terrain précedent le porche, les flêches indiquent la direction de la pente
ital. Pendenza (la freccia indica il punto più basso)
рус. Стрелка наклона /закрашена - в пещере, не закрашена - вне пещеры/

No.20 engl. Height above sea level in metres
es. Altura sobre nivel del mar (en metros)
fr. Repère d'altitude exterieure à la cavité, altitude absolue par rapport à la mer
ital. Quota, sopra il livello del mare
рус. Над-внем моря

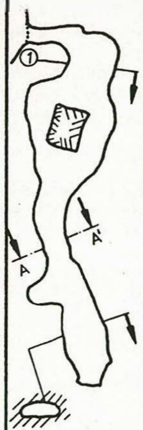
No.21 engl. Passage or roomheight (distance floor to roof in metres)
es. Altura de la galeria (de suelo à bôveda) en metros
fr. Différence de hauteur du sol au plafond de la cavité
ital. Altezza della volte (nel punto indicato)
рус. Высота прохода, высота пространства /от дна до кровли/

No.22 engl. Height difference in relation to entrance (floor, in metres)
es. Desnivel con respecto a la entrada (en metros)
fr. Différence de hauteur par rapport à l'entrée de la cavité
ital. Dislivello rispetto all'ingresso principale
рус. Разность высот по отношению к входу

No.23 engl. Cleft, fissure
es. Diaclase, grieta
fr. Diaclase, fissure
ital. Diaclasi, fessura
рус. Трещина

No.24 engl. Fault
es. Falla, dislocación
fr. Discordance, faille de dislocation, flexure
ital. Faglia
рус. Нарушение, сброс

No.25 engl. Bedding plane
es. Plano de estratificación
fr. Joint de stratification
ital. Giunto di stratificazione
рус. Плоскость наслоения

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
26	0,5	0,35		Schnitte (dünne Linie), schmaler Pfeil zeigt die Blickrichtung
	0,35	0,25		Alle Schnittdarstellungen zur leichten Erkennung Schraffur unter 45° (ISO - Empfehlung) Benennung der Schnitte mit Buchstaben oder Zahlen
27	0,7	0,5		Längsschnitt im Grundriss (dicke Strich-Punkt-Linie), breiter Pfeil zeigt die Blickrichtung
28	0,35	0,25		Wechselschraffur für umgelagerte Felsmasse (Tektonik) z.B. Deckenbruch

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No.26

engl. Cross section, arrows in direction of sight, small arrows, sections hatched at 45° as ISO, sections marked with letters or numbers

es. Sección (linea fina); la flecha fina indica la dirección de mira.
Contornos de secciones rayados bajo 45° para obtener mayor claridad (recomendación de la ISO)
Denominación de las secciones con letras o cifras.

fr. Repère et direction de vue en coupe transversale, petite flèche, hachures des coupes égale à 45° ISO

ital. Sezione trasversale (freccia fine = direzione dello sguardo)

рус. Поперечные разрезы, профили, стрелка в наиравленни взора, маленькое изображение штриховку разрезов выполнить под углом 45°
Маленькая стрелка - профиль, поперечный разрез

No.27

engl. Sectional elevations in groundplan, big arrows in direction of sight, with thick line-point-line

es. Sección longitudinal en la planta indicada con linea fuerte de punto y raya; la flecha fuerte indica la dirección de mira

fr. Repère et direction de vue en coupe longitudinale, grande flèche

ital. Sezione longitudinale (freccia in neretto = direzione dello sguardo)

рус. Продольные разрезы, стрелка в наиравлении взора или вида, крупное изображение
Большая стрелка - продольные разрезы, возможно вертикальная проекция

No.28

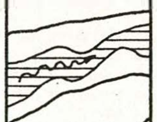
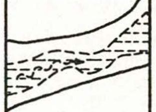
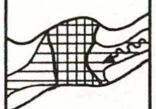
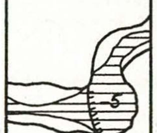
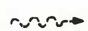
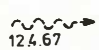
engl. Tectonically formed cave or breakdown (hatching, direction varying)

es. Roca dislocada (por acción tectônica) indicada por medio de rayado alternado. Por ejemplo derrumbamiento (compârese 26)

fr. Cavité tectonique par ex. par effrondement

ital. Cavita tettonica, per es. per crollo

рус. Передвинутые скальные горные породы, тектонически образованная часть пещеры

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
29	0,25	0,25		a) Höhlengewässer mit Fliessrichtung (waagrechte Schraffur)
				b) Höhlengewässer mit Fliessrichtung zeitweise
30	0,25	0,25		a) Siphon (waagrechte und senkrechte Schraffur).
				b) Siphon, zeitweise
31	0,5	0,35		Wasserfall mit Angabe der Falltiefe in Meter
32	0,35	0,35		a) Fliessrichtung
				b) Fliessrichtung, zeitweise
				c) Fliessrichtung, zeitweise Planaufnahme erfolgte am 12.4.67 bei trockenem Gerinne

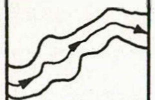
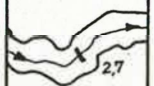
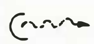
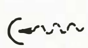
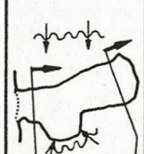
engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavitès
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No.29
engl. Cave water, direction of flow, horizontal hatching (a) permanental cave water, (b) temporary cave water (33)
es. (a) Curso de agua (rayado horizontal) y sentido de la corriente
(b) Curso de agua y sentido de la corriente temporal (vèase tambièn 33)
fr. Plan d'eau souterain (a) permanent, (b) pèriodique (33)
ital. Corso d'acqua sotteraneo (a) permanente, (b) temporaneo
рус. Пещерные русла с направлением течения /горизонтальная штриховка/
а/ постоянные б/ временные
29,33 в зависимости от ширины потока и масштаба плана

No.30
engl. (a) Siphon, vertical and horizontal hatching
(b) siphon, temporary
es. (a) Sifòn (rayado horizontal y vertical)
(b) sifòn temporal
fr. (a) Siphon, perenne
(b) siphon, pèriodique
ital. (a) Sifone
(b) Sifone, temporaneo
рус. Сифон а/ постоянный б/ временный
/вертикальная и горизонтальная штриховка/

No.31
engl. Waterfall with height (depth) in metres (34)
es. Cascada con indicaciòn de la altura de caida (en metros) (vèase tambien 34)
fr. Cascade avec hauteur de chute en mètres (34)
ital. Cascata (34)
рус. Водопад с указанием высоты ; 31,34 в зависимости от ширины потока и масштаба плана

No.32
engl. (a) Direction of flow, (b) temporary direction of flow, (c) temporary direction of flow, mapping on 12.4.67, dry water course
es. (a) Sentido de la corriente
(b) Sentido de la corriente temporal
(c) Sentido de la corriente temporal: topografia efectuada el 12/4/67 con cauce seco
fr. Cours d'eau souterain (a) perenne, (b) pèriodique, (c) avec date d'observation, cours d'eau aride
ital. Corso d'acqua (a) perenne, (b) temporaneo
(c) temporaneo, rilievo eseguito il 12.4.67 a secco
рус. Пещерные воды, направление теченря
а/ постоянные б/ временные
в/ с датой наблюдения

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
33	0,5	0,35		a) Höhlengewässer mit Fliessrichtung
				b) Höhlengewässer mit Fliessrichtung zeitweise
34	0,5	0,35		Höhlengewässer mit Wasserfall Fallhöhenangabe in Meter
35	0,5	0,35		Höhlengewässer, Versickerung im Sediment an unbestimmbarer Stelle
36	0,35	0,35		a) Wasseraustritt, Quelle
				b) Wasseraustritt, zeitweise
37	0,35	0,35		a) Schluckstelle, Schwinde
				b) Schluckstelle, zeitweise
				
38	0,35	0,25		flächiger Wassereintritt
				a) Wassereintritt flächig aus der Wand b) Wassereintritt flächig aus der Decke (nur Schnittdarstellung)

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No. 33
engl. Cave water course with direction of flow (a) permanent, (b) temporary
es. (a) Curso de agua y sentido de la corriente (b) Curso de agua y sentido de la corriente temporal (véase también 29)
fr. Ruissellement souterain, direction d'écoulement (a) perenne, (b) périodique
ital. Corso d'acqua (a) perenne, (b) temporaneo
рус. Пещерные русла с направлением течения а/ постоянные б/ временные 29,33 в зависимости от ширины потока и масштаба плана

No. 34
engl. Cave water course with waterfall and height (depth) in metres
es. Curso de agua con cascada; altura de caida en metros (véase tambien 31)
fr. Cascade avec hauteur de chute en mètres
ital. Cascata
рус. Водопад с указанием высоты;31,34 в зависимости от ширины потока и масштаба плана

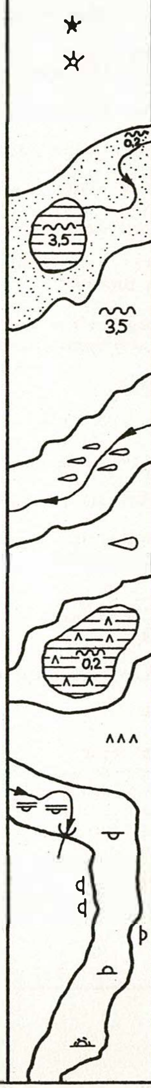
No. 35
engl. Cave water course, ooze (soak away) in the sediment
es. Curso de agua, pérdida en lugar indeterminable del sedimento
fr. Perte dans les dépots sédimentaires
ital. Perdita in sedimenti
рус. Пещерные воды, просачивание в осадок

No. 36
engl. Spring, resurgence (a) permanent, (b) temporary
es. Fuente (a) perenne, (b) temporal
fr. Source ou résurgence dans la cavité (a) perenne, (b) périodique
ital. Sorgente in una galleria (a) perenne, (b) temporanea
рус. а/ Выходы воды постоянные, источник б/ Выходы воды временные

No. 37
engl. Sink, swallow (a) permanent, (b) temporary
es. Pérdida (a) perenne, (b) temporal
fr. Perte dans la cavité (a) perenne, (b) périodique
ital. Perdita in una galleria (a) perenne, (b) temporanea
рус. Место поглащения в пещере а/ постоянные б/ временные

No. 38
engl. Water entry, seepage (a) wall, (b) roof
es. Infiltración de agua (a) a lo largo de una pared (b) desde la bovèda (sólo se representa como sección)
fr. Infiltration d'eau perenne (a) paroi, (b) plafond
ital. Infiltrazione d' acqua (a) parete, (b) volta
рус. Вход инфильтрационной воды а/ стена б/ кровля

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
39	0.25	0.25		a) Tropfwasserloch, aktiv b) Tropfwasserloch, inaktiv
40	0,35	0.25		Wassertiefe, Angabe in Meter
41	0,35	0.25		Fliessfacetten
42	0,35	0,25		Wasserfläche mit schwimmenden Kalkhäutchen
43	0,35	0.25		a) Kolk, überflutet b) Kolk (Boden) c) Kolk (Wand) d) Kolk (Decke) e) Kolk, versintert



engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус Сигнатуры для чертежи пущеры

No.39
engl. Drip water hole (a) active, (b) inactive
es. Origen de goteo (a) activo, (b) inactivo
fr. Trou d'érosion dut aut dégouttement (a) actif, (b) inactif
ital. Pozetto di stillicidio (a) attivo, (b) inattivo
рус. Отверстие капающей воды а/активное б/неактивное

No.40
engl. Water depth (in metres)
es. Profundidad del agua en metros
fr. Profondeur de l'eau (mêtres)
ital. Profondità dell' acqua
рус. Уровень воды

No.41
engl. Flow markings (scallops)
es. Huellas de corriente
fr. Facette d'érosion fluviatile
ital. Scultura alveolari
рус. Эрозионная фасетка

No.42
engl. Water with floating calcite film
es. Superficie de agua con membranas calcáreas flotantas
fr. Plan d'eau recouvert d'une pellicule de calcite
ital. Acqua con pellicola di calcite
рус. Водная поверхность с плавающим кальцитом

No.43
engl. (a) Pot, flooded (overflowed), (b) pot, floor, (c) pot, wall (d) pot, roof (e) pot, with flowstone
es. Marmita (a) inundada (b) en el suelo (c) en la pared (d) en la bóveda (e) concrecionada
fr. (a) Marmite noyée, (b) marmite d'érosion (au sol) (c) niche d'érosion (dans la paroi, (d) dôme d'érosion (au plafond) (e) marmite concrêtionnée
ital. (a) Marmitta allagata, (b) marmitta al suolo, (c) marmitta alla parete, (d) marmitta inversa alla volta (e) marmitta concrezionata
рус. Промоина а/наводненная промоина б/дно в/кровля г/стена д/натечная промоина

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
44	0,35	0,25		Anastomosen
45	0,35	0,25		Wassergeräusch, gehört am 14.12.61
46	0,35	0,25		Luftzug, bemerkt am ...
47	0,35	0,25		flächige Vereisung
48	0,35	0,25		Schnee, Firn

engl. Cave Map Symbols es. Signos de los Mapas Cavidados fr. Signes pour Plans des Cavités	ital. Segni per Cavita рус. Сигнатуры для чертежи пущеры

No. 44 engl. Anastomoses
es. Anastomosis
fr. Anastomoses
ital. Anastomosi
рус. Анастомозы

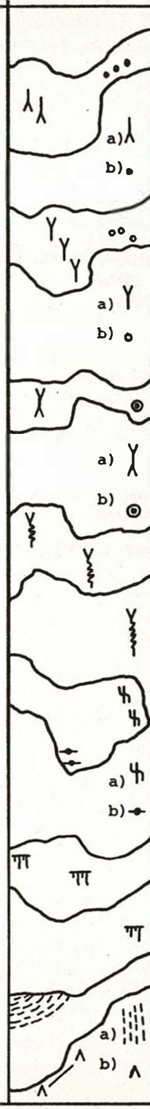
No. 45 engl. Sound of running water (heard on ....)
es. Sonido de agua, oido el 14/12/61
fr. Bruit de ruissellement, d'ésoulement, chute d'eau (date..)
ital. Ruscellamento, udito il (data)
рус. Шум воды, всегда слышно / при сомнении с указанием даты /

No. 46 engl. Draught, (observed on ....) air current
es. Corriente de aire, sentida el .....
fr. Courant d'air (constaté le ....)
ital. Corrente d'aria (con data)
рус. Сквозняк /наблюдался 15.12.67 г. в 17 часов/

No. 47 engl. Surface iceing (observed on ....)
es. Cubierta de hielo en el suelo (con fecha)
fr. Plan de glace (observé et daté le ...)
ital. Ghiaccio (con data ....)
рус. Плоскостное оледенение с указанием даты лед на дне

No. 48 engl. Snow, firn (observed on ...)
es. Nieve (con fecha)
fr. Neige (date ....)
ital. Neve (data ....)
рус. Снег / с датой /

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
49	0,35	0,35		Stalagmit, a,b wahlweise
50	0,35	0,35		Stalaktit, a,b wahlweise
51	0,35	0,35		Tropfsteinsäule, a,b wahlweise
52	0,35	0,35		Sinterfahne
53	0,35	0,35		Helektiten, Excentriques
54	0,35	0,35		Sinterröhrchen, Makkaroni
55	0,35	0,35		flächige Versinterung, a,b wahlweise



engl. Cave Map Symbols es. Signos de los Mapas Cavidados fr. Signes pour Plans des Cavités	ital. Segni per Cavita рус. Сигнатуры для чертежи пущеры

No.49
engl. Stalagmite (a,b) alternative
es. Estalagmita (a) o (b) alternativamente
fr. Stalagmite (a.b) alternative au choix selon l'echelle du plan
ital. Stalagmiti (a,b) alternativa
рус. Сталагмит а/б/ выборочно

No.50
engl. Stalagtite (a,b) alternative
es. Estalagtita (a) o (b) alternativamente
fr. Stalagtite (a,b) alternative au choix selon l'echelle du plan
ital. Stalattiti (a,b) alternativa
рус. Сталактит а/б/ выборочро

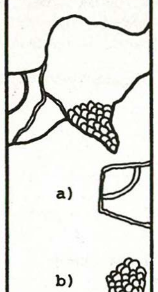
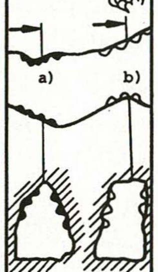
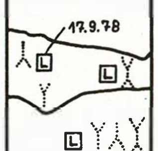
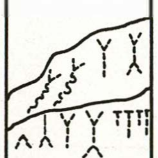
No.51
engl. Stal-column, stalacto-stalagmite (a,b) alternative
es. Columna (a) o (b) alternativamente
fr. Colonne stalagmitique (a,b) alternative au choix selon l'echelle du plan
ital. Colonne stalatto-stalagmitiche (a,b) alternativa
рус. Сталактитовая колонна а/б/ выборочно

No.52
engl. Drapery or curtain
es. Cortina
fr. Draperie
ital. Concrezione a cortina
рус. Натечная картина

No.53
engl. Helictit (a,b) alternative
es. Helictita; concreción excéntrica (a) o (b) alternativamente
fr. Excentriques (a,b) alternative au choix selon l'echelle du plan
ital. Concrezioni eccentriche (a,b) alternativa
рус. Гелектиты /эксцентрики/

No.54
engl. Straws
es. Estalagtita tubular, macarrón
fr. Concrétion fistuleuse, (maccaroni)
ital. Stalattiti tubulari, maccheroni, spaghetti
рус. Натечные трубки /макароны/

No.55
engl. Flowstone (a,b) alternative
es. Colada (a) o (b) alternativamente
fr. Plancher concretioné ou sol revêtu de calcite (a,b) alternative
ital. Colata stalagmitica sul pavimento (a,b) alternativa
рус. Плоскостные натечные образования /донный натек/ а/б/ выборочно

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
56	0,35	0,25	 a) b)	Sinterbecken (gross) Sinterbecken (klein, flächig)
57	0,35	0,35	 a) b)	a) flächige Sinterbildung b) Montmilch
58	0,35	0,35		Kristalle
59	0,35	0,35		Sinterähnliche Formen z.B. Lehmstalagmiten
60	0,35	0,35		Sinter im Abbau (korrosiv)

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

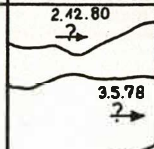
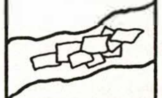
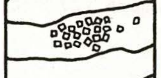
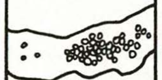
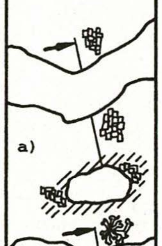
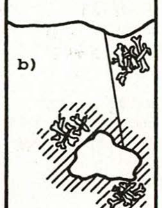
No.56 engl. Gour pools, rimstone pools (a) large, (b) small
es. Gours (a) grande, (b) pequenos, formando una superficie
fr. Gour (a) grand (b) petit
ital. Concrezioni a vaschetta (gours) (a) grandi, (b) piccole
рус. Натечный бассейн а/большой б/ маленький

No.57 engl. (a) Flowstone, walls and roof
(b) Moonmilk
es. (a) Colada
(b) Leche de monte (Mond(t)milch)
fr. (a) revêtement de calcite du plafond ou des parois
(b) Montmilch (Bergmilch), lait de lune
ital. (a) Concrezioni, parietali, volta
(b) Latte di monte, latte di luna
рус. а/ Натек в кровле или натечные отложения на стене
б/ Горное молоко, кровля или стена

No.58 engl. Crystal formation
es. Cristales
fr. Cristallisation
ital. Cristalli
рус. Образование кристаллов

No.59 engl. Concretions not calcite (clay, loam,etc.)
es. Configuraciones parecidas a concreciones, por ejemblo estalagmitas de fango
fr. Concrétion non calcitique (silicieux, limoneux, etc.)
ital. Concrezione non calcitica (sabbiosa, argillosa, etc.)
рус. Конкреции /также пещерный суглинок и т.п./

No.60 engl. Corrosive destroyed flowstone formation
es. Concreción en estado de decomposición (por corrosión)
fr. Concretionnement ancien en décalcification
ital. Concrezioni in disfacimento
рус. Натек разрущен человеком

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
61	0,5	0,35		Gangerweiterung (mit Datum)
62	0,35	0.25		Blockwerk
63	0,35	0.25		Schutt, Bruchmaterial (scharfkantig)
64	0,35	0.25		Kies, Geröll, Geschiebe
65	0,35	0.25		Ablagerungen, Sedimente H Humus T Ton L Lehm S Sand
66	0,35	0.25	a) 	a) Brekzie
			b) 	b) Knochenbrekzie

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No.61 engl. Artificially enlarged passage (with date)
es. Galeria ensanchada artificialmente (con fecha)
fr. Passage forcé (dynamitage, traveaux de terrassement, date)
ital. Passaggio forzato (con data)
рус. Искуственные прорыв или расширение прохода, с датой

No.62 engl. Boulder, large breakdown
es. Bloques
fr. Grands blocs de pierre
ital. Massi (grandi dimensioni)
рус. Система блоков

No.63 engl. Rubble (sharp cornered, small breakdown)
es. Pedrisco, cascotes
fr. Remplissage, éboulí de pierres aux angles vifs
ital. Massi (piccoli dimensioni)
рус. Обломки гориых пород, обрушенные породы, не окатанные

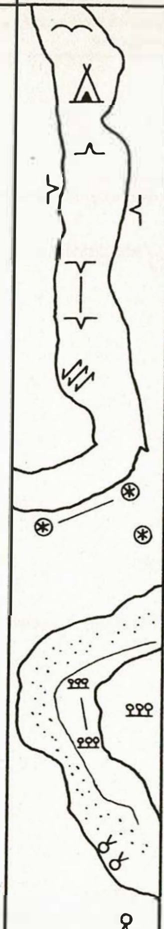
Nr.64 engl. Gravel, pebbles (rounded stones)
es. Cantos rodados, gravas
fr. Debris d'érosion fluviale, fluviau glacière (gravier)
ital. Ghiaia
рус. Валуны /окатанные породы/

No.65 engl. Sedimentation (Humus, Clay, Loam, Sand)
es. Sedimentos (Humus, Arcilla, Fango, Arena)
fr. Sediment (Humus, Marme, Argile, Sable)
ital. Sedimenti (Humus, Limo, Argilla, Sabbia)
рус. Отложения - гумус, глина, суглинок, песок

No.66 engl. (a) Debris, (b) bone debris (remains)
es. (a) Brecha (b) brecha ósea
fr. (a) Breccite, (b) breccite d'ossement
ital. (a) Breccia, (b) breccia ossifera
рус. а/ брекния, б/ костоносная брекчия

Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
67	0,35	0,25		Konglomerat
68	0,35	0,35		zerstörte Sinterformen Zerstörung
69	0,35	0,35		Abfälle, Müll
70	0,35	0,35		Kadaver
71	0,35	0,35		Fundstelle (geschichtliches Material)
72	0,35	0,35		Grab (menschlich)
73	0,35	0,35		Fundstelle menschlicher Knochen
74	0,35	0,35		Fundstelle tierischer Knochen
75	0,35	0,35		a) Fossilfundplatz (tierisch)
	0,35	0,35		b) Fossilfundplatz (pflanzlich)
76	0,35	0,35		Grabungsstelle (keine Gangerweiterung)

engl. Cave Map Symbols es. Signos de los Mapas Cavidados fr. Signes pour Plans des Cavités	ital. Segni per Cavita рус. Сигнатуры для чертежи пущеры
No.67	engl. Conglomerate es. Conglomerado fr. Conglomérat ital. Conglomerato рус. Конгломерат
No.68	engl. Damage, hammer with appropriate symbol es. Destrucción: martillo y signo del objeto destruido fr. Dèterioration ou destruction ital. Concrezioni distrutte рус. Поврежденные образования /молоток относится к соответствующему символу/
No.69	engl. Rubbish (date) es. Basura (con fecha) fr. Ordure abandonnè (date) ital. Rifiuti abbandonati (con data) рус. Отходы - мусор с датой
No.70	engl. Cadaver (date) es. Cadâver (con fecha) fr. Charnier (date) ital. Cadaveri (con data) рус. Трупы, с датой
No.71	engl. Historic site es. Sitio arqueològico fr. Gisement archèologique ital. Sito archeologica рус. Доисторическое место находи
No.72	engl. Grave or burial (human) es. Tumba (humana) fr. Tombe (protohistorique, prèhistorique, historique, rècente) ital. Tomba рус. Могила /человека/
No.73	engl. Bones (human) es. Huesos humanos fr. Ossements (humains) ital. Ossa (umane) рус. Кости человека
No.74	engl. Bones (animal) es. Huesos animales fr. Ossements (animaux) ital. Ossa (animali) рус. Кости животных
No.75	engl. Fossil site (a) animal, (b) vegetable es. Hallargos fòsiles (a) animales, (b) vegetales fr. Fossiles (a) animaux, (b) vègètaux ital. Reperti fossili (a) animali, (b) vegetali рус. а/ ископаемые / животные/ б/ ископаемые /растения/
No.76	engl. Site of dig (no further passage widening) es. Excavaciòn fr. Ouilles ital Scari рус. Место раскопок /нет расширения прохода для прохождения/



Nr.	Strichstärke im System 0,7	0,5	Signaturen	Beschreibungen, Bemerkungen
77	0,35	0,35		Guano
78	0,35	0,35		Biwak
79	0,35	0,35		a) Rippen am Boden (kein Sinter) b) Rippen an den Wänden c) Rippen an der Decke
80	0,35	0,35		Karren
81	0,25	0,25		Eiskristalle durch Kondensation
82	0,25	0,25		Blumenkohlsinter
83	0,35	0,35		Paletten, Diskus- oder Scheiben-sinter

engl. Cave Map Symbols
es. Signos de los Mapas Cavidados
fr. Signes pour Plans des Cavités
ital. Segni per Cavita
рус. Сигнатуры для чертежи пущеры

No. 77
engl. Guano
es. Guano
fr. Guano
ital. Guano
рус. Помёт

No. 78
engl. Bivouac
es. Vivac
fr. Bivouac
ital. Bivacco
рус. Бивак

No. 79
engl. Ribs, (no stal); (a) floor, (b) wall, (c) roof
es. Aletas (a) en suelo (no concreciones) (b) en les paredes (c) en la bôveda
fr. Lames (fore, rèsultant d'èrosion par disolution) (a) au sol, (b) à la paroi, (c) au plafond
ital. Lame (a) sul pavimento, (b) paietali, (c) sulla volta
рус. Ребра /нет натека/ а/ дно б/ стена в/ кровля

No. 80
engl. Karren (cave)
es. Lapiaz
fr. Lapiaz (cavitè)
ital. Lapiaz (cavita)
рус. Карры, шратты

No. 81
engl. Ice cristals from condensation
es. Cristales de hielo (por condensaciôn)
fr. Givre de condensation
ital. Ghiaccio
рус. Ледяные кристаллы, образованные путем конденсации

No. 82
engl. Cauliflower stal formation
es. Concreciôn en forma de coliflor
fr. Concretionnement granulaire (chou-fleur)
ital. Piccole concrezioni diffuse, a cavolfiore
рус. Натек в виде цветной капусты

No. 83
engl. Disc, shield
es. Concreciôn en forma de disco, escudo
fr. Disques de colonne
ital. Concrezione "disco" piatta forma
рус. Натек с плитой на кровле /на анл. яз. disc /

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Holarctic Cave Mites of the Family Rhagidiidae (Actinedida: Eupodoidea)

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Abstract

The Rhagidiidae are introduced and the cavernicolous species are discussed. Troglophilic and troglobitic species can be distinguished by their morphological adaptations, so-called troglomorphisms. All the known Holarctic cave species are listed. Probable cave vicariation is mentioned. Collection methods in caves, preservation, and further studies of these mites are outlined.

Zusammenfassung

Die Raubmilben der Familie Rhagidiidae werden als obligate Höhlenbewohner vorgestellt. Troglophilous - und Troglobiontenarten könnea verläslich nach ihren morphologischen Adaptationen unterschieden werden - sog. Troglomorphismus. Alle bisher bekannten Höhlenarten der Milben der Familie Rhagidiidae sind im Verzeichnis eingeführt. Es ist die voraussichtlich Höhlenvikariation mancher europeischen Arten eingetragen. Es sind die Methoden des Sammelns in den Höhlen, der Konservierung und die Methoden des weiteren Studiums dieser Milben eingeführt.

Introduction

Predatory mites of the family Rhagidiidae were discovered by biospeleologists by the second half of the nineteenth century, e.g. Poecilophysis spelaea (Wankel, 1861) and P. weyerensis (Packard, 1888). The majority of rhagidiids are soil forms, but at present about 30% of the species are cavernicolous forms seemingly concentrated in the Holarctic region. Two cave species are now known from the Neotropical/Nearctic transition zone in Mexico. Schuster (1969) reported non-cave forms from tropical South America and other species are known from the Antarctic and Subantarctic regions. We assume that, owing to their ecological affinity to cool, moist and dark environments, they occur in caves in other biogeographical regions as well.

The most extensive and substantial works on the European cave material of this family were published by Willmann (1932, 1934, 1935, 1936, 1939, 1941, 1953, 1954). Later they were followed by others such as Lombardini (1951), Turk and Turk (1952), Cooreman (1959), Turk (1972), Baltac (1973, 1974, 1976), Rack (1974) and Zacharda (1978, 1980).

In North America cave rhagidiids were studied by Packard (1888), Banks (1897) and Banta (1907). Recently Holsinger (1965), Elliott and Strandtmann (1971) and Elliott (1976) published their contributions to the taxonomy and zoogeography of the Rhagidiidae in North American caves. At present, the cave rhagidiids of the U.S.A. and Mexico are being studied and new species with pertinent zoogeographic data will be described soon (Zacharda and Elliott, 1981 a, b; Zacharda and Welbourn, 1982).

Unfortunately data on the cave rhagidiids of other parts of the Holarctic region are quite limited. Morikawa (1963) described Rhagidia Uenoi from several limestone caves and R. japonica (= Poecilophysis pratensis?) from a mine and forest litter in Japan. Shiba (1969, 1971a) reported Rhagidia longisensilla (= Shibaia coreaensis) from a limestone cave in South Korea and R. crenata (Shiba, 1969) from a lava cave in western Japan as well as from Japanese forests. The taxonomic status of some of these species is uncertain and the types should be reviewed. Regardless of the taxonomic problem, it appears that R. uenoi may be troglobitic while the other species are troglophilic.

We must stress that although many scientific papers on rhagidiids have already been published, the correct identity of the species, especially in older papers and species lists (Wolf 1934-37; Thor and Willmann, 1941) often has been obscure. At present a revision of the known world rhagidiid fauna (Zacharda, 1980) allows reliable identification of most species. Other cave species in need of taxonomic review are Rhagidia trisetata Elliott and Strandtmann, 1971 (troglophile, Mexico, S.L.P.); Troglocheles conciana (Lombardini, 1951) (troglobite, Italy); R. odontochela Turk, 1972 (troglobite?, Great Britain); and R. vitzthumi Turk, 1972 (? Great Britain).

Troglobitic and Troglophilic Rhagidiidae

As shown in Table 1, thirty reliably distinguishable rhagidiids have been found in caves (or mines) of the Holarctic region up to the present. Eighteen species are troglophiles, and some of these are probably troglobites "in statu nascendi" (see below). Twelve species are troglobites.

Holsinger (1965) and Elliott (1976) disclosed in cave rhagidiids evident morphological adaptations to life in caves, such as eyelessness, depigmentation of the integument, attenuation and elongation of the appendages and chaetotaxy, and a remarkable development of some special sensory organs. Recently, the morphological adaptations in the troglobitic Rhagidiidae were evaluated by Zacharda (1979 a, 1980) and named "troglomorphisms". In the Rhagidiidae they are the elongation and attenuation of the legs, pedipalps, chelicerae and chaetotaxy, the depigmentation of the very thin integument, and sometimes eyelessness (Fig. 1). Teh epigean cave rhagidiids are usually larger than the smaller hemiedaphic or euedaphic ones. Their special sensory organs, the so-called "rhagidial organs" located on tarsi I, II, and (exceptionally) III, are often strikingly developed. The rhagidial setae are enormously enlarged or increased in number, and the special sensory lancetform seta on tibia II is often hypertrophied and protruding from its insertion pit. The latter adaptation has evolved in parallel in several North American and European troglobites.

As far as is known, in caves the Rhagidiidae feed on Collembola (Zacharda, 1978) and therefore their chelicerae and laterally attached pedipalps are elongated and adapted for grasping the voluminous prey. We must stress, however, that troglomorphisms are often quite specific in the Rhagidiidae. For example, in Poecilophysis wolmsdorfensis (Willmann) the rhagidial setae are rather reduced while in Troglocheles strasseri (Willmann) they are unusually increased in number, or in Rhagidia varia (unpubl. species) the rhagidial setae are enormously enlarged (Fig. 1).

In the troglophilic rhagidiids we find only adaptations to life incool, moist and dark habitats, i.e. a fine depigmented integument and sometimes eyelessness, but the conspicuous troglomorphisms are always missing.

In some, undoubtedly troglobitic species, e.g. Troglocheles strasseri s.l. (Zacharda, 1980: 646-658) inhabiting vast karst areas in West and Central Europe, or Traegaardhia dalmatina (Willmann) from caves of the Balkan peninsula (Zacharda, 1980: 718-719), or Rhagidia varia from Virginia (Zacharda and Welbourn, in press), the strikingly large and unusual variability of their adaptive, derivative troglomorphisms is remarkable. But if we examine smaller, local populations isolated in caves, we can see that these local populations differ one from another and they have less variation. In these cases we assume that the phenomenon of cave vicariation, supported by geographical and geomorphological isolation of the local cave population, should be taken in consideration. Unfortunately, the present shortage of material does not allow us to draw more detailed conclusions on cave vicariation in the Rhagidiidae.

Distribution

Genuine troglobitic rhagidiibs are known to inhabit only caves, while the troglophiles commonly occur also outside the caves. In some species, however, their position is not quite clear in this respect. For example, Poecilophysis spelaea (Wankel) (= Rhagidia recussa Sig Thor) bears only indistinct troglomorphisms, but at present this species is known only from caves in Furope where it is often very abundant (Zacharda, 1978). No findings outside the caves have been reported up to the present except for that by Sig Thor (1909) from the Shara-Ullach Mountains, North

Siberia. It is not out of the question that there may be a population of this species living outside the caves somewhere in the North Siberian tundra, while all the European populations occur only in caves as troglobites "in statu nascendi".

As an analogy, the North American rhagidiid Robustocheles hilli (Strandtmann) was originally described from lichens in Alaska, later found in the tundra of the Canadian Arctic Archipelago (Zacharda, 1980), but in the temperature U.S.A. it has been found only in caves (Elliott, 1976; Zacharda and Welbourn, 1982), where it is a very abundant and common rhagidiid. This same probably applies to the North American rhagidiid Foveacheles tuktoyaktukensis Zacharda, discovered in Arctic Canada and in Greenbrier Caverns, WEst Virginia (unpubl.). Of course, both species bear no troglomorphisms and if they occur in the U.S.A. only in caves (not yet verified), they should be considered post-glacial relicts surviving in caves during post-Wisconsin time (Munroe, 1968; Matthews, 1979).

To summarize, we expect that evolutionarily older and conspicuously, morphologically specialized troglobites are distributed in relatively small areas, e.g. Elliotta howarthi (Elliott), Flabellorhagidia pecki Elliott, Troglocheles strasseri (Willmann), etc., while evolutionarily younger troglobites "in statu nascendi", or post-glacial relict troglophilic species, bearing only indistinct troglomorphisms, e.g. Poecilophsis spelaea (Wankel), occupy larger areas. Only troglophilic rhagidiids can facultatively occur in caves of both the Palearctic and Nearctic regions, e.g. Poecilophysis weyerensis (Packard), P. pratensis (C. L. Koch), Rhagidia diversicolor (C. L. Koch). Many more species are expected.

Collection and Further Study

Further extensive collection of cave rhagibiids throughout the world is still highly desirable to expand our knowledge of their classification, bionomy and evolutionary adaptations. We must stress, however, it is also important to collect these mites in the vicinity of caves to find which "troglophilic" species occur outside the caves and which do not.

Because season-dependent life cycles have been disclosed in some species (Zacharda, 1979 b, 1980), it is best to repeat collections several times a year. Then adults, which are indispensable for correct specific identification, are more likely to be collected.

The Rhagidiidae are usually observable as small, whitish, spider-like creatures running here and there on the substrate. We can collect them using a fine, alcohol-soaked artist's brush or a small aspirator containing 80-96% ethyl alcohol. Especially in caves these mites can also be picked up from pool surfaces using a small wire noose. Samples of cave substrate can be desiccated in a Berlese-Tullgren apparatus (Krantz, 1978). Moist to wel soil samples must be transported on wire nettings in boxes with solid walls to protect them against pressing and sticking. However, this is not a very efficient method!

Pitfall traps, small jars about 8 cm in diameter, containing 3% formaldehyde solution and sunk to ground level, are a surprisingly successful method of collecting rapidly moving rhagidiids, especially when we use a bait, e.g. a sterile wafer which should be placed on the substrate close to the pitfall trap. The bait attracts cave decomposers, mainly Collembola and, consequently, also their predators (Zacharda, 1978: 216).

Further study of the Rhagidiidae requires free preparations, specimens being preserved only in alcohol and not embedded permanently as is customary.

Table 1. A list of the cave Rhagidiidae of the Holarctic region.

Troglophilic species
* cave record, otherwise epigean Robustocheles robusta Zacharda, 1980. Czech., W. Ger.*

R. infernalis Zacharda & Elliott, 1982 a. Mex.: Veracruz.*

R. hilli (Strandtmann, 1971). U.S.A.: Alaska, Ut.* Can.:N.W.T.

Rhagidia diversicolor (C.L. Koch, 1838). Czech, W. Ger.*, U.S.A.*

Poecilophysis faeroensis (Tragardh, 1931). Faeroe Is., W. Ger.,* Czech.

P. pratensis (C. L. Koch, 1835). U.S.A.: Alaska, Ha.; Czech; W. Ger.?; Japan? (mine and forest).

P. weyerensis (Packard, 1888). U.S.A.: Va*, Ky*, Missouri* N.M*; Mex.: S.L.P*, Czech.

P. wankeli (Zacharda, 1978). Czech* (and epigean), Austria.

P. melanoseta Zacharda & Elliott, 1982 b. U.S.A.: Calif* (and epigean)

P. extraneostella Zacharda & Welbourn, 1982. U.S.A*

Foveacheles osloensis (S. Thor, 1934). Czech., W. Ger* Austria, Norway.

F. holsingeri Zacharda, 1980. U.S.A.: Ky* (Mammoth Cave).

F. harzensis Zacharda, 1980. W. Ger*

F. tuktoyaktukensis Zacharda, 1980. Can.:N.W.T.; U.S.A: W. Va*

F. magna Zacharda, 1980. W. Ger*

F. terricola (C. L. Koch, 1835). W. Ger*

F. auricularia Zacharda & Elliott, 1982 b. U.S.A.: Calif*

Shibaia longisensilla (Shiba, 1969). Czech.; Austria; U.S.A.: Alaska, Ha., N.M* Ark* Japan.

Troglobitic species

Elliotta howarthi (Elliott, 1976). U.S.A.: Wa., Id.?

Poecilophysis spelaea (Wankel, 1861). Czech., Pol., W. Ger., Belg., Swiz., Rom., Engl.

Poecilophysis wolmsdorfensis (Willmann, 1936). Czech., Pol., W. Ger., Yugo., Rom., U.S.A.?

Troglocheles strasseri (Willmann, 1932). Yugo., Austria

T. vornatscheri (Willmann, 1953). Austria

T. gineti (Cooreman, 1959). France, W. Ger.

Flabellorhagidia pecki Elliott, 1976. U.S.A.: Idaho.

Foveacheles titanica Zacharda & Elliott, 1982 b. U.S.A.: Calif.

F. paralleloseta Zacharda & Welbourn, 1982. U.S.A.

Traegaardhia dalmatina (Willmann, 1939). Yugo., possibly W. Ger. & France.

Rhagidia varia Zacharda & Welbourn, 1982. U.S.A.: Va.

Shibaia coreaensis Zacharda, 1980. S. Korea.

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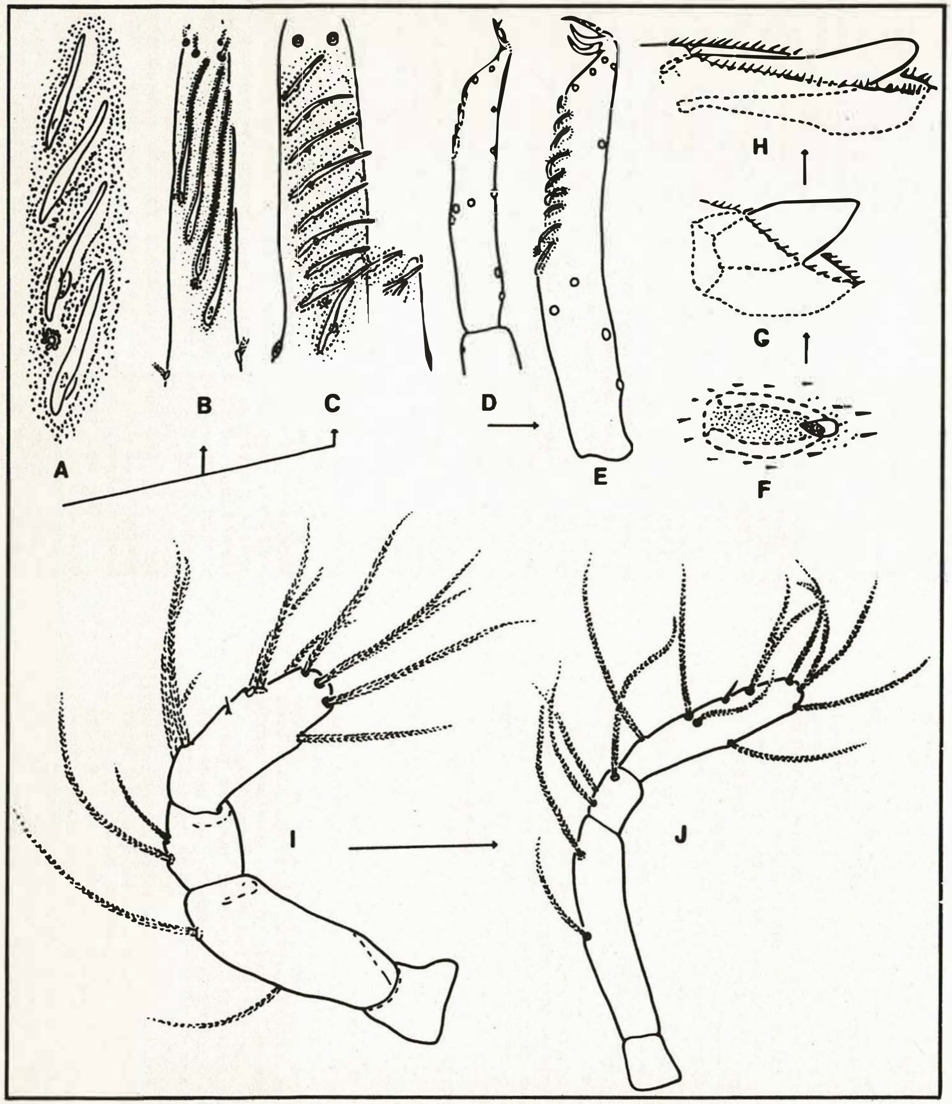

Figure 1. Some troglomorphisms in Rhagidiidae: A,B,C, - rhagidial organs in: A- non-troglomorphic Rhagidia gigas; B- troglomorphic R. varia; C- troglomorphic Troglocheles strasseri s.l.; D,E- tarsus I in profile in: D- non-troglomorphic Rhagidia gigas; E- troglomorphic Troglocheles strasseri s.l.; F,G,H- lanceolate seta on tibia II in: F- non-troglomorphic Foveacheles osloensis; G- partly troglomorphic Poecilophysis spelaea; H- troglomorphic Elliotta howarthi; I,J- pedipalps in: I- non-troglomorphic Rhagidia gigas; J- troglomorphic Troglocheles strasseri s.l.

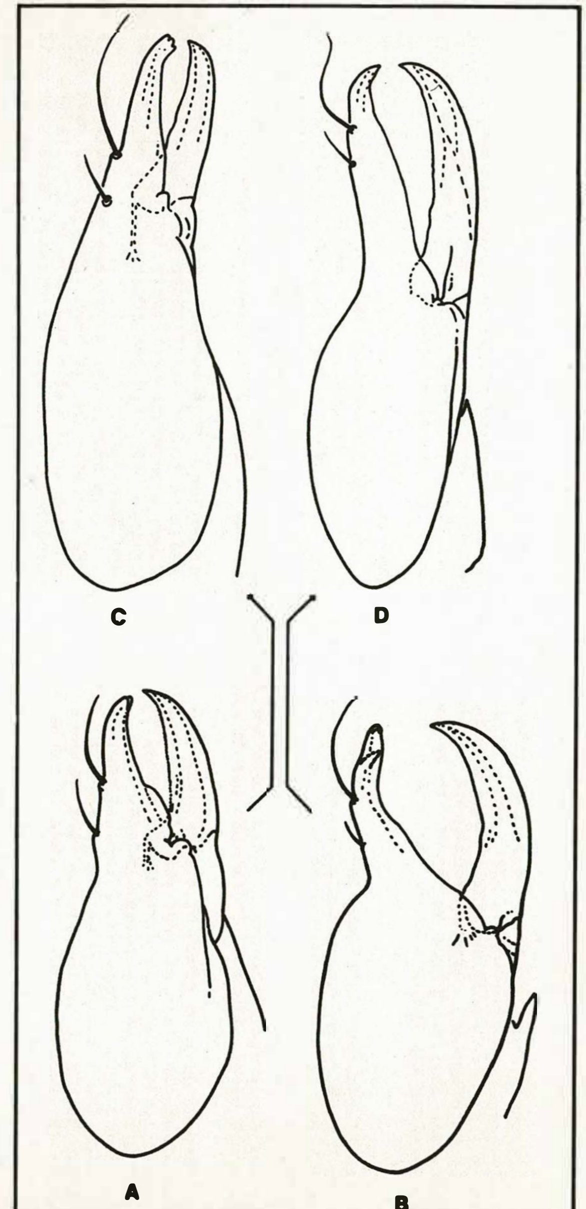

Figure 2. Cheliceral types in; non-troglomorphic species: A- Rhagidia gelida; B- Poecilophysis macquariensis; and troglomorphic species: C- Elliotta howarthi; D- Troglocheles strasseri s.l.

Horsethief Cave: An Early Pleistocene Cavern

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Abstract

Horsethief Cave is a maze cave, developed by phreatic waters moving along joings of Laramid and possibly also of Mississippian ages, in the Madison Limestone. The steepest hydraulic gradient toward the Bighorn River controlled main passage directions, while mixing corrosion governed their vertical development. Cavern development occurred when the Amsden Formation, which acted as an aquifer, was still in place on top of the Madison Limestone. The cave's relationship to erosional surfaces along the Bighorn River projects an early Pleistocene age for cave development.

Zusammenfassung

Die Pferdebiebhoehle ist eine Labyrithhoehle die durch Untergrundgewaesser entwickelt wurde, die den Kontakten von Laramiden und moeglicherweise auch Mississippi Formationen im Madison Kalstein folgten. Die tiefste Hydraulische Neigung dem Bighorn flusse zu wurde von den Hauptdurchzugsrichtungen kontrolliert waehrend die horizontale Entwicklung durch mischende Korosion kontrolliert wurde. Die Entwicklung der Hoehlen geschah als die Amsden Formation welche als wasserhaltige Schichte diente noch ueber der Madisonkalstienschichte lag. Die Hoehlenbeziehung zur erosionalen Oberflaechengestaltung entlang des Bighornflusses projektiert ein fruehes Pleistocaenalter fuer Hoehlenentwicklungen.

Horsethief Cave is located south of the Wyoming-Montana border at an elevation of 4685 feet (1428 meters) in a plateau (Little Mountain) formed from gently dipping Madison Limestone of Mississippian age. The plateau is formed across the crest of the asymmetrical Porcupine Creek anticline on the west flank of the Bighorn Mountains in the Middle Rocky Mountain Province (Frenneman, 1981). The cave is found in a partially dissected dipslope upon which there are residual hills of the Pennsylvanian Amsden Formation (Figure 1). Several small canyons, roughly following the dip, drain the area in a southwesterly direction. Less than one mile (1.6 kilometers) north of Horsethief Cave, Porcupine Creek has cut Devil Canyon, exposing rocks as old as upper Devonian along 800 foot (244 meters) vertical walls. Approximately one mile (1.6 kilometers) west of Horsethief Cave, the Bighorn River flows northward in a meandering, 600 foot (183 meter) deep canyon superposed across the northern end of the Bighorn Mountains.

Horsethief Cave with its adjacent and interconnected neighboring cave, Bighorn Caverns, forms a complex joint controlled maze cave system with an estimated 20 miles (32 kilometers) of passages (figure 2). With only a few exceptions, passage forms where unaltered by breakdown are phreatic in nature. Most large passages have been altered by breakdown, and surface sediments have been washed into the cave in many locations. Additionally, dripstone features and crystal growths (primarily gypsum) are found throughout the cave. No surface expression of the cave system other than its entrances is currently observable on Little Mountain. Debris from the eroding Amsden Formation has filled and obscured sinks and former collapse entrances.

The cave system is found in the upper part of the Madison Limestone in a unit consisting of 145 feet (44 meters) of tan, finely crystalline, and thinbedded limestone with zones of breccia (Richards, 1955). The breccias contain limestone fragments in red siltstone or claystone matrix similar to the basal part of the overlying Amsden Formation. These zones of breccia are concentrated at the top and bottom of this upper unit of the Madison, and in part represent late Mississippian karst topography (Thom. 1935: Richards, 1955). Collapse structures are common in this unit, yielding a great variety of strikes and dips.

The major part of the cave itself varies between 60 and 120 feet (18 to 37 meters) below the top of the Madison Limestone. Some narrow fissures, however, extend to the top of the Formation, being roofed with breccia and in some cases siltstone from the Amsden Formation. Narrow fissures can be seen in the ceilings of major passages, as well as at various angles to them. The variations in vertical positions of major passages are due primarily to varying amounts of passage collapse and infilling with breakdown.

The joint orientations which control passage development are related to Laramid, and possibly also Mississippian age structures in the vicinity (Sutherland, 1976). These joints offer a great variety of directions for potential passage orientations. The dip of the Madison Formation is to the southwest near the cave system, and the Bighorn River lies directly west of the cave system (figure 1). A rose diagram of lines of survey in Horsethief Cave (figure 3) shows that main passage orientations and their controlling joints are primarily east-west, with secondary trends shifting toward a southwesterly direction. This indicates that the steepest hydraulic gradient toward the Bighorn River exerted greater influence on which particular joints became main passages than did the southwesterly dip of the Madison Limestone.

The angular grid pattern of a network type maze which stands out in many parts of the cave system can be seen in the cave map (figure 2). Palmer (1975) attributes this type of passage pattern to uniform diffuse groundwater recharge from an overlying formation or surface. Solutionally enlarged fissures extending to the top of the Madison Limestone as mentioned previously support this interpretation. The Amsden Formation, which has been described as an aquifer (Thom, 1935) is the most probable source for uniform diffuse recharge to the Madison Limestone. Tertiary sediments on Little Mountain or traces thereof in cavern fills indicates that the Amsden Formation probably still covered the Madison Limestone during the Tertiary Period. This reinforces the contention that the Amsden Formation was the aquifer responsible for uniform diffuse recharge to joints in the Madison Limestone during cavern development.

The development of large rooms and passages in Horsethief Cave appears to have begun as a modification of the lower portions of solutionally enlarged fissures. Such development appears generally to have taken place in the vicinity of 90 feet (27 meters) or greater below the top of the Madison Limestone. Where large rooms have not formed below fissures, spongework and maxes occassionally are present. Since these modifications of fissures do not extend for any great vertical distance, increased solutional activity of the waters which enlarged the fissures is thought to have taken place at that level. Mixing corrosion as descriped by Bogli, 1964 (in Jennings, 1971) presents the most probable cause of such vertical restrictions on phreatic passage development. Secondary waters for mixing with water descending from the Amsden Formation could have easily been supplied from a bedding plane, or possibly even the paleokarst within the Madison.

The relative age of development of Horsethief Cave can be determined from the preceeding description of the cave and its surroundings, when compared with the erosional history of the Bighorn River (Mackin, 1937 and 1947; merrill, 1974). Since the gradient from Horsethief Cave to the Bighorn River determined which joints in the limestone became main passages, the river must have been incised to a position lower than that of the cave system. Otherwise phratic passage development would have been wither random in orientation, or the dip of the Madison Limestone would have influenced the orientation of main conduits.

The absence of passage modification by vadose waters in the cave system shows that the phreatic enlargement of the cave ended rather abruptly. One may conclude that the supply of water to the cave also decreased rapidly, negating any chance for vadose modifications. Such a change in hydrology in the cave system most likely occurred during a period of rapid downcutting by the Bighorn River to the west, and by Porcupine Creek to the north. This situation is reinforced by the lack of evidence for any subsequent reflooding of the cave system at a later time. Once the cave drained, it remained drained.

The age limits on the development of Horsethief Cave are as follows: 1) it formed before the Amsden Formation was removed from Little Mountain while the Bighorn River was at an elevation somewhat lower than the elevation of the cave; 2) the Bighorn River was not incised so deeply that a vadose cave system formed rather than a phreatic one; and 3) the end of phreatic cavern development occurred when the Bighorn River and Porcupine Creek rapidly downcut their channels, draining the cave quickly enough to preclude vadose modification of passages, and removing the large supply of water available for cave expansion.

The highest and oldest terrace in the northern part of the Bighorn Basin is the Tatman Mountain surface along the Greybull River, which flows into the Bighorn River 40 miles (72 kilometers) southwest of Horsethief Cave. Assuming past gradients of the Bighorn River to be similar to those at the present, the Bighorn River near Horsethief Cave was flowing at an elevation approximately 100 feet (30 meters) higher than the present cave entrance during the time of the cutting of the Tatman Mountain surface. Phreatic cavern development probably took place after the cutting of this surface.

The next lower terrace, the YU Terrace, just northwest of Tatman Mountain and alos of early Pleistocene age (Merrill, 1974), can be used to project a relative elevation of the Bighorn River west of Horsethief Cave approximately 700 feet (213 meters) below the present cave entrance. The present surface of Little Mountain near Horsethief Cave, which may in part represent an erosional terrace (Sutherland, 1976), slopes westward toward a river level about 500 feet (152 meters) below the cave entrance. The approximate slope of the passages in Horsethief Cave, which have not been altered by breakdown, points toward a Bighorn River elevation about 250 feet (76 meters) below the present cave entrance. Phreatic development in Horsethief Cave and draining of the cave system probably took place prior to the cutting of the YU Terrace.

The geomorphic study of Horsethief Cave as related to its surroundings provides a means of determining the relative age of the cave system. The phreatic development of Horsethief Cave most likely occurred between the time of the cutting of the Tatman Mountain surface and the Yu Terrace. The relative age of the cave systems development is therefore early Pleistocene. This relative age determination can now be useful as a time frame for studies within Horsethief and other related caves on Little Mountain.

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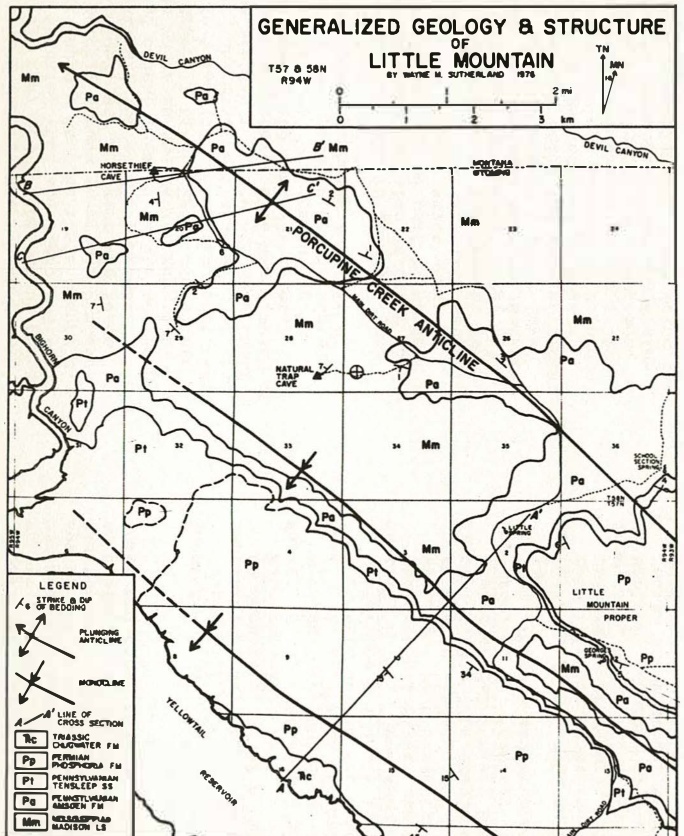

Figure 1

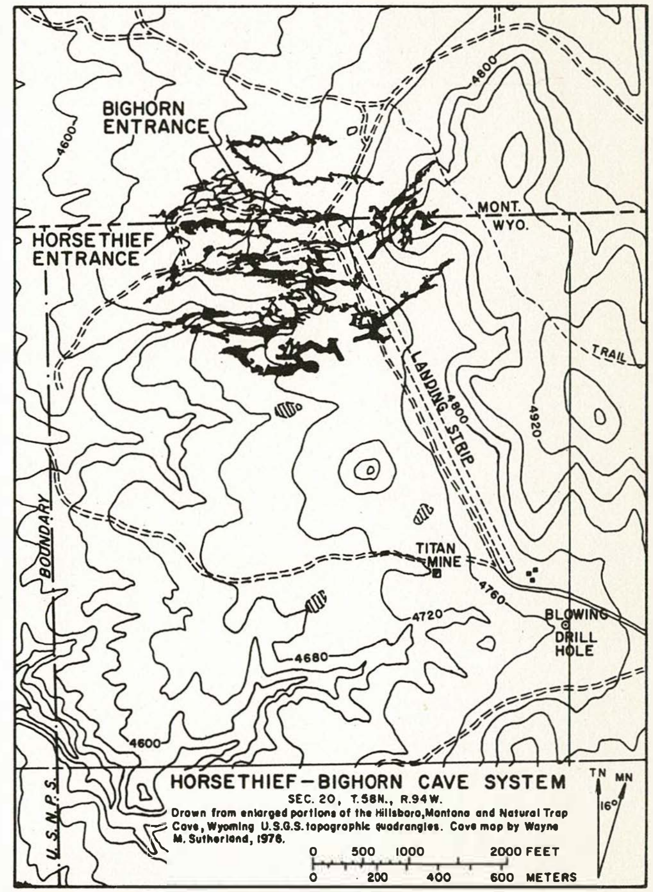

Figure 2

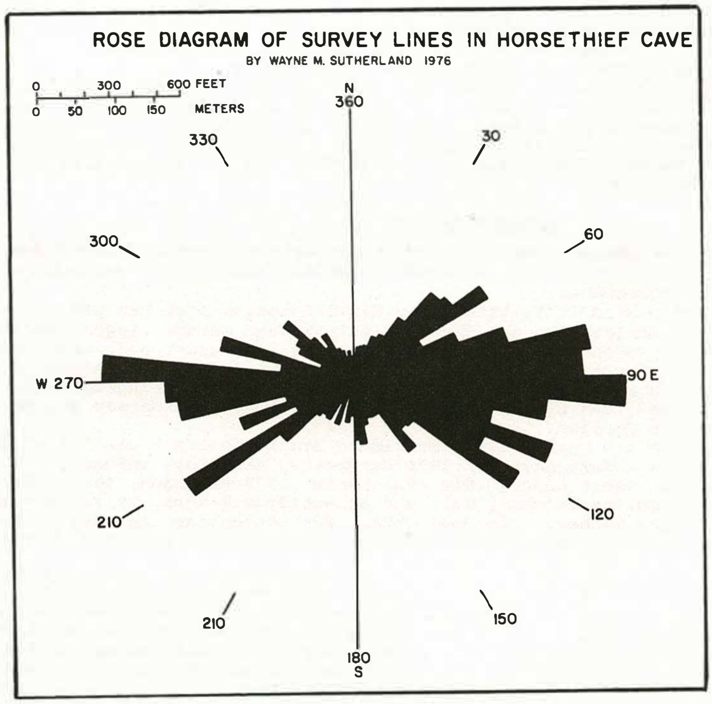

Figure 3

Ecosystem Of A Deep Confined Aquifer In Texas

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Abstract

Studies of the Edwards Aquifer in Texas were initiated in 1973 and are continuing. More than 50 wells have been sampled. Most of the wells flow under artesian pressure from depths varying from 58 m to 610m below the surface. Aproximately 40 species (including 3 vertebrates) have been found in this unique system. Fossil energy is hypothesized as a major source of energy input into this ecosystem. This source of energy has not been previously considered important in subterranean aquatic ecosystems. These studies have provided good evidence for support of this hypothesis.

Zusammenfassung

Untersuchungen in dem Edward-Grundwassersystem von Texas wurden 1973 begonnen und werden noch weitergeführt. Mehr als fünzig Brunnen wurden durch Proben untersucht. Die meisten Brunnen fliessen unter artesischem Druck aus Tiefen von 58 m bis 610 m unter der Oberfläche der Erde. Bis jetzt sind ungefäahr 40 Arten (darunter drei Wirbeltiere) in diesem einzigartigen System gefunden worden. Vermutlich gibt Fossilenergie diesem Oekosystem die grösste Menge der Ernährung. Zum ersten Mal wird Fossilenergie als eine wichtige Energiquelle in einem unterirdischen Grundwasserökosystem angesehen. Diese Untersuchungen lassen eine solche Hypthese unterstützen.

The Toohey Ridge Cave System - A Geographical Overview

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Abstract

The Toohey Ridge Cave System (Roppel Cave) is located in south-central Kentucky, one kilometer east of Mammoth Cave National Park. With presently over thirty-seven kilometers of surveyed passages, Toohey Ridge is the second longest cave of the region .

The Toohey Ridge Cave System is developed in limestone of middle to upper Mississippian age and is overlain by a caprock consisting of upper Mississippian aged sandstones and shales, forming a 'roof' to the underlieing cave passages. Dip is gentle, and to the northwest.

Being located in an area of intense groundwater basinal migration, the Toohey Ridge Cave System has developed into a complex array of tubes and canyons. This system of passageways exhibits a multitude of drainage 'trends', forming a paleo-hydrological puzzle that has yet to be solved. Water in the cave system flows to at least two major active springs.

Geographically, the cave system can be divided, quite definitively, into major sections -- the Old Cave, and the New Cave. The Old Cave, that which was foudn immediatley after the cave's '76 discovery, is a complicated shaft drain system of limited extent; whereas the New Cave, that found after Labor Day, 1978, is more of the classic combination of sinkhole plain, valley, and shaft drain systems that make the caves of Central Kentucky so large. Potential in Toohey Ridge for finding cave is great, and should prove to be an invalueable peice to this immense subterranean puzzle that exists in the Central Kentucky Karst.

Zusammenfassung

Das Toohey Ridge Höhlensystem (Roppel Höhle) liegt in dem sudsentralen Teil des Staats Kentucky, 1 km östlich entfernt von Mammoth Cave National Park. Die Höhle hat gegenwärtig eine vermessene Länge von 37 km sie ist die zweitlängste Höhle des Gebietes.

Das Toohey Ridge Höhlensystem wird in Kalkstein des Mittlermississippischen und Obermississippischen Alters entwickelt. Sandstein und Schieferton des Obermississippischen Alters liegen über die Höhle: die bilden ein "Dach" für die unterliegenden Höhlengänge. Die Neigung ist leicht nach dem Nordwest.

Das Toohey Ridge Höhlesystem liegt in einem Gebiet, in welchem findet sich intensive Grundwasserfortzierten Reihe von Röhen und Schluchten, und zeigt das Gangsystem eine Menge Drängetendenze. Diese Tendenze bilden ein palähydrologisches Rätsel, das niemand bis jetzt gelöst hat. Das Wasser aus der Höhle fliesst nach wenigsten zwei grössen tätigen Quellen.

Das Toohey Ridge Höhlensystem kan mann in zwei bestimmte Stücke teilen - die "alte" Höhle und die "neue" Höhle. Die alte Höhl3 wurde sofort nach der 1976 Entdeckung der Höhle gefunden. Sie ist ein kompliziertes Schachtdränsystem mit wenig Länge. Die neue Höhle, 1978 gefunden, zeigt das klassische Muster des Zentralkentuckykarsts, Dolinenflächen, Tal, und Schachtdränsysteme, welche die Höhlen des Zentralkentuckykarsts ziemlich gross machen. Die Möglichkeit fur Höhlenganentdeckung in Toohey Ridge ist gross, und das Toohey Ridge Höhlensystem ist ein wichtiges Stück des Rätsels des Zentralkentuckykarsts.

The Mammoth Cave Region is certainly one of the most famous cave regions in the world. Within this area lie six caves with surveyed lengths of more than fifteen kilometers, and four of these have lengths in excess of twenty-five kilometers. Hundreds of other caves of lesser extent randomly dot the landscape. It is becoming increasingly apparent that each of these caves is an explored fragment of the longest cave network on Earth .

One kilometer east of Mammoth Cave National Park lies a major cave-bearing ridge named Toohey Ridge. This ridge rivals in size to those ridges containing sections of Mammoth Cave, presently the longest known cave on Earth. Similar geologic and hydrologic conditions that formed Mammoth Cave appear to have also operated within Toohey Ridge. Toohey Ridge should eventually yield an immense cave system, also of extraordinary length. During 1974, the first systematic search for the hypothesized Toohey Ridge Cave System was begun. By mid-1976, the effort appeared to be doomed; two years of diligent effort yielded only one cave of nay length, and this barely exceeded one kilometer in length - clearly not the much hoped-for system.

During April, 1976, one cave found on Toohey Ridge became the site of an extensive excavation, in an effort to follow an elusive breeze beyond the initial shaft complex. This became known as Roppel Cave, and by August, 1978, approximately 4.5 kilometers had been surveyed.

During early September, 1978, what could be called "the break-through" was made. A narrow canyon penetrating beneath Dry Valley was pushed into the periphery of Toohey Ridge, yielding an upper level trunk network underlying the north-east lobe of Toohey Ridge. To date, in excess of forty kilometers of cave have been surveyed, with an additional ten kilometers explored.

As stated before, Roppel Cave is part of an extensive karst drainage system, both past and present. Passages in Roppel Cave can be correlated to those in neighboring Mammoth Cave and other caves. As a result, studying Roppel Cave is congruent to studying the entire Mammoth Cave Region. This paper will provide a close look at Roppel Cave, with an additional perspective given to Roppel Cave as part of the complete drainage picture.

For descriptive purposes, Roppel Cave can be broken into two separate entities, the Historic Section and the Main Section. The Historic Section is defined as the cave that was known prior to Labor Day, 1978, and its associated passages. The Main Section is the cave area found principally after Labor Day, 1978. This area can be exclusively defined as those passages beyond the S-64 Pit. This partition works out quite well since the Historic Section, with minor exception, bears little genetic relationship to the Main Section, enabling each to be easily described separately.

The Historic Section

The Historic Section is reached via the active drain to Coalition Chasm (Arrow Canyon), the entrance shaft complex. The Historic Section consists mainly of an intricate shaft-drain network that drains the flanks of the southwest corner of Eudora Ridge. Passages in this section tend to be small and difficult to traverse. Three major east-west drainage corridors can be observed in this section. These are:

- Grim Trail
- Fossil Avenue
- Fishook Canyon

Grim Trail is the most northern, and perhaps the oldest of the three corridors. Noew abandoned, Grim Trail once drained waters westward from the two primary sources in opposing extremes of the Historic Section. From the south, waters originating from shafts near Fishook Canyon flowed through a one-half meter high, five meter wide phreatic tube, 500 meters long, known as C Crawl. Geologically, Grim Trail is anextension of C Crawl, whose ultimate destination is not yet known. It is likely that Grim Trail will be found to lead to a drainage net beneath Dry Valley. From the north, Arrow Canyon was a later tributary to the Grim Trail corridor, completing an excellent example of a dendritic drainage system.

Downcutting in Fishook Canyon led to the abandoning of C Crawl and the formation of the southern-most east-west drainage corridors. Fishook Canyon waters flow down rapidly dropping canyon systems to a yet to be determined point. Exploration of Fishook Canyon has barely yet begun.

With the abandonment of C Crawl, the only recharge for Grim Trail remaining was Arrow Canyon, which with subsequent downcutting, broke through a lower chert-zone forming Bicentennial Shaft and the resultant drain. This chain is one kilometer long and is a tributary to the Crayfish River Passage, a low-level drainage conduit underlying Dry Valley. The Bicentennial Shaft drain apparently formed under mixed phreatic and vadose conditions resulting in a highly irregular canyon passage with several instatnces of positive gradient. At present, this drain has been abandoned for a lower, unexplored bedding-plane conduit.

Fossil Avenue, an abandoned high level conduit, lies between the Fishook Canyon and Grim Trail corridor. The source of Fossil Avenue is not known, but is speculated to be shafts and associated valleys at the eastern flanks of Eudora Ridge. Vivian Way is a connected eastern extension of Fossil Avenue about two hundred meters long and three meters high and wide. Fossil Avenue has been modified heavily by shaft development, however its true dimensions appear to be about two meters high and five meters wide. Fossil Avenue terminates in breakdown beneath Dry Valley, but its continuation has been found in the Main Section.

The Main Section

The Main Section is reached via an abandoned drain to Coaliton Chasm. This drain, the S Survey, intersects an old shaft drain system that eventually provides access to a trunk network beneath the northeast lobe of Toohey Ridge.

The Main Section is notable because of a network of trunk passages about seven kilometers long. At first appearance, it seems that many drainages converged here. However, this trunk network is actually a complex of distributaries, piracies, and cutoffs having perhaps just one source that is only now becoming understood. Passages in this trunk network range from two to six meters high and five to ten meters wide and exist on two principal levels. This trunk network provides access to at least two groundwater basinal drainages--Turnhole, to the south, and Pike, to the north.

Arlie Way is the lowest of the Main Section trunk passages. Drainage in Arlie Way is still puzzling. To the south, Arlie Way intersects the main compnent of Turnhole Spring Drainage, Logsdon's River. Logsdon's River can be followed two kilometers downstream before dumping and flowing into Proctor Cave of the Mammoth Cave System. A physical connection here is not likely. Logsdon's River flows through a tubular conduit two meters high and five meters wide. In the upstream direction, Logsdon's River has only been followed a short distance, but it is likely that this conduit is traversable for several kilometers.

The Black River Complex is a mjor shaft drain system reachable via Arlie Way and drains northward to join a major valley drain, Elysian Way. The active stream, Black River, drains shafts on the periphery of a large sinkhole. This area is quite confusing with its multi-tiered canyons and tubes. This is due to the fact that Black River Complex has been the victim of a zone of wandering basinal boundaries of two major springs. This has resulted in innumberable flow reversals that provide a fascinating potential for further discoveries.

As stated earlier, Elysian Way is a major drain to Dry Valley. Its source has not yet been explored but Elysian Way has been followed far to the north, yielding a continuously traversable passage five kilometers in lenght. Dimensions vary from two meters high and six meters wide in the upstream segment to 20 meters high and six meters wide in the downstream direction. Farther downstream, the passage exhibits an intricately braided pattern in three levels. Exploration has stopped in the downstream section at base-level passage. Elysian Way appears to ultimately be a tributary to Salts Cave of the Mammoth Cave System.

At a point 1.8 kilometers from the end of Elysian Way a major tributary is encountered. This passage, the BWOB, drains a large valley to the east and has recently been explored three kilometers. The BWOB should prove as equally impressive as Elysian Way in length and grandeur.

In the upstream return, the valley drainage of Elysian Way is proving to be remarkably complex. After recent exploration, Elysian Way has been foudn to be merely the basal component to an immense canyon system having at least five majors levels. This system will likely be pushed far southward to the limits of Dry Valley.

Each trip made into the system reveals scores of leads of high complexity. Exploration is geared to extending the limits of the system into areas of large ridge in both Toohey and Euodra Ridge. It is entirely probable that the length of the Toohey Ridge Cave System will exceed 100 kilometers. Eventually a connection to Mammoth Cave may also be found, but this remains to be seen.

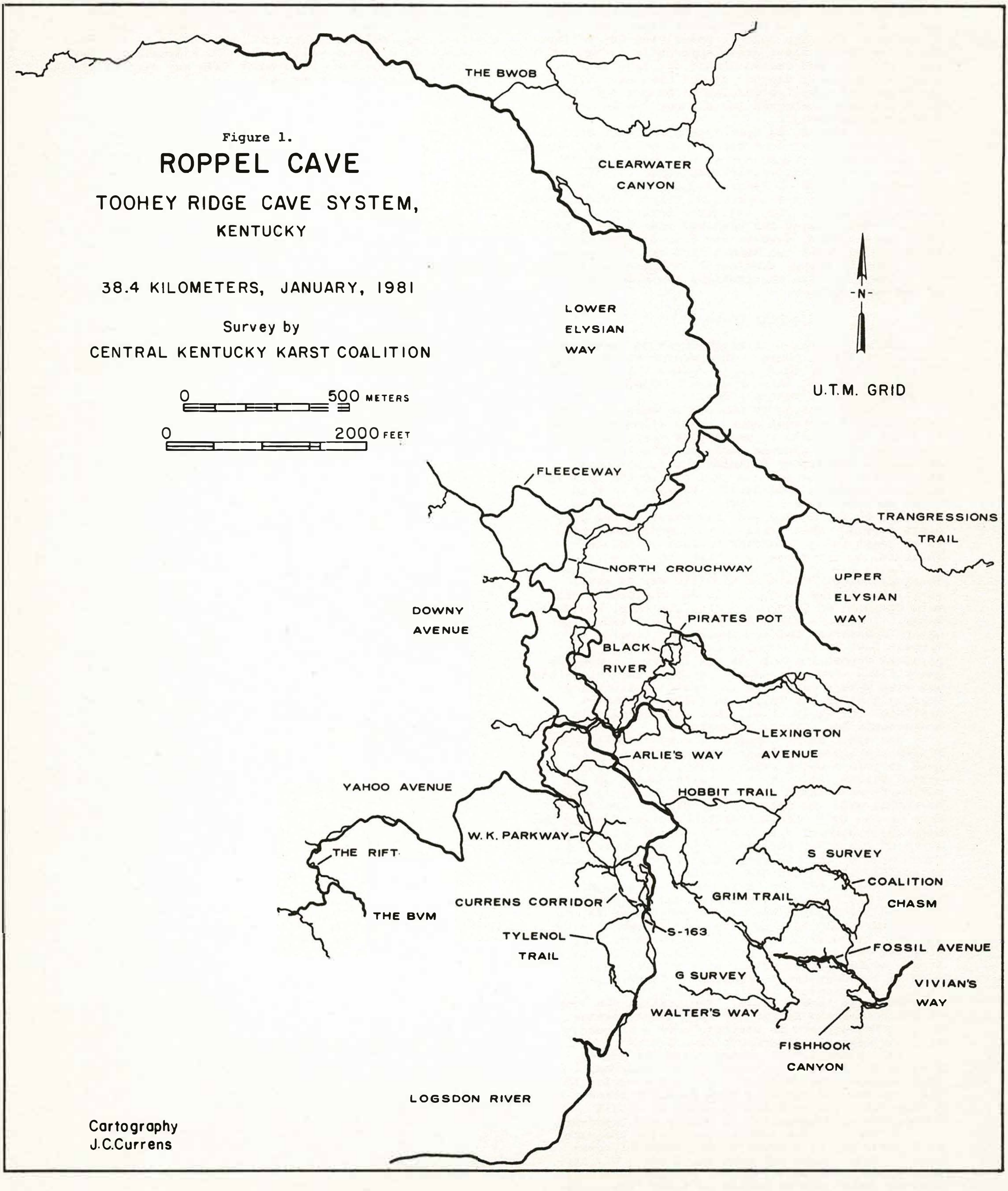
Figure 1.
ROPPEL CAVE
TOOHEY RIDGE CAVE SYSTEM,
KENTUCKY
38.4 KILOMETERS, JANUARY, 1981
Survey by
CENTRAL KENTUCKY KARST COALITION
0
500 METERS
0
2000 FEET
THE BWOB
CLEARWATER
CANYON
LOWER
ELYSIAN
WAY
-N-
U.T.M. GRID
FLEECEWAY
TRANGRESSIONS
TRAIL
NORTH CROUCHWAY
UPPER
ELYSIAN
WAY
DOWNY
AVENUE
PIRATES POT
BLACK
RIVER
LEXINGTON
AVENUE
ARLIE'S WAY
YAHOO AVENUE
HOBBIT TRAIL
W. K. PARKWAY
THE RIFT
S SURVEY
COALITION
CHASM
CURRENS CORRIDOR
GRIM TRAIL
THE BVM
TYLENOL
TRAIL
S-163
FOSSIL AVENUE
G SURVEY
VIVIAN'S
WAY
WALTER'S WAY
FISHHOOK
CANYON
LOGSDON RIVER
Cartography
J.C.Currens

Large Cave-System Database Management - A Simple Concept, Yet A Complex Solution

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Abstract

The logistices of surveying a large cave system covering a large geographical area, possibly including many individual caves, has always been a complex problem. To be able to keep large amounts of survey data organized in a logical fashion, and to be able to process this data quickly and efficiently is just one aspect of the surveying of large cave systems. With computers ever increasing in their capabilities, survey-reduction programs have also advanced in their capabilities accordingly.

For the large endeavor of surveying the Toohey Ridge Cave System (Roppel Cave), under the direction of the Central Kentucky Karst Coalition (CKKC), a complex database management and analytical computer prgram was written to handle the large amounts of survey data that is being assimilated in the Coalition's Exploration and Survey Program. During the computer program's design, it was deemed beneficial that this program be able to support two or more survey nets with two or more individual origins; as in the case of hanging surveys, unconnected caves, etc. Storing these different nets on the same database was purely a data management problem, once thought out clearly; but, when two or more nets become one, many of the stations' coordinates need to be fixed to one common origin. To solve this problem, complex routines were designed that would be able to determine what net should be adjusted; and be able to locate and adjust each station's coordinates in that net. This was found to be an exceedingly difficult problem, and involved techniques not commonly used in programs of this type. The result was aprogram that could be relied upon to handle any number of caves within a common database reliably and efficiently, with minimal manual intervention from the user.

Zusammenfassung

Das Vermessen einse grossen Höhlensystem, das unter einer grossen geographischen Grundfläche lieget und wahrscheinlich viele verschiedene Höhlen einschliesst, ist immer ein komplexes Problem. ein Bestandteil des Problems is die Not, eine Menge Vermessensdaten logisch zu organisieren und schnell und wirksam zu verarbeiten. Computerfähigkeiten nehmen immer zu, und die Fähigkeiten der Höhlenvermessensprogramme werden somit besser.

Das Vermessen des Toohey Ridge Höhlensystem (Roppel Höhle), unter der Leitung der Central Kentucky Karst Coalition (Vereinigung für Furschung in dem Zentralkentuckarst), ist eine grosse Bemühung. Ein kompliziertes Computerprogramm für Datenbehandlung, Datenverabeitung, und Datenanlyse wurde geschrieben, die Menge von Vermessensdaten zu behandeln. Während des Aufzeichens dieses Programms war es für zuträglich gehalten, das Programm die Fähigkeit zu geben, wenigstens zwei verschiedene Vermessensnetze mit wenigstens zwei Herkunfte zu verarbeiten (z.B., nicht verbundene Vermessensreihen, individuelle Höhlen) Die Lagerung von diesen verschiedenen Netze auf dem gleichen Datensystem war ein reines Datenbehandlungsproblem. Aber, wenn zwei oder mehr Netze zusammenkommen, viele Messpunktokoordinaten müssen auf einer allgemeinen Herkunft befestigt werden. Die Lösing dieses Problems macht notwendig komplexe Programmbestandteile, die entscheiden, welche Netz angepasst werden muss, und also finden und anpassen die Koordinaten für jeden Messpunkt der anpepasste Netz. Das war ein äusserst schwieriges Problem, und machte notwendig die Anwendung von Methoden nicht gemeinschaftlich benutzt für solche Programme. Das Ergebnis war ein Computerprogramm das vertraulich ist, viele Höhlendaten innerhalb ein allgemeines Datensystem wirkend und mit minimalem Eingriefen von dem Programmbenutzer zu verarbeiten.

Anyone that is involved in the survey of a large cave system is certainly cognizant of the intrinsic difficulties of such an undertaking. Unfortunately, the complexity of the problem is not often known until it is nearly too late to implement a database management system that becomes so greatly needed.

In the survey of the Toohey Ridge Cave System, the Central Kentucky Karst Coalition has been in the process of implementing such a database management system. With over fifty kilometers of survey logged, this is no small task. In the design of this database system, it was found that multiple survey net with perhaps multiple origins should be able to be stored within the same database. In turn, what follows from this is that survey nets with multiple origins be able to be merged into a single net with just one unique origin. This proved to be a most difficult problem.

As in any design problem, one aim is to design the program with as little intervention as possible from the user. In the program written for Toohey Ridge, the only knowledge required from the user in regards to the contents of the database, is information concerning tie-ins, so new additions to the survey net can be entered properly. Given this "black-box" perspective, when two unique survey nets are joined, the program, independent of the user intervention, makes a judgement of which is the primary survey-net, determines the displacement coordinates between the secondary and primary nets, and resolves the coordinates of the secondary net to reflect the primary net's origin. Once this is done, the two nets have become one in virtually an automatic fashion.

In this paper, what will be addressed specifically is the relevent information required within a database of multiple nets, and how these nets are merged into one, once they are connected.

Identification Of Survey Nets

For multiple surveys to be stored within the same database, each survey must be uniquely identifiable from each other. The Coalition database is keyed according to survey; that is, each survey party performs one survey. One must note that there exists a possibility that all or parts of several survey nets may exist within the bounds of one survey. Given this possibility, flagging each survey with a net identifier was not the answer. So to account for these multiple nets within a survey record, each survey shot entry within a record contains a key that is unique to each survey net. In the Coalition database, the key was formed by a concatanation of date and time.

Determination Of Which Is The Primary Net

This is improtant because when two nets are connected, a choice has to be made of which will have its coordinates adjusted to the other nets origin. Undoubtedly, there exists imnumerable schemes for the evaluation of which is the primary and secondary nets. One way would be chronological; use the older of the two as the primary net. By using the above mentioned flagging variable, this would merely be a straight comparison, with the older net being the lesser value of the flags. The value of the flag is determined by the time of entry of the first survey of the net. On the other hand, the size of the net may be a consideration, but this would require an extensive bookkeeping system to implement. Realistically, however, the choice should perhaps ultimately be made by the user whose judgement may be the most sound.

Determining The Secondary Net's Displacement From The Primary Origin

Once two nets have been connected, and the secondary and primary nets have been determined; it becomes a trivial matter to evaluate the secondary net's displacement from the primary origin. By focusing on the point of connection, this can be done. The point of connection is the one common point within the two nets that has been defined from two differing origins. The difference of the two coordinates of the connecting station determines the displacement values. Thus:

$$(Dx, Dy, Dz) = (Px, Py, Pz) - (Sx, Sy, Sz)$$

where "D" is displacement, "p" one are the coordinates of the connecting station from the primary origin, and "S" are those from the secondary origin. These displacement values can then be added to each station within the secondary net to resolve the secondary net's coordinates to the primary origin.

Resolving Secondary Net To Primary Origin

Now that the secondary and primary nets have been determined, and the subsquent displacements evaluated, the task remaining is to resolve all the coordinates of the stations in the secondary net to reflect the primary origin. This can be done by checking every station within the database and making the proper adjustments, if the station lies within the net in question. However, in some of the large caves, this could involve ten-thousand comparisons or more; if the secondary net is small, this could prove a quite wasteful effort. To overcome this potential waste, a recursive routine was developed that minimizes the number of comparisons required. To accomplish this, each record has a variable that contains the record number of each survey that is immediately adjoining. There is always at least one entry in the variable, unless the survey is independently a complete survey net (a hanging survey would fall into this situation). Exhibit I illustrates this. Here, two survey nets and their associated representation as within the database are shown. Any survey net can be represented by using the variable as shown at the base of the exhibit. As can be seen, some surveys contain parts of both nets; this can be done without any confusion.

By using the above-mentioned variable, a routine was designed to build a nodal-tree that enables the routine to cover all surveys that contain stations within the survey net. The root-node will be the record)survey) in the secondary net that contains the connecting station. How the routine designed for Toohey Ridge accomplishes this tree-building is shown in Exhibit II. This is built utilizing the survey nets in the previous Exhibit and are connected as shown by the dashed line.

To insure that the routine does not enter an infinite loop, it is important to keep track contînously of what has been done. This is done by keeping a list of all surveys that have been active within the routine. As survey nets are often quite interconnected, the list can be checked by the routine to ascertain if a survey needs to be activated.

A node is terminated (the routine regresses one level in the tree) when one of two events occur:

1. No directly adjoined surveys exist that can be resolved.
2. No stations within the activated survey that are members of the secondary net exist.

By a node terminating, this implies that the tree cannot be built any deeper from the node in question. "1" can occur if the directly adjoining surveys have already been resolved at sometime earlier within the routine. "2" can occur when activated node is of another survey-net

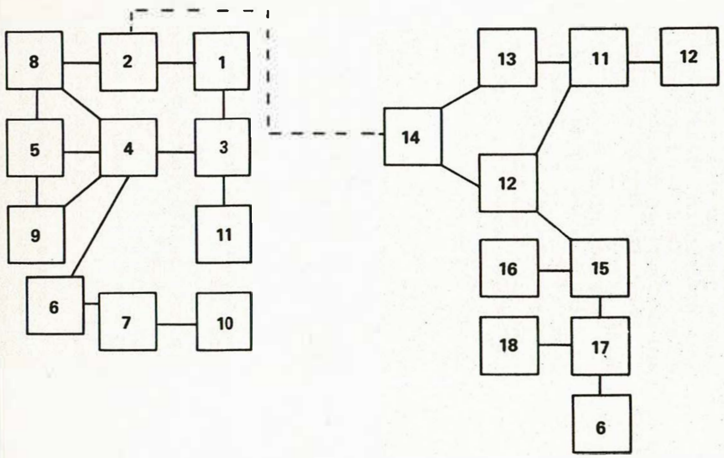
In Exhibit II, record (survey) 14 is the root node. When the routine activates a node, first its coordinates are resolved, checking Constraint 2. If Constraint 2 is met, then Constraint 1 is checked. If there exists adjoining surveys to the active node that have not yet been active, the routine proceeds deeper to activate a new node. When a node is terminated, the routine regresses, activating, once again, the next higher-level node. Eventually the root node will be terminated, and the secondary net is resolved.

As stations are being resolved, the survey net flag (DATE//TIME) is adjusted to reflect the flag of the primary net. If this is not done, the program cannot accurately identify individual survey nets, and the database will be destroyed.

As can be seen, the routine to merge nets into one is very risky to the integrity of the database. Design and implementation must be done very carefully. The routine is very reliable once fully impelemented; however, in testing, it isn't uncommon for it to become necessary to rebuild a database completely if the test has failed.

Much can be written on database management in large survey projects. However, the subject is much too broad to fully discuss here. What has been attempted here is to develop a means that multiple survey nets may be contained within the same database with a high degree of confidence while yet easing the burden of the user, which is an important concern. If the little user-intervention is required, a data base can take care of itself.

Two Survey Nets and Respective Database Configuration



SURVEY RECORD		FIRST-ORDER CONNECTED SURVEYS
1	–	3,2
2	–	1,8
3	–	1,11,4
4	–	3,8,5,9,6
5	–	9,4,8
6	–	4,7,17
7	–	6,10
8	–	2,4,5
9	–	4,5
10	–	7
11	–	12,13,3
12	–	11,14,15
13	–	14,11
14	–	12,13
15	–	16,17,12
16	–	15
17	–	15,6,18
18	–	17

Exhibit I

Tree-Building in Routine to Resolve Coordinates of Secondary Net

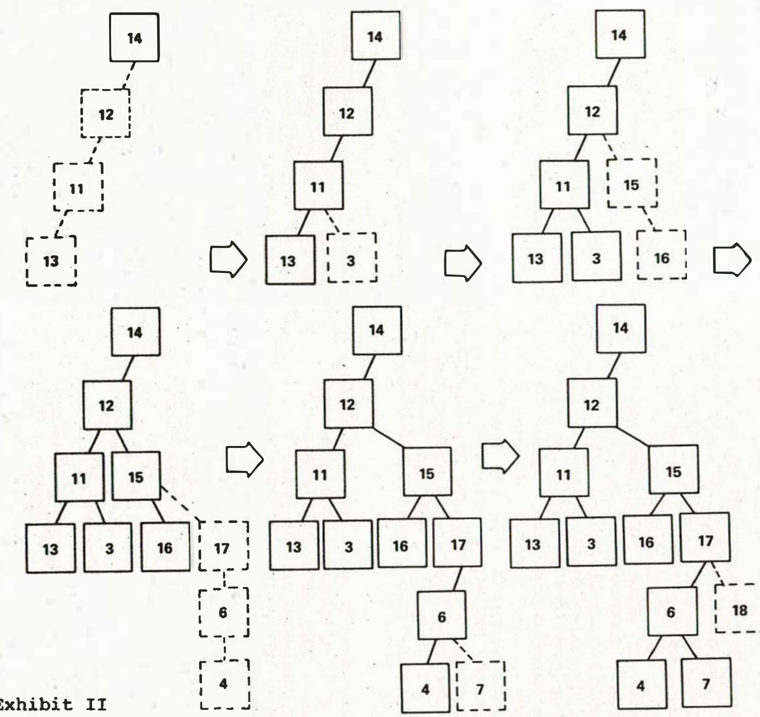


Exhibit II

The Zoogeography of Eastern North American Cave Collembola

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Abstract

The distributions of 92 species of collembola found in Eastern North Americuan Caves is examined in detail. The distribution patterns followed by these species can be classified in five categories: 1) Epigeic species with rare opportunistic cave occupation, 2) Troglophilic species with opportunistic cave occupation, 3), Troglophilic species with scattered pockets of cave adaptations and occupation, 4) Troblobites with a single successful cave invasion and subsequent largely underground spread and 5) Troglobitic species which have evolved separately in different systems by parallel speciation. Troglomorphy tends to increase as we move from pattern 1-4 or 5. The caves occupied by these species can be broken into three major categories: A) glaciated area caves, B) Heartland caves, and C) non-glaciated non-heartland caves. The three cave areas show very different patterns in cave occupation and in major taxonomic groups. Thus distribution pattern 2 dominates in A and C caves and patterns 4 and 5 in B caves. Taxonomic groups show similar differences with the subfamily Entomobryinae, which shows the greatest troglomorphy, dominating in B caves while the families Isotomdae and Onychiuridae which show the least troglomorphy dominated in A caves. Type C caves are intermediate and have the highest percentage of Tomocerinae and Sminthuridae which are intermediate in degree of troglomorphy. As always in Collembola, the species found in caves appear to be derived from litter or soil dwelling forms showing various levels of apparent pre-adaptation to cave life. The cave fauna shows relationships both in Europe and Asia. A few species showing distribution patterns 1 and 2 are also found in Europe. All species of patterns 3,4 and 5 are limited to North America.

The collembola are the most ubiquitous terrestrial cave arthropods. In the U.S. they are found in every well collected cave system. They show all levels of cave adaptation and their analysis should prove informative in understanding the nature of cave adaptation. In this paper I shall attempt a brief overview of our knowledge of the distribution of Eastern U.S. cave collembola and offer some hypotheses concerning the method by which they achieved their present distribution. Much of the material in this work is extracted from a much longer paper presently in press (Christiansen 1981). Readers are referred to this paper for more details concerning distribution of particular general or species or the phylogeny of the various groups concerned.

The cave collembola east of the great plains are far better known than any other nearctic group of the order, thanks to the efforts of Tom Barr, Stewart Peck, John Holsinger, James Gardner, and a host of other speleologists. In addition, other authors have done some analysis of the phylogeny of a number of groups. Thus this is a fertile field for zoogeographic study.

Caves Studied

The caves in the area under consideration fall into 3 major groups. The first is the group that we will call the heartland (see figure 1). This includes the caves of the six major Southeastern systems (Barr 1968). The second is the glaciated region (see figure 1). Even though many of these escaped actual glaciation it is unlikely (for many reason) that their group includes southern caves outside the heartland. Most of these in the present study are in Missouri and Arkansas. Troglobitic forms are largely limited to caves of this and the heartland areas.

Nature of Cave Occupation

Cave collembola vary greatly in their patterns of cave distribution. These can be classified in five categories: 1) Primarily surface species with rare opportunistic cave occupation, 2) Primarily rare species with opportunistic cave occupation, 3) Troglophilic species with scattered pockets of cave adaptations and occupation, 4) Troglobites with a single successful cave invasion and subsequent largely underground spread and 5) Troglobitic species which have evolved separately in different systems by parallel speciation. Troglomorphy tends to increase as we move from pattern 1-4 or 5. Some of the species displaying pattern 1 are probably trogloxenes but most of the type 1 forms as well as all of type 2-5 forms are troglophiles or troglobites.

Either type of animal may display varying degrees of troglomorphy, or clear specialization for cave life. Troglocites appear to spread largely underground although short above ground hops may occur. Troglophile distributions are of two sorts. In one type, cave invasion is opportunistic, i.e. wide spread and apparently only limited by suitable empty niches. In the second, cave occurrence is clumped and limited, suggesting rare successful cave invasions followed by underground and/or short hop spread. In this latter type of troglophile as well as many troglobite distributions there are occasional populations in isolated caves. In some cases this is probably the result of either isolated invasion or parallel evolution. In other cases it is impossible to tell whether this is the case or the distribution is a vestige of a now broken, but previously continuous range. Clumping of localities occurs even in patterns of opportunistic species. In some cases this probably is merely a reflection of very extensive opportunistic invasions in areas where little competition exists in the caves. In other situations it appears that there are scattered pockets of successful cave adaptations in a generally oportunistic species.

In the next few sections distributions of some of the major groups of Eastern Nearctic cave collembola will be examined and an analysis of biobeographic patterns will be presented. Throughout this work I shall use the terms parallel speciation. This concept was first developed by Christiansen and Culver (1968). It refers to the independent parallel development of the same morphospecies by two separate lineages. It is therefore an extremely precise parallel evolution where the end products resemble each other so closely in behaviour, form and ecology that they can be called members of the same species.

The collembola have about 100 species known from eastern Nearctic caves (see table I). As can be seen in this table, the different genera are very differently distributed across cave occupation classes. Thus the families Isotomidae Hypogastruridae and Onychuridae dominate in occupation types 1 and 2. While the family Entomobryidae dominates in categoary 4 and 5.

Cave occupation type 1 includes the great majority of species found in caves and represents the simplest level of cave life. These forms are generally selected species and are the most common surface forms of their genus with opportunistic cave invasions. In most of the genera there is a single species which is the common one in this category. The second category is only weakly differentiated from the first. The primary difference is that unlike the first group these species are more common in caves than in surface habitats. It is interesting to note that in two of these cases where there is no dominant species in category 1 there is one very dominant species in category 2. Category 3 includes a number of species which are only assumed to be troglophilic i.e. they are nontroglomorphic forms with a few scattered cave collections or one known locality in a cave. Categories 4 and 5 are sometimes difficult to distinguish.
Patterns 1-4(5) clearly represent a gradient both in troglomorphy and the degree of cave limitation or troglobity.

It is noteworthy that the types of cave distribution are not equally distributed in the 3 major cave regions (see table II). Category 1 is the dominant type in glaciated cave, 2 in non-heartland non-glaciated caves and 4 and 5 in heartland caves. All other types seem to shift appropriately except for category 3 caves which stay at approximately the same percentage throughout.

In a simialr and related fashion the different taxa are not uniformly distributed. There is a steady increase in the role of the Entomobryinae and a decrease in the Onychiuridae and Isotomidae as one moves from glaciated to non-heartland unglaciated to hearland caves. The other groups are most important in non-heartland unglaciated caves and least in heartland. These last are the only ones to show a great deal of troglomorphy outside of the heartland. They are the only groups to show high troglomorphy in western caves. In contrast the one species of Entomobryinae (Pseudosinella violenta) which has extensively invaded southwestern caves shows very little troglomorphic adaptation. The pacific coast troglobitic or troglophilic Sinella species also show little troglomorphic adaptaion.

PSEUDOSINELLA & SINELLA. The most interesting distributions are in the genera Pseudosinella and Sinella. These together include the great majority of the troglomorphic species (see table I) and have the largest contiguous cave ranges. Most cave species of the genus Sinella fall into tow groups here named teh avita and barri lineage after their putative most primitive forms (see figure 4). The species avita, alata, cavernarum, basidens and krekeleri all belong to the former while barri, hoffmani and agna belong to the latter group. The two groups occupy essentially non-overlapping ranges with the barri lineage more southern and eastern than the avita lineage. The actual distributions of the species concerned is totally allopatric and highly subdivided, however, neither group extensively occupies any central region of the heartland or unglaciated marginal caves. Rather they seem to occupy northern and eastern margins of the heartland and scattered caves between the Missouri-Arkansas and heartland regions. The genus is also well represented in California caves with 2 apparently troglogitic species. The distribution of the more or less primitive or advanced species is also of interest (see figure 2). Figure 2 shows the levels of troglomorphy of the various cave populations of the two major lineages of cave Sinella following the system developed earlier (Christiansen 9161). It is clear that the most advanced forms are seen in the northern heartlands and the most primitive in the southern and western localities. It can also be noted that troglophilic forms (troglomorphic or not) and non-troglomorphic forms which are known only from caves (i.e. apparent troglobites) all have highly fragmented ranges. In contrast the troglomorphic troglobites have generally compact ranges and are generally the sole Entomobryinae occupyiing their cave systems. At the other extreme the widely scattered populations of S. barri argue for a previously continuous range now fragmented into discrete cave refugia. Single surface collection of these species is from Fayette Co., Indiana well outside the present range of the cave forms. S. hoffmani poses a different problem. Here it is difficult ot see whether the present fragmented distribution is the result of paralled evolution from a barri- like ancestor or represents the vestiges of a previously continuous range. There are three surface collections. The first is in West Virginia near a cave entrance. The other two, from North Carolina, are questionable indentifications and well outside the present cave range of the species. The genus Pseudosinella presents a very different picture. First we have a large number of surface species found in one or a few cave collections. Second the highly troglomorphic species belong to 4 apparently unrelated lineages (see figure 3). The members of the espana group (2 species) and P. certa are anomolous all are highly troglomorphic and have no close cave inhabiting relatives. The P. argentea group contains, in order of increasing to troglomorphy, P. aera, argentea, nata, and pecki. P. aera has a highly disjunct range and includes the westernmost cave forms of the group. P. argentea is the primary form in Missouri and Arkansas and shows a considerable array of levels of adaptation. It is disjunct elsewhere and occupies a few scattered heartland caves.

P. pecki is the only troglomorphic species of the group and is the southernmost cave Pseudosinella known. The hirsuta lineage includes 6 species and has been extensively discussed elsewhere (Christiansen & Culver 1967). Here I will only note that it dominates the central heartland caves. The P. orba group includes P. testa, P. orba and P. sp W. These occupy eastern heartland caves and are generally more primitive in the northern and more advanced in their southern caves.

Conclusions

The cave collembola of eastern North America have invaded three major types of cave systems (glaciated, heartland, and non-glaciated non-heartland). In each they have made the invasion in a series of different fashions (see Table I), representing different evolutionary strategies and different leves of adaptation to cave life. The most intense adaptation to cave life, reflected in the greates troglomorphy and the associated troglobitic patterns of cave distribution dominate in the subfamily Entomobryinae and the heartland cave regions. The least intense adaptation reflected in the least troglomorphy and most opportunistic cave distribution, dominate in the Isotomidae and Onychiuridae and the glaciated cave regions.

References

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__________ (1981), The Zoogeography of Cave Collembola East of the Great Plains. Bull, N.S.S. in press.

Christiansen, K. and Culver, D. (1968). Geographical variation an Evolution in P. hirsuta. Evol. 22:237-255.

TABLE II. Summary of Groups and Cave Occupation Types of the Three Major Eastern Cave Areas

A) Taxonomic groupings - no. of records and percentage of total samples.

Group	Glaciated area %	Glaciated area No.	Non-heartland unglaciated %	Non-heartland unglaciated No.	Heartland %	Heartland No.
Entomobryidae						
Entomobryinae	16	30	30	115	72	385
Tomocerinae & Oncopodurinae	18	34	20	76	12	64
Sminthuridae	14	27	29	110	11	57
Onychiuridae	25	47	6	24	4	21
Isotomidae	27	50	15	56	5	29
Non-Entomobryinae	84	158	70	266	28	
B) Cave Occupations Types						
1	49	83	29	107	13	60
2	34	57	45	167	26	124
3	13	22	15	58	15	70
4&5	4	7	11	43	46	214

Table I. Patterns of Cave Occupation Major Genera in Eastern Caves

(numbers = no. of species in each category)

Category No.	1	2	3	4	5
Description	Epigeic forms with opportunistic cave occupation	Troglophile Forms with opportunistic cave occupation	Troglophile non-troglomorphic apparent Troglobites with scattered successful cave invasions	Troglomorphic Troglobites with single cave invasions	Troglomorphic troglobites with parallel speciation
Family					
Entomobryidae					
Sinella	2	1*	2*	4	1
Pseudosinella	4	2*	4*	7*	4*
Tomocerus	3	1	1	1	0
Oncopodura	0	0	1*	1*	0
Isotomidae					
Isotoma	6	1	0	0	0
Priosotoma	6	0	0	0	0
Folsomia	5	1	1	0	0
Hypogastruridae					
Neanura	4	0	0	0	0
Hypogastrura	7	0*	2*	1	0
Onychiuridae					
Onychiurus	11	2	4	1*	0
Tullbergia	6	1*	1*	1*	1*
Sminthuridae					
Arrhopalites	3	1	1*	1*	1*
Neelus					

*These categories have some species of doubtful placement.

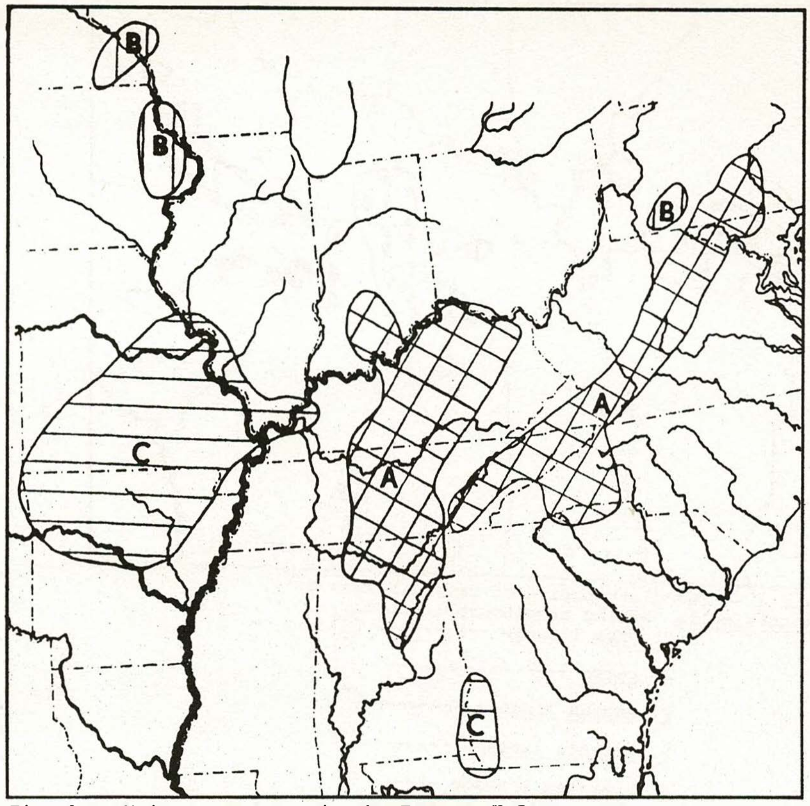

Fig. 1 -- Major cave areas in the Eastern U.S. with known collembolan faunas. A) Heartland and adjunct regions. B) Glaciated region caves. C) Unglaciated non-heartland caves.

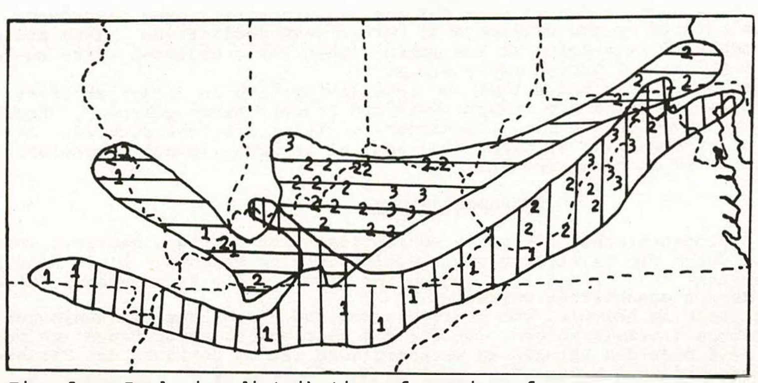

Fig. 2 -- Inclusive distribution of species of Sinella avita and S. barri lineages.

S. avita lineage ---------

A. barri lineage ---------

Lines drawn joining widely separated actual pockets of occupation. Numbers represent levels of troglomorphy (Christiansen 1961) of actual areas of occupation. 1 represents least and 3 most troglomorphic.

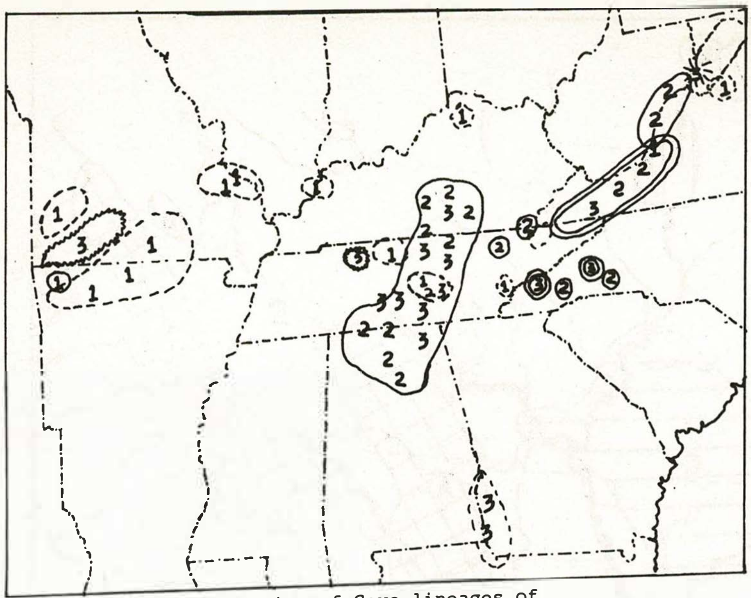

Fig. 3 -- The distribution of Cave lineages of Pseudosinella having troglomorphic forms.

P. orba lineage ---------- ◎

P. certa -------------------

P. espana lineage -------- ◯

P. hirsuta lineage ------- ○

P. argentea lineage ------

Numbers represent levels of troglomorphy as in figure 2.

Regressive Evolution and Phylogenetic Age

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Abstract

The question of the phylogenetic age of cave animals has frequently been discussed. A helpful dating possibility is offered by the existence of marine cave derivatives. They are characterized by the beginning of a process of regression at the moment, when their biotopes - the so-called marginal caves - are isolated from the sea by marine regressions.

It has been demonstrated on this basis that the cave living fish and crayfish of marine ancestry lifing in Yucatan have developed extremely reduced eyes and pigment since pliocene. Freshwater species which colonized the caves only during pleistocene or later are less reduced. It is shown that the degree of reduction of cave animals of other geographical regions (Israel, Jugoslavia, Eastern Africa, North America) will fit in these results.

Zusammenfassung

Die Frage nach dem phylogenetischen Alter von Höhlentieren ist haufig diskutiert worden. Eine gute Datierungsmöglichkeit ist durch die Existenz mariner Höhlenderivate gegeben. Diese sind dadurch charakterisiert, daß der Regressionsprozeß einsetzt, nachdem ihr Lebensen die sogennannten Küstenhöhlen, durch einen Hebungsprozeß vom Meer a geschnitten wurden.

Auf diese Weise läßt sich am Beispiel von Höhlenfischen und -krebs der mexikanischen Halbinsel Yucatán und des Jordangrabens (Israel) zeigen, daß für die fast vollständige Reduktion von Augen und Melaninpigment der Zeitraum seit Ende des Pliozän zu veranschlagen ist Im Verlaufe des Pleistozän in die Höhlen eingecrungene Süßwasserformen haben einen geringeren Reduktionsgrad von Auge und Pigment. Es wird aufgezeigt, daß sich auch der Reduktionsgrad von Höhlentieren aus anderen Regionen (Nordamerika, J Jugoslawien,Ostafrika) in die am Beispiel Yucatáns gewonnenen Erkenntnisse einpassen lüßt.

A Late Pleistocene Chronologic Record in Southeastern Minnesota

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and

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Abstract

Age data resulting from U-series dating of speleothems indicate that within the karst terrain of southeastern Minnesota at least three separate periods of calcium carbonate deposition occurred in the caves, joints, and fractures.

The oldest group of ages range from 163±15ka to 101±6ka. When compared to the deep sea core record, this 66-ka growth interval falls within at least part of the Illinoian Glaciation and the Sangamon Interglaciation. Within this interval water flowing through a portion of Mystery Cave resulted in the deposition of approximately 3 meters of sediment. A profile now exposed through this deposit is capped by three layers of flowstone, reanging in age from 147±6ka at the base to 104±4ka at the top. These ages imply that conditions in southeastern Minnesota during the late Illinoian were not cold enough to inhibit speleothem growth.

The second group of ages ranges from 59±5ka to 35±2ka on samples both from Mystery Cave and from a sediment-filled passage exposed in a quarry a few kilometers away. These ages apparently represent an interval during the Wisconsinan Glaciation when conditions were favorable for the deposition of calcium carbonate.

The third group of ages ranges from 15.4±0.7ka to present. Meltwater from the retreating of the Des Moines ice lobe deposited a sediment layer within Mystery Cave that is capped by flowstone dated from 12.5±0.7ka to 8+0.4ka.

Zusammenfassung

Ergebnisse von Urandatierungen an Tropfsteinablagerungen zeigen mindestens drei verschiedene Perioden von Kalziumkarbonat Ablagerungen in den Höhlen, Spalten und Bruchzonen innerhalb des Karstes im Südosten von Minnesota.

Die älteste Gruppe von Daten reicht von 163±15 Ka bis 101±6 Ka. Verglichen mit Tiefseebohrkernergebnissen fällt dieser Ablagerungsintervall von 66 Ka wenigstens in einen Teil der Illinois Vereisung und des Sangamon Interglazials. Während dieses Zeitraums wurden durch Wasser, das durch einen Teil von Mystery Cave floss, etwa 3 m Sedimente abgelagert. Ein jetzt offengelegter Schnitt durch diese Ablagerung ist von drei Schichten von Höhlenkalkstein überlagert, deren Alter von 147±6 Ka in der untersten bis 104±4 Ka in der obersten Schicht variiert. Diese Altersbestimmungen deuten darauf hin, dass die klimatischen Verhültnisse in Südost Minnesota während des ausgehenden Illinoian nicht kalt genug waren, Tropfsteinablagerungen zu verhindern.

Die zweite Gruppe von Altersbestimmungen reicht von 59±5 Ka bis 35±2 Ka und enthält Ergebnisse von Mystery Cave und von Sedimentablagerungen in Höhlräumen die jetzt in einem Steinbruch einige Kilometer entfernt freigelegt sind. Diese Daten stellen offensichtlich einen Zeitraum während der Wisconsin Vereisung dar, währenddessen das Klima Kalziumkarbonat Ablagerungen begünstigte.

Die dritte Altersgruppe reicht von 15.4±0.7 Ka bis zur Gegenwart. Schmelzwasser von der Des Moines Gletscherzunge liessen Sedimente in Mystery Cave zurück, die von einem von 12.5±+.7 Ka bis 8±+.4 Ka datierten Höhlenkalksteinschicht überlagert werden.

Introduction

U-series dating of speleothems within the karst developed in southeastern Minnesota extends the Pleistocene chronologic record of Minnesota beyond the range of ^{14}C. U-series dating of speleothems from caves has been applied in several previous investigations of Pleistocene climate and chronology (e.g., Harmon et al, 1978). However, the only previous work in mid-continental North America is from Coldwater Cave in Iowa (Koch and Case, 1974; Harmon et al, 1979).

Geological Setting

Southeastern Minnesota contains approximately 600 m of Paleozoic strata resting unconformably on Precambrian sedimentary and crystalline rocks. The Paleozoic section, which ranges in age from Late Cambrian to Middle Devonian, is capped locally with Cretaceous deposits, and is generally mantled with Pleistocene glacial drift. The regional dip of the sedimentary rocks is about $0^{o}13'$ to the southwest.

Karst features are known throughout southeastern Minnesota (Figure 1). The karst has developed primarily in the Middle to Upper Ordovician and Middle Devonian limestone and dolostone, especially along the northeast edge of an upland plain, in response to incision of the Root River (Wopat, 1974). Karst development has been controlled further by three major joint sets, trending to the northeast, east, and northwest.

Relatively little is known about the glacial history of southeastern Minnesota. There is no evidence of the late Wisconsinan glacial ice deposits east of the Bemis moraine, although a loess cover has been ^{14}C dated between 16,500 and 27,000 B.P. (Wright, 1972). Units of Pleistocene till and outwash have been mapped throughout much of southeastern Minnesota but are not assigned to a specific glacial event (Goebel and Walton, 1979). Dakota County contains red drift originally mapped as Illinoian but not tentatively classes as early Wisconsian (Wright, 1972). Beneath the presumably older than the red drift lies a gray drift, which extends to the south into Fillmore County (Figure 1), where it is associated with units of apparently older weathered drift and residuum. In the absence of radiometric ages, these units are mapped (Goebel and Walton, 1979) as pre-late Wisconsinan, although they may be of Illinoian or Kansan age.

Material for the present study was collected from the karst terrain in Fillmore County. Most samples are from Mystery Cave, (T. 102N., R. 12W., sec. 20) near Spring Valley, Minnesota. This cave, which currently has 18.3 km of mapped passage, acts as a subterranean meander cutoff for the South Branch of the Root River. It appears to have served a similar function in the past. Two other sites a few kilometers from Mystery Cave -- Fairview Blind Valley to the north (T. 102N., R. 12 W., sec. 6) and Rifle Hill Quarry to the east (T. 120N., R. 12W, sec. 35) -- also provided material for dating.

Results and Discussion

U-series ages were determined with standard analytical procedures. Forty-seven ages were determined from 24 speleothems, some of which have previously been reported (Lively and Alexander, 1980). Calculated ages, uranium concentrations, and isotope activity ratios are shown in Table 1. The oldest age group, ranging from 163±15 ka to 101+6ka contains 18 age dates from 13 samples. The samples from this group were collected from three different parts of Mystery Cave (Figure 1): the west end of 5th Avenue, 4th Avenue, and Enigma Pit.

Age determination from the bottom of stalagmite MC-4, and from MC-6, indicate that deposition at the west end of 5th Avenue began approximately 160ka ago, correlative with the maximum low sea level (stage 6 of Shackleton and Opdyke, 1973) associated with the Illinoian Glaciation (Gascoyne et al, 1979). Sample MC-4 stopped growing at 125±8ka, possibly due to the influx of sediment now capped by the flowstone MC-5, which is dated at 101±6ka (an average of three separate analyses). Because only bottom and top ages were obtained on MC-4, we cannot be sure that the stalagmite grew continuously over the indicated time interval. MC-20, from the sam location, began growing somewhat later, 147±12ka, but still during the Illinoian Glaciation. The age at the top indicates it stopped growing about 107±5ka -- approximately the time of deposition for flowstone MC-5. Although the range of dates spans 66ka, the lack of resolution of the dating in these samples or the response of the cave to more regional climatic conditions does not allow a close correlation of speleothem deposition with the relatively rapid fluctuations observed in global sea levels (Bloom et al, 1974).

Rimstone samples collected in 4th Avenue record two episodes of standing water (possibly reflecting increased precipitation in southeastern Minnesota), approximately 120ka (MC-26, MC-18) an 100 ka (MC-17).

The oldest age from Enigma Pit, 146±10ka (MC-16), is from the bottom of a sequence of three flowstone layers that overlie approximately 3 m of unconsolidated gravel, sand, and silt. A piece o drapery from a nearby well dates from 143±9ka to 131±6ka. These dates indicate that this part of the cave became active about 145ka in Illinoian time before the beginning of the Sangamon Interglacial, with both continuous (drapery) and intermittent (flowstone) deposition. The upper two flowstone layers, separated by layers of laminated fine silt (MC-14 and MC-13), were dated at 125±11ka and 104±4ka respectively. The 125ka age correlates with the older rimstone pool in 4th Avenue and the end of growth of MC-4 in 5th Avenue. This also is the time of the last interglacial maximum and a sea level stand higher than at present (Gascoyne et al, 1979; Shackleton and Opdyke, 1973; Bloom et al, 1974; Harmon et al, 1978). The 104+4ka date (as well as the 102±5ka date from 4th Avenue) correlates with a warm period in Kentucky and West Virginia (Harmon et al, 1978) and a raised sea level stand at 107±9ka (but lower than the present) in New Guinea (Bloom et al, 1974). The interruption of carbonate deposition at Enigma Pit and the formation of the laminated sites between the separated flowstone layers resulted from flowing water. As elsewhere in the cave, deposition of calcium carbonate at Enigma Pit ended at around 100ka, which in the "long" Wisconsinan chronology may correlate with the beginning of the Wisconsinan ice age (Terasmae and Dreimanis, 1976). Sediment deposition in the older parts of the cave was very limited after 100ka, although there is evidence that passage were eroded by streams at lower elevations in the cave. Furthermore, following 100ka breakdown has occurred in all of the dated parts of the cave.

The data in Table 1 record an apparent break in speleothem deposition between 100ka and 60ka, with a resumption of deposition beginning about 60ka and lasting until 35ka. MC-19 is a white crystalline stalagmite recovered from the west end of 5th Avenue at approximately the same location as the older samples. A distinct layer in the center of the stalagmite indicates a growth discontinuity, which is supported by a gap in the ages listed in Table 1. MC-19 shows growth 59±5ka to 55±5ka, a 17ka hiatus, and then further growth from 38±2ka to 35±2ka. Although errors associated with the age determinations overlap, the ages are in the correct stratigraphic order and could represent the true depositional age. The reason for the hiatus is probably hydrologic, rather than climatic, as MC-21 and RHQ-a,c,d (Table 1) were growing during the hiatus.

The overall time interval from 59ka to 35ka coincides with several dates obtained from Coldwater Cave in Iowa (Koch and Case, 1974). In the central Great Lakes region the time period 60ka - 40ka is identified as the Port Talbot Interstade (Terasmae and Dreimanis, 1976).

There is no evidence of carbonate deposition in Mystery Cave between 35ka and 15ka, presumably because of the onset of the late Wisconsinan Glaciation, which lasted in southern Minnesota until approximately 13ka, by which time the Des Moines lobe had retreated from its terminus in Iowa (Wright, 1972).

The latest period of carbonate deposition in Mystery Cave began about 15±0.7ka and continues throughout the present. Although the Des Moines lobe ice was little more than 100 km to the west of Mystery Cave at 14ka, conditions in southeast Minnesota were apparently not cold enough to prevent speleothem growth. A speleothem found growing in Coldwater Cave, northeastern Iowa, from 25±4ka to 6±1ka, provides further indirect evidence of climatic conditions favorable for active speleothem growth in southeastern Minnesota during the late Wisconsinan. Isotopic paleotemperature determinations on this sample indicate a temperature minimum from 17ka to 15ka followed by a gradual warming (Harmon et al, 1979; Koch and Case, 1974).

A 50-cm sequence of flowstone in Mystery Cave, MC-7, 8,9, indicates continuous calcium carbonate deposition over the period from 12.6±0.4ka to 8±0.4ka. This flowstone caps a sediment layer composed of sorted gravel, sand and silt. The older date from the bottom of the flowstone indicates that the sediment may have been deposited by meltwater from the retreat of the Des Moines lobe ice. This deposit can be traced in a northeast direction through the cave for more than a kilometer, becoming progressively thinner and finer grained. A thin flowstone cap over the deposit in another part of the cave, MC-1, dated at 12.5±0.7ka.

Summary

The late Pleistocene record from southeastern Minnesota as determined from speleothems begins at approximately 160ka. Although the present karst activity may have begun during the early Pleistocene (Wopat, 1974), we have yet to date speleothem deposits that corroborate this contention. Sedimentological investigations indicate that at various times much of the cave has been below the water table, and/or filled with sediments, some of which have been removed by subsequent erosion. These events certainly would have inhibited or contributed to the destruction of any evidence of earlier speleothem deposition. In addition, the presence of drift identified as pre-late Wisconsinan in the area implies that glacial ice may have covered the cave prior to 160ka, and that the cave may have provided an outlet for sediment-charged waters beneath the glacier. The cave could have been significantly enlarged at this time, with concurrent erosion of older speleothems.

The evidence presented in this paper imples that speleothem studies from caves of mid-continental North America, in relatively close proximity to glacial ice advances, may provide a chronometric and climatic scheme separate from, but supplemental to, Pleistocene sea-level or deep-sea core studies.

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Table 1

Uranium Concentration, Activity Ratios, and Calculated Ages

Sample No.	U ppm	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age X 10^3 yrs. B.P.	Sample and location description
MC-2	9.8	1.499 ± .016	0.799 ± .036	640	151 ± 13	Enigma Pit flowstone 7% yield of Th
MC-2a	11.9	1.520 ± .018	0.877 ± .035	149	183 ± 17	Enigma Pit stalagmit base - recrystallized
MC-3h	0.1	2.677 ± .127	1.272 ± .047	134	>300	W. end of 5th Ave. stalagmite bottom
MC-3g	0.1	2.664 ± .183	0.791 ± .050	12	136 ± 12	W. end of 5th Ave. stalagmite middle
MC-3	0.1	2.542 ± .144	0.754 ± .038	19	126 ± 11	W. end of 5th Ave. stalagmite middle
MC-3c	0.2	2.416 ± .099	0.807 ± .034	42	142 ± 11	W. end of 5th Ave. stalagmite top
MC-4a	0.2	1.975 ± .108	0.854 ± .039	54	163 ± 15	W. end of 5th Ave. stalagmite bottom
MC-4hg	0.2	2.151 ± .182	0.743 ± .027	77	125 ± 8	W. end of 5th Ave. stalagmite top
MC-5	0.1	2.603 ± .109	0.636 ± .036	1000	97 ± 8	W. end of 5th Ave. flowstone
MC-5a *	0.2	2.230 ± .146	0.662 ± .032	33	104 ± 8	replicate analysis avg. 101±6
MC-5b *	0.1	3.050 ± .170	0.673 ± .089	17	104 ± 21	replicate analysis 11% yeild of Th
MC-6	0.1	2.101 ± .085	0.854 ± .028	31	161 ± 10	W. end of 5th Ave. flowstone
MC-10a *	0.6	1.406 ± .047	0.649 ± .032	11	106 ± 9	Enigma Pit drapery inner portion
MC-10b *	0.6	1.512 ± .068	0.699 ± .038	15	119 ± 11	Enigma Pit drapery outer portion
MC-11a	0.3	1.309 ± .037	0.763 ± .024	126	143 ± 9	Enigma Pit drapery inner portion
MC-11b	0.3	1.477 ± .022	0.737 ± .019	41	131 ± 6	Enigma Pit drapery outer portion
MC-13	0.3	1.512 ± .027	0.645 ± .015	32	104 ± 4	Enigma Pit flowstone top
MC-14	0.8	1.337 ± .048	0.710 ± .036	38	125 ± 11	Enigma Pit flowstone middle
MC-16	5.9	1.473 ± .011	0.782 ± .028	224	146 ± 10	Enigma Pit flowstone bottom
MC-16a	5.3	1.773 ± .014	0.801 ± .017	394	147 ± 6	replicate analysis of bottom flowstoen
MC-17 *	0.7	1.508 ± .045	0.636 ± .020	11	102 ± 5	4th Ave. rimstone
MC-18 *	0.7	1.285 ± .019	0.698 ± .019	177	122 ± 6	4th Ave. rimsteon
MC-20a	0.1	2.625 ± .149	0.811 ± .037	37	142 ± 12	W. end of 5th Ave. stalagmite bottom
MC-20b	0.2	2411 ± .074	0.678 ± .019	45	107 ± 5	W. end of 5th Ave. stalagmite top
MC-26	1.4	1.330 ± .018	0.693 ± .016	71	120 ± 5	4th Ave. flowstone (rimstone)
MC-26a	1.8	1.437 ± .032	0.312 ± .009	27	40 ± 1	4th Ave. stalagmite bottom-resting on MC-26
MC-26b	2.0	1.436 ± .018	0.683 ± .022	28	115 ± 6	4th Ave. stalagmite middle
MC-26c	2.0	1.386 ± .022	0.714 ± .016	63	125 ± 5	4th Ave. stalagmite upper middle
MC-19 *	0.1	4.094 ± .455	0.443 ± .030	6	59 ± 5	W. end of 5th Ave. stalagmite bottom
MC-19 *	0.1	4.404 ± .405	0.422 ± .033	11	55 ± 5	W. end of 5th Ave. stalagmite lower middle
MC-19 *	0.1	4.208 ± .267	0.303 ± .014	15	38 ± 2	W. end of 5th Ave. stalagmite middle
MC-19 *	0.1	4.760 ± .375	0.289 ± .017	15	35 ± 2	W. end of 5th Ave. stalagmite top
MC-21	2.0	1.929 ± .033	0.334 ± .008	30	43 ± 1	Mud Slide Stalactite
RHQ-a *	0.4	1.390 ± .057	0.366 ± .026	4	48 ± 4	flowstone
RHQ-c *	0.6	1.409 ± .081	0.384 ± .024	4	51 ± 4	flowstone
RHQ-d *	0.6	1.454 ± .050	0.341 ± .019	8	44 ± 3	flowstone
ZB-1 *	0.1	1.268 ± .063	0.230 ± .027	6	28 ± 4	flowstone 7% yield of U, 3% yield of Th
ZB-2 *	0.3	1.478 ± .074	0.390 ± .033	3	52 ± 6	flowstone 11% yeidl of Th
MC-1	1.0	1.534 ± .046	0.110 ± .006	17	12.5 ± 0.7	Angel Loop flowstone
MC-7 *	1.4	1.380 ± .025	0.111 ± .004	6	12.6 ± 0.4	Bomb Shelter flowstone bottom
MC-8 *	0.5	1.407 ± .018	0.087 ± .004	12	9.8 ± 0.5	Bomb Shelter flowstone middle
MC-9 *	0.4	1.495 ± .028	0.071 ± .004	12	8.0 ± 0.4	Bomb Shelter flowstone top
MC-24 *	1.7	1.674 ± .025	0.078 ± .004	6	8.8 ± 0.5	Wind Tunnel stalagmite
MC-25	1.6	1.766 ± .025	0.113 ± .003	18	13 ± 0.4	Wind Tunnel stalagmite bottom
MC-25a *	1.5	1.719 ± .037	0.108 ± .006	6	12.3 ± 0.7	replicate analysis of bottom
MC-25b *	1.2	1.611 ± .047	0.113 ± .005	6	12.9 ± 0.6	Wind Tunnel stalagmite top
MC-27 *	1.6	2.012 ± .039	0.134 ± .005	3	15.4 ± 0.7	Discovery Route flowstone

* ^{230}Th activity corrected by subtracting the ^{232}Th activity (assuming $^{230}Th/^{232}Th = 1$)
Samples numbered MC, Mystery Cave; RHQ, Rifle Hill Quarry; ZB, Fairview Blind Valley.
The ages listed in italics, MC-2a, series MC-3, and MC-26a,b,c exhibit secondary uranium movement following deposition and do not meet the requirements for a closed system; although reported above, these samples are not included in the discussion. MC-10a,b also show an age reversal, but the ages overlap within the one sigma error so the reversal may only be apparent.

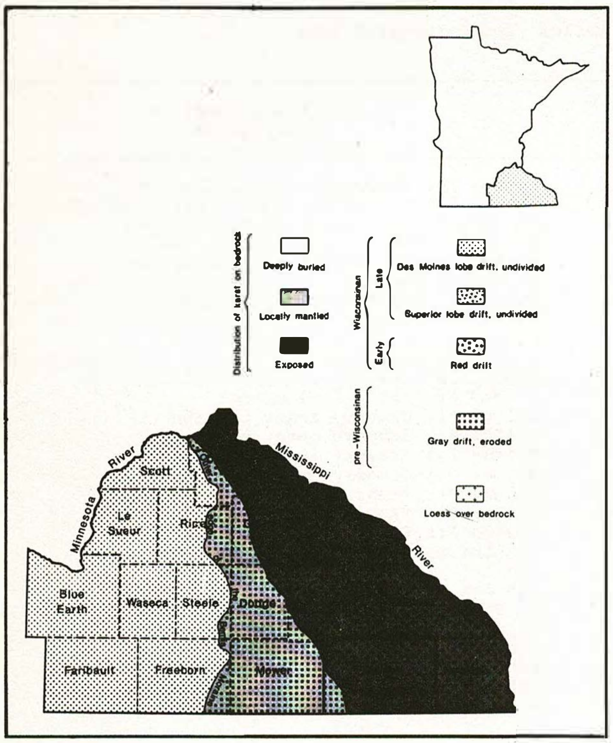

Figure 1: Location Map of Southeastern Minnesota. Distribution of the karst terrain in relationship to Pleistocene glacial drift.

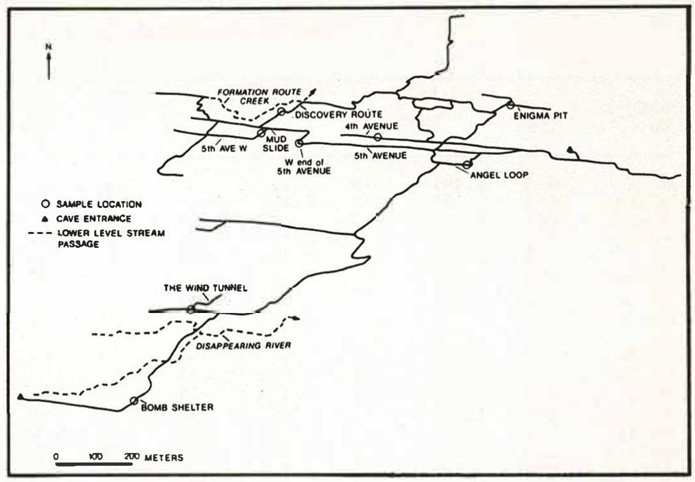

Figure 2: Simplified Plan View of Myserty Cave.

Hydrochemical Facies - A Method to Delineate the Hydrology of Inaccessible Features of Karst Plumbing Systems

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Abstract

Details of unknown and inaccessible features of a drainage network can be determined by use of hydrochemical facies. Function, behavior, source area, and character of karst water can be identified by virtue of their respective chemistries. Total Hardness, P_{CO2}, and SI_c are the most useful parameters, but more detailed analysis (i.e. more parameters) will improve resolution of the technique, through regression and correlation analysis. Systematic sampling of accessible points within a drainage network (springs, sumps, cave streams, swallets, resurgences, etc.) can, in combination with more traditional observations, delineate the physical construct of the entire plumbing system. Method is of particular importance if direct access to a large portion of the system is difficult, dangerous, and/or physically impossible. An example is given for a large karst network` Sinking Valley Resurgence Complex, Pulaski Co., Kentucky, USA.

Zusammenfassung

Die Detaile der unbekannte und unzügangliche Hauptzuge der abfluss Netzwerk können bei die benutzung Hydrochemi Gradiente bestimmen werden. Die Funktion, Betragen, ursprung Gegende, und Charakter des Karst Wasser können von die Beseihung diese betreffend Chemic identiferen werden. Das Ganzehärte, P_{CO2}, und SI_c sind die meist brauchbar Parameter, aber mehr eingehend Analyse (mehr PARAMETER) werden die Aufflössung des Technique durch Regression und Wechselbeziehung Koeffiziente Analyse verbessern. Die systematisch Proben der zuganglich Punkte darinnen abfluss Netzwerk (Quelle, Sumpfe, Höhlestrome, Swallet, Weideraufliessen, a.s.w.) können zusammen mit den mehr traditionell Beobachtung den physikal Konstruktion des ganz abfluss Netzwerk beschriben. Die Methode ist besonders wichiekeit wenn der gerade nach den gross Portion des System ist schwer, gefährlich, und/oder körperlich unmoglich. Ein Beispeil für ein grosse Karst Netzwerk wird gegeben: Sinking Valley Resurgence Complex, Pulaski Co., Kentucky, USA."

Introduction

The term hydrochemical facies refers to the dynamic aspects of karst water chemistry. The role karst water plays as a solvent allows it to carry a record of its past history. It is therefore possible to determine the physical construct of a karst network geometry from water analysis data. While useful alone as a model constructing method or stream tracing technique, it is of the most value when combined with other indirect methods such as Flood Pulse Analysis (Christopher, 1980) and traditional stream tracing.

Chemical Anomalies - Groundwater Pollution

An unexpected or very unusual chemistry can certainly be exploited. Most cases are instances of pollution. If unique, and a single point source can be identified, the pollutant can be used for stream tracing. Examples are many: chlorides from petroleum producing brimes (Brown, 1966): point source nitrates (Johnson, 1978)' and heavy metals (Quinlan, 1978).

Natural Water Chemistry

A more common scenario is not one of exotic chemical anomalies, but natural water chemistry. The earliest concise ideas of utilizing water chemistry for stream tracing was Richardson (1968). The technique was to systematically sample, in a single day, all accessible areas in a drainage network. The hope and intent was to obtain recognizable chemical trends and to construct a model of the drainage geometry, and refine this by subsequent investigation. By inspection of analysis data, deductions concerning a cave and its proximity could be obtained, even with just a few parameters. For such simple approaches, one is restricted to short distances on the order of a few hundred meters, before errors become appreciable.

Large Karst Networks

These same ideas may be extended to the increased distances and complexities encountered in large systems. Expanding analysis to all major species normally present in natural water and comparing trends amongst them would help. Including conductance, direct measurement of aggressiveness, and the calculated parameters SI_c and P_{CO2} are also useful. Important improvements are statistical methods` Analysis of Variance (Significance testing) and Correlation Coefficients. Repeated, systematic sampling is necessary for the statistics, so studies in seasonal trends, erosion rates, and the development of a data base are incorporated as direct benefits.

Hydrochemical Facies Concept

Chemical kinetics (White, 1977), carbonate solution processes and equilibria, and ultimately the cave system's geometry (including factors leading to its speleogenesis) are all intrinsic to subsequent effluent water chemistry passing through such a system. Physical construct geometry source areas (soil water, swallet water, allogenic water, etc.) flow regime, residence times, -- all indicate function and behavior of the solution cavities being transversed by the effluent water.

Delineation of Plumbing Characteristics

Karst waters appearing at a cave stream, sump, or resurgence can be categorized into its hydrologic role or position in the karst environment by virtue of its chemistry. Drake et (1973) did this using SI_c and P_{CO2} as the most significant parameters. Schuster et al (1971, 1972) classed springs into two broad end members of conduit and diffuse flow using the Coefficient of Variation of Total Hardness. Smith et al (1976) used similar ideas to clarify swallet and percolation water and its characteristics.

For use in delineating, modeling, or tracing modes, hydrochemical facies concepts are greatly enhanced by identifying the flow characteristics.

A given water parcel would be subject to far fewer disturbances, dilution, equilibria changes, and other modifying errors if residence times in the unknown sections of the system were reduced. Conduit flow (pipe flow) is desirable, and if its presence can be confirmed, the reliability and confidence of the facies method would be enhanced even over long distances. No problems with conduit scenarios have been encountered up to 8 km, and multiples of that distance could be achieved if intermediate sample points were accessible. The potential for this method is often overlooked.

An Example: Sinking Valley Resurgence Complex

Sinking Valley is a major cave system located in Pulaski Co., Ky (about 150 km east of Mammoth Cave area). It is developed in massive bedded, high purity (96-98% $CaCO_3$) upper and middle Mississippian limestones. Annual precipitation is about 119cm/year. Basin in irregularly shaped, but is approximately 80 km^2 (boundries still not completely known). As no surface drainage exists in Sinking Valley, the uneven rainfall (highly concentrated, local thunderstroms common), combined with fluvial debri and sediments constricting access, and rapid runoff (cleared lands) make direct access difficult. Exploration, stream tracing, and chemical evidence indicate much of system is permanently inundated (a phreas). Figure 1 shows geogrphic distribution of the major sample points of the Sinking Valley System.

Sample Program

Major attention was focused on the resurgence area. Exploration has indicated the existance of an integrated drainage network with conduits of large size (Figure 2) averaging 15m x 7m from resurgence to headward areas. 115 samples were taken at least monthly during the period April 1971-December 1980. 35 of these samples were taken in 1979, a more typical precipitation year. 1980 was a year of severe drought, during which the remaining 80 comprehensive samples were taken. Average Total Hardness, geometric means for SI_c and -Log P_{co2} (calculated as per Christopher, 1978) and Coefficients of Variation of Tot. Hard. are given in Table 1. The effect of hte drought is to bias the numbers toward diffuse flow character. This effect is shown by contrasting the figures for Short Creek 1979/1980, as Short Creek is a (perhaps THE) major resurgence for Sinking Valley.

Date Interpretation

Cave sites A,B,D, and J (See Figure 1) all give access to a major stream. An Analysis of Variance was done to test the hypothesis that these samples were taken from a single population (one and the same stream or plumbing system). An actual F statistic calculation = 0.62 was significantly less than the expected F=2.92 (with appropriate sample degrees of freedom and significance level of 5%). Thus there is no evidence in the evidence in the samples to indicate samples did not come from the same population. This is not a proof, but simply gives no evidence in the samples to indicate samples did not come from the same population. This is not a proof, but simply gives no evidence to the contrary at 5% significance level. A correlation coefficient matrix was prepared for all major sample points of interest to show relationships (Table 2). This same data set showed strong correlation. A & D have been dye traced confirmed.

Characteristics of Resurgence Area (See Figure 1, 2 and Table 1)

(ABDJLMN) are all conduits as determined from data in Table 1 and describes the flow path for Sinking Valley drainage rising at Short Creek. D's lower SI_c value may be a sampling artifact due to sampling an 8m deep lake restricting access at the very large entrance. Scallops direction indicates lake may be a separate input of deeper phreas circulation, which would explain the higher P_{co2}. J (Short Creek) is a year round major spring with average discharge about $1.5m^3$/sec, exceeding $3m^3$/sec a few times a year in floods. Normally, water sinks in the cave and reappears in S.C. Continued (L), S.C. Outlet (M) and finally discharges into Buck Creek by a series of distributary springs (N).

(CFHIK) are all diffuse flow springs averaging 50-70 mg/liter more Tot. Hard. than Short Creek. Wider range for C.V. values may be due to catchments containing both soil and bare rock cover (discussed by Cooper et al, 1977). The 3 major Burdine Valley springs (C) were once thought related to main Sinking Valley flow, but chemistry disproves that. They rise from independent catchments and are eventually tributary to Short Creek, as are FHIK. B. Pot Spring is unusual. It has a poor, indirect plumbing connection to the main flow. There is little mixing or convection. Spring is often saturated in summer, while B. Pot Cave never is. Only 50 m apart, at similar elevations, BP Cave cannot discharge water (enclosed in a 15 m deep sink) while BP SPRG discharge can vary from its normal zero to 3+ m^3/sec in flood (discharging large volumes of sediments and tree trunks). B. Pot Spring functions as an overflow or pressure release value for main flow in floods. B.P. Swallet is sinkpoint for B.P. SPRG floodwater. Its entrance contains a small spring year round, once thought to relate to Pleasant Run Spring (H). No correlation is evident, so Swallet source is unknown.

Sinking Valley Main Flow Summary

Chemical data can describe the role a sample point plays in the karst environment. Short Creek is representative of the main flow behavior. Large karst systems are likely to have many inputs and have contributions from both conduit and diffuse flow. Not reflected in the averaged data (Table 1) are seasonal trends (not shown-space restrictions). Under different flow conditions, one contribution may dominate the other. For Short Creek, P_{co2} of conduit and diffuse depend on source area. The -Log P_{co2} range was 1.87 - 2.68, and indicate flow contribution to main discharge.

Table 1

	Average Tot.Hard (mg/l $CaCO_3$)		Av.SI_c	-Log P_{co2}	% CV
A-Big Sink Cave	127	conduit	-0.47	2.25	18
B-Price Cave	130	conduit	-0.40	2.23	19
C-Burdine Valley Springs					
3 representative	208		+0.06	2.03	8.1
6 other seeps in area					
D-Boiling Pot Cave	161	conduit	-0.27	2.13	15.3
E-Boiling Pot Spring	153		+0.05	2.49	20
F-Diffuse Spring Above (E)	202		+0.44	2.66	13
G-Boiling Pot Swllt	189		-0.23	2.06	13
H-Plesant Run Spring	215		+0.15	2.22	7
5 other seeps which run dry in area	204		+0.09	2.17	8
I-Squalid Manor Sprg	201		+0.09	2.18	9.9
J-Short Creek					
1979 Values	125	conduit	-0.47	2.28	24.5
1980 values	147	conduit	-0.31	2.27	25.5
K-Bovine Spring	190		+0.05	2.10	11
L-S.C. Continued 1979 values	126	conduit	-0.46	2.26	25
M-S.C. Outlet Cave (1979)	128	conduit	-0.46	2.26	25
N-Distributary Springs at Buck Creek	NOT SAMPLED				

Table 2

	A	B	D	E	G	H	J
A-Big Sink							
B-Price Cave	0.94						
D-B.Pot Cave	0.93	0.96					
E-B.Pot Sprg.	0.26	0.31	0.38				
G-B.Pot Swallet	0.44	0.58	0.17	0.07			
H-Pleasant Run	0.08	0.11	0.29	0.07	0.01		
J-Short Creek	0.95	0.99	0.94	0.29	0.21	0.05	

Correlation Coefficients

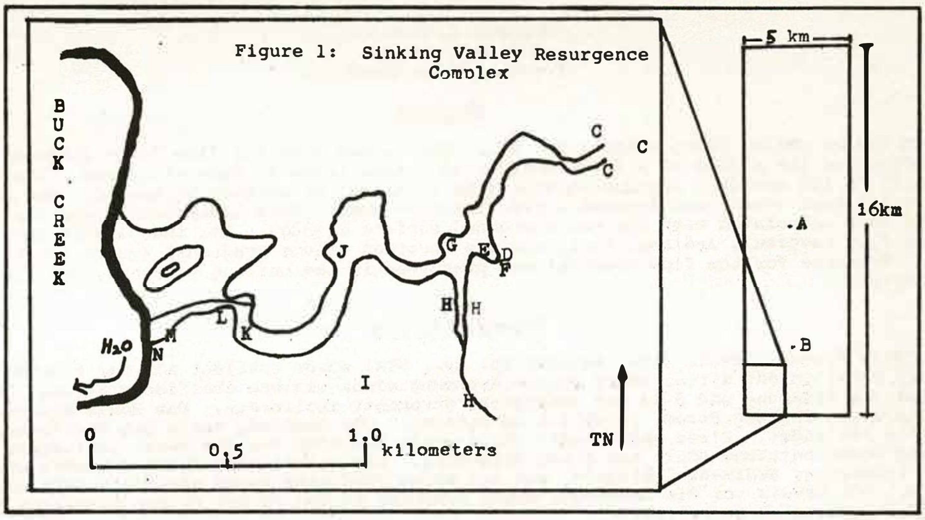

Figure 1: Sinking Valley Resurgence Complex

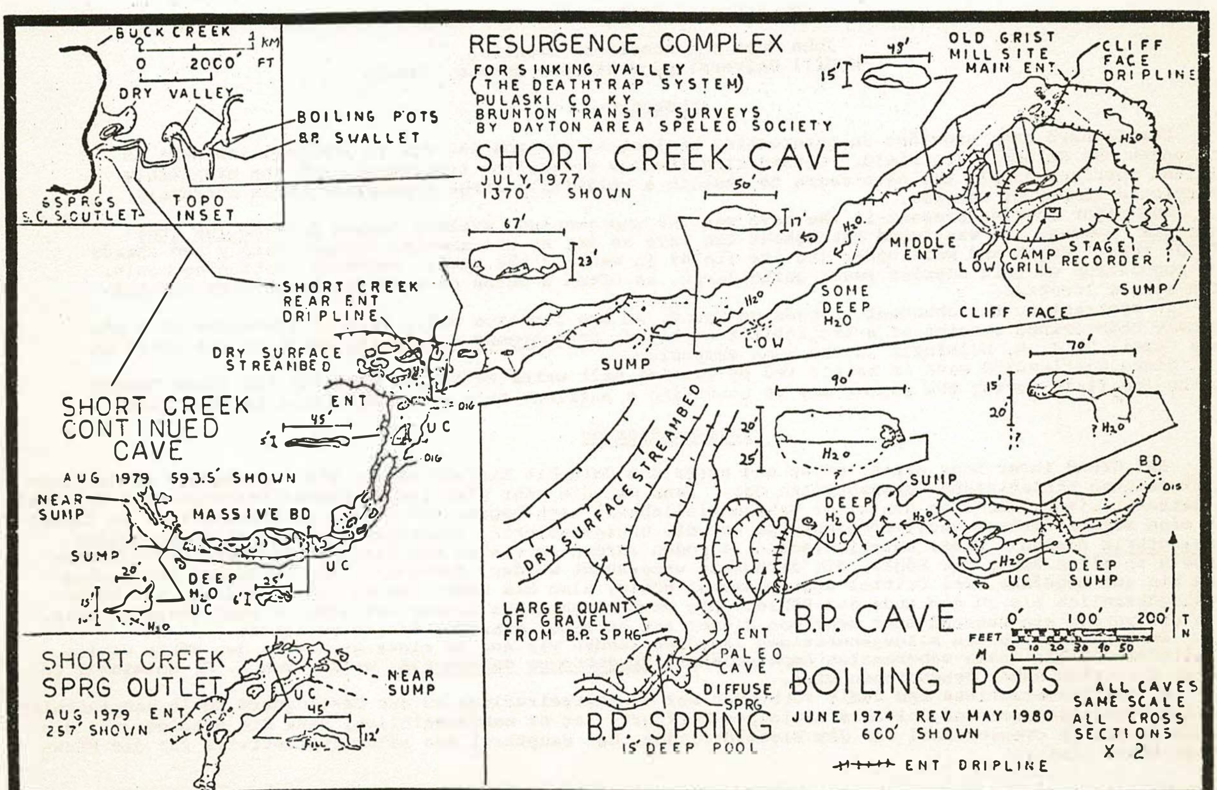

Figure 2: Short Cave Creek Resurgence

Dynamic Readjustments in a Cave System Speleogenesis - A Result of a Base Level Surface Stream Abandoning 8km (5 miles) of a Surface Meander Streamed

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Abstract

A large cave system (Wells Cave, Pulaski Co. Ky., USA) formed with its flow field directed to a discharge point located in the middle of a large meander of a base level surface streambed. The surface stream cut through a neck of the meander, abondoning some 8 km (5 miles) of surface streambed. The cave system had to adjust to its base level, now located 1.6km (1 miles) away. This independent cave was formed as a meander cutoff cave associated with the now abandoned surface meander. The independent network tube was subjected to flow reversal, sedimentation, and was regarded (floor gradient) toward the now distant surface stream. Evidence for the flow reversal was preserved in the ceiling gradient, passage morphology, and network geometry.

Zusammenfassung

Ein grosse Höhle System ("Wells Cave, Pulaski Co. Ky., USA) wurde gebildet mit das Flussenfled gerichtet nach ein entlader Punkt in das Mittel einer grosse Krümmung eines Thalweg oberfläche Strom. Der oberfläche Strom abschneidet die Krümmung und 8 km der oberfläche Strombett isolierete. Das Höhle System musste sich anordnen nach dem neuen Thalweg Strom, jetzt 1.6 km enfernt. Die Anordung wurde bei Verbindungen mit ein selbständige Höhle vollendet. Diese selbständig Höhle wurde bebildet von die jetzt isolierete Krümmung als eine Krümmung abgeschnittene Höhle bei diese Beziehung. Die selbständig Röhre Netzwerk wurde geändert bei dem flussen Umkehrung, Sedimente ablagern, und der Boden Gradiente wurde geneigete nach den jetzt enfernt oberfläche Strom. Der Beweis vor die Umkehrung wurde bewahrte in den an der Decken Gradiente, Höhlegang Morphologie, und die Netzwerk Geometrie.

The Fauna of Castleguard Cave

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Abstract

Castleguard cave provides an interesting biological environment due to its position next to and under the Columbia Ice Field. Considering the low prevailing temperature and the presumably limited nutrient supply the cave seems to sustain a relatively large population of an extremely restricted number of species.

The major species present in the cave was the unpigmented, eyeless isopod Salmasellus steganothrix Bowman. It was found throughout the cave as far as was sampled (approximately two thirds of the total length and well under the ice field) in many of the small, sediment containing pools. The population of this species seems quite large, as often a dozen or more specimens were sighted at a single location.

In contrast to the abundant isopods we found, at one location only, several specimens of a previously undescribed species of a troglobitic amphipod, Stygobromus canadensis which is discussed in more detail by J. R. Holsinger in the same symposium.

Since Castleguard cave is mainly fed by glacial melt water we sugges that the red algae common on the ice field during the summer may be providing a nutrient source for the fauna in this cave.

Zusammenfassung

Auf Grund ihrer Lage direkt neben und unter dem Columbia Eisfeld stellt die Castleguard Höhle einen interessanten biologischen Lebensbereich dar. Wenn man die sehr niedrige Durchschnittstemperatur der Höhle in Betracht zieht, als auch den aller Wahrscheinlichkeit nach begrenzten Vorrat an Nährstoffen, so findet man eine relativ grosse Bevölkerungsgruppe war die unpigmentierte, augenlose Isopodenart Salmasellus steganothrix Bowman. Diese unterirdischen Isopoden wurden in vielen der kleinen, Sediment enthaltenden Tümpeln in allen Zonen der Höhle, die daraufhin untersucht wurden, gefunden. Ihr Vorkommen erstreckte sich bis auf ungefähr zwei Drittel der gesammten Höhle, also bis unter das Columbia Eisfeld, und höchstwahrscheinlich bis zu dem Ende der Höhle. Die Bevölkerungszahl dieser Art scheint sehr gross zu sein, denn oft wurden ein Dutzend oder mehr von dieser Art an einer einzigen Stelle gesichtet.

Im Gegensatz zu den allgegenwärtigen Isopoden fanden wir nur an einer Stelle in der Höhle einige Mitglieder der bis dahin unbekannten Amphipodenart Stygobromus canadensis, welche von J. R. Holsinger in diesem Symposium näher beschrieben wird.

Da der Wasserzufluss und damit verbunden der Nährmittelzufluss zu der Castleguard Höhle hauptsächlich von den Schmelzwassern des Columbia Eisfeldes herführt, ist es wahrscheinlich, dass die Rotalgenart, die man im Sommer in grosser Zahl auf dem Eisfeld findet, den Hauptteil des Nährmittelvorrates für die Fauna dieser Höhle liefert.

Ecological Analysis of Terrectral Invertebrates in a Venezuelan Cave

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Abstract

These are the results of a five-day investigation in "Cueva del Agua," Anzoátegui State, Venezuela, during December of 1978. The study included the measurement of climatic parameters and the chemistry and physics of the soil. Diversity indices of the soil and superficial fauna inside and outside the cave were determined. One of the sampled zones is inhabited by oilbirds, Steatornis caripensis. The population size of one species of Gryllidae, Tenebrionidae and Carabidae, respectively, were determined.

The exterior zone contains the greatest fauna diversity. In contrast with the other zones, with relatively similar characteristics, the third zone, the "Salón de los Guácharos", is rather different. It contains more individuals but not the greatest diversity.

Zusammenfassung

Vorgestellt werden die Ergenbnisse einer fünftägigen Untersuchung, die im Dezember 1978 in der "Cueva del AguaÄ im Staat Anzoátegui (Venezuela) durchgenfürhrt wurde. Die Untersuchung schloss die Bestimmung von klimatischen Parametern und von physio-chemischen Eigenschaften des Bodens ebenso ein wie die Indizierung der verschiedenen Organismen in der Erde und an der Erdoberfläche ausserhalb der Höhle und in drei verschiedenen Zonen im Inneren. Eine diezer Zonen ist von Guá charos (Steatornis caripensis) bevölkert. Es wurde die Vorkommenshäufigkeit einer Gattung der Gryllidae festgestellt, ebenso wie der Tenebrionidae und der Carabidae.

Die grösste Unterschiedlichkeit wurde in der äusseren Zone festgetellt. Während zwei der inneren Zonen ähnliche Eigenschaften auf weisen, ist die dritte, der "Salón de los Guácharos," weitgehend verschieden aufgrund von bestimmten Eignschaften, da hier eine grössere Anzalh von Individuen anzutreffen sind, ohne dass deshalb jedoch ein höhere Grad von Verschiedeheit festzustellen wäre.

Introduction

Barr (1968) in a study of cave ecology reports that the limiting factors for species in that environment are humidity an nutrients availability. Poulson and Culver (1969) determined the diversity of terrestrial arthropods communities in Flint Ridge Cave System (Kentucky). They found that the species diversity is correlated with substrate diversity and the organic matter content.

The study of cave communities in the neotropics has not gave yet beyond the description stage. This work focuses in on the terrestrial invertebrate communities in "Cueva del Ague", Anzoategui State, Venezuela, and compares them with an exterior area, so as to infer the effect of the cave environment on these communities.

Materials and methods

The five-day investigation took place during December 1978. The cave was divided in three interior zones and one exterior zone, each of 60 m^2 for sampling. One of these zones is inhabited by oilbirds, Steatornis caripensis Humboldt. The invertebrates were counted by visual procedure and direct collection from the floor. The population size of one species each of Tenebrionidae, Gryllidae, and Carabidae were estimated by the Peterson-Lincoln modified capture-recapture method (Delay, 1975). A Brillouin index (Pielou, 1966) was used for estimating the invertebrate diversity.

Continous records of humidity and temperature were obtained using a thermohigrograph in the exterior and interior zones. Evaporation and temperature and relative humidity variations were taken dialy throughout the five day.s Physical and chemical soil parameters as pH, conductivity, texture, and organic matter (as the percentage of weight loss by incineration) were also determined.

Results and Discussion

Table 1 shows the results of two coleopteran populations estimates from two different cave zones, plus the population size of Gryllidae in several cave zones. Large variations are observed in the estimates for the same population. Possibly the tagging pigments affected the insects because of the significantly number of marked insects recaptured than were originally painted. The biggest error in the estimate of N is in M, which is overestimated in case of death of a large amount of marked insects. Nevertheless, this method is useful for a preliminary approximation that tries to find an order of magnitude which is indispensible for the estimate of terrestrial populations and the study of their dynamics (Delay,1975).

The determination of climatic parameters (table 2). revealed these as quite constant, with only minimum variations that seem to correspond with exterior variations, these being of a larger magnitude. These variations were found in a zone only 130 mts from the mouth, and in zone IV (fig.1), that should have an entrance nearby though with the oilbirds fly. The relative humidity and evaporation stayed constant in in the internal zones. The 100% humidity and zero ml/cm^2/day evaporation rate are indoubly caused by the course of water in the cave.

When the substrate characteristics from the four zones are compared (table 3), it is foudn that zone IV has the largest amount of organic matter, conductivity, and acidity. This due to the fact that this substrate is compodsed mostly of oilbird guano, which is largely made up of regurgitated seeds. The exterior soil (zone 1) is humic, with much vegetable matter. The soil from zones II and III have similar characteristics. Both zones are periodically flooded and this explains the relatively lwo valors of organic matter as compared with other zones.

The soil substrate data shows high proportions of sand and clay in zones I - III, which is comparable with data from other caves, such the "Cueva de Baruta" in Venezuela. It has a 47% sand and 53% clay content (Urbani, 1970). Zone IV has similar proportions of silt and clay, which are lower than sand.

Teble 2 shows that zone I contains the greatest diversity of counted organism, followed by zone IV. Even though the small size of the sample doesn't permit a correlation analysis, a certain relation can be infered from the organic matter and fauna diversity. One should note that while zone IV has the greatest number of individuals, it has less species than zone I. The other two zones has the same number of species.

It is possible that the large availability of nutrients favors expanded organisms' density, but only for certains species adapted to the cave environment.

The highest diversity of organisms from within the soil is observed in zone I. The diversity indices are quite similar for the interior zones, taking into account Brillouin's index variation range. It is curious to note that the lowest diversity is in zone IV, which contains more than the number of individuals than zone I. Most of the individuals (294) belong to the beetle species of the Tenebrionidae family.

Obviously, there are factors other than the amount of organic matter that intervene in the species diversity.

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TABLE 1 ESTIMATION OF TENEBRIONIDAE, CARABIDAE AND GRYLLIDAE

POPULATIONS BY METHOD OF MARKING AND RECAPTURE

Zone	Family	Marked Insects (M)	No Estimations	Total of Captured Individuals	Marked and Recaptured Individuals	Estimated Population $N = \frac{M(T-1)}{(R+1)}$	Mean N	Variance (s)	5 Confidence Interval
I	Tenebrio-nidae	37	1	53	35	53.44			
			2	32	11	92.58	102.09	52.21	(-0.24,204.42
			3	52	11	153.25			
II	Carabidae	77	1	70					
			2	90	13	379.50			
			3	96	23	255.54	369.76	79.79	(213.37,526.15
					12	444.23			
II	Gryllidae	58	1	103	38	151.69			
			2	62	9	353.80	526.16	484.24	(-411.93,1.475.26
			3	112	5	1,073.00			
III	Gryllidae	37	1	22	4	155.40			
			2	30	5	178.83	247.08	138.99	(-25.35,519.50)
			3	23	1	407.00			
IV	Gryllidae	32	1	73	3	576.00			
			2	116	6	525.71	905.90	615.48	(300.44,2.112.24
			3	213	3	1,616.00			

TABLE 2 CLIMATIC PARAMETERS AND SPECIES DIVERSITY AT EACH ZONE

Zone	Species diversity determined as $H = \frac{1}{\bar{N}} \lg \frac{N!}{\bar{N}_i!}$	Where N = Individuals, S = species	Climatic Parameters: Daily $\bar{T}$(C°)	Daily $\bar{T}$(C°)	Daily $\overline{R.H.}$ ( )	Daily $\overline{R.H.}$ ( )	Evaporation (ml/cm²/day)
	N S H	N S H					
I	200 52 1.03	154 29 1.03	22.1	3.37	97.5	1.0	0.04
II	157 7 0.39	68 11 0.58	22.8	0.40	100.0	0.0	0.00
II	50 7 0.53	27 11 0.69	22.2	0.00	100.0	0.0	0.00
IV	749 22 0.92	411 25 0.55	21.8	1.51	100.0	0.0	0.000
	Superficial	In Soil					

TABLE 3 SUBSTRATE CHARACTERISTICS

H_2O in air dried substrate	Organic content (wt. loss by ignition	p H	Conductivity (mhos/cm)	Texture (particles proportions		
				% Sand (20.005 mm)	%Silt (0.05-0.002)	%Clay (0.002)
7.70	19.23	7.7	0.169	34.99	15.17	49.84
1.60	6.65	8.2	0.095	41.06	18.29	40.65
2.75	4.67	8.1	0.114	34.20	24.67	41.13
10.62	79.45	5.5	1.912	56.52	23.19	20.29

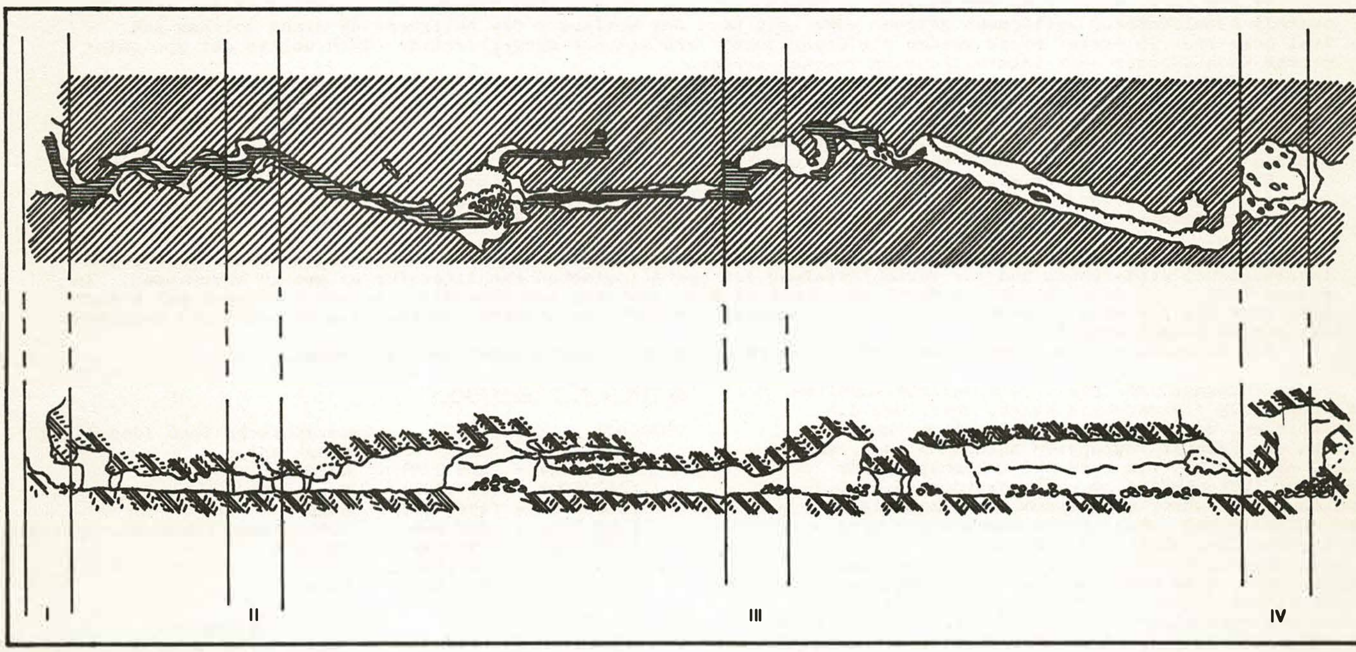

Figure 1: "Cueva Del Agua" Anzoategui, Venezuela showing the sampled zones. (From Bol. Sociedad Venez. Espel. 1(1) 1967

Thesaurus of Hungarian Speleology, Project of an International "Speleosaurus"

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Abstract

The speleological technical bibliographies in Hungary and in other countries do not satisfy the needs of researchers looking for scientific literature in connection with some complex problem. Though publications of speleological interest can be separated, no further classification can be carried out.

Our aim is to create an appropriate speleological thesaurus based, first of all, on Hungarian circumstances but containing, in the same time, the possibility of enlarging it for international use.

Our speleological thesaurus follows the method of the Geosaurus, i.e. each notion (means) is indicated by a number (and an expression). The first digit of the number indicates the widest group used in the system, while all the following digist stand for the smaller group of inner classification. The last digit is maintained for later results.

The Hungarian speleoogical technical literature was elaborated by light punch card system. Experience has proved that the elaboration of 100,000 publications on 400-500 light punch cards (1 card = 1 notion or means) is still worthwhile. Above this number the use of a computer is advisable.

After the discussion of the paper we recommend the system to beintroduced into international use. In case the thesaurus is accepted the national biblioргaphies would immediately become international, since the saem interpretation corresponds, more or less, to the same notions. Accordingly we suggest to add one or two (or more) six-digit numbers to the notions of the articles, which method would make the entry of all publications intelligible for everybody irrespective of language differences.

For the above discussed speleological thesaurus we suggest the name "Speleosaurus".

Zusammenfassung

Die gegenwärtig existierenden ungarischen und internationalen speläologischen Fachbibliographien ermöglichen keine Recherche nach gleichzeitig mehreren Stichwörten. Die allgemeinen Bibliographien für Geologie, Hydrogelogie usw.erlauben zwar das Auffinden der Publikationen, die irgendein speläologisches Thema behandeln, doch können die für die Höhlenforschung wichtigen Spezialgebiete nich unterschieden werden.

Da bis jetzt kein Thesaurus bekannt geworden ist, der für die bibliographische Bearbeitung der speläologisches Fachliteratur vollkommen geignet wäre, hat sich der Verfasser die Ausarbeitung eines solchen zum Ziel gesetzt. In erster Linie wurden die ungarischen Verhältnisse berücksichtigt, doch sollte der spelaologische Fachtesaurus auch internationalen Zwecken genügen.

In dem vom Verfasser (in Anlehnung an der "Geosaurus") zusammengestellten Begriffssytem der Speläologie wird jeden Begriff eine verbale Bezeichnung und eine mehrstellige Zahl zugeordnet. Die erste Ziffer dieser Zahl verweist auf den höchstrangigen Oberbegriff des betreffenden Begriffes, die darauffolgenden Ziffern drücken eine begriffliche Unterteilung im Dezimalsystem aus. Die letzte Zahlenstelle dient als Reserve für kunftig eventuell notwendig werdende Unterteilungen.

Zur bibliographischen Bearbeitung der ungarischen speläologischen Fachliterature wurden Sichtlochkarten gewält. Die Erfahrung hat gezeigt daß etwa 100000 Publikationen mittels 400-500 Lochkarten noch in praktisch brauchbarer Form erfaßt werden können. Bei einem größeren Volumen ist die Anwendung elektronischer Rechner zweckmäßig.

Es wird der Vorschlag gemacht, den in der Arbeit vorzulegenden Thesaurus nach entsprechender Diskussion international einzuführen und zur Verschlüsselung der speläologischen Fachliteratur allgemein anzuwenden. In diesem Fall wären fdie nationalen Fachbibliographien ohne weiteren Arbeitsaufwand sofort international brauchbar, denn die für eine eindeutige, von Übersetzungsschwierigkeiten unabhängige Charakterisierung des Inhaltes der Publikationen ermöglichen.

Zur Bezeichnung des vorgelegten Thesaurus wird der Name "Speleosaurus" vorgeschlagen.

Jeder Forscher, der die speläologische Fachliteratur auch nur einigermaßen kennt, weiß, daß die Informationen, die man über die einzelnen Publikationen den Fachbibliographien entnehmen kann, sowohl auf nationaler, wie auch auf internationaler Ebene rect lückenhaft sind. Die nationalen Bibliographien leiden unter mangelndem Dantenmaterial und unter sprachlichen Schwierigkeiten; deshalb sind ihre Angaben lückenhaft und ungenau.

Die geschilderten Schwierigkeiten legen den Gedanken nahe, eine Bibliographie zusammenzustellen der ein einheitlicher Fachthesaurus zugrunde liegt. Es wird der Vorschlag gemacht, vorerst die nationalen Bibliographien aufgrund des international angenommnen Fachthesaurus zusammenzustellen. Diese können in den einzelnen Ländern auf Sichtlochkarten leicht gespeichert und gehandhabt werden: die internationale Bearbeitung kann dann ohne Änderung der Daten mittels elektronischer Rechner erfolgen.

Die Numerierung der bibliographischen Einheiten könnte in jedem Land mit 1 beginnen, dieser Nummer müßte dann ein aus einem Buchstaben und zwei Zahlen bestehende Bezeichnung des Landes vorangehen (der Buchstabe könnte der Anfangsbuchstabe des englischen Ländernamens sein). Zur Charakterisierung des Inhaltes der Publikation könnte eine Gruppe sechsstelliger Zahlen dienen, die den einselnen Stichwörtern des Fachthesaurus entsprechen.

Die vollständige Wiedergabe des von uns ausgearbeiteten Thesaurus (vorgeschlagene Bezeichnung: "Speleosaurus") ist hier wegen des beschränkten Umfanges nicht möglich. Es soll hier deshalb lediglich seine Struktur Charakterisiert werden. Einige Beispiele snind zur Veranschaulichung seiner Form angeführt.

Bei der Ausarbeitung des "Speleosaurus" waren uns Frau I. Szabó und K. Plihál durch Ratschläge und wertvolle Bemerkungenbehilflich. Ihnen sei auch an dieser Stelle unser Dank ausgesprochen.

Abriß des Speläosaurus

	(000.001) - (999.999)	Geographische Lage (des Karstobjektes)
	(000.001) - (209.999)	Europa
	(210.000) - (299.999)	Sowjetunion
	(300.000) - (499.999)	Asien
	(500.000) - (499.999)	Australien, Ozeanien, Ostindien
	(600.000) - (849.999)	Amerika
	(850.000) - (949.999)	Afrika
	(950.000) - (999.999)	Ozeane
1.	000.001 - 012.199	Identifizierung
	000.001 - 005.999	Autoren und besprochene Personen
	006.000 - 008.999	Farm der Veröffentlichung
	009.000 - 009.499	Publikations sprache
	009.500 - 009.999	Sprache der Zusammenfassung
	010.000 - 010.399	Erscheinungsland
	010.400 - 011.699	Beilagen zum Text
	011.700 - 012.199	Erscheinungsjahr
2.	012.200 - 013.999	Organisations-und Rechtsangelegenheiten
3.	014.000 - 014.999	Sprotliche Höhlenforschung
4.	015.000 - 016.999	Höhlennutzung
5.	017.000 - 019.999	Hohlenschutz
6.	020.000 - 199.999	Reserve
7.	200.000 - 399.999	Geräte, Instruments und ihr Gebrauch
8.	400.000 - 949.999	Wissenschaftliche Ergebnisse
	400.000 - 429.999	Archäologie
	430.000 - 449.999	Paläontologie
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Entwicklung Und Typologie Von Pseudokarst - Untergrundformen der Aussenflyschreise in Den Westkarpaten

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Im Gebiet der Mährisch-Schlesischen Beskyden (CSSR) und des Beskid Slanskiego, die ein Einheitsgebiet vomGesichtspunkt der Geographie und der Geologie im äusseren Flyschkreis der Westkarpaten bilden, werden schon mehrere Jahre Erforschungen über die Entstehung und Entwicklung der Untergrundformen von diesem Gebiet gemacht. Es ist nur noch zu bemerken, dass diese Entwicklung hängt mit den bekannten Karstprozessen nicht zasammen. Infolgedessen, dass die Oberfläachenmodulation, dir morphologische Durchläufe von unterirdischen pseudokarstlichen Formen, tektonisch-petrographische Bedingungen undgleichzeitige Dynamik von primären vertikalen Rissen verfolgt wurden, konnte man ein Diagramm der Entwicklung von den pseudokarstlichen Höhlen, die in den Flyschsandsteine herausgebildet wurden, bestimmen. Die unterirdischen Formen in Gebiet des äusseren Flyschkreis der Karpaten sind keine zufäligen Formen: wie ihre Typologie, Entwicklungsverwandschaft und geologische Homogenität beweist, muss man ihr Entstehen als ein Ergebnis der zweiten und dritten Phase von Tertiärentwicklung des ausseren Kreises von Westkarpaten ansehen. Eine weitere Entwicklung ist dann mit den Periglaziärvorgängen, (besonders im Pleistozän) und mit den gleichzeitigen Böschungsprozesse verbunden. Die Entwicklung der pseudokarstlichen Formen von mährisch-schlezischen Flyschen, die eine Bedingung in der Entstehung der terzären Flyschgeosynklinale hat. kann man vom Gesichtspunkt der Stadien von geologischen und zerstörenden Prozesse in drei Phasen unterteilen.

1. Die Entstehungphase von tektonischen Störungen.

Unter dem Einfluss von starken tektonischen Bewegungen und Sinken von mancher Gebiete, gebildeten Flyschgebirgskammes,wurden die oberen Flyschüberschiebungsrückenlinie der Magurordnung zerbrochen und deformiert durch die Systeme von Risse und Spalte, die sich unterschiedlich kreuzen und die beruhigende Höhe der äusseren Flyschgebirgskette von Westkarpaten tief zerstört haben. Auf dieser Weise sind die ganzen Systeme von Risse und Löse entstanden, die sich mit den heschichteten Flächen von sich gesetzen, kompakten, lehmigesienhaltigen, feinkörnigen Sandsteine, die an den gefügigen, tonhaltigen Zwischenschichten mit zeitweise vorkommenden Lagen von grogkörnigen Sandsteine liegen, kreuzen. Die entstandenen Löse und tektonischen Risse, dessen Richtung parallel mit dem Gebirrgsmassiv führte, eine wichtige Rolle für die weitere Entwicklung von pseudokarstlichen Formen in den Beskyden, gespiel haben.

2. Die Phase der aktiven Erweiterung von tektonischen Störungen und der Entwicklung von pseudokarstlichen ritzigen Höhlen

Die zweite Phase von der Entwicklung der unterirdischen pseudokarstlichen Formen verlauft in der Periode des jüngsten Pliozän und binnen der ganzen Periode von Pleistozän Die weitere Entwicklung und Erweiterung haben einige Faktoren aktivebeeinflusst`

a. Die Gravitationsverschiebung.
Die tief verletzten Formationen der Sandsteine sind stufenlos unter dem Einfluss von Gravitationseinwirkung zusammengestürtzt und zwar auf den schrägen Berabhänge und sie haben verbreitende Risse geschaffen, die weiter überdecken verrammelt durch zerbrochene Blöcke wurden, dessen Abspalterung ein Netz von den Löse leichter machte.

b. Eine intensive Frostverwitterung.
Das Gebiet des äusseren Flyschkreises befand sich an der Gränz des mit Eis bedeckten landes am Norden. Dieses Land ergriff das Gebiet von Beskyden und insebesonderes in den älteren Glaziälen bewirkte es ein Durchfrieren des verletzten Gesteines und eine fortlaufende Erweiterung von den Rissen, die in der ersten Phase entstanden sind. Auf die gleiche Weise wirkte auch das Wasser, das durch die terziären tektonischen Störungen durgedrungen ist und das bei dem glazialen Erfrieren eine Druckdestruktion und eine Modelierung von erweiterten Risse verursachte. Die Eislinsen, die in den erweiterten Horizontalrisse und in den geschichteten Flächen entstanden, wurden insbesonders in den Interglaziälen als Gleitflächen, über die die ganzen Felsblöcke und Massive abgefallen und verschoben sind, wirksam. Nach der Eisschmelze wurden die erweiterten Risse durch freigemachten Sandsteinbänke und Geröll vershüttet, die die Decken und in den tiefen Risse frei gelegten Etagen bildeten.

c. Eine struktuelle und litologische Präedisposition.
Die Anwesenheit von intergeschichteten Lettenzwischenschichten zwischen den Bänken und den Schichten von Flyschsandsteine bewirkte die Leichtigkeit und den Charakter der Bewegung von den Sandsteinbänke, welche über diese gefügige Unterlage rutschten und die entstandenen Risse überdeckten, oder einige Terrassenschwebendestufen die in die Flyschschsinten eingeschnitten wurden, bildeten. Die überwiegende horizontale und neigende Ablagerung von den Bänkenschichten hat den Charakter und die Richtung der Bewegung von Steinmassen bedingt. In den Stellen, wo sich die tektonischen Störungen und Risse kreuzen und verbinden entstanden unter der Einwirkung von allen Faktoren umfangreiche systeme von Rissgänge und grösseren Höhlen, dessen Böden mit dem Autochtonfeinschlag von den Sandsteinfelsen, mit den Lehme und mit dem Humus volgefüllt wurden.

3. Die Rezentphase von der Modellierung der pseudokarstlichen Risshöhlen

Die letzte Phase von der Modellierung der Morphologie bei den Risshöhlen in den Beskyden lauft binnen der ganzen Periode des Quartärs bis heutige Tage durch. Bei unserem Klima kozertriert sich der gleichzeitige pseudokarstliche Prozess auf die mechanische Zerstörung der gefügigen Konglomerate und der grobk-rnigen porösen Sandsteine, welche gleichzeitig die Lehme und den Splitt wegspülen. In den dynamischen Teilen und in den Teilen, die sich in der Hähe von Eingang und Oberfläche befinden, zeigt sich auch der Einfluss von klimatischen und Temperaturänderungen.

Als stärkste Rezäntfaktor wirkt dabei die Tätigketi und die Wirkung des Wassers, das an die schwach gekalkte Tonsteine herabfliesst. Diese Tonsteine bilden die Zwischenschichte und die Kitte, die sich zwischen den Sandsteinschichten befinden. Über diese so verletzten und freigemachten Gleitenflächen geben sich die frei gelagerten und eingekeilten Felsblöcke und Felsbanken in Bewegung.

Die Morphologie von den pseudokarstlichen Höhlen
Es gibt verschiedene Höhlen und Höhlensysteme. Bei diesem ~~Typ von pseudokarstlichen Formen überwiegen~~ gerade, risserweiterte Gänge, welche eine Länge von einigen Meter erreichen. Die Höhlen mit einem mehr komplizierten Bau, sind durch die Systeme von Risse und Dome, die sich verschiedenartig kreuzen und die eine Länge von 300bis 400 m erreichen, repräsentiert. (Zum Beispiel die Höhle "Cyrilka", die eine Länge von 320 m aufwiest, oder die Höhle "Vtrech kopcach" mit der Länge von 450m.) Bei den Risse, die in der vertikaler Richtung durchlaufen, überwiegen in den Karpatenflyschen so einige, die eine Tiefe von 70 m aufweisen, (zum Beispiel die Höhle "Knehynska" 1964 Jahr). Eine überhangende Terassenordnung und die eingekelten Felsblöcke geben den vertikalen pseudokarstlichen Lokalitäten einen Eindruck, dass sie in mehreren Stockwerke gelagert sind. Die tiefen erweiterten Risse bilden in diesen unterirdischen Formen einige Abgründe mit der Tiefe bis 14 m, (z.B. die Höhle, "knehynska", die Höhle "Malinowska") und die hohen Rissdome, welche auf den Hauptrichtungen von den tektonischen Störungen begründen sind. Die Form der Eingangsöffnungen und der Gänge ist analogisch. Die Öffnungen, in meisten Fällen haben sie eine Form von schmalen Mannlöcher oder Risse, befinden sich zwischen den freien Blöcke und führen in die horizontalen Gänge. Diese Partien weisen am meisten führen in die horizontalen Gänge. Diese Partien weisen am meisten einen verschiedenen Charakter und ist vonder Mächtigkeit der Flyschbänke abhängig. Die Rissgänge zeichnen sich durch die Regelmässigkeit und durch die rechteckige Kreuzung aus. Die Gänge, welch zwischen den abgestürzten Blöcke und Einstürze entstanden sind, weisen neinen unregelmässigen und chaotischen Charakter aus. Die Decken von dieser Gänge sin durch die monolitischen, überdeckten Sandsteinbänke oder durch die eingekelten Blöcke gebildet. Diese bilden auch oft die Scheidenwände und die Schwellen oder Stufen, welche eine verschieden Höhe aufweisen.

Die Sekundärformen
Alle pseudokarstlichen Lakalitäten in den Beskyden sind nur Primärformen. Die Sekundärformen kommen allgemein nicht auft. Wir treffen aber auch isolierte, unerherbliche Formen von der Sekundarverzierung. Es handelt sich um einige kleine Sandsteinstöcke mit der Länge von 5-10cm, die in der neuen Partie von der Höhle "Cyrilka" entdeckt wurden und um weitere hineinlaufenden Formen von der Sinterrinden und Spritzentragformen besonders in den

den Höhle von der mährischen Partie der Beskyden und des Gebirges Javorniky. Es sind die Warze-Sspringantragformen aus der Höhle "Pod karzatelnou", die hineinlaufenden Rinden in der Höhle "Lisci dira" in dem Berg "Mazak", oder 15 cm lange Flosse in der Höhle "Knehynska" bekannt. Sie entstanden am meisten als Ergebniss von dem chemischen Absetzen des Kalziumkarbonats, das in den Infiltrationswässer gelöst wurde und das von den Kalkenbindenmittel und von dem Zwischenschichten in den Flyschsandsteine ausgelaugt wurde. Nur die Stöcke in der Höhle "Cyrilka" stellen ein Ergebniss der klasischen Karstentwicklung und des reich gasättigen Wassers, das floss von den grobkornigenporösen Sandsteine herab, die mit Kalkitte ausgefüllt wurden, dar. Diese Formen finden wir auch in den Lokalitäten, welche näher der Insel von den Kalksteinen "Stramberk" liegen. (Diese Insel greift in den Rand der Flyschzone ein.)

Die Oberflächenformen von den Pseudokarstlichenrayons der Beskyden

Die Entstehung und die weitere Entwicklung der unterirdischen Pseudokarstformen änderten und denundierten auch das Oberflächenrelief. Die tektonischen Risse und später die Höhlen entstanden meistens an den Neigungbergabhänge an der südlichen und südöstlichen Seite in der Höhe von 1000 bis 1250 m. Nach dem Abschub der ganzen Flyschzonen, nach dem Entstehen von geöffneten Schluchten und Stufen, sind auch nach der Quartärplanierung von Lösse und Schutt im Terrain tiefe Stufen, Terrainvertiefungen, Terraindurchfälle und Frierschrotte geblieben. Manche von den Oberflächenformen des Flyschkreises erinnern durch ihre Formen und Funktionprozesse an die Karsteinbohrungen, welche sich über den engen Risse gestallten. Diese engen Risse ziehen des Niederschlagswasser, den Löss und die Lehme herab, die dann stufenweise dieselben verschlammen. Manche Einbohrungen entstanden auch über den Höhlenpartien, die nahe zu der Oberfläche gelagert sind und sie dienen dergleichen. Ihre Existenz bestätigen im Untergrund die Anschwemmungen von Lehme und Feinschotter sowie auch kleine Seen. Eine spezielle Form stellen kleine Sandsteinfelser, dar, welche über die Denudationsoberfläche bis in die Höhe von irgeneiner Meter steigen. Diese kleinen Felser sind hier in der Rolle eines Überrestes vonden bearbeiteten, gefügigen Schichten der Sandsteinschwellen und der blossen Bänke.

Die Oberflächenreste von den Quartär - Periglaziärvorgänge sind auch die Ketten von Sandsteinschwellen und von herabhängenden Felswände von der Höhe auch über 10 m, welche an den Kanten der Bergabhänge durch das Abbrechen der herabhängenden Flyschblöcke, durch die Erweiterung der Parallelrisse, welche mit dem Bergabhangabschub der nieder belegten Flyschschollen und ihrer allmählichen Denudation verbunden sind, entstanden. Eine typische Oberflächenform in der Flyschgebirgskette von Beskyden stellen umfangreiche Schutt - und Felsblockbergabhänge, die durch die Einwirkung von Gletscher entstanden, dar. Solche zahlreiche Felsoberflächenformen werden aber meistens nicht durch die Unterirdischen Systeme Begleitet.

Die Möglichkeit einer weiteren Erforschung

Durch das Verfolgen irgendeiner Begleitoberflächenformen der pseudokarstlichen Lokalitäten und durch ihres Verallgemeinern für den ganzen äusseren Flyschumkreis der Karpaten kann man solche Lokalitäten bestimmen, wo wir eine Existenz der unterirdischen Formenvoraussetzen können. Trotzdem kann man nur schwierig darüber sprachen, dass eine ganze Reihe von typischen pseudokarstlichen Oberflächenerscheinunger existiert, welche die unterirdischen Systeme, wie es in den Karstgebieten ist, (z.B. Einbohrungen, Hervorquellen, Abgründe) vorausbestimmen würde. Im Rahmen der praktischen Erforschungen und der Ausnutzungarbeiten im Gebiet von Beskyden wurden die Erkenntnisse, die aus dem Verfolgen von Terrainversenkungen, von Bergabhängeausgleiten, von Fristschrotte und von Felsenschwelle und Riefen hervorgegangen sin, ausgenutzt. Dessen Ergebnis kann man in der Entdeckung von drei Höhlen "Na Zaryjich", einiger Höhlen unter der Bergspitze "Knehyna", einer Höhle "V Stolovie" u.a. wahrnehmen. Weitere Aufschlussarbeiten in den abgesteckten Lokalitäten folgen: es handelt sich um die Gebiete von Schlezischen und Slowakischen Beskyden.

Im Verlauf von diesen Arbeiten kann man nur schwierig einen systematischen Übergang der Oberflächenformen in die Unterirdischen Formen, oder eine logische, angebundene Anordnung des Verlaufes von den unterirdischen Lokalitäten annehmen. Der Verlauf und des Anbinden sind meistens zufällig und chaotisch, wie es auch der Fall von der Kompaktheit der Wände und der Decken in den Rissgänge ist. Die Möglichketi einer Durchdringung indie unterirdischen Teile kann man meistens an den höhergelegten Kanten der abgetrennten Gebirggsketten oder an Ränder von kompakten Felswänder, die zum grössten Teil schon mit denudierter Oberfläche und Löss bedeckt sind, über der Terrainversenkung oder über den Rillen voraussetzen. In allen Fällen sind aber diejenigen Teile, welche eine Verbindung mit der Oberfläche darstellen, mit Steine und schutt zugedeckt.

Ähnliche Voraussetzungen und Dispositionen über eine Existänz von pseudokarstlichen Höhlen, welche durch die beschriebene Vorgänge entstanden, weisen auch die Flyschgebiete der Oskarpaten an der Westukraine auf. Dort sind die Gravitations- und Frostverwitterte Prozesse unter derselben petrographischen, geomorphologischen und tektonischen Bedingungen durchgelaufen.

Schlusswort

Das Begiet der Mährisch-Schläzischen Beskyden und des Beskids Slonskiego bilden einen ganzen Westrand des äusseren Flyschumkreises der Karpaten, der eine eigene geologische und tektonische Entwicklung in dem Zyklus von der Alpinfaltenbildung aufweist. Diese Entwicklung had diesem Gebiet eine eigene geomorphologische Struktur und des Oberflächenerelief gegeben. In der Abhüngigketi and den Prozessen bei der Entwicklung von der Magurschichtenfolge der Godulsandsteine und der Flyschen, sind in dem ganzen Gebiet der Beskyden die tektonisch-verschüttenden unterirdischen Risse und Höhlen, die sich infolgedessen, dass die periglaziären Vorgänge waren, durchgelaufen waren, in die interirdischen Höhlen und Systeme, welche in allen verfolgten Punkten eine geomorphologische Verwandschaft und einen gleichartigen Entwicklungsdurchlauf, entwickelt haben, entstanden. Ausser der Überinstimmung von der morphologischen Entwicklung, von dem petrographischen Bau, von den mikroklimatischen und hydrologischen Prozesse, weisen die pseudokarstlichen Höhlen im hanzen Gebiet weitere gemeinsame Zeichen auf. Die überwiegende Mehrheit der Hauptrichtungen von den Risse und Gänge wurde in der Richtung 90-270° gebildet unddie Mehrheit von den bisher bekannten Lokalitäten nahm seinen Ursprung an den südlichen oder südöstlichen Bergabhänge. In allen Fällen treffen wir sie unter dem Niveau der Bergspitze in der Seehöhe von 1000 und 1250 meter. Auch die Hpufigkeit der Höhlenlokalitäten, (heute kennen wir 33 Höhlen mit der Gesamtlänge ihrer Gänge von 1900 meter und haben wir sie beschrieben', und die Dislokation über einem erheblichen Gebiet des ganzen äusseren Umkreises von den Westkarpten stellt einen Beleg über eine typische unterir dische Erscheinung für diese geographische Lage dar. Es handelt sich also nicht nur um örtliche und zafälige Formen, sondern um typische Formen für das Begiet des äusseren Umkreises von Westkarpaten, die durch die petrographische, geomorphologische und tektonische Entwicklung gegeben sind, bei der auch die Gravitations - Frostverwitterungs- und Böschungsprozesse ihre Wirkung ausgeübt haben. Man kan also auf dieser Basis in der praktischen Speleologie neue Entdeckungen sowie auch das Durchdringen in die grösseren Riss- Verschüttungs-Pseudokarstsystems erwarten.

Hoehlenforschung in Der Schweitz

Urs Widmer

Abstract

1. Information is given on the topographic structure of Switzerland, which is dominated by the two mountain ranges of the Jura and the Alps, as well as on the location of the main caves in the karst areas of the subalpine region (Voralpen) and the Jura.
2. The technique of caving; single rope methods are used (chest Jümar and hand Jümar with foot-slings).
3. Beginning with the prehistorical speleology of the 19th century and the discovery of the Hölloch in 1875 a historic survey is presented, honoring the achievements of the early 2+th century, that led directly to the foundation of the SSS.
4. The Swiss Speleological Society (SSS), its organization, its tasks and activities.
5. Invitation to foreign cavers to contact local groups, to ensure efficient and friendly co-operation.

Zusammenfassung

1. Orientierung über die topographische Struktur der Schweiz, die bestimmt wird durch die beiden Gebirgszüge des Juras und der Alpen, sowie über die Lage einiger wesentlicher Höhlen in den Karstgebieten des Juras und der Voralpen.
2. Skizzierung der Technik der Höhlenbefahrung. Schöchte werden vorwiegend an Einfachseilen mit Seilklemmen befahren.
3. Beginnend mit der prühistorischen Höhlenforschung des 19. Jahrhunderts und der Entdeckung des Höllochs (1875) führt ein Ueberblick von den Leistungen des frühen 20. Jahrhunderts zur Gründung der SGH!
4. Die Schweizerische Gesellschaft für Höhlenforschung (SGH), ihr Aufbau, ihre Aufgaben und Aktivitäten.
5. Einladung an die ausländischen Forscher zu einer wirkungsvollen und freudlichen Zusammenarbeit.

1. Lage und Charakteristik der schweizerischen Karstgebiete

Die Schweiz liegt mitten in Europa, zwischen Frankreich, Deutschland, Oesterreich und Italien. Ein grosser Teil des Landes wird vom Hochgebirge, den Alpen eingenommen. Im Norden durchzieht der Jura die Schweiz und setzt sich nach Frankreich fort. Das Mittelland dazwischen ist ein flaches bis sanft hügeliges Gebiet mit Moränenuntergrund.

Während die Zentralalpen nicht aus verkarstungsfähigem Gestein bestehen, sind die nördlichen und südlichen Voralpen vorwiegend aus Kalkdecken aufgebaut. Hier finden sich verschiedenste Karstgebiete. Im Osten schliessen die wichtigen österreichischen Höhlenregionen an.

Der Jura enthält als ausgesprochenes Kalkgebirge zahlreiche Höhlen, die aber mit wenigen Ausnahmen nicht sehr bedeutend sind.

Im östlichen Schweizerjura herrschen tafelförmige Hochflächen vor, die durch Kastentäler voneinander gestrennt sind. Charkteristisch für die übrigen Teile des Juras sind die langgezogenen Rücken, durchschnitten von kurzen Quertülern, den Klusen.

Zahlreiche Balmen, Dolinen, Ponors und blinde Täler sind die auffallendsten Oberflächenformen, Nachkte Karrenfelder sind im Jura selten. Der grüne Karst dient vorwiegend als Wald- oder Weideland.

Höhlen mit kurzen Schächten, Canyongängen, fortgeschrittener Inkasion und recht grossem Tropfsteinschmuck sind vorherrschend. Viele Höhlen sind nicht mehr aktiv. Die Gänge sind teilweise sehr eng und wechseln ihre Richtung entsprechend zweier tektonischer Hauptrichtungen.

Die Jurahöhlen haben Tiefen bis zu 180 m und Längen bis zu 1.5 km. Die grossen Ausnahmen sind das Nidlenloch mit einer Tiefe von 414 m, der Gouffre du Petit-Pré (389 m) und die Grotte de Milandre mit 11 km Gesamtlänge.

Milandre ist zugleich eine der wenigen Flusshöhlen der Schweiz. In einer weiteren, der Orbe-Quelle, wurden vor kurzem durch Tauchvorstösse neue Gänge erschlossen.

Im Jura werden heute kaum noch neue Höhle entdeckt. Die Forschung besteht darin, die einzelnen Objekte zu vermessen und zu inventarisieren. Für Teilgebiete des Juras sind Höhlen entdeckt. Die Forschung besteht darin, die einzelnen Objekte zu vermessen und zu inventarisieren. Für Teilgebiete des Juras sind Höhlenkataster in Bearbeitung oder liegen bereits publiziert vor.

Im Gegensatz dazu ist die Höhlenforschung in den Voralpen in vollem Gang. Der alpine Karst entstand in Schichten, die stark gefaltet, gebrochen und umgeworfen wurden. Das rauhe Gebirgsklima und auch die Gletscherüberdeckung führten zur Entstehung von ausgedehnten öden Karrenfeldern. Die Besonderheiten des alpinen Karstes schaffen auch besondere Probleme für den Forscher. Die Eingänge der meisten Alpenhöhlen sind nicht allzu leicht erreichbar und während vieler Monate schneebedeckt. Sehr viele Schächte sind nach wenigen Metern verstürzt, sodass der Zugang zu tieferliegenden Systemen erzwungen werden muss.

Das ausgedehnteste Karstgebiet der nördlichen schweizerischen Voralpen finden wir zwischen Linthtal und Urnersee; hier erstreckt sich als bekannteste Höhle das Hölloch im Muotatal mit 140 km Länge und 856 m Höhendifferenz. Oestlich davon wurde vor wenigen Jahren der Schyzerschacht entdeckt; sein Eingang liegt fast 1000 m höher als der Höllocheingang. Er bildet einen Hauptwasserzubringer des Höllochs, von dessen hintersten Regionen er kaum 200 m entfernt ist. Es ist allerdings nicht abzusehen, ob eine begehbare Verbindung gefunden werden kann, da dazwischen eine tektonische Störungszone liegt. In der unmittelbaren Umgebung liegt der Discoschacht und weitere Objekte, deren Erforschung noch kaum begonnen hat. Eine Verbindung von Discoschacht - Schwyzerschacht - Hölloch ergäbe ein System mit 1400 m Höhenunterschied.

Oestlich dieser Region finden wir in der Nordostschweiz Karst in der Sulzfluh, im Alpstein und in dem Churfirsten; dies bergen mehrere tiefe Schachthöhle, einige davon weisen Direktschächte von über 100 m auf (z.B. Wart-Donnerloch 176 m, Köbelischöhle 154 m/ 367 m Gesamttiefe). In den letzten Jahren wurden verschiedene Schächte zum Selunhöhlensystem zusammengeschlossen (2.8 km Länge, 278 m Höhendifferenz). Das Seichbergloch besitzt trotz einer Tiefe von 446 m keine wesentlichen Schächte. Unterhalb der Churfirsten tritt die Rinquelle aus, die durch Tauchexpeditionen auf 1.9 km erkundet werden konnte.

In den luzerner und berner Voralpen liegen Schrattenfluh (Reseau des Lagopedes 4.2 km / 478 me), Hohgant und Siebenhengste. Das Reseau der Siebenhengste ist ein weit verzweigtes Netz mit 840 m Höhendifferenz: die verschiedenen Forschungsteams hängen laufend neue Karrenschächte daran und vermassen bisher 40 km Gänge. In unmittelbarer Umgebung liegt das Faustloch (4.5 km / 700 m) etwas weiter entfernt der Bärenschacht (1.2 km / 565 m) und die Beatushöhle (8.4 km / 312 m). In letzter Zeit wurde auch die Abklärung der unzähligen weiteren Schächte in Angriff genommen, wobei mehrere vielversprechende Objekte gefunden wurden (Haglätsch, Määnderhöhle, K2). Die ganze Region von der Schrattenfluh bis Siebenhengste wird unterirdisch entwässert: Fäbeversuche bewiessen den Zusammenhang mit einer Unterwasserquelle im Thunersee (Bätterich -60m)

Nach Westen setzen sich die nördlichen Voralpen in Stockhorn - und Sanetschgebiet)Reseau du Potteux 7.5 km / 250 m) fort. Der Karst der freiburger Alpen liegt hoch und unzugänglich: er wird erst seit kurzem untersucht und gilt als sehr aussichtsreich (Gouffre des Morteys -328m). Im Gebiet bei Leysin wurden vor einem Jahr die Grotte Froide an den seit langem bekannten Gouffre Chevrier angehängt (3.7 km / 6+7 m/.

Am Karst der südlichen Voralpen hat die Schweiz leider nur einen sehr geringen Anteil, ganz im Gegensatz zu Italien.

Der Flächenanteil an verkarstungsfähigem Gestein in der Schweiz beträgt ca 20%. Wenn auch die Karstgebiete selbst nicht sehr dicht besiedelt sind, so beziehen doch etwa 15% der Schweizerbevölkerung ihr Trinkwasser aus

Karstwasserreserven. Hier stellt sich der Höhlenforschung eine bedeutende praktische Aufgabe: die Reinhaltung dieser Gewässer zu überwachen.

In der Schweiz liegen fast alle Höhlen im Kalk. Eine Ausnahme bildet die Grotte de Saint-Leonard (im Wallis), eine Gipshöhle mit einem grossen unterirdischen See (230 m lang, 15 m breit); sie ist als Schauhöhle zugänglich. Weitere Schauhöhlen befinden sich im Jura und den Voralpen: meist sind nur recht kleine Teile Höhlen touristisch eingerichtet, die schöneren Partien dem Forscher vorbehalten.

2. Die Technik der Höhlenbefahrung

Wurden noch vor 10 Jahren bei der Befahrung von Schachthöhlen Strickleitern verwendet, so hat seither die französische Vertikalbefahrungstechnik auch in der Schweiz eingebürgert; seit 5 Hahren hat sich die Einfachseilmethode durchgesetzt. Die Einrichtung erfolgt fast ausschliesslich mit Spits, da die Verhöltnisse andere Verankerungen selten zulassen. Die Morphologie der Schächte verlangt zumeist viele Umhängestellen; deshalb ist die 'rope walker' Methode ungeeignet. Wir benützen einen am Sitsgurt fixierten Jümar und einen Hand jümar mit Fussschlingen. Leitern werden nur in speziellen Fällen eingesetzt, zum Beispiel als permanente Einrichtung nach engen Canyonstrecken. Die zumeist dreckigen und nasskalten schweizer Höhlen fordern eine warme Bekleidung: isolierende Unterziehkombis, PVC Anzüge, Gummistiefel, in extremen Fällen Latex - oder sogar Neoprenanzüge Durch die Besonderheiten des Höllochs - tiefliegender Eingang und viele aufsteigende Forsetzungen entwickelten sich Kletterstangenmethoden für die Bezwingung der Schlote. Aufgrund der ausserordentlichen Ausdehnung wurde die Benützung von Biwaks zur Gewohneheit: Aufenthalte von einer Woche sind hier nichts ungewöhliches. Zumeist arbeiten mehrere kleine, 2-3 Mann/Frau starke Teams parallel.

Die Forschungsmethoden der verschieden höhlenforschenden Vereinen sind sehr unterschiedlich, Gesamtschweizerisch ist man jedoch bestrebt, Höhlen- und Karstphänomene möglichst umfassend zu untersuchen. Die Schweizerische Gesellschaft für Hohlenforschung bemüht sich, ihren Mitgliedern durch Kurse die Grundlagen der Speläologie, sowie die neuesten Erfahrungen der Vorstosstechniken zu vermitteln.

Das Höhlentauchen hat sich in den letztens 5 Jahren stark entwickelt, wobei die aktiven Höhlentaucher immer noch eine sehr kleine Gruppe ausmachen. Unter ihnen haben sich zwei Interessentenkreise herausgebildet, die einen betrachten Siphons als Hürden für die dahinterliegenden Gänge, die andern beschäftigen sich nur mit Siphonbefahrung. Im Gegensatz zu Höhlensystemen in andern Löndern, wo nach Ueberwindung von Siphons weitere bedeutende Fortsetzungen erschlossen werden, sind in der Schweiz die Chancen für erfolgreiche Vorstösse erfahrungsgemäss gering.

Neben den Vorstössen in Neuland und dessen Vermessung werden von einzelnen, entsprechend qualifizierten Forschern auch biospeläologische und karsthydrologische Untersuchungen gemacht. Neuerdings bemühen sich verschiedene junge Zoologen um eine Bestandesaufnahme der vielerorts vom Aussterben bedrohten Fledermausarten. In ausgewählten Höhlen ist die Höhlenfauna studiert worden.

Vielerorts sind Wassermarkierungen durchgeführt worden, an einzelnen Karstquellen wurden permanente Messgeräte installiert. Von Mitarbeitern des Hydrogeolgischen Institus der Universität Neuenburg werden geophysikalische Methoden (Seismik und Elektrik) zur Lokalisierung potentieller Höhlenstandorte angewendet. In den letzten Jahren wurde ein umfassendes Computersystem zur Auswertung der Höhlenvermessung entwickelt. Die Pläne der grossen Netzwerke (Hölloch, Siebenhengste) können damit laufend auf dem neusten Stand gehalten werden.

3. Geschichtliches

Die Höhlenforschung der Schweiz ist im Vergleich zu andern europäischen Ländern recht jung. Im Volksglauben spielten Höhlen zwar schon von alters her eine Rolle und werden in vielen Sagen und Legenden erwähnt. Erste Berichte über Höhlenbegehungen stammen aber erst aus dem 18. Jahrhundert.
Ende 19. Jahrhundert begannen die urgeschichtlichen Forschungen in Höhlen, welche den Steinzeitmenschen Schutz boten (Wildkirchli, Höhlen im Simmental und Jura). Die prähistorische Forschung bewegte sich jedoch nur in den Eingangspartien der Höhlen. Das weitere Vordingen ins Berginnere begann ers im 20. Jahrhundert. Weit über die Landesgrenzen hinaus bekannt wurde das 1875 entdeckte Hölloch im Muotatal. Zu dessen Erforschung bildete sich, ausgehend vom Schweizerischen Alpenclub, die AGH (Arbeitsgemeinschaft Hölloch). Von 1955-1967 galt das Hölloch als die längste erforschte Höhle der Welt.

Auch im Jura begannen sich verschiedene Forscher für die Speläologie zu interessieren, meist ausgehend vom weitverzweigten Karstwassernetz (z.B. Ajoie). Die Jurahöhle Nidlenloch war während 14 Jahren (1909-1923) mit 394 m Tiefe die tiefste bekannte Höhle der Welt.

1939 wurde in Genf die Schweizerische Gesellschaft fär Höhlenforschung (SGH)/ Soiete Suisse de Speleologie (SSS) gegründet. In der Folge schlossen sich verschiedene Höhlenforschervereine dieser gesamtschweizerischen Organisation an, oder es wurden regionale SGH - Sektionen gegründet. Neben dieser grössten Gemeinschaft von Höhlenforschern bestehen in der Schweiz bis heute zahlreiche unabhängige Vereine und Gruppen, die sich häufig auf die Erforschung eines einzelnen Objektes konzentrieren.

In dieser Vielfalt der Bemühungen, die Aussenstehenden als Zersplitterung erscheinen könnte, spiegelt sich eine wesentliche schweizerische Eigenart, der Föderalismus. Sie ist eine tragende Komponente der politischen Schweiz, der Verbindung von 26 souveränen Kantonen mit 4 Landessprachen, die ihrerseits aus zahlreichen Dialekten bestehen.

4. Schweizerische Gesellschaft für Höhlenforschung (SGH)

Ein Zentralvorstand leitet die SGH, die einerseits aus Lokalvereinen, den Sektionen, sowie wenigen Einzelmitgliedern und andererseits aus verschiedenen Kommissionen besteht. Kommissionen sind für spezielle Aufgaben gebildet worden, zum Beispiel für die Publikation der Zeitschrift "Stalactite" und allfälliger Kongressakten, das Archivieren der Forschungsresultate, die Durchführung von Weiterbildungskursen, die Organisation des Rettungswesens, die Betreuung wissenschaftlicher Projekte und den Schutz von Höhlen und Karstlandschaften. Die SGH führt auch eine Zentralbibliothek, die unter anderm in Auftrag der U.I.S. das Bulletin bibliographique speleologique (Speleological Abstracts) herausgibt.

Die Schweizerische Gesellschaft für Höhlenforschung hat etwa 800 Mitglieder, die sich auf über 30 Sektionen verteilen. Obwohl diese Lokalvereine autonom sind und häufig ihre eigenen Forschungsgebiete haben, zeigt die neuste Entwicklung, dass sich vermehrt guttrainierte Forscher aus verschiedenen Sektionen zusammenschliessen, um gemeinsam ein grösseres Projekt zu verwirklichen. Für die Untersuchung einzelner Regionen wurden so spezielle Arbeitsgruppen gebildet. Zum Beispiel koordiniert die "Höhlenforschungsgemeinschaft Region Hohgant" (HGH) die internationale Zusammenarbeit in der Gegend Hohgant-Siebenhengste.

5. Schlussgedanken

Die schweizerischen Karstgebiete enthalten Höhlen in verschiedensten Ausprägungen und stellen dankbare Ziele für ausländische Teams dar. Wir heissen Besucher gerne willkommen, seien es nun Forscher oder Touristen. Auch wir erweitern gerne unsern Horizont und lassen uns im Ausland von ungewohnten Karsterscheinungen faszinieren. Dabei finden wir es unerlässlich, solche Ausflüge mit unsern Gastgebern zu planen. Immer wieder konnten wir so von den Erfahrungen anderer Teams lernen und uns als Forscher orientieren.

Deshalb bitten wir auch unsere Gäste: sucht kameradschaftlichen Kontakt und Susammenarbeit, damit Missverständnisse ausbleiben. Die Schweiz soll kein El Dorado für Speläisten werden, die in energischen Handstreichen Höhlen abhaken wollen. Wir möchten nicht in Zukunft Höhlen revidieren, die nachlässig erforscht sind, well auf publikumswirksame Resultate erpichte Höhlensportler rasch zum vermeintlich tiefsten Punkt vorstiessen. Den seriösen Touristen ebnen wir gerne die Wege zu den interessantesten Zielen, die Forscher finden die zu erfolgreicher Arbeit notwendige Integration in unseren Gruppen. Nur so kommen wir alle zu einer optimalen Auswertung unserer ZEIT UND Anstrengung.

In diesen Sinne hoffen wir bald einige Besucher bei uns begrüssen zu dürfen, welche unsere Karstlandschaften achten und mithelfen wollen, diese zu erhalten.

Erhaltungsprobleme in Eishöhlen

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Abstract

In the northern Alps there are numerous caves in which ice can be found the whole year over. Some of these are open to the public. The majority of them are so called dynamic ice caves having at least two entrances.

With the example of the Eisriesenwelt (Salsburg, Austria) some special problems appearing in this ice cave are dealt with in this paper.

In general, protection of stalagmites and stalactites and other cave substance against wanton or careless destruction is the main task of cave protection, as such destructions cannot be repaired by nature during one or two more human generations.

In ice caves however there is a continuous alternation of the ice not only according to the season but also from year to year.

Ice cave protection should therefore cover all tasks to maintain the natural rhythm of ice in the cave.

The term "dynamic ice cave" in contrast to the term "static ice cave" was originally chosen due to considerable natural cave ventilation being responsible for ice alternation within the cave.

Consequences and explorations resulting from human interference an ice alteration are discussed.

Results of explorations over a period of more than 100 years in this cave, which was opened to the public more than 60 years ago, permit to give a report on experiences made there. In other concerns it is referred to further exploration. It is made clear that maintenance of cave temperature, cave ventilation and water flow are of decisive importance.

The paper further deals with questions of construction and maintenance of passages for public and the effect of visits on large scale on the life of ice and the cleanliness within the cave.

Finally questions of suitable cave illumination are discussed.

Zusammenfassung

In den nördlichen Kalkalpen finden sich zahlreiche Höhlen in denen ganzjährig Eis anzutreffen ist. Mehrere dieser Eishöhlen sind als Schauhöhlen erschlossen. Überwiegend handelt es sich hiebe um sogenannte dynamische Eishöhlen, die über mindestens zwei Tagöffnungen verfügen. Am Beispiel der Schauhöhle Eisriesenwelt (Salsburg, Österreich) werden die auftretenden Sonderprobleme behandelt.

Im allgemeinen stellt der Schutz von Tropfsteinen und des sonstigen Höhleninhaltes vor mutwilliger oder fahrlässiger Zerstörung die Hauptaufgabe des Höhlenschutzes dar, da solche Beschädigungen in den Zeiträumen eines oder mehrerer meschlicher Leben von der Natur nicht wieder gutgemacht werden. In Eishöhlen herrscht jedoch ein dauernder Wechsel sowohl nach derEishöhle muß sich daher darauf erstrecken, den naturgegebenen Rhythmus der laufenden Veränderungen zu erhalten. Wurde die Bezeichnung dynamische Eishöhle - zum Unterschied von statischer Eishöhle - ursprünglich wegen der beträchtlichen aber auch im Bereich der Luftbewegung gewählt, so kann die Dynamik auch im Bereich der Änderungen des Höhleneises festgestellt werden. Folgen und Forschungen, die sich aus menschlichen Eingriffen in den Bewegungsablauf ergeben, werden untersucht. Forschungsergebnisse aus einem Zeitraum von über 100 Jahren - hievon über 60 Jahren in Schauhöhlen - erblauben es, gesicherte Erfahrungsberichte zu geben, wogenen in manchen Belangen auf noch durchzuführende For schungsarbeit verwiesen werden muß.

Ohne weiters verständlich ist, daß die Erhaltung der Temperaturverhältnisse, der Windführung und des Wasserhaushaltes von entscheidender Bedutung ist. Im Vortrag wird weiters auf Fragen des Einbaus und der Erhaltung von Erschließungsanlagen, Auswirkung des Massenbesuches auf den Bestand der Eisfiguren und die Sauberkeit der Höhle hingewiesen. Abschließend werden Fragen der angemessenen Beleuchtung erörtert.

1. Situation

Die Eisriesenwelt im Tennengebirge bei Werfen, ca. 40 km südlich von Salsburg ist seit 1879 in der Literatur bekannt und seit 1920 als Schauhöhle in Betrieb. Der Haupteingang liegt 1.640 m über dem Meeresspiegel und zwar ca. 1.100 m über dem Salzachtal. Zahlreiche Schächte, die bisher allerdings noch nicht befahren werden konnte, stellen die Verbindung mit der rund 500 m höher gelegenen Kalkhochfläche dar.

Bekanntlich basiert das Prinzip der dynamischen Eishöhle auf folgenden Grundlagen:

Die Temperaturen in der Höhle schwanken nur gering um den Gefrierpunkt. Im Sommer liegen die Außentemperaturen westlich darüber. Die relativ kältere und daher schwerere Höhlenluft zieht daher durch den Haupteingang ab. Die von oben angesaugte Luft durchströmt die Schächte und einen Großteil der Höhle, wird dort abgekühlt und erreicht den Eisteil bereits ohne wesentliche Wärmeenergien, sodaß as erst in den Monaten Juli und August zum Abschmelzen der kleinen Eisfiguren kommt. Ab Oktober sinken die Außentemperaturen zumindest teilweise wieder unter dem Gefrierpunkt. Dies führt zu einer Umkehr der Wetterbewegung mit dem Erfolg, daß nunmehr die kalte Luft beim Höhlenteil abkühlt. Das Sohin bis zum Frühjahr unterkühlte Gestein stellt die ideale Voraussetzung für die Erneuerung der Eisbildung durch eindringendes Schmelzwasser dar.

2. Erschließung

Ohne Eingriff in die natürlich entwickelten Gegebenheiten ist eine Erschließung nicht möglich. Derzeit besuchen rund 130.000 Personen die Höhle. Die Jahresfrequenz entspricht somit der 4-fachen Einwohnerzahl der Tagungsstadt. Um diesen Verkehrsstrom zu bewältigen, mußte vom Talboden ungefähr bis zur halben Höhe eine schmale Bergstraße angelet werden. Die restlichen 500 m Höhenunterschied überwindet seit 1955 eine Seilbahn. Das Schutzhaus, das nahe dem Höhleneingang liegt, konnte vis vor 25 Jahren nur in einem 2-3 stündigen Fußmarsch erreicht werden. Einen nicht unbeträchtlichen Eingriff in die Natur stellt eine Lawinengalerie unmittelbar vor dem Eingang dar. Diese erwies sich als notwendig, weil auch bei schönem Wetter immer wieder Steinschlag auftritt. Es kommt aber auch während der Betriebszeit vom Mai bis Oktober mitunter zu Schneefällen, die eine akute Lawinengfahr brigen. In der Höhle selbst konnte mit relativ geringen Änderungen der natürlichen Verhältnisse das Auslangen gefunden werden. Für die Weganlagen wurde überwiegend Holz verwendet, die an Steilstellenmittels Rohrgeländer gesichert sind. In der Eisriesenwelt erfolgt die Beleuchtung durch Karbidlampen, die en die Besucher ausgefolgt werden und entzündet der Führer an besonders attraktiven Punkten ein hell euchtendes Magnesiumband. Besonders durch diese Art der Beleuchtung unterscheidnet sich die Eisriesenwelt von der zweiten großen österreichischen Eishöhle, der Dachsteineishöhle.

3. Auswirkungen

3.1. Die Einbauten selbst (Bretter, Geländer) haben auf den Eishaushalt keinen nennenswerten Einfluß ausgeübt. Weder ist im Bereich der Wage eine besondere Zunahme noch ein größeres Abschmelzen des Eises feststellbar. Diese Festellung gilt allerdings nur mit einer einzigen Ausnahme: Circa 1930 hatte man zum Schutz der Besucher vor herabfallenden Eisteilen aus Stahlseilen ein Netz quer durch die Höhle angebracht. Dieses Netz hatte eine Breite von circa 20 m und schloß den Höhlenraum auch in seiner gesamten Höhe bis zu rund 5 m ab. Im Bereich dieses Netzes kam es zu einer außerordentlich verstärkten Eisbildung, sodaß nach wenigen

Jahren der gesamte Hohlraum, mit Ausnahme des künstlich offengehaltenen Wegbereiches, abgeschlossen war. In der dahinter gelegenen Hymirhalle strieg der Eisboden um rund 10 m an. Inzwischen wurde das Gitter entfernt und kommt es zu keinem weiteren ungewöhlichen Ansteigen des Eises.

Der Bretterweg war vorerst so konstruiert, daß der Belag bei Schwankungen der Eishöhe entsprechend gehoben oder gesenkt werden konnte. Dies erforderte lange Geländersäulen, die optisch störten. Nach mehrjähriger Erfahrung konnte festgestellt werden, daß die Eisschwankungen innerhalb des Jahres völlig unerheblich sind. Nur an manchen Stellen schmolz während der Sommermonate weniger Eis ab, als in Frühjahr aufgebaut wurde. Insoweit dies die Gefahr der Beeinträchtigung der Benätzbarkeit der Wege mit sich barachte, konnte durch ganz gerinfügige Maßnahmen, wie die Anlage von kurzen Gräben auch hier eine weitgehend konstante Situation geschaffen werden. Die nunmehr in gesamten Schauhöhlenbereich angebrachten festen Einbauten stellen nicht nur eine beträchtliche Erhöhung der Sicherheit, sondern auch eine optisch westlich günstigere Wirkung dar.

Wettertür

Im Rahmen der Ausführungen zur Situation wurde bereits erwähnt, daß die Abschmelzwirkung des Höhlenwindes im Sommer nicht allzugroß ist, weil die Luft am Weg durch die Schächte bis in die Luft am Weg durch die Schächte bie in die Eingangsnähe viel Wärme verliert. Der starke Wind an Engstellen wurde von Besuchern als unangenehm empfunden. Eine Wettertüre im Bereich des Einganges hat die Luftzirkulation wesentlich herabgesetzt. Man glaube hiedurch, als Nebenwirkung eine bessere Speicherung der winterlichen Kälte über die Sommermonate zu erreichen. Eine derartige Wirkung konnte jedoch nich festgestellt werden. Vielmehr dürfte die durch den Höhlenbesuch der Höhle zugeführte Wärme den Konservierungseffekt zumindest aufgehoben haben. Die vorhandene Wettertüre verschließt daher nunmehr den Haupteingang nicht völlig, sondern führt lediglich zu einer gewissen Bremswirkung und somit Verminderung der Lufgeschwindigkeit.

3.2 Wärmeentwicklung. Bei sommerlichen Hochbetrieb besuchen täglich circa 2.000 Personen die Höhle. Es entspricht dies circa 30 - 40 Führungsgruppen. Je Gruppe kommen 10 Karbidlampen zur Verteilung. Bei einer Aufenthaltsdauer von circa 1 1/2 Stunden ergibt sich daher eine Funktionsdauer in der Größenordnung von rund 500 Lampenstunden pro Tag. Dies entspricht einer kontinuierlichen Erwär mung durch das Brennen von 20 ununterbrochen in Betrieb befindlichen Karbidlampen, wobei sich bei der Verwendung von 14 l Brenner ein theoretischer Wert von circa 4 KW feststellen läßt. Die Wärmeentwicklung in ähnlicher Größenordnung dürfte durch das Abbrennen der Magnesiumbeleuchtung entstehen. Schließlich ist auch die Wärmeastrahlung der erwähnten 2000 Besucher zu berucksichtigen, die rechnerisch ebenfalls in der Größenordnung von 10 KW über den Tag verteilt, angenommen werden kann. Zusammen ergibt sich somit während der Hauptbetriebszeit eine tägliche Wärmezufuhr in der Görßenordnung zwischen 10 und 20 KW kontinuierlich. Diese nicht unbeträchtlichen Energien haben in der Eisriesenwelt jedoch im Großen und Ganzen zu keinen einwandfrei erfaßbaren Einflüssen auf die Eisbildung geführt. Die erwähnte Luftbewegung ist offenbar in der Lage, diese Energien ohne weiteres absuführen.

Nicht mit Sicherheit kann ausgeschlossen werden, daß durch den Besuch der Zeitpunkt zwischen der Frost - und Tauperiode etwas verschoben wird. Dieser Zeitpunkt wird aber bereits durch zahlreiche natürliche Vorgänge, die in ihrer Komplexität nur schwer erfaßbar sind, wesentlich beeinflußt. Da beispielsweise die Auswirkung des Verlaufes der Temperaturkuve und der Verteilung und die Menge des Niederschlages auch in nicht erschlossenen Höhlen bisher nicht eindeutig erfaßt wurden, können dezeit auf Schauhöhlen bezughabende Feststellungen nicht getroffen werden.

Lediglich bei bestimmten Eiskleinformen, wie insbesondere beim Rauhreif kann in einzelnen Extremsituationen ein Einfluß des Besuches eindeutig festgestellt werden. In der Eisriesenwelt herrscht der größte Besucherandrang bei schlechtem Wetter, wenn sonstige Ausflüge ins Hochgebirge oder zu den Badeseen sich nicht lohnen. Da aber an solchen Tagen auch im Hochsommer die Außentemperaturen verhälnismäßig nieder liegen, kommt es zurgeringsten Wetterführung. Menschliche Ausdünstung, verstärkt durch die nasse Kleidung in Verbindung mit den Oxydationsprodukten vor allem der Magnesiumbeleuchtung, führen an solchen Tagen zu starker Nebelbildung in der Höhle. Fällt eine derartige Situation noch in die Nähe der jahreszeitlichen Temperaturumschlages, kann man einen sehr raschen Verfall der Kleinformen des Eises feststellen.

Wenn solcher Art offenbar der Einfluß der Erschließung zumindest auf die Kleinformen erwiesen zu sein scheint, darf aber auch hier die Überdeckung durch natürliche Vorgänge nich übersehen werden. Auch in nicht erschlossenen Eishöhlen bzw. Höhlenteilen kommt es innerhalb der Höhle zum schnellsten Temperaturanstieg nicht etwa in einer besonders schönen und daher warmen Witterungsperiode, sondern auch bei maßigen Temperaturen, vor allem bei starken Regenfällen auf die bereits schneefreie Gebirgsoberfläche. Der Grund liegt zweifellos in der im Wasser gespeicherten beträchtlichen Wärmemenge, die in steilen Gerinnen (Hauptschächte) kaum an die Umgebung abgegeben und erst in den größeren Höhlenräumen freigesetzt wird.

4. Verunreininungg

Während alte Schauhöhlen häufig mit den Resten unbrauchbar gewordener Erschließungsanlagen, wie vermodertes Holz und verrostetem Stahl zu kämpfen haben, werden in den letzten Jahrzehten derartige Rückstände üblicherweise nicht mehr in der Höhle gelagert. Jedem für die Erhaltung von Höhlen - besonders Schauhöhlen - Befaßten sind jedoch die absichtlich von Besuchern weggeworfenen Gegenstände zur genüge bekannt. Die fast unendliche Liste reicht vom Kaugummi bis zum Jausenpaket, vom Zuckerlpapier bis zu Kleidungstücken. Allein dieser Unrat erreicht im Sommer einen Anfall von 5 - 10 l pro Tag. Bei der täglichen Reiningung sind überdies zahlreiche von Besuchern auf Eis und Fels angebracht Inschriften zu entfernen. Hiezu kommt weiters der von den Besuchern, inseondere bei nasser Witterung an den Schuhen in die Höhle hineingetragene Schmutz. In der Eisreisenwelt hat sich eine jährliche Herbstreiningung mittels Wasserpumpe sehr gut bewährt.

5. Zusammenfassung

Die Eisreisenwelt Werfen - Salsburg ist nunmehr seit über 100 Jahren bekannt und wird seit mehr als 60 Jahren als Schauhöhle geführt. Die Besucherzahl von jährlich ca. 130.000 Besuchern bedingte zahlreiche Eingriffe in die natürlichen Gegebenheiten. Trotzdem konnten in der Höhle keinerlei grundlegende Tendenzen zu einer Änderung der westlichen Komponenten des Höhleneises festgestellt werden. Innerhalb der letzten 100 Jahre ist die gesamte bekannte Eismenge im erschlossenen Bereich der Höhle sicherlich angestiegen, wenngleich genaue Messungen nicht vorliegen. Kleinfiguren wurden während der bekannten Zeit eher weniger. Inwieweit diese Veränderungen von der Erschließung oder von natürlichen Gegebenheiten beeinflußt wurden, konnte bisher nicht eindeutig klargestellt werden.

Dargestellt wurden hier im wesentlichen nur die Aspekte, die sich wegen der Besonderheit des Eises als interessierender Höhleninhalt der Schauhöhle ergeben. Selbstverständlich bestehen auch in der Eisriesenwelt die im allgemeinen bei Schauhöhlen festzustellenden Probleme, wie Fotografiererlaubnis, Gruppengröße ect. Abschließend sei noch bemerkt, daß die berichteten Feststellungen und gezogenen Schlußflogerungen primär nur für die Eisriesenwelt Geltung haben. Vor einer Übertragung der Gegebenheiten auf andere Eishöhlen wird gewissenhaft zu prüfen sein, ob die dortigen Voraussetzungen, denen der Eisriesenwelt gleichen.

Manganese Deposition in Limestone Caves

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Abstract

The black manganese mineral most commonly found in limestone caves is birnessite, $CaMn_6O_{13}\cdot 3H_2O$, in which the manganese is fully oxidized. Water containing chemically reduced manganese derived from decayed leaves may mix with oxygenated cave-stream water during the winter flood season, causing the water to become supersaturated with respect to birnessite, at which time bacteria probably participate in the deposition of the birnessite. Three other black manganese minerals--romanechite, rancieite, and todorokite--in which the manganese is not fully oxidized, also occur rarely in caves where sealed from the air by confining mineral matter. These minerals may have formed by the alteration of birnessite deposites that contained a reducing agent such as particles of plant tissue.

Zusammenfassung

Das üblicherweise in Kalkhöhlen gefundene schwarze Mangan-Mineral ist Birnessit, $Ca_6Mn_{13}\cdot 3H_2O$. Das Mangan in Birnessit tritt in voll oxydierter Mn^{4+}-Form auf, da es sich vermutlich in sauerstoff-reichem Wasser bildet. Das Wasser, das chemisch reduziertes Mangan enthält, stammt aus der mit verfaulten Blättern angereicherten Bodenschicht, von wo es vermutlich während der Winterregenzeit in den Karstkörper sichert und sich dabei mit sauerstoffreichem fliessendem Karstwasser vermischt. Dabei reichert sich das Wasser soweit mit Mangan an, dass es zur Übersättigung und Birnessit-Bildung kommt. Bei der Ablagerung dieses schwarzen Materials spielen vermutlich auch Bakterien eine Rolle.

Introduction

Limestone caves can serve as natural reaction vessels for the study of low-temperature geochemistry. Environmental conditions in caves are exceptionally stable, and more than 100 minerals are known to form in that environment (Moore and Sullivan, 1978). Because rates of reaction at low temperature are slow, reactants and products that are difficult to relate to each other in short-term laboratory experiments can often be studied profitaby in this natural setting.

Black manganese oxides in caves are similar to manganese concretions in soil, to oxidized manganese ore deposits, and to marine manganese nodules. Study of the mineralogy of all these types of deposits has been difficult. Their extremely fine grain size, as revealed by electron microscopy, approaches the wavelength of X-rays, so that X-rays diffraction spacings used for mineral identification are often poorly recorded.

Natural low-temperature manganese deposits range in grain size, however, and some individual deposits can be characterized confidently by X-ray diffraction. In 1956, Jones and Milne named the mineral birnessite from a soft black cement between pebbles in a glacial-outwash gravel at Birness, Scotland. In 1964, birnessite was reported as a speleothem from a coarsely crystalline example at the core of a calcite-coated stalactite in Weber Cave, Iowa (Moore and Nicholas, 1964).

During July 1979, chemical studies at a manganese-deposition site in Matts Black Cave, West Virginia, shed light on the depositional process. The results of that field investigation, along with analytical work on samples from Matts Black Cave and from other manganese-bearing limestone caves are summarized here.

Eberhard W. Werner participated in the field work in West Virginia. I am also indebted to Bruce W. Rogers and William B. White for helpful discussions, and to White for infared spectrograms. Charles E. Roberson, Kam W. Leong, and Philip A. Baedecker carried out the laboratory analyses, and Robert L. Oscarson recorded the electron micrographs. The manuscript was reviewed by John D. Hem and David Z. Piper.

Depositional Environment

Matts Black Cave is the mouth of one of several karst springs that flow into Spring Creek, near Renick, West Virginia. It formed in Carboniferous limestone that contains thin shale interbeds. A stream resurges at the back of the cave traverses the somewhat irregular main passage for 135 meters to the relatively small entrance, where it percolates out through breakdown to the slope above Spring Creek.

The black manganese mineral coats the ceiling, walls, and breakdown blocks throughout the passage. It is thickest on the ceiling (which is about 6 meters above the cave stream) and thinnest near the stream. Except for a few thinly coated loose pebbles, it does not coat sand and gravel in the stream. Typically, the ceiling deposit is 10 mm thick and soft, whereas the wall deposit is 2 mm thick and hard and glossy.

Matts Black Cave floods periodically during times of high runoff. Many erosional scallops cut the limestone walls, and the manganese mineral coats some scallops rather thickly, whereas others that intersect them are entirely bare. This observation is compatible with that reported for a surface stream in Georgia (Carpenter and Hyyes, 1980). Individual mosaic tiles were sampled weekly from a large number cemented to a submerged concrete block, and the manganese deposition was found to be continuous over a year, without changes in rate due to the seasons. But the deposits on nearby native rocks were only three times as thick as those which formed during one year on the tile; such a small difference suggests that erosion must affect these surface-stream deposits at irregular intervals.

The evidence from Matts Black Cave suggests that chemical deposition and physical erosion compete. The thick soft ceiling deposit seems to be little affected by flood scour, whereas the thin hard wall deposit represents a residue only of the most firmly attached material, and even it is removed locally during extreme erosion.

Source of the Manganese

Chemical analyses determined the composition of a sample of stream water in Matts Black Cave and of a sample of water dripping from a crack in the mineral-encrusted ceiling (Table 1). At the cave temperature of 14°C, the dissolved-oxygen value of 8.6 mg/L for the stream equals 84% of saturation with respect to atmospheric oxygen. Such oxygenated water is supersaturated with respect to manganese minerals at its pH of 7.5 and Mn content of 0.012 mg/L (Hem, 1978).

The much lower Mn value of 0.002 mg/L in the drip water suggests that downward percolating water is not a major source of Mn in the cave.

Stagnant ponds in sinkholes that feed the cave-stream system are the most likely source for the manganese. Slack and Feltz (1968) have shown that a stream choked with leaves can develop a Mn content of 4.8 mg/L in water with a dissolved-oxygen content of nearly zero. The manganese in the cave may come from chemically reduced water from sililar sources, supplied during periods when the cave is running full.

Fully oxidized manganese minerals, although common in nature, have not been produced directly from solution in the laboratory, although they can be synthesized by treating incompletely oxidized minerals with acid (bricker, 1965). Many investigators have suggested that the natural products might form through the action of bacteria. Noting that holes about the size of the sheaths of Mn-depositing bacteria occur in some cave-manganese deposits (Fig. 1), we suggested such a depositional agent for the cave deposits (Moore and Sullivan, 1978). Manganese minerals collected from Matts Black Cave during the present study were cultured by Kenneth H. Nealson, Scripps Institution of Ocanography. He reports a rich culture of sheathed species of the genus *Leptothrix*, along with several other unsheathed gram-negative Mn oxidizers.

Mineralogy

Previously we identified the mineral in Matts Black Cave to be birnessite and published a scanning electron micrograph of it (Moore and Sullivan, 1978). Infared spectrograms, when compared with those of Potter and Rossman (1979), have verified that identification (Fig. 2). Chemical analyses of birnessite from this site and from two other caves are given in Table 2, and X-ray diffraction traces in Figure 3.

Published analyses have shown that some natural and artificial birnessites are not fully oxidized (Burns and Burns, 1979). To learn the amount of Mn^{4+} versus Mn^{2+} and Mn^{3+} in the birnessite from Matts Black Cave, we determined the oxidation number of ceiling and wall samples by reducing them with oxalic acid. After subtracting for the iron in the samples, assuming it to have been fully oxidized initially, an oxidation number of 4.0 was obtained for both samples. These results verify that the Mn in the birnessite from Matts Black Cave consists entirely of Mn^{4+}.

Birnessite contains variable amounts of Ca, Mg, Ba, Na, and other cations, and the ration of intrinsic divalent cations to Mn is about 1:6 (Burns and Burns, 1979). Birnessite from marine manganese nod nodules contains mainly Mg, and birnessite from limestone caves contains mainly Ca. An end-member formula adopted here from cave birnessite is $CaMn_6O_{13}\cdot 3H_2O$.

Scanning electron micrographs of coarsely crystalline birnessite from Weber Cave, Iowa, look as though they consist of vergrowths deposited on initial tiny scales (Fig. 1). A reticulated pattern retains approximately the spacing inferred to have been established by the sheath size of *Leptothrix discophora* or related species of bacteria.

Although birnessite is by far the predominant manganese mineral in limestone caves, three other minerals have been reported: rancieite, $Mn^{2+}Mn_4^{4+}O_9\cdot 3H_2O$, in Mammoth Cave, Kentucky (Richmond and others, 1969); todorokite, $CaMn^{2+}Mn_5^{4+}O_{12}\cdot 3H_2$), in Jingemia Cave, Australia (Bridge and others, 1978); and romanechite, $BaMn^{2+}Mn_8^{4+}O_{16}(OH)_4$, in Jasper Cave, South Dakota (Moore and Sullivan, 1978). Each of these minerals contains manganese that is not fully oxidized.

Marine manganese nodules are known to consist of birnessite in the outer layers and todorokite in the interior (Piper and Williamson, 1981). The partly reduced minerals, both in manganese nodules and in limestone caves, probably form by alteration from birnessite in the confined interior of the deposits, where free oxygen is excluded. In caves, the reducing agent is most likely to be finely divided particles of plant tissue.

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Table 1. Water analyses (mg/L), temperature (°C), and pH of samples from Matts Black Cave, West Virginia, July 1, 1979.

Sample	Fe	Mn	Ca	Mg	Na	HCO_3	SO_4	O_2	Temp.	pH
Ceiling drip	.06	.002	46	23	1.5	250	12	--	13.9	8.22
Cave stream	.24	.012	24	2.4	1.1	77	5	8.6	14.0	7.50

Analysts: C. E. Roberson, Fe, Mn, Ca, Mg; E. W. Werner, Na, SO_4; in field, HCO_3, dissolved O_2, temperature, pH.

Table 2. Chemical analyses of birnessite samples from limestone caves.

Element	Matts Black Cave, W. Va., ceiling, leach residue 17.8%	Matts Black Cave, W.Va., wall, leach residue 24.9%	Weber Cave, Iowa	Tom Moore Cave. Mo.
Atomic absorption (leachable weight percent)				
Mn	27.6	25.7	43.1	25.8
Fe	2.9	2.3	---	---
Ca	1.8	.62	---	---
Ba	.68	.92	---	---
Mg	.44	.35	---	---
Na	.13	.10	---	---
K	.12	.11	---	---
Ni	.12	.11	.27	.07
Co	.05	.06	.15	.05
Zn	.04	.04	.05	.05
Sr	.04	.02	---	---
Cu	.02	.01	.01	.01
Neutron activation (weight percent)				
Fe	3.97	3.08	.65	2.75
Ba	.73	.79	1.53	1.94
Co	.041	.045	1.89	.038
Zn	.033	.038	1.08	.063
Neutron activation (mg/kg)				
Cr	30	30	< 30	50
Hf	2	5	<3	12
Sb	2	2	2	3
Th	13	10	2	14
Sc	14.8	10.7	.8	7.5
La	170	180	< 6	200
Ce	300	340	10	270
Nd	210	200	<200	210
Sm	57	54	< 2	39
Eu	11.8	10.7	< .2	7.0
Gd	57	50	<20	28
Tb	---	6.8	< 2	3.5
Tm	1.7	1.7	<2	1.5
Yb	12.0	9.5	<5	10.9
Lu	1.6	1.4	< .5	1.4

Analysts: C. E. Roberson, K. W. Leong, P. A. Baedecker

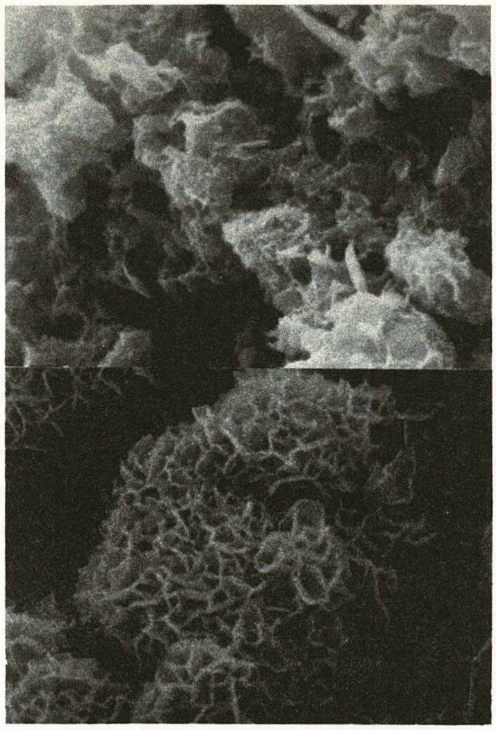

Figure 1. Scanning electron micrographs of birnessite: top, typical sample showing bacterial (?) cavities, Tom Moore Cave, Missouri; bottom, coarsely crystalline sample showing reticulated overgrowths, Weber Cave, Iowa; frame widths, 12 micrometers.

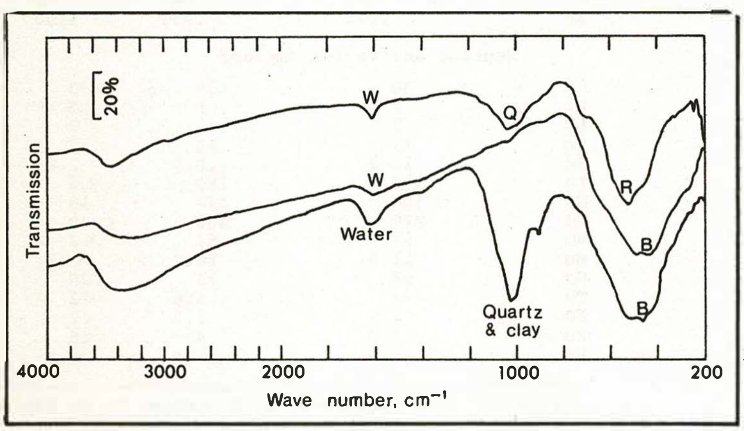

Figure 2. Infared spectrograms: top, romanchite, Jasper Cave, S. Dak.; middle, birnessite, Weber Cave, Iowa; bottom, birnessite, Matts Black Cave, W. Va., ceiling.

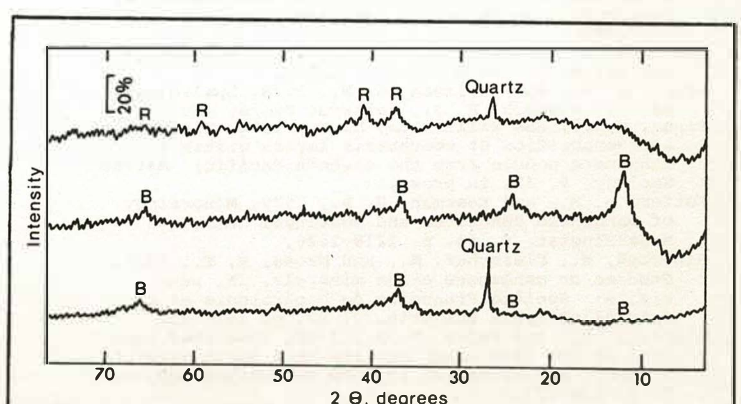

Figure 3. X-ray diffractograms: top, romanechite, Jasper Cave, S. Dak.; middle, birnessite, Weber Cave, Iowa, bottom, birnessite, Matts Black Cave, W. Va., ceiling.

Fauna of Anchialine (Coastal) Cave Waters, its Origin and Importance

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Abstract

In the introduction an attempt has been made to define some terms on the basis of new determinations. A "cave" can be characterised by a certain degree of darkness as well as by a lack of greater amounts and variety of food (the latter being as important as darkness) and the lack of variety of competitively strong inhabitants. "Troglobites" are defined as the biota, bound to the cave environment by some abiotic and/or biotic (competition e.g.) circumstances. "Anchialine cave waters" are defined as coastal cave waters of mixohaline character, regardless of the cave's history (unlike Riedl's "marginal cave").

Several examples indicate, that the immigration of some higher taxa into anchialine caves (1) occur in wide areas (Spelaeomysis, Hadzia s.l. circumtropically), (2) from different directions (Ophidiidae probably from the abyssal, Typhlatya from the littoral, Niphargus from fresh waters e.g.), and (3) could have extended through longer time periods (Typhlatya Pliocene-Holocene e.g.). The causes underlying immigration from the sea are mostly of biotic character, more conservative elements being displaced by modern, stronger competitors, (Typhlatya is one of the last marine Atyids, Spelaeomysis is a rather primitive Mysid, Niphargus spp. are primarily blind etc.). Regressions of the sea in the geological past are only of secondary importance since such oscillations have always been two slow to force the animals to remain outside the sea. Since intensive carstification cannot occur below the sea-level, the regressing sea also cannot leave behind cave-like fenomena.

Many so called "marine relics" in continental cave waters have evidently immigrated via surface waters (Marifugia e.g.) where they have sometimes even undergone speciation (Monolistrini e.g.). Even all known troglobitic animals from the anchialine cave waters of the Yugoslavecoast show sighns of a previous life in (probably subterranean) fresh waters, either by their distribution or by a preference of lower salinities. It is significant that most relevant taxa from the Carribean realm (s.l.) are also found in fresh waters.

Zusammenfassung

Man wird anfangs versucht, einige Termina neu zu definieren. Für die "Höhle" als ein Habitat ist der Futtermangel und der Mangel der konkurierenden Arten bedeutsamer als der Lichtmangel an sich. Als "Troglobionte" sollte man die Tier bezeichnen, die aus irgendwelchen Gründen unfähig sind, ausserhalb Höhlen zu leben; meistens sind dazu stärkere Konkurrenten ausserhalb der Höhlen verantwortlich und nicht die Gebundenheit der Höhlentiere an spezifische abiotische Faktoren. Als "anchialine Höhlengewässer" sollte alle mixohaline Höhlengewässer an den Küsten betrachtet werden, ohne Hinsicht auf ihre Geschichte.

Einige Beispiele zeigen uns, dass die Einsiedlung einiger höheren Taxa in anchialine Höhlengewässer (1) verläult an grossen Arealen (z.B. circumtropisch), (2) verläuft von verschiedenen Richtungen (aus dem Littoral, aus dem Abyssal, aus den Süssgewässern), (3) kann sich an eine lange Zeitspanne ausdehnen (z.B. Pliozän-Holozän). Die Ursache ist wahrscheinlich meistens eine biotische; konservative Elemente wuden von jüngeren, stärkeren Konkurrenten aus verhältnissmässig günstigen marinen Habitate verdrägt. Die Regressionen der Meere haben nur eine sekundäre Bedeutung.

Viele sogenannte marine Relikte in continentalen Höhlengewässern sind in die Höhlen über die superfiziellen süssen Gewässer eingedrungen; verwunderlicherweise gilt das sogar für einige Arten der mixohalinen Höhlengewässern. Der direkte Weg aus dem Meere in die Höhlen wurde also nicht so oft benutzt, wie einige Autoren vermuten.

Introduction

During work on the subject a need arose for checking the correctness and completeness of some established definitions and terms.

What is a cave? As in speleobiologically richer regions "cave-fauna" can be ± clearly distinguished from interstitial fauna, a cave can't be - from the biologist's point of view-simply defined as a "hypogean habitat". It also differs from some other hypogean or semi-epigean habitats. I would designate the cave-habitat as a spacious yet closed life space; these characteristics result in the darkness, the small energy (food) content, scarcity of inhabitants, and some other secondary viz. tertiary features. From an ecological point of view the lack of food and the lack of competitors may sometines be more important than the lack of light itself. Thus some habitats that are not really caves in the speleological meaning of the word, can also be defined as "cave-like".

What are anchialine cave waters? Riedl introduced the term "marginal cave" for caves which either still contain brackish water or which supposedly did in the geological past. As the term is not completely unequivocal and sometimes involves some speculation, I use the term "anchialine cave waters" for a similar habitat, one with ecological characteristics of cave water evidently influenced by the sea (hydrological connections). In coastal areas such habitats include all water filled hollows in the karstified carbonate rocks as well as hollows in primarily porose volcanic and coral rocks.

What is a troglobite? Or-what binds troglobites to the hypogean habitat? There have been many attempts to classify the inhabitants of caves, but all (or allmost) of them agree that troglobites (or whatever adequate term they do use) are by definition obligatory inhabitants of the subterranean habitat. The real nature of such ecological specialization is usually not discussed. But is is usually evident from the context, that physiological specialization to abiotic conditions of the cave habitat are responsible for it.

A number of morphologically "higher specialized troglobites" have in certain circumstances been found in the illuminated sites, on the other hand many "normal" animals are still known only from dark caves. To again avoid speculation we would do best to define troglobites as organisms adapted to abiotic (climatic) and biotic conditions of cave habitats, which can't bear abiotic and/or biotic conditions of epigean habitats. In most cases it is obvious that only in competition with stronger epigean animals the cave ones are not able to rebuild the epigean populations.

Some relevant habitats

Marine caves s.str. are otherwise a special marine habitat and not an anchialine one, but they are nevertheless interesting for our consideration. They are inhabited by marine animals only, the most characteristic being of the abyssal facies (Stenopus spinosus, some Pisces Ophidiidae), archaic forms (Spongiaria Pharetronida), or very euryoecious (Filogranula annulata). The continuous gene flow between populations in different marine habitats has prevented specialization of animals to this particular one.

Lava tubes in the Canary Islands (Jameos del Agua) contain euhaline water but connections with the open sea are quite poor. The accessible pools are inhabited mostly by some abyssal organisms (Munidopsis polymorpha e.g.) which there form comparatively dense populations thanks to the presence of richer supplies of food (Algae in illuminated parts of caves).

Anchialine pools in oceanic islands are in fact windows into the systems of hollows in lava or coral rocks. The water is usually euhaline at the coast line and becomes more and more diluted in the pools further inland. With decreasing salinity the marine benthic associations become more and more impoverished and some typical inhabitants of this habitat prevail: the shrimps Procaris spp., Halocaridina spp., Ligur uveae, Hadziide Amphipods etc. Many of these inhabitants exhibit some characteristics of cave animals (reduction of eyes, depigmentation or red color, nocturnal habits).

All of the above mentioned habitats can be of great age as recent hollows can be bound to older ones.

Cave waters of the Yugoslav Adriatic coast are mostly accessible through the vertical shafts, which also provide a locally rich supply of food. Communications with the sea are not very intense, salinities range from euhaline to limnic calues, O_2 content is low or even zero. Only the highest salinities allow penetration of some marine animals (Filograna annulata, some Copepoda e.g.), other regions are inhabited of blind and depigmented animals of certain freshwater origin (Niphargus hebereri, Diacyclops spp.); even the Yugoslav species of Hadzia and Monodella must be of limnic provenience as they avoid higher salinities. The population densities seem to be limited only by food supply, salinity, by the local presence of epigean competitors and not at all by the presence of sunlight or by the lack (or even absence!) of diluted oxygen. The karst in the Yugoslav coast may be of the Pliocene or early Pleistocene age, but during the Pleistocene today's coastal zone was not in contact with the Sea.

Cave waters of the Caribbean region, sometimes mixohaline, mostly fresh are inhabited by many animals which show clear relationships with marine relatives (Cyathura spp., some Decapoda Palaemonidae), and partly perhaps with abyssal ones (Barbouria cubensis, some Pisces Ophidiidae). It is significant, that many "marine relic" species show no inclination for more saline habitats (some Hadziid Amphipods).

Some species viz. groups of inhabitants should be discussed from an ecological and zoogeographical point of view in order to understand the history of of fauna in concern.

Genera Diacyclops, Acanthocyclops, and Metacyclops (Copepoda) are widely distributed and contain many extremely euryoecious species, which may inhabit ephemere fresh waters, but also saline and subterranean ones. A couple of species are endemic in the Adriatic basin, living almost exclusively in anchialine cave waters, but all most always in nearly limnic conditions.

The genus-group Antecardinina-Typhlatya-Typhlopatsa-Stygiocaris (Decopoda Natantia) and to a great extent even the genus Typhlatya itself, inhabit anchialine waters and cave waters near the coasts in a great range circumtropically. They show different degrees of eye reduction and other signs of adaptation to the underground. It is one of the rare Atyidae-groups still connected with the sea.

Genus Spelaeomysis (Mysidacea) shows a similar wide distribution. Its representatives live in anchialine and fresh coastal cave waters but also in other types of unfavourable habitats. They exhibit different degrees of depigmentation and eye reduction. It is a quite primitive type of Mysida.

The genus group Ligur-Barbouria (Decapoda Natantia) inhabits different types of anchialine waters in the Indopacific and in the W. Atlantic, sometimes also living under otherwise unfavourable conditions (but neither marine nor hypogean). But a related species inhabits deeper waters in the Mediterranean. Munidopsis polymorpha from the Canary Islands also has only abyssal relatives (and might even live in the depths).

Genus Niphargus (Amphipods) is geographically restricted to a greater part of Europe (and the Near East), where a lot of species live in fresh subterranean waters, and some also in epigean (of the "extreme habitat" type) or anchialine ones. Niphargus hebereri, a very common inhabitant of anchialine (but also fresh cave waters, is an extremely euryoecious organism which can occur at 0 - 15% salinity, oil pollution, presence of H_2S, lack of O_2, presence of sunlight.

Family Hadziidae (Amphipoda) inhabits with its numerous species different types of coastal marine, anchialine, and hypogean fresh to hypersaline waters. Most species have been found in the wider Middle American (Caribbean - Texas) and Mediterranean region and some also in the Indopacific. The eyes are (seldom) poorly developed or lacking. Even most species from coastal caves avoid higher salinities.

Ordo Thermosbaenacea seems to inhabit only the most diverse types (fresh to hypersaline, "cold" to thermal, interstitial and cave waters) of hypogean waters of the Mediterranean and Caribbean to Texas. They seem to be very euryoecious but week competitors (Adriatic species can be driven into higher salinities and into anoxic layers by stronger Amphipoda).

"Marine relics" in continental caves of Dinardes. Many continental cave animals have been by most authors characterised as marine relics only because their nearest living relatives are found in the sea. Perhaps we could factually treat as marine relics, not only those species which immigrated directly from the sea, but also those which immigrated via epigean fresh waters, without previous speciation; the Polychaete Marifugia cavatica certainly inhabited freshwater lakes before coming underground, as it lives in some separated river basins. But the genus Troglocaris must had differentiated some species in epigean waters before immigrating into caves. The distribution of taxa of Monolistrini also clearly indicates that an intense speciation already occured in epigean rivers at the end of Pliocene. All populations of most of the above mentioned species, when immigrating underground underwent only parallel adaptations to the new habitat.

Some Possible Conclusions About the Immigration of Animals into Cave Waters

The time of immigration. Some authors are trying to determine for entire groups of species (genera) the time of immigration from the sea into continental resp. cave waters. How questionable such efforts can be is nicely illustrated by the case of Typhlatya and Spelaeomysis; some species can be already highly specialized freshwater troglobites (probably of the Pliocene age) when others are at the same time still living in semiepigean and mixohaline habitats and are still pigmented. The Hadziid Amphipods are also a phyllogenetically coherent group, having at the same time marine representatives, as well as such, which are supposed to live in continental (? and hypogean) waters already from cretaceous times. It seems that the end of Pliocene/beginning of Pleistocene was the most prolific time for the development of the aquatic cave fauna in the Dinarides; but even this needn't be the case in other regions.

The cause of immigration. Regressions of the sea in the geological past have very often been held responsible for the penetration of marine animals into fresh and cave waters. Sometimes it is evident-if not explicitely mentioned-that regressions should force some animals to adapt to fresh water because they live in residual lagoons or similar habitats. Anchialine pools can also be one of such habitats. But we have to take in consideration the fact that such geological events are in most cases slow enough to enable animals to escape from such traps. Otherwise such habitats occur with the same (hypogean ones even with higher) frequency at coasts where the sea is at the moment in regression, as where it is in the transgressional phase. So the regressions of the sea seems to have greater zoogeographic consequences than ecological ones.

Some abyssal species seem to be able to penetrate sporadically into anchialine shallow water habitats, where they are ± isolated from the main populations and likely to develop into true cave animals. Where cave waters are not yet inhabited by richer specific fauna, the way from marine and mixohaline interstitial waters into caves is also possible.

There is no doubt that some very successful epigean species are widening their areas by penetration into freshwater and underground. But the fact that the "younger" cave animals have often near relatives in other extreme habitats, indicates that the main reason for immigration is their competitive weakness, which however must be accompanied by a great amount of ecological (resp. biological) euryvalency. The usual phylogenetical conservatism of freshwater and particularly cave animals in comparison with their marine relatives also confirms this hypothesis.

It is very likely at least for some species of the Yugoslave coast that they were already adapted to fresh cave waters but they had to escape into anchialine ones, which were not so densely populated.

The place of immigration. Some of the above mentioned groups were often supposed to be relics of the old tethyan fauna. It is very doubtful whether such an open sea as the Tethys must have been, had its distinct own faun. The large number of hadziid species e.g. in some parts of the former tethyan basin may simply be the consequence of conditions in the Mediterranean and in the Caribbean, which caused a higher degree of speciation. All of todays species living here could one by one have differentiated from a very small number of marine ancestors (such live also outside the tethyan basin). Otherwise seem the direct way from the sea into caves not to have been used as frequently as usually supposed.

Note. The present paper is an immoderately condensed summary from the compilation on which the author worked some years ago; the work has been temporarily interrupted because of an enormously increased input of new data in last years. A large number of publications have been consulted, which however can not be listed here.

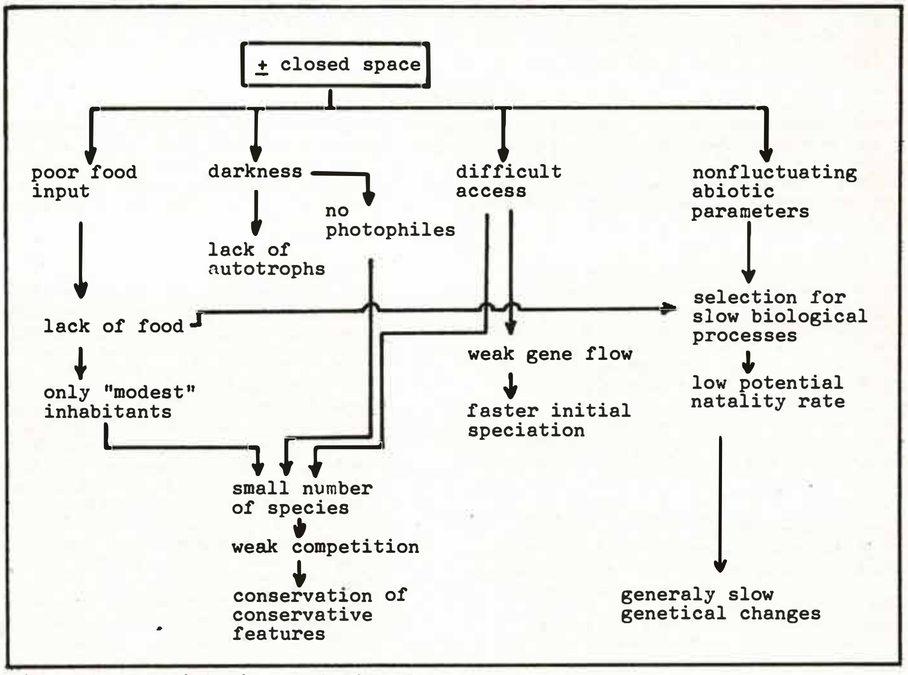

Figure 1: Possible interrelations between some features of cave habitats.

Dissolution Experiments with Facets

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Abstract

Caves developing in non-turbulent water display a unique morphology: horizontal solution ceilings and smooth sidewalls (or facets) sloping at about 45o. Both are produced by gravitational convection. Three sets of dynamic dissolution experiments with gypsum facets of different angles were conducted: Constant volumes of water were allowed to approach saturation. Experimental difficulties, hydrodynamic principles and the results as to their bearing to the phenomenological 45° dissolution optimum are discussed.

Zusammenfassung

Höhlen, die sich in nicht-turbulentem Wasser bilden, besitzen eine typische Morphologie: horizontale Laugdecken und glatte Seitenwände (die Facetten) mit einer Neigung von etwa 45°. Beide morphologischen Elemente werden durch Gravitationskovektion erzeugt.

Drei dynamische Lösungsversuchsserien mit verschiedenen Winkeln wurden mit Gipsfacetten durchgeführt: dabei wurde die Aufhärtung eines konstanten Wasservolumens verfolgt. Experimentale Schwierigkeiten, hydrodynamische Vorgänge und die Versuchsergebnisse und ihre Bedeutung für das phänomenologische 45° - Lösungs Optimum werden kiskutiert.

A Comparison of Expected Survey Errors with Closure Adjustments

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Abstract

Least squares closure adjustments were performed on seven sets of cave survey data that contain multiple closure networks. The function chosen for weighting the survey strings has little effect on the total amount of adjustment. In a careful survey, the errors are two or three times what would be expected from the precision of the measurements. The errors in each of the three coordinate directions are about the same.

Zusammenfassung

Kreisverschlussanpassungen von Höhlenvermessungsdaten nach der Geringstquadratmethode wurde für sieben Reihen von Höhlenvermessungsdaten, die mehrfache Verschlussnetzen einhalten, ausgeführt. Die gewählte Funktion, die den Reihen relative Bedeutung gibt, hat wenig Einfluss auf die Gesamtsumme der Anpassung. Selbst wenn man sehr achtsam vermisst sind die Vermessensfehler zwei-oder dreimal grösser als was man von der Präzision der Messung erwartet. Die Fehler sind in jede der drei Koordinatrichtungen ungefähr gleich.

How do actual cave survey errors compare with what would be expected from the precision of measurements? I attempt to answer some parts of this question by using a computer program to adjust closure networks in cave surveys. My study focuses on three specific parts of the error problem as follows:
1. Compare methods for weighting the strings of survey shots in the closure network.
2. Compare the closure adjustments with what would be expected from the precision of the measurements.
3. Compare closure adjustments in different coordinate directions.

Techniques Used-Computer Program and Weighting

I have written a computer program, CMAP 14, that does a simultaneous least squares closure adjustment of a survey network. It identifies the junctions in a cave survey and assigns weights to the srings of survey shots connecting the junctions. It then performs the adjustment of the coordinates of the junctions. It tabulates the amount each string was changed.

There are several different functions that might logically be used for weighting. I tried the following: Variance-a variance is assigned to each survey shot, based on the assumed errors of measurement. The variances are summed to get the variance of a string. The weight assigned to the string is 1. variance. This weighting will in theory give the most probable locations for the junctions.
Standard deviation-this is the square root of the variance. The adjustment of each string tends to be proportional to the three-dimensional probable error in the string. Unfortunately, standard deviation is a non-linear function. The probable errors and the location of a station in the middle of a string changes when that station becomes a junction.
Length-the weight is inversely proportional to the lenght of the string and the adjustment is distributed throughout the string on the basis of length. This is the Compass Rule of land surveyors.
Number-the weight is 1.0 over the number of survey shots in a string. This is a nod to the early work of Mike Luckwill (1970), who weighted each string equally. However, I refuse to be that crude. (He knew about weighting; see Luckweill, 1969).

In order to obtain a variance for the coordinate change in a single survey shot, the random errors in the measurements must be either known or assumed. The horizontal and vertical angles are normally read to the nearest degree and are often read more precisely. My model assumes a uniform distribution of ±0.5 degree for both angles. Distances can easily be measured to within one centimeter. With hand-held survey instruments there is a station position error. Neither the survey instruments nor the target light are held exactly on the survey station. Position error could be a systematic error. With different surveyors and different directions of travel, we may hope it takes on the aspects of a random error. I lump distance and position errors into one error with a standard deviation of 2.0 inches (5.0 cm). The variances due to angular and position errors are added to get the variance for a single survey shot. It is assumed that the variances in all directions are equal.

Data Samples-Cave Surveys with Closures

I studied actual cave surveys that contain multiple closure networks. I could have used single closure loops. However, on a single closure, particularly one with few survey shots, there is a chance of being especially good or bad. The multiple closure networks provide the opportunity to study many closures simultaneously. Furthermore, most of my closures are part of large networks; single closures would have to be broken out of larger systems.

Data set 1, part of the Trout Cave survey, was done by seven different instrument readers. They used Suuntos and took both foresights and backsights on every shot, which means that each angle was measured twice and that blunders were detected at once. Sets 2 to 5 were each done by one survey team on one survey trip. This eliminates any systematic errors due to different instruments and instrument readers. The two Suunto readers were very experienced. The two Brunton readers were inexperienced, but both were civil engineers and careful workers. Data sets 1-5 have only short strings of survey shots between junctions. Sets 6 and 7, which have both short and long survey strings, were added to the study. Unfortunately, both were done by several different surveyors, some of whome were inexperienced. In the Bat Room of Hellhole I had to teach at least two instrument men how to use a Brunton compass. The data sets include survey data that is not part of loop systems. It was easiest to leave it in and let the computer sort things out.

Comparison of Weighting methods

All the weighting methods resulted in approximately the same amount of adjusting. In retrospect this should not be surprising, since a misclosure must be adjusted by the amount of the misclosure. There ares ome differences, but nothing significant.

In six of seven cases, the length weighting gave the lowest maximum percentage adjustment. In five of seven cases, the use of standard deviation weighting minimized the maximum of the ratio of adjustment of probable error. The low maximum values must be made up by larger adjustment ratios in some of the other strings, since the total adjustment is about the same regardless of weighting. Whatever function is chosen as a weighting function tends to be equalized among the strings by the least squares adjustment procedure.

Amount of Adjustment Compared to Probable Error

If measurements in three orthogonal directions have the same variance, then the vector sum of the erros errors will have a Maxwell distribution. This distribution peaks at a value equal to one standard deviation. This may be the reason for the widespread confusion between probable error and standard deviation.

The sum of the probable errors was compared with the sum of adjustments on the survey strings. All of the surveys have errors worse than what the model predicts on the basis of precision of measurement. The best survey was done with both foresights and backsights on every shot, which suggests that the foresight/backsight procedure has merit. The next best survey was done with a tripod-mounted Brunton. Data set 3 was found to contain blunders in the vertical angles and set 6 has sections done by unskilled surveyors in awkard passage.

It appears that the assumptions in the model underestimate the errors in a careful survey (excluding the two worst cases) by a factor of roughly two or three. I can not determine what combination of the error assumptions should be relaxed.

Comparison of Errors in Different Directions

Some cavers tell of making connections between caves and finding that the surveys agreed better in the vertical direction than in the horizontal. Irwin and Stenner (1975) claim that their data shows that horizontal misclosures are greater than the vertical by the ratio of 3 to 2. I do not see how their data shows this, although the conjecture may be true. It must be remembered that the horizontal misclosure is the vector sum of components in two directions and should exceed the vertical by the ratio of 2 to 1 if the variances are equal in all directions. Excluding sets 3 and 6, it appears that the errors in each of the three coordinate directions are about the same on any given survey, although individual surveys differ in accuracy.

	1 TROUT CAVE	2 THORN MTN.	3 SHIPP ROOM	4 SINKS OF GANDY	5 SINKS OF GANDY	6 BAT ROOM	7 KEE CAVE
SURVEY SHOTS	199	30	35	67	34	144	84
LENGTH (FEET)	4646	659	1038	1697	873	2917	2187
STATIONS	175	27	28	55	29	136	75
CLOSURES	25	4	8	13	6	9	10
JUNCTIONS	36	7	9	17	7	11	17
STRINGS FORMED	60	10	16	29	12	19	26
STRINGS ADJUSTED NUMBER	57	9	15	26	12	18	25
STRINGS ADJUSTED SHOTS	133	15	22	40	15	77	51
STRINGS ADJUSTED LENGTH	3007	337	707	1195	450	1672	1177
COMPASS/CLIN.	Suunto	Brunton	Brunton	Suunto	Suunto	mixed	mixed
NO. OF INST. MEN	7	1	1	1	1	7	4
FORE/BACK SIGHTS	yes	no	no	no	no	no	no

Table 1: Data Sets Used in this Study

DATA SET	WEIGHTING METHOD	ADJUSTMENT ON STRINGS (FEET)		PERCENTAGE ADJUSTMENT		ADJUSTMENT STAND. DEV.		PERCENT OVERALL
		MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	
1	NUMBER	.1	2.2	.16	11.85	.24	5.72	1.04
	LENGTH	.1	2.3	.17	4.13	.26	6.23	1.03
	STD. DEV.	.03	2.11	.19	11.71	.16	5.61	1.02
	VARIANCE	.08	2.33	.16	9.94	.24	6.18	1.03
2	NUMBER	.10	1.47	.77	2.82	.46	3.08	1.53
	LENGTH	.05	1.15	.40	2.76	.24	3.62	1.48
	STD. DEV.	.08	1.11	.66	2.76	.39	3.63	1.48
	VARIANCE	.07	1.35	.59	2.42	.35	3.18	1.51
3	NUMBER	.42	4.03	1.01	8.81	1.46	10.70	3.32
	LENGTH	.43	3.40	1.07	8.17	1.51	9.37	3.33
	STD. DEV.	.37	3.19	.90	8.72	1.31	9.58	3.27
	VARIANCE	.44	3.64	1.06	8.28	1.49	9.32	3.33
4	NUMBER	.13	3.12	.39	4.92	.61	7.56	2.15
	LENGTH	.07	2.68	.55	4.66	.32	6.56	2.16
	STD. DEV.	.15	2.44	.46	5.30	.75	5.98	2.17
	VARIANCE	.12	2.71	.55	4.69	.57	6.63	2.16
5	NUMBER	.15	1.90	.38	2.64	.54	4.80	1.70
	LENGTH	.14	1.88	.51	2.63	.61	4.76	1.70
	STD. DEV.	.11	1.74	.45	3.01	.48	4.39	1.69
	VARIANCE	.15	1.91	.46	2.66	.63	4.84	1.70
6	NUMBER	.09	6.75	.29	4.74	.36	8.56	1.53
	LENGTH	.09	6.49	.58	3.84	.12	8.23	1.53
	STD. DEV.	.12	4.77	.35	7.92	.43	6.04	1.50
	VARIANCE	.10	6.78	.37	3.73	.46	8.59	1.53
7	NUMBER	.18	10.14	.67	4.16	.59	9.48	2.30
	LENGTH	.11	8.16	.40	3.33	.36	7.63	2.23
	STD. DEV.	.27	6.19	.98	4.62	.87	6.65	2.28
	VARIANCE	.13	9.13	.49	3.48	.44	8.54	2.25

Table 2: Comparison of Weighting Methods

SURVEY DATA SET		1	2	3	4	5	6	7
SUM OF PROBABLE ERRORS (STANDARD DEVIATION), FEET		19.30	2.65	4.67	8.06	3.34	8.20	7.80
SUM OF STRING VECTOR ADJUSTMENTS	FEET	31.0	5.1	23.5	25.8	7.6	37.6	18.1
	REL. P.E.	1.6	1.9	5.0	3.2	2.3	4.6	2.3
SUM OF X-ADJUSTMENTS		16.7	3.13	8.0	12.3	4.04	14.1	7.9
SUM OF Y-ADJUSTMENTS		15.7	3.11	4.7	13.7	4.08	22.9	8.3
SUM OF Z-ADJUSTMENTS		14.2	1.90	19.5	11.8	3.75	21.5	12.3

Table 3: Comparison of Adjustments in Different Coordinates

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La Médicalisation des Secours en France, Le Point en 1980

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L'organisation des secours en France fait l'objet d'une autre communication. Rappelons-en les principaux rouages: cette organisation est centrée sur les départements à la tête desquels se trouvent le conseiller technique, émanation de l'autorité du Préfet.

Ce conseiller technique a pour mission d'organiser les différentes équipes de spéléologues, de les entrainer, de diriger les opérations de secours. A l'échelon national, le Spéléosecours Français (SSF) regroupe les conseillers technique et travaille avec la commission médicale de la fédération qui tente de regrouper les médecins spéléologues actifs.

La démonstration de l'intérêt de la médicalisation des secours au travers d'expériences vécues pousse à une organisation encore meilleure.

Qu'Apporte Cette Médicalisation?

- Un diagnostic ou plutôt une approche de diagnostic. L'hostilité du milieu souterrain est un obstacle à un examen approfondi: température, lumière, le médecin ne possède rien d'autre que ses yeux, ses oreilles et ses mains. Ce diagnostic va conditionner le déroulement du secours.

exemples: utilité ou non d'un brancard, arrêts...

- Un soutien moral, au blessé, à l'équipe de secours. Ceux qui ont participé à des secours réels connaissent l'importance d'un tel apport.

- Une réanimation cardiovasculaire par un abord veineux quasi sytématique permettant: la compensation d'un choc hypovohlémique, la réhydratation de victimes épuisées. Ces deux gestes, permettant une évacuation dans de meilleures conditions évitant parfois des complications graves voire une issue fatale

- L'analgésie: La lutte contre la douleur permet de diminuer l'état de choc, de réaliser le brancardage dans de bonnes conditions.

- Une réanimation respiratoire éventuelle en assurant la liberté des voies aériennes par une intubation trachéale, dans le cas d'un traumatisme cranien par exemple.

- Un début de traitement: Le parage de certaines plaies, l'immobilisation de fractures permet d'éviter des complications ultérieures.

exemples: ostéite en cas de fractures ouvertes importantes, choc hémorragique.

A la lecture de ce qui précède, on se demande pourquoi cette médicalisation n'est pas encore réalisée systématiquement? Elle présente malheureusement un certains nombre d'impératifs.

Les Impératifs Imposes par la Médicalisation des Secours:

- Matériel: les plus faciles à résoudre. Le matériel médical doit être prêt, conditionné, entretenu. L'improvisation en la matiere fait courir le danger de voir ce matériel inutilisable au moment voulu.

- l'équipe médicale: Centrée sur le médecin spéléologue si possible anesthésiste réanimateur, actif en spéléologie.

Lorsque l'on connait les activités professionnelles des médecins, le principal problème est la disponibilité des médecins.

Ces Trois Exemples Permettent de Mesurer le Benefice Retirer par la Médicalisation des Secours.

- premier exemple: trou du Garde en Savoie

- cavité dont l'accès se fait en voiture, caractéristique: progression en méandres avec quelques passages étroits, notamment en sommet de puits.

- à la cote -100 m., un spéléologue a fait une chute et s'est blessé a l'épaule. L'accident a eu lieu en début d'après-midi, l'alerte est donnée à 19 H 15. L'équipe médicale est constituée par un médecin anesthésiste-réanimateur et un auxiliaire médical; cette équipe, munie du matériel médical adapté est acheminée par hélicoptère jusqu'à l'entrée de la cavité, l'accident ayant en lieu à 100 km.

L'accès au blessé se déroule sans problème avec l'équipe de spéléologues savoyards. Après examen, le diagnostic posé est: luxation antéro-interne de l'épaule sans autre lésion.

Le blessé est installé, une perfusion de sérum glucosé à 10% est posée. La réduction sera réalisée par l'injection intraveineuse de 5mg. de valium et 2 mg. de phénopéridine. Après une attente de 30 minutes pour surveillance, le blessé ressort par ses propre moyens l'épaule encore analgésiée par la phénopéridine; celle-ci n'a pas été immobilisée étant donné les difficultés de progression.

-Une radio de contrôle satisfaisante sera effectuée le lendemain matin

Il est inutile de démontrer dans ce cas que le déroulement du secours a été facilité par l'intervention d'une équipe médicale dans la cavité. Le brancardage d'un blessé, l'épaule luxée aurait été aléatoire et aurait certainement aggravé l'état de la victime.

- deuxième exemple: grotte de la Diau en haute-savoie.

- il s'agit d'une traversée d'abord dans un réseau fossile puis dans une rivière souterraine. Les difficultés en sont: la longueur et la survenue de crues éventuelles

- une équipe de six spéléologues s'est engagée dans cette traversée qui dure normalement une dizaine d'heures. L'alerte est donnée 48 heures plus tard, les spéléologues n'étant pas ressortis et une crue étant survenue.

Le déroulement des secours est d'abord rendu très difficile en raison des conditions météo.

Des équipes de recherche sont d'abord engagées sans médecin. Elles font la jonction avec les rescapés 16 h plus tard soit 64 h après leur entrée dans la cavité.

- Le bilan est: Un noyé disparu
trois "fatigués"
deux "épuisés"

Le médecin est demandé car, malgrés des boissons chaudes et autres reconstituants, ils restent prostrés. A l'arrivée du médecin; les deux victimes sont prostrées, tachycardes (I40) avec un pouls filant et une tendance lipothymique.

Les deux sont perfusés avec chacun:
500 cc de glucosé à 10%
500 cc de Ringer Lactate

En 30', l'effet est spectaculaire: ils se sentent beaucoup mieux, leur pouls se ralentit, ils acceptent de prendre une solide collation.

Ils ressortiront de la cavité (Ih30 de progression en rivière) par leur propres moyens, bien encadrés.

Ceci a permi une sortie rapide de la cavité et a évité d'être surpris par une deuxieme crue survenue peu de temps après la sortie de la cavité.

-troisième exemple: Haute-Savoie Plateau des Glières gouffre des 3 mousquetaires.

Gouffre à tendance verticale: Il s'agit d'une succession de puits avec une étroiture verticale à la cote - 60 m, une autre à - 170 m. Cette cavité est en cours d'exploration. Au cours de la descente, un spéléologue se coince dans l'étroiture à -170 m, un autre, en voulant lui porter secours se coince à son tour et décède rapidement sur la corde. Le 3e et dernier membre de l'exploration est coincé en aval.

Les secours sont déclenchés, le groupe de 3 spéléologues n'étant pas réapparus. Lors de l'arrivée de l'équipe de secours, le spéléologue coincé sera resté 26 h sur son baudrier et présente des périodes de conscience et d'inconscience.

L'équipe médicale sera appelée à ce moment là; elle comprend un médecin, un auxiliaire médical. A l'arrivée auprès de la victime, celle-ci présente: un état de conscience fluctuant un pouls difficilement perceptible, des mains oedématiécs, une douleur très vive au niveau de la racine des membres inférieurs, une température $< 35°$

Le traitement institué sera: Perfusion de 500 cc de glucosé à 10%, 500 cc de Ringer Lactate réchauffé sur le générateur à acétylène. Après une amélioration, la victime absorbe une boisson chaude très sucrée.

La victime a été brancardée sauf dans l'étroiture ou elle a été hissée à l'aide d'un baudrier.

-L'évolution ultérieure a été marquée par:
Une poussée thermique à 40°
Une évolution de gelures aux 4 extrémités ayant nécessité une arthrodèse P1 P2 des 2e et 3e orteils aux deux pieds.

L'intervention d'une équipe médicale a permi d'éviter sans doute une issue fatale.

-Maintenant deux autres exemples:
-chute dans un puits d'entrée de 40 m, décès de la victime pendant la remontée celle-ci souffrait d'une hémorragie interne.
-Fracture ouverte de jambe, très hémorragique, brancardage sans déchocage: les suites sont marquées par une anurie de trois semaines et la survenue d'une ostéite.

En Conclusion

A l'issue de cette communication, étayée par des exemples vécus, j'aimerais que les interlocuteurs soit convaincus de:
- la nécessité de se donner les moyens de faire descendre un médecin sous terre; médecin rompu aux techniques de réanimation d'urgence. Dans la mesure du possible ce médecin devra être intégré à l'équipe de premier secours.
-l'inutilité de brevetés ou compétents en secourisme pendant le déroulement du secours; leur place se situe avant l'arrivée du médecin.

Il faut des techniciens de la spéléologie pendant le secours.

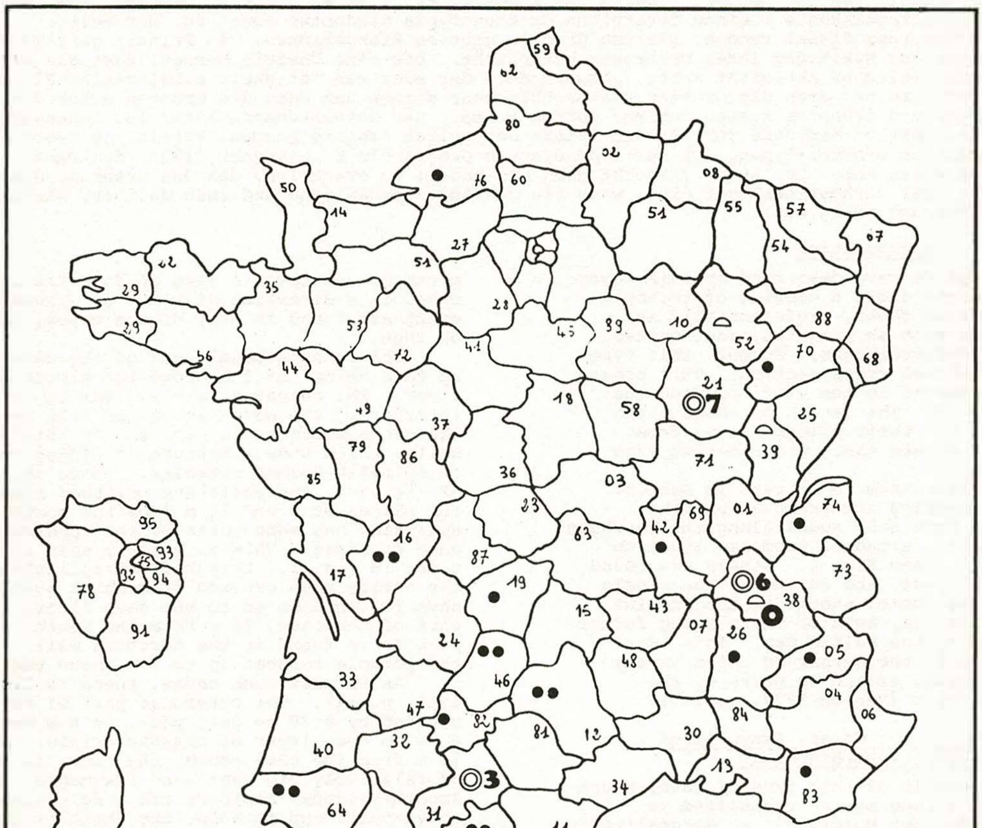

Figure 1. REPARTITION DES MEDECINS SPELEOLOGUES EN FRANCE AU 1.1.81

Remargues: il y a peu de médicins de haut niveau technique
il y a peu de plongeurs qui pratiquent réguilièrement cette activité
beaucoup de médecins font de la spéléo peu de temps donc mise à jour annuelle

Tunnel Caves in Swedish Noncalcareous Rocks

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Abstract

The special type of cave described in this paper is a cave formed in a crevice of tectonic origin in noncalcareous rocks. Secondly this type of cave has a pear-shaped cross section. This cross section is often repeated in the cliff outside the cave mouth. Caves of this type seem to be rare in Sweden, and only about 50 examples are known at present. Most of these caves are found along the northern Baltic coast of Sweden, situated from sea level up to about 200 m a.s.l. Others are found on the Swedish west coast, and inland in the middle of Sweden around the former shores of the Ancylus Lake and the Litorina Sea, both of these being former postglacial stages of the Baltic Sea. This type of cave is not known by the author to exist in any other part of the world, except in parts of the Norwegian Atlantic coast.

The origins of these round, polished caves are discussed. Principally, two theories are used to explain their origin. One theory states that the caves were the result of glacial activity, expecially the erosive activity of the subglacial rivers. The other theory states that the caves are shore phenomena, and that the caves are formed by abrasion in present and past shores. The second theory is supported by the author in thispaper, which contains descriptions, plates and surveys of this special type of cave, which was named a "tunnel cave" by the Swedish geographer E. Ljunger (1924). The author also tries to make a model which explains the origins of these caves, predicting when they are formed and the period of time required for their formation.

Zusammenfassung

Der besondere Grotten-Typus, der hier beschrieben wird, ist eine Grotte, gebildet in einer Kluft tektonischen Ursprungs in nicht-kalkhaltigem Felsen. Zweitens besitzt dieser Grotten-Typus eine birnenförmige Querabteilung. Diese Querabteilung ist oft auch in der Klippe ausserhalb der Grottenöffnung zu finden. Allem Anschein nach sind Grotten dieses Typus selten in Schweden, nur etwa 50 Beispiele sind zurzeit bekannt. Die meisten dieser Grotten sind längs der nördlichen schwedischen Ostseeküste zu finden. Ihre lage erstreckt sich von Seehöhe 0 bis etwa 200 m über dem Meerespiegel. Weitere Grotten sind an der Westküste zu finden sowie im Landesinneren von Schweden und zwar an den früheren nacheiszeitlichen Entwicklungsstufen der Ostsee. Soweit der Autor weiss, gibt es - ausgenommen gewisse Abschnitte der norwegischen Atlantikküste - einen derartigen Grotten-Typus nirgentwo sonst auf der Welt.

Ueber den Ursprung dieser runden, glatten Grotten gibt es Kiskussionen. Im Prinzip gibt es zwei Theorien, die man zur Erklärung ihres Ursprungs heranzieht. Die eine Theorie besagt, dass die Grotten das Resultat eiszeitlicher Aktivität seien, imsbesondere der erosiven Tätigkeit subglazialer Flüsse. Die andere Theorie meint, dass die Grotten Küsten-Phänomene seinen und dass die Grotten durch die Abrasion heutiger und früherer Küsten geformt worden seien. Der untenstehende Autor ist Anhänger dieser zweiten Theorie. Die vorliegende Schrift des Autors beinhaltet Beschreibungen, Tafeln und Uebersichten zu diesem speziellen Grotten-Typus, der vom schwedischen Geographen E. Ljungner (1924) den Namen Tunnelgrotte erhalten hat. Der Autor versucht auch ein Modell zu erstellen, das den Ursprung dieser Grotten erklärt, das darüber Auskunft gibt, wann sie gebildet worden sind und auch darüber, wieviel Zeit für ihre Formung nötig war.

Introduction

The special type of cave described in this paper is, first a cave formed along a crevice of tectonic origin in noncalcareous rocks, preferentially in coarse-grained rocks such as granites, anothosites, metagreywackes and metasediments. Second, this type of cave has a pear-shaped cross-section. This cross-section is often repeated in the cliff outside the cave-mouth, see Fig. 2. The length of these caves varies from 5 to 30 m. Their height varies from 5 m to more than 10 m, and their width varies from 0.5 m to about 5 m.

Caves of this type seem to be rare in Sweden, and only about 50 examples are known at present. Most of these caves have been found along the Northern Baltic Coast of Sweden, situated from sea level up to about 200 m a.s.l., see Fig. 1. Others are found on the Swedish West Coast, and inland in the middle of Sweden, around the former shores of the Ancylus Lake and the Litorina Sea, both of these being former post-glacial stages of the Baltic Sea. This type of cave is not known by the author to exist in any other part of the world, except on parts of the Norwegian Atlantic Coast (Reusch 1877, p. 195).

Description of the Caves, Exemplified by Stora Lidbergsgrottan

As a typical example of this type of cave, Stora Lidbergsgrottan (this name may be translated as "the big cave at Lidberget Mountain") at Nordmaling in Northern Sweden will be described, see Fig. 2. This cave is formed in an escarpment of metasedimentary rocks facing east. The cave is one out of ten such caves found along this escarpment, and it is situated at an altitude of 85 m a.s.l. The mountain is situated 10 km away from the nearest present coastline, the coastline being toward the southeast, and no other mountain is found between Lidberget and the coastline. Just below the cave, at the foot of the cliff, there is a big field of cobble-stones.

The cave is formed along a crevice of tectonic origin, striking N 86° E. In the upper, outer part of the cave the width of the crevice is 1-2 m, and it narrows inside to an average of 0.5 m, closing in completely in the innermost part of the cave. The dip of the crevice, 60° to the N., creates a kind of roof for the entire cave. Between 16-18 m from the mouth of the cave, a dyke of dolerite intersects the cave, in a direction of N 50° W. These dykes of dolerite are found in many of the caves, but not in all of them.

The concave basal part of the cave is polished, up to a height of 5 m above the almost horizontal cave floor. The concavity varies from the mouth toward the interior of the cave, as can be seen by comparison of the cross-sections in Fig. 2. In this respect the walls, which show a texture of ridges resemble those in spirally-formed potholes. Above this concave part of the cave, the walls are polished almost flat, except for places at 8 and 12 m from the mouth, where frost-splitting has made parts of the uppermost walls of the cave collapse. This is clearly seen in the cross-sections in Fig. 2. Lesser frost-splitting is found along the entire open crevice from which weathered fragments have fallen down on to the cave floor. In the innermost part of the cave, 18 m from the mouth, a sort of half-pothole is found in the northern wall. The round rim of the pothole reaches up to 2 m above the floor.

As in most such caves, there is little infill (Tell 1969, p. 14). The outermost part of the cave floor is covered by a 30 cm deep pool, on the bottom of which is a 30 cm deep layer of organic origin. Between 4 and 10 m from the cave mouth, the floor is covered by a bank of relatively big weathered fragments, and some round, smoothly-eroded boulders are also present. In the above-mentioned pothole, the depth of the sediments is 60 cm. The sediments include gravel, with mixed in round eroded and weathered finer sediments and finer materials such as clay.

Previous Research to Explain the Origin of the Caves

Generally two theories have been used to explain the origin of the caves. One theory claims that the caves were the result of glacial activity, especially the erosive activity of the sub- and postglacial rivers. The other theory suggests that the caves are shore-phenomena, and that such caves are also formed by abrasion in present shores.

The Glacial Theory

This theory rests on the idea that these caves can be considered horizontal potholes. Hence, explanations

of the origin of vertical potholes could also be used to explain the origin of these caves.
The vertical potholes can be divided into two groups according to the time at which they were formed:
1) Potholes of recent origin and 2) fossil potholes. The formation of recent potholes has been researched in Sweden by Ångeby (1951), who describes them as "fluviatile phenomena of erosion", which means that they were created by eddies and water-rollers in running water. The fossil pothole, according to Ångeby, developed in the same way as those of recent origin, in sub-glacial and latero-glacial times. Since Ångebys publication, potholes have been described by Markgren (1962-63), Johnsson (1956) and Dahl (1965). These later publications suggest that the potholes were formed in glacial times. According to this description, the caves could be horizontal potholes, formed in glacial and sub-glacial rivers. The Swedish speleologist Leander Tell returned to this theory several times. In 1977 he wrote in the NSS Bulletin: Most cauldrons are vertical, but horizontal ones also exist. --The largest horizontal pothole, of Räckeberga Kyrka at Torsböle in Northern Sweden, is 25 m long, 8 m high and 6 m wide; two adjacent ones are also quite large (Tell 1877, p. 112). In a paper for the 6th International Congress of Speleologi he writes: "This cave has been hollowed out in granite by ice, and shows erosional marks from glacial streams," (Tell 1973, p. 403). Räckeberga Kyrka is situated within the area researched by the author, and the cave is similar in type to the one described above.

The Abrasion Theory

In 1917-19 Henrik Munthe, one of the pioneers in Swedish speleology, made an inventory of all Swedish caves known at that time (Munthe 1920). He wrote: "Another type of cave - and to them most of our caves belong - have been formed by the work of waves on exposed cliffs, especially when these consist of limestone or other hard rocks which are broken through by crevasses and diaclases--these caves often have a more or less marked, rounded form, depending on several factors such as the petrographic character of the rock, the longer or shorter time whereby the waves have had occasion to work, and the quality of abrading tools in the form of cobble-stones, sand, etc, that the waves have had at their disposal", (Munthe 1920, p. 10).

Erik Ljungner (1924) describes what he calls "tunnel caves" from the Swedish WEst Coast, and he points out that these caves are typical examples of marine abrasion. This theory he develops in his doctoral thesis (Ljungner 1927-30, p. 432-476). Here he he defines two types of "tunnel caves". First, there are those formed near a cobble-field, where the boulders from the field were tools for the abrasion which formed the cave. Second, there are those caves formed where no field of cobble-stones is present, but where materials quarried away from within the cave by the waves became tools which further enlarged the cave.

The next Swedish scientist to deal with cave formation by shore abrasion was Sven E. Behrens. He too notes the neighborhood of cobble-fields to these caves. He discusses the possible factors affecting shore abrasion (Behrens 1953, p. 181). These are: 1) The dimensions of the waves. 2) The angle between the waves and the shore line. 3) the quality of the rock. The dimensions of the waves depend in turn on: 1) The strength and durability of the wind. 2) The depth of the sea. 3) The fetch of the sea. The ways in which these different factors could affect the caves are discussed below.

Discussion

The Glacial Alternative of Cave Formation.

The directions of movement of the last glaciation, in the area investigated along the Baltic Coast of Sweden, see Fig. 1, was towards the south. The erosional forms created by a moving ice-sheet strike mostly in the direction of the moving ice. This is not the case with the caves. In the neighborhood of the caves, no striae or p-forms have been discovered. The cliff surfaces are mostly just as much polished as those of the caves.

As regards the possibility of post-glacial and latero-glacial streams, there are no other indications of stream erosion except for a few semi-cirrcular potholes near the cobble-fields, and near some of the caves. Post-glacial streams might have formed waterfalls down the escarpments which contain the caves. The erosion due to such a waterfall would surely have polished the upper parts of the crevices in and outside the caves. The upper parts of these crevices, both in and outside the caves, are mostly weathered. Rounded boulders stuck in between the walls of the caves and in the crevices are also brought in from below, which would not have been the case if they were brought in by a waterfall.

The Shore Abrasion Alternative of Cave Formation.

As pointed out above, there is no evidence of glacial or glaciofluvial formation of the caves. Most of the facts point toward an abrasive origin. It is therefore necessary to investigate the altitude and exposure of the caves, in relation to past levels and post-glacial stages of the Baltic Sea.

The caves investigated are mostly situated along the coasts of the Litorina Sea, which reached a level of 124 m above the present sea. Some others are found along the shores of the Ancylus Lake between 124 m a.s.l. and 180 m a.s.l. The highest shoreline of the area varies between 272 m in the north and 285 m in the southern part of the area investigated. Fig. 1.I. shows the distribution of the caves at different altitudes, and these can be compared with the distribution of the altitudes of caves on the Swedish West Coast, on the same figure.

The exposure of the caves toward the past shorelines can be seen in Fig. 1.II. The few caves exposed towards the SE can be explained by the distribution of protecting, high islands in the southern parts of the area investigated. The greatest fetch would be attained by winds from S to SE, where fetches of about 600 km were possible (Hörnsten 1964, p. 184). From the east fetches of about 300 km were possible, The exposure of the eastern caves can be contrasted with that on the Swedish West Coast, Fig. 1,III, investigated by Ljungner (1927-30) and Sjöberg (1978).

The Development of Tunnel Caves

Morphological Development. Ljungner (1927-30, p. 469) described two types of tunnel caves, as seen above. The second type, where no cobble-field is found in the neighborhood of the cave, will be discussed here in more detail. Ljungner constructed a mathematical formula for the morphological development of this type. Fig. 3 shows how the cave can be divided into the cave-crevice (a+b) and the concave polished part of the cave (c,c′). In the ideal case, $a + b = c + c'$. That is to say, the quarried block material corresponds to the concave polished parst of the cave. Supply and demand are equal. Usually however, $a + b \neq c + c'$. Different possibilities exist here. One is $a \simeq b + c + c'$. The total height of the crevice is dominant in this case. Another is $a + b > c + c'$. Only a part of the quarried material has been used in this case. Another possibility is $a + b < c + c'$. In this case it is necessary to count on provision of material from outside the cave. Davies (1977, p. 83) writes: "Greater quarrying means more tools for abrading waves".

Ljungner's formulas are independent of the post-glacial isostatic land uplift, which in Northern Sweden in early post-glacial times was about 15 cm/year, and which now has slowed down to 0.8 cm/year. If we include this factor in trying to explain the origin of these caves, we can start the discussion at the moment when the foot of the cliff is about 10 m below the surface of the sea. "Below that depth erosive capacity is negligible", according to Rice (1977, p. 359).

Weathering, quarrying and cavitation produce the boulders which collect at the foot of the cliff. Cavitation excavates crevices and zones of natural weakness in the cliff. The upper and outer part of the cave crevice is opened up, as in a in Fig. 4. Here the creation of the cave is in an initial stage. Meanwhile, the land is rising. The boulders at the foot of the cliff can now be moved by the waves and the breakers. The walls of the crevices are beginning to be hollowed out. The conditions for this work become more and more favorable, as the cobble-field is transported closer and closer to the surface. The basal parts of the crevice become more and more polished and rounded, and the bottom of the cave fills up with rounded boulders. The conditions for creation of the cave are then optimal. The landuplift continues, until the basal parts of the cave are less and less often reached by the breakers. The cave then apsses into a recessive stage of evolution. The heavy evacuation from breakers now begins to draw the rounded boulders out of the cave, and under favorable conditions, the cave can be totally cleared of boulders.

Time Required for the Formation of the Caves. From this model of cave formation a formula has been derived for the length of time required to form the caves. The time required is equal to:

$$\frac{\text{the cave passage's height in mm}}{\text{isostatic uplift in mm/year}} + \text{n years}$$

where n varies with the rate of uplift, but is not more than several hundred years. This formula measures the mean time for the formations of the cave to within about 1,000 years.

Subjectively, this seems to yield a very short time of formation, but if we compare these caves with vertical potholes, then we can find interesting measurements for the latter. Angeby (1951, p. 67) describes an example from a water-power plant in Nor Northern Sweden, where a pothole with a diameter of 1-1.5 m and a depth of 1-1.5 m was formed in 10 days in concrete, with a flow of 5 m^3/sec. of water. In another example (p. 58) he mentions an average deepening of potholes in granites, of 3 cm per year. Angeby adds that it is possible for the rate of erosion to increase with further deepening of the pothole.

If the postulations discussed above are correct, then one can calculate the ages of the caves by plotting the altitudes of the caves on a diagram of the isostatic uplift in the area. This indicates, see Fig. 5, that a cave at an altitude of 180 m a.s.l. has an age of about 8,000 years, and that Lidbergsgrotten at an altitude of 85 m a.s.l. is about 5,000 years old.

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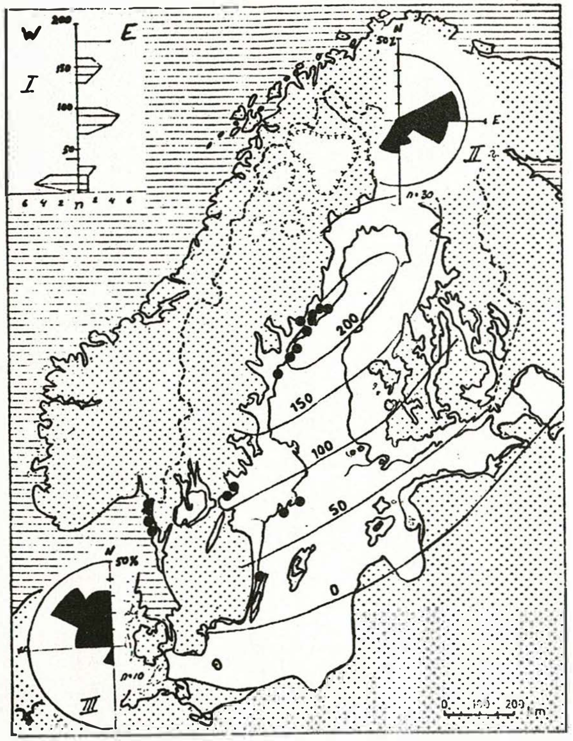

Figure 1. The Ancylus Lake about 8,700 years b.p., with with approximate isobases for every 50 meters (after G. Lundqvist 1963). The black dots show areas with tunnel caves.
I. The distribution of altitudes of the caves on the west- and north-east-coast of Sweden.
II. The orientation of the cave mouths in per cent of the number of measurements made on the north-east coast. The material is divided into 30° classes. n = 30.
III. The orientation of the cave mouths on the west coast. n = 30.

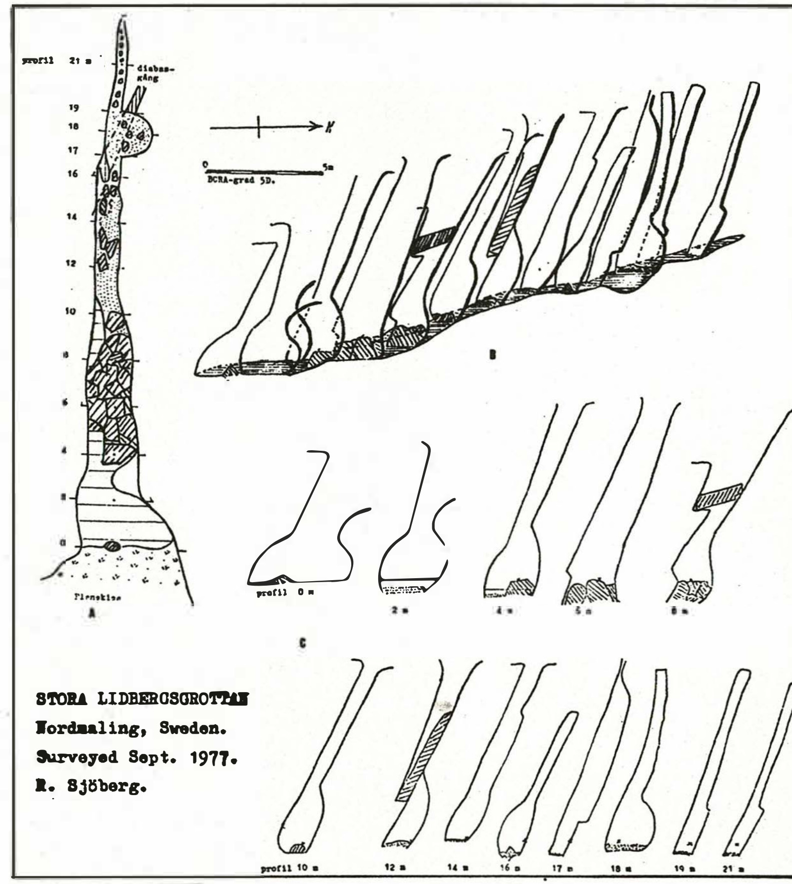

Figure 2. Survey of Stora Lidbergsgrottan. UIS grade 5. A = plan. B = 3 D extension of the cave. C = Cross sections for every 2 meters.

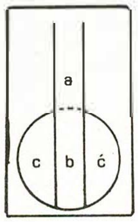

Figure 3. Morphogenetical divison of a tunnel cave, according to Ljungner. a + b = the cave-crevice. c + c´ = the concave polished part of the cave.

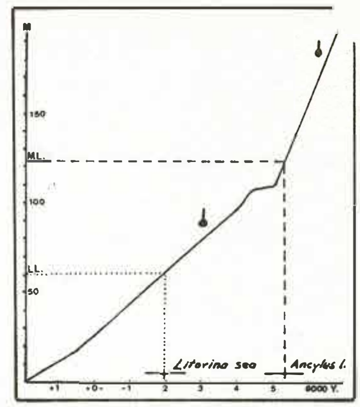

Figure 5. Diagram showing the isostatic uplift in North-Eastern Sweden. By plotting the altitudes of the caves on the diagram one can calculate their age.

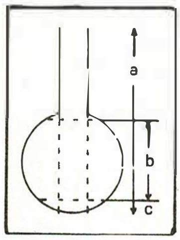

Figure 4. Morphological stages in the formation of a tunnel cave. a = the initial stage. b = the optimal stage. c = the recessive stage.

Cave Systems Speleogenesis at the Karst Poljes of Slovenia (NW Yugoslavia)

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Summary

The majority of classical karst cave systems is accessible on the ponor side of karst poljes: on the runoff side or between adjoining karst poljes the cave systems are accessible exceptionally. The known systems include active and passive channels where different cave sediments are conserved.

The stratigraphically dated cave sediments reflect the development of particular and common cave systems in the extension of one karstic river basin.

The new investigation results indicate that in speleogenesis quaternary geomorphologic history and climatic conditions and the geologic setting of the region are reflected. A test geochronologic ranging of cave systems development at the karst poljes will be introduced.

Résumé

La plupart de réseaux de grottes dans le karst classique est accessible dans la partie ponore de poljés karstiques; dans la partie d'affluence ou dans le karst entre deux poljés voisins est accessible exceptionellement. Les réseaux sont composés par les galeries actives et passives où beaucoup de sédiments sont conservés.

Stratigraphiquement datés dépôts de grottes reflètent le developement des réseaux particuliers ou communs dependant d'un bassin karstique.

Les résultats récents de recherches nous prouvent que dans la spéléogenèse reflètent l'histoire géomorphologique quaternaire, les conditions climatiques et structure géologique régionale. L'essai de ranger géochronologiquement le developement de réseaux le long de poljés karstiques sera introduit.

Zusammenfassung

Die Mahrzahl der Höhlensysteme des klassischen Karstes ist an der Ponorseite der Karstpoljen zugänglich; an der Zuflussseite oder im Karst zwischen den nachbarten Poljen sind sie nur ausnahmsweise zugänglich. Die Systeme bestehen aus bewässerten und trockenen Gängen mit verschieden erhaltenen Höhlensedimenten.

In den stratigraphisch datierten Höhlensedimenten spieglet sich die Entwicklung der einzelnen und gemeinsamen Höhlensysteme eines Karstflussbereiches.

Die neueren Forschungsergebnisse zeigen, dass sich in der Speläogenesis die quartäre geomorphologische Geschichte und die Klimaverhältnisse als auch der regionale geologische Bau spiegeln. Ein Versuch, die Entwicklung der Höhlensysteme an den Karstpoljen geochronologisch einzugliedern, wird vorgestellt.

Ecology of Crayfishes from West Virginia Caves

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Abstract

The crayfishes, Cambarus nerterius Hobbs and Cambarus bartonii (Fabricus). were studied to determine their life history and ecology within a cave habitat. Bransfords and McLaughlin-Unus caves in Greenbrier County, West Virginia (USA) were used for this study. C. nerterius, a probable troglobite, is reported from 11 caves in Greenbrier County. Superficially, C. nerterius resembles cave-dwelling members of C. bartonii. C. nerterius has not undergone the extreme morphological changes associated with troglobites. C. bartonii, a troglophile, is reported from a number of West Virginia caves.

Mark and recapture was used to determine individual growth rates and population numbers, structure and movement. Collection of data was monthly from October 1978 through November 1979. Data collected indicate that breeding for both species probably occurs in the fall with young entering the population in late summer and early fall. Females with cement glands were observed beginning in late October and November. Eggs are laid and carried during late spring and summer. Female C. nerterius in berry were observed in August, 1980. An increase of young- of -the year occurs in September, October, and November. Molting occurs in the spring following peak run-off and in the fall.

Both caves are fed by surface streams and are subject to extreme fluctuations in water levels. During the study period precipitation and stream flow have been 24% above average and the overall populations of both species have declined. There seems to be little movement of the populations within the streams. The number of males and females are about equal.

Zusammenfassung

Die Krebsen, Cambarus nerterius Hobbs und Cambarus bartonii (Fabricus), werde studiet un eucher zu achen icher Leben historie und ecologie in einer Grotte heim. Bransfords und McLaughlin-Unus Grotten in Greenbrier County, West Virginia (USA) wurde gebrauch fur disen exjuninenten. C. nerterius ein moglichen Höhlen leber, est repotiert von 11 Höhlen in der Greenbrier County. An der tope C. nerterius sicht aus wie Höhlen-house jrark auf C. bartonii. C. nerterius hast nich durchgehd die ganze morphological shiften dass hat mit troglobites. C. bartonii, a troglophile ist repotiert von verschieden Höhlen auf West Virginia.

Marken und es noch ein mal uber zu gehen wurde braucht um sicher zu machen die individuale wie schnell die Einwohneren wurde grosser und mehrer. Zusammen brauchen auf data war in alle monaten von Oktober 1978 bis November 1979. Die Data zeigte dass der war mehr machtin beide sorten in September-November dann und die unger kommt in die Summer und fruh September. Die Feminins war obseviert in die start auf Oktober und November. Eiren wurde galegt und mitgebracht in Summer und fallen. C. nerterius um berren wurde gessehen in August 198+. Ein grossere auf dem Ihie kommt in September, Oktober, und November. Es kommt schwacher in September.

Beide die Höhlen ist geest mit Wasser und die objecten op zum wasser speigel. In dem Penoden auf studieren und wasser fliessen wurde 24% auf die nomale und die menschen auf beide sorten hat autgebt. Da ist einkleiner bewegun in die menschen im Wasser. Die feminienen und Maskeilinen sind ungefar dieselbe.

Introduction

The genus Cambarus, the dominant element of the southern Applachian crayfish fauna, includes species ranging from Wisconsin to New Brunswick and southward to Texas and the panhandle of Florida. Only in the mountains, portions of the Cumberland Plateau, the Highland Rim, the Peidmont, and the caves of the Ozark region does Cambarus dominate the crayfish fauna (Hobbs, 1969).

C. bartonii ranges from New brunswick southward to northeastern Georgia and westward to Kentucky and Ohio (Hobbs, 1969). It is found in small springs and creeks of the mountains. The species is referred to as troglophilic since it is not confined to caves and populations are usually not very distant from entrances.

C. nerterius, first described in 1964, has subsequently been collected from a total of 11 caves in the Greenbrier Valley of West Virginia. With one exception, a cave in the Elk River drainage of Pocahontas County, all other collections are from the Greenbrier River drainage. Hobbs (1969) states that subterranean waters of the Elk and Greenbrier watershed probably represent a Pleistocene refugium sought by the ancestors of C. nerterius.

C. bartonii and C. nerterius may occupy the same cave. In Greenbrier County, both species have been collected from the Culverson Creek Cave System, Ludington Cave and Buckeye Creek Cave. C. nerterius is often found distant from cave entrances and does not occur syntopically with C. bartonii (Holsinger et al. 1976).

Superficially, C. nerterius resembles cave-dwelling members of C. bartonii. The chelae of C. nerterius are more slender and elongated, the fixed finger of the chela has deep dorsal and ventral impressions at the base, and the areola is more densely studded with punctations. The antennal scale is broader in older specimens, there are small lateral spines and the edges of the rostrum are thinner. At present, C. nerterius is considered troglobitic, being taken only from cave streams. It has not, however, undergone the extreme morphological changes associated with troglobires (i.e., loss of pigment, eye degeneration, attenuation of appendages) (Holsinger et al. 1976). Pigmentation in C. nerterius is the same as cave-dwelling C. bartonii.

Methods and Materials. Bransfords Cave and McLaughlin-Unus Cave (of the Culverson Creek Cave System) are part of the Culverson Creek drainage. The cave entrances are 5 km apart. Six stations were sampled in the Bransfords stream and three in the Wildcat stream of McLaughlin-Unus. The substrate of the cave streams at selected stations consists of areas of small gravel, silt, and vegetative debris with some larger rocks.

Each month the stations were sampled using baited, modified minnow traps. Bait consisted of punctured cat tuna cans or bacon in a punctured film canister. The traps were allowed to remain for a few hours to overnight. Hand netting was also used.

The marking techniques were patterned after Cooper (1975). Processing crayfish began with sex determination. Males were identified as form I or form II. Females were checked for cement gland development. Females with developed cement glands were checked for oocyte development.

The carapace was dried using a terry cloth towel prior to numbering with fingernail polish. Polish was applied using a thin water color brush. Missing, damaged or regenerate appendages were noted to aid in identification of recaptures with lost numbers. Carapace length was measured using a vernier calipher. Chela length and width of males were also measured. Exoskeleton condition was rated using a scale of 0 to 4, with 4 being very firm and hard.

Crayfish were injected with Bates numbering machine ink using a 1 cc plastic syringe. The ink was injected ventrally at the juncture of two segments of the abdomen, keeping the needle parallel to the muscle just beneath the cuticle and injecting anteriorly. The ink is retained during subsequent molts. Crayfish were returned to the stream after processing.

Air and water temperatures were recorded. Observations concerning the habitat were made.

Results and Discussion. Data could not be collected in December, 1978 and February and March, 1979 due to heavy rains and snow melt. The streams were flooded and silty. The Wildcat stream in McLaughin-Unus Cave rose approximately 7 meters higher than normal in February. Stream levels were higher than normal during all of 1979. Precipitation for the year was 24% above average. Based on sample size and observations, the populations may have declined as a result of the high water and silty conditions.

A total of 214 C. bartonii were processed during the study. Lincoln-Peterson estimate of population size is 187 using data for October and November 1978. Sex percentages indicate that both sexes were active and equally subject to capture. Although form II males were more prevalent in all but one sample (Table 1), an increase in form I males occurs in the fall. The smallest form I male measured 25 mm carapace length. Females with cement glands were observed during the fall. The smallest female with cement glands and developing oocytes was 34.4 mm carapace length.

A total of 198 C. nerterius were processed. Lincoln-Peterson estimate of population size is 181 using data from the fall of 1978. As with C. bartonii, samples were not biased for either sex. An increase in form I males was evident in August 1979 (Table 2). The smallest form I male measured 25.4 mm carapace length. Females with cement glands were observed during the fall months. The smallest female having gland development measured 27.2 mm carapace length.

One female C. nerterius in berry was observed during August 1980 in the McLaughlin-Unus stream while the author was participating in a mapping trip. Collection was not possible. A week later a female was collected from General Davis Cave in Greenbrier County. A total of 165 eggs were attached with a mean size of 2.8 mm. The only previous collection of a female in berry was May 1964 from Culverson Creek CAve. No C. bartonii with eggs was observed during the study.

Exoskeleton data and observations indicate two periods of molting for most individuals. Molting occurs in the spring following peak run-off and in the early fall (Tables 1 and 2).

Data collected during this study indicate that the life cycles of C. nerterius and C. bartonii are similar to other cave crayfish of the United States temperate regions. Breeding occurs in the fall with eggs laid and carried during spring and summer months. Young enter the population during late summer and fall months.

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Table 1. Summary of data for Cambarus bartonii. All numbers are percent of total sample. S = sample size, I = form I males, II = form II males, M = males, F = females, Fg = females with cement glands, <20 = specimens with carapace length less than 20 mm, <25 = specimens with carapace length less than 25 mm but not less than 20 mm, Sf = exoskeleton not hard and firm, R = recapture.

Date	S	I	II	M	F	Fg	<20	<25	Sf	R
14 Oct 78	45*	6	42	53	40	0	13	33	48	0
04 Nov 78	50	6	42	48	52	10	12	30	52	22
06 Jan 79	1	0	0	0	100	100	0	0	0	0
27 Jan 79	2	0	50	50	50	50	0	0	0	50
21 Apr 79	9	11	22	33	67	0	0	22	11	11
19 May 79	21*	4	38	43	33	34	38	52	38	0
20 Jun 79	25	24	36	60	40	8	0	20	20	32
10 Jul 79	14	7	57	64	36	0	0	21	14	21
13 Aug 79	26	19	31	50	50	0	8	27	19	35
08 Sep 79	27	19	48	67	33	0	0	19	4	26
27 Oct 79**	29	41	21	62	38	17	3	7	3	52
11 Nov 79	20	15	55	70	30	0	0	10	0	50

* some juveniles could not be sexes
** traps were in for 2 weeks because of overnight flooding

Table 2. Summary of data for Cambarus nerterius. All numbers are percent of total sample. S = sample size, I = form I males, II = form II males, M = males, F = females, Fg = females with cement glands, <20 = specimens with carapace length less than 20 mm, <25 = specimens with carapace length less than 25 mm, Sf = exoskeleton not hard and firm, R = recaptures.

Date	S	I	II	M	F	Fg	<20	<25	Sf	R
15 Oct 78	12	8	42	50	50	0	17	42	75	0
05 Nov 78	39*	5	31	36	48	10	15	49	33	10
11 Nov 78	27	19	44	63	37	4	19	41	33	26
06 Jan 79	13	38	46	85	15	15	0	15	0	46
27 Jan 79	7	43	43	86	14	0	0	14	0	57
21 Apr 79	13	15	23	38	62	0	8	31	15	15
19 May 79	23	0	43	43	57	0	17	52	52	30
20 Jun 79	17	6	35	41	59	0	12	41	18	59
10 Jul 79	21*	9	38	48	43	0	14	57	24	24
13 Aug 79	22	41	9	50	50	0	18	32	27	32
08 Sep 79	29	3	38	41	59	0	38	72	45	14
27 Oct 79	7*	0	29	29	43	29	29	43	0	14
10 Nov 79	6	17	33	50	50	17	0	17	0	33
29 Dec 79	5	0	20	20	80	20	0	0	0	40
07 Jan 80	20	5	45	50	50	0	20	30	5	10

* some juveniles could not be sexed

Etude des Conditions Climatiques Pour la Conservation des Grottes Ornées Deux Interventions: Lascaux et Font de Gaume

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Résumé

Les grottes ornées préhistoriques, témoins de l'activité artistique humaine plusieurs fois millénaires, sont parvenues jusqu'à nous grâce à des conditions de conservation favorables; depuis leur découverte, par suite des modifications dues à des aménagements, l'équilibre dans lequel elles se trouvaient a été compromis.

Comprendre les mecanismes qui assurent leur conservation nécessite, entre autres, la connaissance des conditions climatiques: circulation de l'air à proximité des parois, temperatures de l'air et de la roche, teneur en vapeur d'eau de l'atmosphere, taux de gaz carbonique. A partir de ce que nous pouvons considérer comme un bilan de santé de chaque oeuvre, de chaque cavité, il sera possible de déterminer une intervention pour préserver ou améliorer les conditions de conservation.

Pour la grotte de Lascaux, les études menées ont conclu à la nécessité de maintenir les paramètres de l'air aussi près que possible de leur valeur d'équilibre, ce qui a conduit aux conditions actuelles de la cavité. A la grotte de Font de Gaume, les recherches faites pour concilier les visites de la cavité et les nécessités de la conservation des figures rupestres, ont montré un cycle annuel du taux du gaz carbonique et une élimination naturelle de ce gaz grâce aux mouvements de convection de l'air. Cette élimination insuffisante en période estivale a dû être renforcée par l'action d'une turbine.

Abstract

Prehistoric decorated caves, witnesses of man's artistic activity for several thousand years, have reached us thanks to conditions which have favored their preservation. Since their discovery their original balance has been compromised following the changes made for their presentation to the public. To understand the mecanisms which assure their conservation requires among other things, an understanding of the climatic parameters: the circulation of air near the walls, the temperature of the air and of the rock, and the humidity and carbon dioxide content of the atmosphere in the cave. On the basis of this, which we can consider as a bill of health for each rock painting, it will be possible to decide on what should be undertaken to preserve or improve the conditions of conservation for each cave.

For the Lascaux cave studies have shown the necessity of keeping the nature of the air as close as possible to its original balance; this has led to the conditions at present in force in the cave.

In the Font-de-Gaume cave, research has been done to reconcile visits to the cave with the need to conserve the rock paintings; the research has shown the existence of an annual cycle of a rise of carbon dioxide and its elimination due to movements of convection in the air. This elimination is not sufficient in the holiday period and has to be reinforced by the use of a turbine.

De nombreuses oeuvres préhistoriques pariétales situées dans les grottes ont subi des altérations au cours des millénaires, ce qui explique le faible nombre parvenu jusqu'à nous. Tel que nous les connaissons, leur état est conditionné par plusieurs facteurs climatiques (température de l'air, de la roche, teneur en humidité et en anhydride carbonique de l'atmosphère), géologiques (circulation d'eau, suintement...) et anthropiques (pollution due aux visiteurs, aménagement). Tous ces facteurs contribuent à régir une stabilité qui semblait, à première vue, mise en place de manière durable; pourtant certaines figurations et cavités se dégradent. Quelles solutions apporter à ces problèmes? d'abord, il nous faut obtenir le maximum de données par la mesure de paramètres physiques portant sur l'évolution des caractéristiques du milieu souterrain, ensuite le bilan de ces documents permettra d'orienter une intervention favorable à la conservation des oeuvres rupestres. Nous présentons deux exemples qui illustrent ces interventions, l'un sur la grotte de Lascaux à Montignac, l'autre sur la grotte de Font de Gaume aux Eyzies.

1. Grotte de Lascaux

A la grotte de Lascaux, indépendamment de l'agression biologique des parois ornées sous la forme de dissémination de colonies d'algues ayant nécessité sa fermeture, s'est posé le problème de la restauration de l'équilibre qui avait favorisé la conservation des peintures et de sa reconstitution.

1. Problèmes

Les parois de la Salle des Taureaux de du Diverticule axial sont recouvertes d'un mince concrétionnement de calcite dit en chou-fleur, qui a servi de support aux peintures magdaléniennes. En milieu calcaire, la stabilité des concrétionnements dépend de la présence d'eau et de la teneur en anhydride carbonique; il pourra donc y avoir des phases de corrosion dûes à la présence simultanée sur les parois de gouttes d'eau de condensation et dans l'air d'anhydride carbonique. Dans ces conditions, de rapides modifications de température de l'air (variations positives) provoqueront, au contact d'une roche plus froide, le phénomène de condensation capable de dissoudre le carbonate et, par ruissellement, d'entraîner les pigments.

2. Mesures prises

La conception par des spécialistes, dont Messieurs L. Pontier, R. Comolet, P.M. Guyon, d'un système de climatisation utilisant les échanges qui se font naturellement par convection dans la cavité entre la Salle des Machines d'une part et la Salle des Taureaux et le Diverticule axial d'autre part, a permis d'éliminer la possibilité de condensation sur les parois ornées et, au contraire, de la favoriser sur un point froid artificiel présent dans la Salle des Machines. Il s'agissait de maintenir à proximité des parois décorées une tension de vapeur d'eau dans l'air inférieure à celle correspondant à la température de surface de la roche.

En pratique, nous provoquerons, à certaines périodes de l'année, la condensation de l'air de la cavité sur deux échangeurs thermiques (échangeurs à ailettes: Fig. 1B) reliés à des groupes réfrigérants externes, alors que la roche de la Salle des Taureaux, encore froide par suite de la lente progression des ondes thermiques hivernales dans le sol, est soumise à l'influence de l'air venant des parties plus exposées aux variations extérieures telles que la Salle des Machines (Fig. 1C)

Une partie de l'année, du 15.6.78 au 19.1.79 pour le cycle climatique 1978-79, les conditions hydriques, après une série de mesures journalières, sont réajustées autour de valeurs qui ont été reconnues comme les plus aptes à assurer la meilleure conservation des peintures. La souplesse du mécanisme permet de contrôler l'humidité de l'air à tout moment et à aucune période il n'y a possibilité de condensation (Fig. 1D). Pour faciliter ce contrôle, la cavité est isolée de l'extérieur par une série de cloisons isothermes et de sas empêchant les échanges directs d'air.

Ces interventions permettent de remplacer partiellement l'effet régulateur de l'éboulis à l'entrée de la grotte, détruit lors des différents aménagements, et de maintenir une certaine humidité hygroscopique sur les parois pour s'assurer de la stabilité des pigments.

II. Grotte de Font de Gaume

Longue d'environ 124 m, elle comporte une galerie principale sur laquelle viennent s'adjoindre: au premier tiers, un petit diverticule doublement coudé accédant directement à l'extérieur, une petite galerie, et dans sa partie décorée après l'étroiture dite du "Rubicon", à droite une galerie latérale au deuxième tiers du parcours, et puis à gauche, une petite salle "le Cabinet des Bisons". Jusqu'au Rubicon, la galerie est peu élevée (de l'ordre de 2 m de haut), après elle a plus de 8 m de hauteur (Fig. 2A).

1. Etude du taux de gaz carbonique

Les mesures systématiques ont commencé matin et soir avant et après les visites depuis 1969 (périodes où il n'y avait pas de limitation des visites) en divers points du réseau. Elles ont été réalisées à l'aide d'un grisoumètre Zeiss et d'un carbonimètre Drager. Ces relevés, en 18 points répartis dans la cavité, ont montré:

- La présence naturelle de gaz carbonique dans la grotte. Ce taux de l'ordre de 0,1 à 0,3 correspond, hors visites, aux valeurs notées dans ce type de cavité subhorizontale.

- Un cycle annuel de variation du gaz carbonique (Fig. 2B)
- Une étroite relation entre la teneur en gaz carbonique de l'air et le nombre des visiteurs (Fig. 2C)
- Le rôle de l'étroiture du Rubicon qui constitue un obstacle entre la partie non décorée et la partie décorée où le taux de gaz carbonique ne descend pas en-dessous de 1 % durant les 3 mois de visites estivales. Cependant, dans certaines conditions de ventilation et de climat externe, au cours de la nuit, l'air de la partie décorée (plus chaud et plus riche en gaz carbonique) diffuse dans le reste de la galerie vers l'entrée; dans la première partie, les mesures du matin indiquent une élévation de la teneur comparée à la situation de la veille. Dans quelques cas, cette venue se traduisait, derrière la porte d'entrée, par un taux de 0,4 % en corrélation avec une baisse de 0,3 à 0,5 % dans la partie ornée.

2. Gaz carbonique et conservation

Le taux de gaz carbonique présent dans la cavité doit en principe être le plus bas possible pour limiter l'agressivité des eaux, en particulier des gouttes de condensation fréquentes en période touristique. Dans l'air chargé de gaz carbonique, la corrosion des roches calcaires peut s'exprimer par la relation globale réversible

$$\underset{\text{solide}}{CaCO_3} + \underset{\text{dissous}}{CO_2} + H_2O \rightleftharpoons \underset{\text{dissous}}{Ca(CO_3H)_2}$$

Dans ces conditions, l'apport de gaz carbonique provoque la formation de bicarbonate soluble, son départ est responsable de la décomposition du bicarbonate et de la précipitation du carbonate de calcium. Quelque soit le taux de gaz carbonique présent dans l'atmosphère de la grotte, les gouttes d'eau de condensation demeurent dangereuses pour les figurations rupestres par les dissolutions qu'elles peuvent produire.

3. Mesures prises et conséquences

a/ Principe

La cavité est dans un environnement exposé aux variations externes, c'est-à-dire qu'à certaines périodes de l'année (hiver, printemps) quelques portions de parois ornées et concrétionnées sont exposées aux ruissellements d'eau d'infiltration et, à d'autres périodes (été), à part les pluies d'orage dont l'influence est limitée par l'évapotranspiration, seul le phénomène de condensation constitue une menace par le risque de dissolution. Dans ces conditions, l'idéal serait de ne pas abaisser le taux de gaz carbonique présent naturellement dans l'air de la grotte lorsqu'il y a ruissellement, afin de diminuer au maximum la précipitation de calcite sur les parois et d'éliminer le gaz l'été lorsqu'il n'y a plus, sur les parois, que l'humidité provenant de l'air (condensation). C'est la solution vers laquelle nous nous sommes efforcés de tendre l'été en éliminant le gaz carbonique et en restreignant la fréquentation touristique, et l'hiver en laissant la grotte retrouver un régime plus naturel proche des conditions qui ont dû règner à cette période pendant des millénaires.

L'élimination du gaz carbonique a été favorisée par l'établissement d'une légère dépression qui facilite les échanges d'air entre la section décorée et la partie d'accès par les deux entrées. Le déficit est compensé d'une manière diffuse et l'air se renouvelle progressivement par la première partie.

Le dispositif mis en place comporte des canalisations partant de trois bouches d'aspiration situées au niveau du sol vers une turbine d'évacuation située dans le Diverticule coudé. L'installation réalisée pour une fréquentation maximale journalière de 650 personnes par groupe de 20, permet de ne pas dépasser un taux de 0,6 % de gaz carbonique dans la galerie ornée grâce à une turbine dont le débit est de 264 m^3/hr. L'air de la partie décorée n'est renouvelé qu'au bout d'une demi-journée de mise en dépression par de l'air venu de la première partie et 12 heures environ sont nécessaires pour l'échange d'un volume d'air équivalent à celui de toute la grotte. Pour éviter toute relation brutale avec l'extérieur, les portes supplémentaires édifiées dans les galeries d'accès restent closes en période touristique pendant le fonctionnement de la turbine. Leur ouverture est rétablie lorsque le nombre de visiteurs est plus faible, la ventilation naturelle devient suffisante et la mise en dépression est supprimée.

b/ Evolution réelle

De nombreux contrôles ont été réalisés après la mise en place du dispositif d'élimination; nous donneront, à titre d'exemple, celui d'août 76 où des mesures ont été faites heure par heure pendant la visite (cf. Tableau ci-après, 650 personnes sont entrées dans la grotte, réparties le matin et l'après-midi.

Heures	Carrefour des 2 entrées	Rubicon	Cabinet des Bisons
10 h	0	0	0,1
11 h	0,1	0,1	0,3
12 h	0	0,1	0,4
13 h	0	0	0,2
14 h	0	0	0,2
15 h	0,1	0,2	0,4
16 h	0,1	0,3	0,5
17 h	0,2	0,2	0,6
18 h	0,2	0,2	0,5
20 h	0,1	0,1	0,4
24 h	0	0,1	0,2
6 h	0	0	0,1

Le lendemain matin, après le fonctionnement de la turbine toute la nuit, le taux de gaz carbonique est pratiquement nul (inférieure à 0,1 %); l'accumulation d'un jour à l'autre n'existe plus.

Depuis 1979, la fréquentation de la cavité a été réduite de nouveau, en raison de difficultés créées par l'encadrement des groupes, le nombre des visiteurs dans ces conditions en pleine saison touristique n'excède pas 450 personnes, ce qui est de très loin inférieur aux valeurs selon lesquelles l'étude a été faite.

Les études et interventions décrites ont permis de maîtiser l'influence du gaz carbonique et de rendre, en période touristique, à la grotte de Font de Gaume des conditions favorables à la conservation des figures rupestres. Dans cette grotte de faible volume, l'incidence de toute perturbation est immédiate et, seul, le dispositif de dépression mis en place permet d'assurer un équilibre. Cet équilibre est précaire et il convient de ne pas le perturber en modifiant les conditions de base de l'étude.

Il nous est agréable de remercier ici Monsieur J. Marsal, Inventeur de la grotte de Lascaux, et toutes les personnes qui, sur le plan administratif et scientifique, nous ont apporté leur aide.

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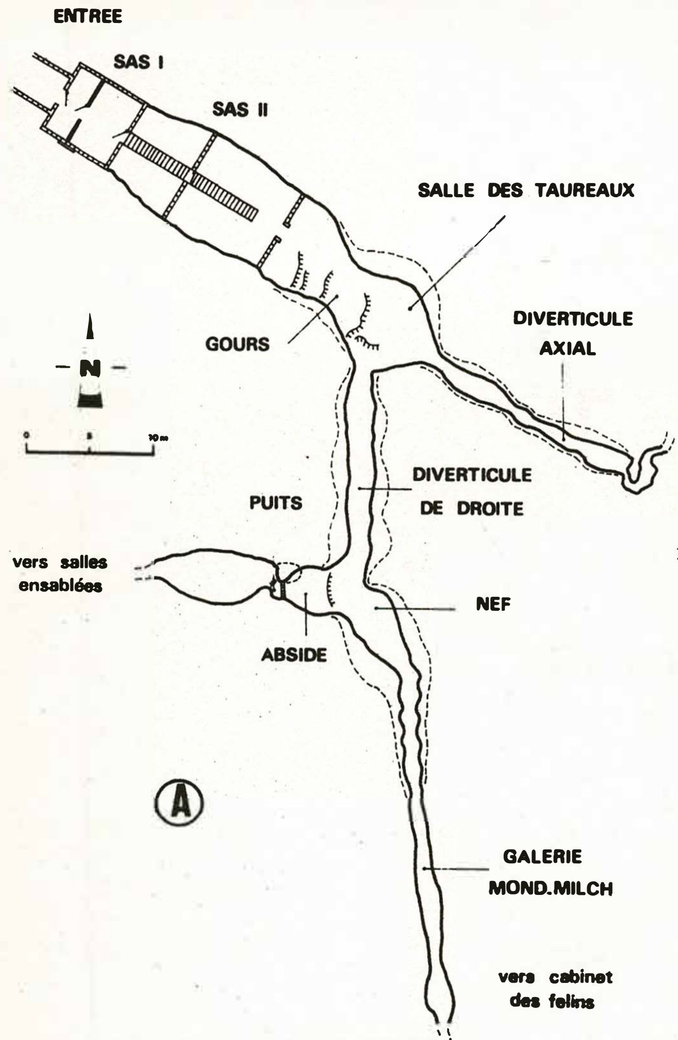
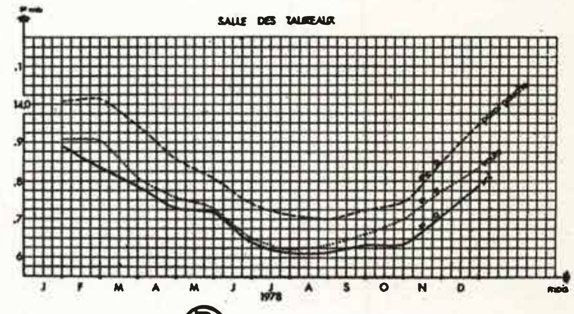
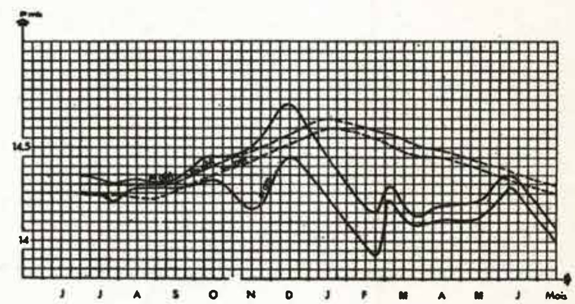


Figure 1A. Plan de la grotte de Lascaux



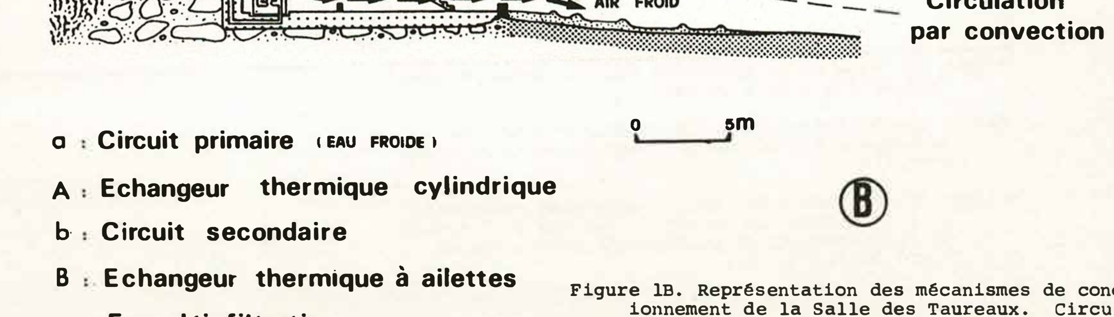
D

Figure 1D. Variations au cours de l'année 1978 des tensions de vapeur (pa) de l'air au sol et à la voûte et celles correspondant à la température de la roche.



C

Figure 1C. Variation annuelle de tension de vapeur maximale et minimale de l'air et celle correspondant à la température de la roche (pspM et pspm de juin 63 à juin 64 dans la Salle des Taureaux).



B

Figure 1B. Représentation des mécanismes de conditionnement de la Salle des Taureaux. Circulation de l'air grâce au phénomène de convection.

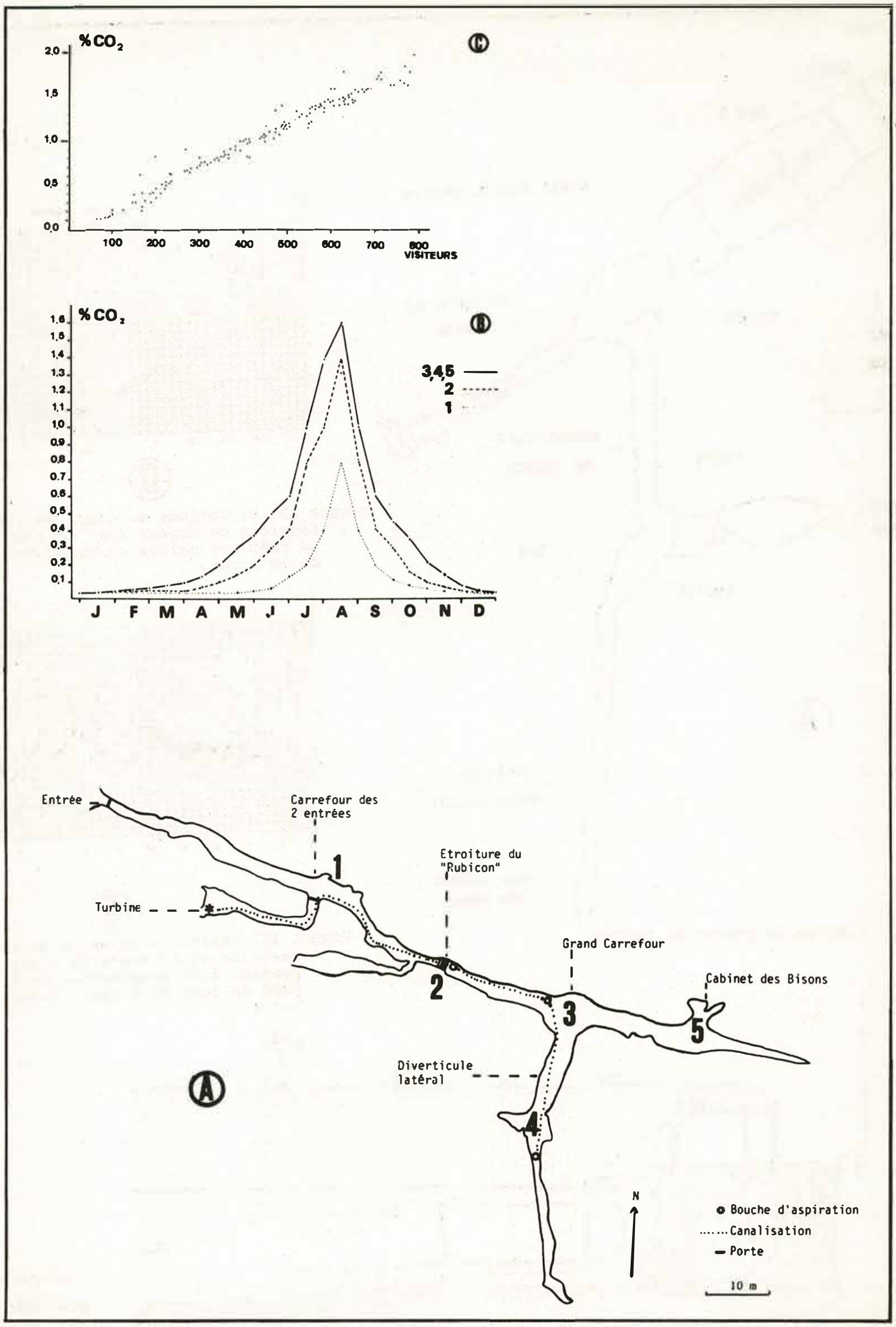


Figure 2A. Plan de la grotte de Font de Gaume .et localisation des points de mesure

Figure 2B. Evolution annuelle du taux d'anhydride carbonique à différents points au cours de l'année 1970.

Figure 2C. Variation du taux d'anhydride carbonique de l'atmosphère de la partie décorée en fonction de la fréquentation touristique avant mise en place de la turbine.

L'Enseignement de la Spéléologie en France: L'Ecole Française de Spéléologie

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Résumé

Commission d'Enseignement de la Federation Française de Spéléologie, l'Ecole Française de Spéléologie a pour objectifs la coordination et la rationalisation de toutes les actions relatives à l'enseignement spéléologique, tant scientifiques que techniques.

Chaque année, à travers une cinquantaine de stages, soit techniques, soit pédagogiques, un millier de stagiaires poursuivent un enseignement dispensé par 200 cadres bénévoles. Répartis sur les différentes zones karstiques françaises (Jura, Alpes, Causses, Pyrénées), les stages durent de 2 à 13 jours.

La filière technique (découverte, formation, perfectionnement) est axée sur les méthodes de progression et la sécurité.

La filière pédagogique (initiateur, moniteur, instructeur) permet la formation des cadres avec la délivrance d'un brevet fédéral (3 niveaux). En effet, il n'existe pas, en France, de brevets d'état (car il n'y a pas de spéléologues professionnels, rémunérés pour l'exploration ou la conduite de groupes sous terre.

Il existe des stages dits "spécialisés": scientifiques, (biologie, géologie, topographie..), secours en site souterrain, plongée souterraine, photographie, cinéma, ceci en liaison étroite avec les commissions spécialisées de la Fédération Française de Spéléologie.

Différents services sont également rendus par l'Ecole: Un service de placement de "brevetés" pour les collectivités et les centres de vacances, Un service de documentation - Bibliothèque pour les stagiaires.

L'Ecole est dirigée à l'échelon national par un directeur, membre du Conseil de la Fédération et une équipe de direction comprenant plusieurs collaborateurs, deux conseillers techniques permanents (mis à disposition par le Ministère de la Jeunesse et des Sports) et une secrétaire. L'Ecole participe activement à la vie du départment Enseignement de l'U.I.S. et souhaite de nombreux échanges entre les différents pays où un enseignement de la spéléologie s'est structuré.

Abstract

The French School of Speleology is a department in the French Federation of Speleology, and aims at coordinating and organizing the teaching of potholing, both in its technical and scientific aspects.

Every year 200 unpaid animators animate about 50 courses, all located in the different French karst areas (Jura, Alps, Causses, Pyrénées). They teach the techniques or the pedagogy of speleology to a thousand trainees.

The French School of Speleology (E.F.S.) has divided its courses into three categories: techniques, pedagogy and specialization. The first two are subdivided into three levels, corresponding roughly to beginners, intermediate and advanced.

Techniques: The teaching focuses on safety and the methods used to explore potholes. Three levels: "Découverte" for beginners, "Formation" for intermediate, and "Perfectionnement" for advanced level.

Pedagogy: The purpose of these periods is to train animators and deliver them a first grade certificate ("Initiateur"), a second grade certificate ("Moniteur") or a third grade certificate ("Instructeur"). In France, there is no national diploma as there are no professional speleologists who would get paid to explore caves or to guide groups.

Specialized training periods are organized as concerns biology, geology, topography and so on, as well as rescue operations, diving, photography, films. This is done with the help of the different specialized federal committees.

Moreover, the E.F.S. offers different services. It provides holiday centers, youth camps with a list of instructors, and trainees with a library.

The E.F.S. is managed by a director who is a member of the federal national board, with the assistance of several collaborators, and two technical advisors from the French Ministry of Sports. And let us not forget a secretary.

The school fully participates in the teaching activities of the International Union of Speleology, and advocates contacts between the different countries where the teaching of speleology has been organized.

On s'aperçoit que l'apparition de la spéléologie, il y a tout juste un siècle, a été immédiatement suivie par la diffusion d'une somme importante de connaissances jusqu'alors ignorées de l'homme. Cependant il a fallu une cinquantaine d'années pour que l'information quitte le cercle très restreint de spéléologues - en général des hommes d'un certain age - de formation scientifique et regroupés dans quelques sociétés savantes. L'aspect pédagogique de la spéléologie se limitait à la transmission des connaissances et de l'expérience acquise par des "maitres" auprès des plus jeunes et d'un public averti, que ce soit sur le terrain lors de la consuite d'explorations, ou dans la presse spéléologique.

Apparition d'un Enseignement Formel de la Spéléologie en France.

A partir de 1945, des jeunes passionnés par la spéléologie se regroupèrent en clubs structurés sur l'ensemble du territoire française; L'évolution a été bien sentie par les personnalités du monde spéléologique qui créèrent le Comité National de spéléologie, regroupant une cinquantaine de clubs. Dès ses premières réunions, les responsables du C.F.S. durent évoquer les problèmes relatifs à l'éducation des pratiquants. En effet, l'enseignement se faisant jusqu'alors tout naturellement dans les sociétés, il n'existait pas un temps spécifique axé sur l'initiation ou le perfectionnement du spéléologue. Les groupes qui se créèrent, en particulier dans le cadre d'associations telles que les Eclaireurs de France, les Scouts, la République des Jeunes (qui donna naissance plus tard aux M.J.C., Maison des Jeunes et de la Culture) (1), pratiquèrent tout-à-fait empiriquement la spéléologie; Sous l'impulsion dynamique de quelques animateurs, les résultats de ces équipes très jeunes furent relativement importants sur le plan de l'exploration. Philippe Renault qui s'est toujours intéressé à l'enseignement de la spéléologie (2) date le début de cette transformation à l'année 1947 lorsque les Eclaireurs de France utilisèrent la grotte de Lombrives, en Ariège, en tant que "grotte-école", pour former leurs cadres. Le premier stage de spéléologie en France est, à notre connaissance due à l'initiative de Robert Bombourg, directeur de la Maison des Jeunes et de la Culture de Villeurbanne -Rhône. Il organisa un stage régional dans le massif du Jura (Ain), en 1950, grâce à l'aide du Service Académique Jeunesse et Sports de Lyon, et la 5ème région militaire, qui regroupa une vingtaine de jeunes spéléologues de plusieurs clubs. A l'échelon national, sous l'égide du C.N.S., Pierre Chevalier et Charles Schaffran organisèrent un premier stage en 1952 sur le Massif de la Dent de Crolles, en Chartreuse (Isère).

Durant cette période, on note l'apparition dans la presse de "manuels", dûs en particulier à R. de Joly, H.-P. Guérin, F. Trombe (3), dont la portée pédagogique fût importante. Quelques articles apparaissent aussi dans des publications de jeunesse, et même au niveau scolaire: 2 fascicules édités en 1950, consacrés aux grottes et à l'exploration souterraine sont dûs à l'Institut Coopératif de l'Ecole Moderne (I.C.E.M., pédagogie Freinet).

La Constitution de L'Ecole Française de Spéléologie.

Il faut attendre 1959 pour que le Comité National de Spéléologie, sous la responsabilité de Jean Corbel et Philippe Renault, organise régulièrement un stage national de spéléologie; Un programme et des méthodes sont définis, ainsi que des brevets d'initiateur et d'instructeur (4). Après la mise sur pied de 5 stages, en 1963, la création de la Fédération Française de

Spéléologie, fusion de deux associations nationales, donne un regain d'activité à la Commission des stages. Pendant toutes les années 60, Michel Letrône -responsable de l'enseignement de la spéléologie en France, à la suite de Philippe Renault en 1962 - met en place une structure dont le principal objectif est de former des responsables de clubs compétents, ouverts à tous les aspects techniques, scientifiques, administratifs et culturels de la spéléologie. Il s'agit de constituer une fédération solide et représentative, un véritable outil de travail indispensable à tous les pratiquants.

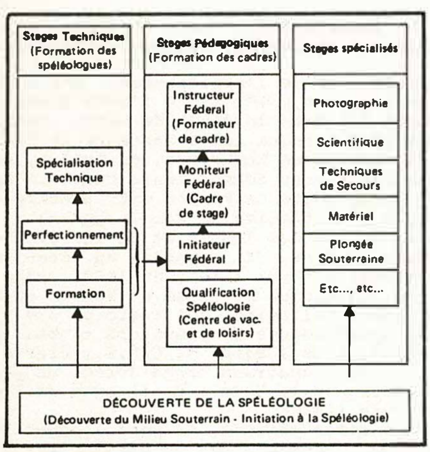
Plusieurs dossiers d'organisation et d'instruction pour les stages virent le jour; On note aussi la diffusion dans un format depoche de 2 petits ouvrages abordant succinctement les aspects techniques et scientifiques de la spéléologie (5). A partir de 1965, outre les stages nationaux d'initiateur, de moniteur et d'instructeur, des stages régionaux d'initiateur 1er degré s'organisèrent dans différentes zones karstiques de France. En 1969, Michel Letrône propose d'adopter l'appelation "Ecole Française de Spéléologie" pour la commission des stages de la fédération; Cette même année les stages nationaux jusqu'alors organisés au Centre National de Plein Air de Vallon Pont d'Arc, en Ardèche, s'implantèrent dans le Vercors, et fût inauguré par le président René Ginet le Centre National de Font d'Urle (Drome).

L'Ecole Française de Spéléologie entre 1970 et 1980.

On constate vers 1970, d'une part une révolution des techniques de progression qui apparait avec l'utilisation systématique du descendeur et du bloqueur Dressler, et d'autre part un développement important d'une nouvelle pratique de la spéléologie, dite "de loisir". Il y a lieu de mentionner la publication en 1973 de l'ouvrage "Techniques de la spéléologie Alpine" par deux instructeurs de l'école: Jean-Claude Dobrilla et Georges Marbach (6), ainsi qu'un nombre important d'articles durant cette décennie sur l'enseignement de la spéléologie, la pratique en centres de vacances, dans les M.J.C., les maisons d'enfants.

L'E.F.S. a de la peine à répondre aux besoins de formation des spéléologues, et en 1970, sur la base des structures régionales solides, il est organisé des sessions départementales d'Equipier de spéléologie, qui regroupent chaque année près de 500 jeunes spéléologues désireux de s'initier aux techniques nouvelles. A cette même époque, l'école programme nationalement des stages spécialisés, scientifiques, techniques et culturels sans délivrance de diplome.

En 1975, il devint nécéssaire pourmieux s'ajuster à la demande des pratiquants de réactualiser la gamme des stages et l'organigramme général des stages est désormais le suivant:



Où en sommes-nous en 1981? Après 6 années de fonctionnement, la grille des stages ne semble plus répondre totalement aux besoins exprimés par le spéléologues; Une pratique de plus en plus de "consommation" de la spéléologie voit le jour, même dans les stages, au dépens de la recherche et de l'exploration. Les prochaines journées d'études nationales de l'école devront essayer d'adapter à nouveau les programmes d'enseignement en réformant fondamentalement les structures actuelles.

Les Stages et L'Enseignement Dispensé par L'Ecole Française de Spéléologie.

L'actuelle grille des stages (7) montre 3 types de démarche après une première initiation; la première utilise la filière des stages techniques, qui est à la base de la formation; la seconde, la filière pédagogique destinée à ceux qui souhaitent encadrer et enseigner; enfin, la troisième, la filière des stages spécialisés répond aux besoins spécifiques de certains spéléologues.

-La découverte de la spéléologie s'est institutionalisée sous la forme d'un stage de quelques jours ou d'un cycle réparti sur plusieurs mois. Il s'agit soit d'une découverte du milieu souterrain (à l'initiative d'associations diverses, avecagrément E.F.S.), soit d'initiation aux techniques spéléologiques (à l'initiative de clubs).

-Les stages techniques à 3 niveaux, formation, perfectionnement et spécialisation sont destinés à former et perfectionner les spéléologues en ce qui concerne les techniques de progression sous terre et les connaissances des règles de sécurité; Les stages de formation se déroulent sous forme de 2 ou 3 week-end, ou sur une période bloquée de 5 jours. Le recrutement est local et l'organisation revient aux comités départementaux. Les stages de perfectionnement et de spécialisation se déroulent sur 9 jours dans des zones karstiques privilégiées et si possible sur un massif même; l'organisation se fait nationalement sous la responsabilité d'une équipe d'instructeurs et moniteurs E.F.S.

-La formation pédagogique Il existe 3 brevets de la fédération, initiateur, moniteur et instructeur, délivrés soit à l'issue d'un stage spécifique, soit dans le cadre d'un cycle après acquisition de plusieurs unités de valeur spécifique. L'initiateur fédéral doit obtenir 3 unités de valeur: technique (suite à la participation reconnue valable à un stage de formation ou de perfectionnement), pédagogique (suite à l'encadrement d'une sortie avec des néophytes), et vie fédérale (participation active à la vie d'un club et d'un comité départemental). Pour obtenir le brevet fédéral de moniteur, il est nécéssaire de participer à un stage national de 13 jours, comprenant des tests techniques éliminatoires et une formation technique et pédagogique complémentaire. A la suite d'une inter-évaluation des cadres et des stagiaires, le brevet de moniteur-stagiaire valide une aptitude à enseigner la spéléologie à tout niveau (encadrement de stages techniques, de collectivités ou de clubs). Comme rien ne saurait remplacer la pratique ce n'est qu'après un premier encadrement jugé satisfaisant que le moniteur stagiaire sera nommé moniteur dans le plein sens du terme. La formation d'instructeur fédéral se fait dans le cadre d'un cycle constitué d'un stage technique et d'encadrements de stages.

Il existe un type particulier de stage depuis 1976: Le stage de qualification spéléologie est organisé conjointement par un organisme de formation d'animateurs de centres de vacances et par l'E.F.S. Depuis 5 ans, à l'issue d'un stage de II jours, les C.E.M.E.A. (Centres d'Entrainement aux methodes d'éducation active) et l'E.F.S. donnent une formation spécifique (moins complète que celle de moniteur) permettant à un animateur d'agir au sein d'une équipe éducative, de respecter les règles d'orientation de l'activité et de savoir passer le relais à un autre responsable, là où s'arrête sa compétence. La fédération a diffusé des recommandations relatives à la pratique de la spéléologie avec des mineurs, en définissant 4 classes de cavités (8).

-classe I: caverne aménagée pour le tourisme.

-classe II: cavité, ou portion de cavité, du type "grotte horizontale" ne nécéssitant aucun matériel autre qu'un dispositif d'éclairage, pouvant présenter quelques passages étroitsmais franchissables avec une civière de secours.

-classe III: cavite ou portion de cavité dont le total des verticales n'excède pas quelques dizaines de mètres (en plusieurs puits distincts de préférence). En cas de présence d'eau, celle-ci doit être calme et peu profonde - absence de crues dangereuses pas de passages etroits qui ne soit franchissable avec une civière.

-classe IV: autres cavités.

Si aucune qualification particulière n'est demandée pour la fréquentation de cavités de classe I, pour les cavités des classes II and III, il est souhaité qu'un membre au moins de l'encadrement habituel ait acquis la qualification spéléologie; S'il est fait appel à un cadre extérieur au groupe, ou s'il s'agit de cavités de classe IV, il est demandé de disposer d'un titulaire d'un brevet de moniteur fédéral validé.

-Les stages spécialisés: A l'échelon régional, des stages peuvent être mis en place pour répondre à un besoin de formation plus spécifique, que ce soit des stages scientifiques, de techniques de secours, de photographie, de plongée souterraine; Deux stages bien particulier sont organisés annuellement à l'échelon national par d'autres commissions nationales, en liaison avec l'E.F.S.; il s'agit du stage de conseiller technique de secours, par le Spéléo-Secours Français, et du stage de perfectionnement à la Plongée souterraine, par la Commission Plongée de la F.F.S.

Moyens et Methodes de Travail de L'Ecole.

Comme nous venons de le préciser, l'objectif principal de l'E.F.S. réside dans l'organisation de différents stages; cependant cette réalisation ne peut se faire sans structure, vu le nombre important de stages, de journées stagiaires et de journées d'encadrement (en 1979, respectivement, 53 stages, 5420 et 1495 journées); Depuis la création de l'E.F.S. plus de 1000 diplomes ont été délivtés. La tache que pouvait faire un seul directeur, bénévole en 1960 avec 1 ou 2 stages dans l'année, a nécéssité un travail d'équipe. Un comité s'est constitué avec des collaborateurs nationaux et 13 correspondants régionaux, animé par le directeur.

En 1981, deux permanents (Conseiller technique Jeunesse et Sport, à disposition de la fédération), et une secrétaire travaillent à temps plein à l'animation des stages de l'école. Le financement de l'école (300.000 F de budget annuel) provient de la participation des stagiaires et d'un apport des finances fédérales, avec des prises en charge de l'état; Une importante somme est consacrée annuellement à l'acquisition de matériel d'exploration utilisé dans les stages nationaux, ainsi que du matériel pédagogique; En particulier un film 16mm couleur sur l'école a été réalisé en 1975 au Centre National de Font d'Urle par Alain Baptizet.

Conclusion

La fédération française de spéléologie est le seul organisme en France représentatif des spéléologues et de la pratique de la spéléologie sous toutes ses formes. Sa commission Enseignement, du fait des diplomes pour l'encadrement qu'elle délivre et des stages qu'elle organise, est amenée à avoir des relations privilégiées avec des organismes pour qui la spéléologie est une activité sportive ou culturelle intéressant enfants, adolescents et adultes dans le cadre des loisirs, du tourisme, de la formation permanente. La pratique de ce type de spéléologie n'a pas les mêmes finalités, mais quantitativement devient plus importante que celle des clubs fédérés... se qui entraine de nombreux problèmes, en particulier pour la préservation du karst, ne pouvant se résoudre que par une éducation. Une certaine recherche pédagogique se fait dans des mémoires réalisés par des éducateurs, animateurs et enseignants d'éducation physique, dans le cadre de leurs diplomes professionnels. Pour assurer un encadrement de qualité, un service de placement fédéral met en relation des organismes recherchant des cadres pour l'animation d'activités spéléologiques, avec des brevetés fédéraux recharchant un emploi saisonnier. D'autre part des contacts et des rencontres se font avec les centres nationaux de plein air et des organismes de formation d'animateurs de centres de vacance, pour mener une reflexion plus complète sur la pratique de la spéléologie hors des structures fédérales.

Enfin à l'échelon international, l'E.F.S. participe activement à l'animation du département Enseignement de l'U.I.S.. Pour des raisons financières il est difficile d'envisager actuellement l'organisation de stages internationaux, mais nous rappelons que les stages de spéléologie se déroulant en France sont ouverts à tous les spéléologues étrangers intéressés, que ce soit au titre d'observateur qu'au titre de stagiaire. De tels échanges ne peuvent qu'être profitables à tous, grâce à une meilleure confrontation des différentes pratiques de la spéleologie, des méthodes d'enseignement et des programmes de formation.

Bibliographie

(1) Il y a actuellement en France plus de 1000 M.J.C., Maison Pour Tous et une cinquantaine de clubs spéléologiques (sur 400 affiliés à la FFS) sont soit des sections de M.J.C;, soit associés à une M.J.C.

(2) Renault (Ph.), 1974 - Passé et avenir de la spéléologie française. Spelunca, 2, pp 33-37.

(3) De Joly (R.), 1947 - Comment on descend sous terre, manuel du spéléologue, L. Jean éd.; Guérin (H.-P.), 1951 - Spéléologie, manuel technique, éd. Vigot; Trombe (F.), 1952, Traité de spéléologie, ed. Payot.

(4) Renault (Ph.), 1960 - Pour un enseignement de la spéléologie..., Bull. pér. Com. Nat. Spél., 4, pp. 18-24.

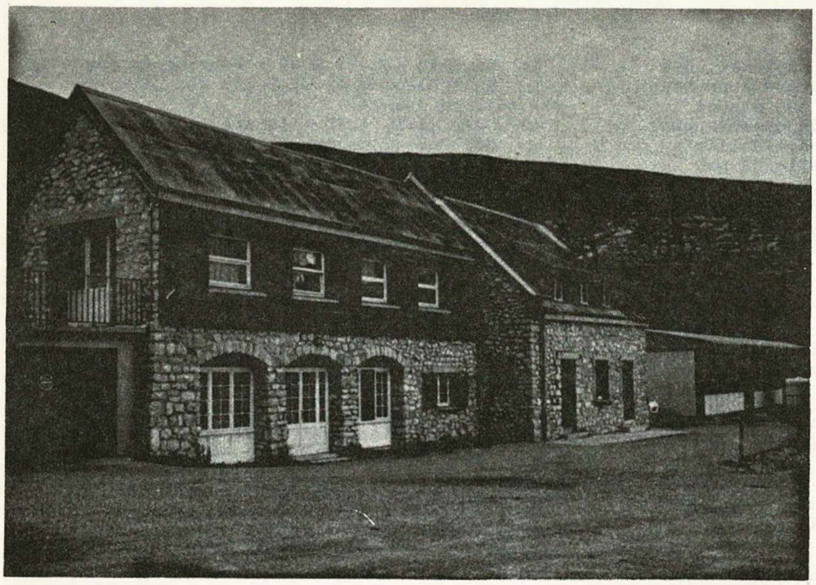
(5) Gèze (B.), 1965 - La spéléologie scientifique, éd. Seuil; Marchand (G.) et coll., 1966 - Spéléologie, éd. 2 coq d'Or.

(6) réédition, 1980 - Marbach (G.), Rocourt (J.-L.), Techniques de la spéléologie Alpine

(7) Ecole Française de Spéléologie, 1979 - L'Enseignement de la spéléologie en France, Spelunca, 2, pp. 65-72.

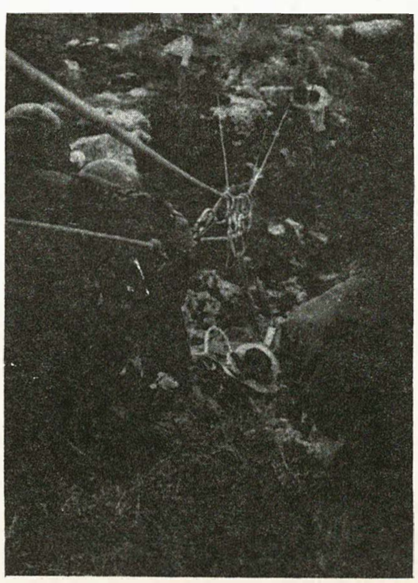
(8) Ecole Française de Spéléologie, 1975 - Spéléologie et sécurité dans les centres de placement hébergeant des mineurs à l'occasion des vacances scolaires, des congés professionnels et des Loisirs. Recommandations de la Fédération Française de Spéléologie. Spelunca, 4, p. 30.

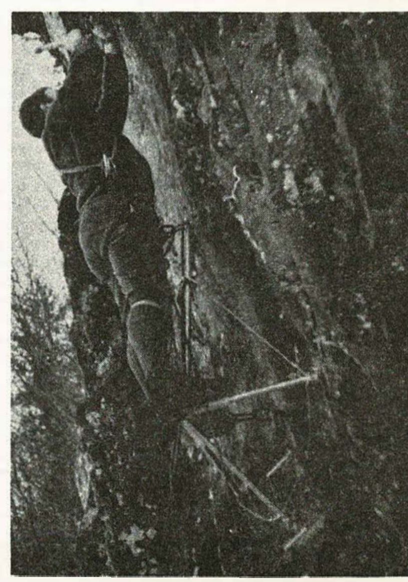
Une importante bibliographie française relative à l'enseignement de la spéléologie a été éditée dans le fascicule, 1979, I, 20 pp., du département Enseignement de l'Union Internationale de Spéléologie; Il comporte près de 300 références, et il est demandé de s'y reporter pour tout ce qui concerne l'enseignement de la spéléologie en France, et les activités de l'Ecole Française de Spéléologie.



1. le centre national de Font d'Urle, Vercors, Drome

2. groupe de travail durant des journées d'études nationales.





3, 4. Exercices en falaise (spéléo-secours, utilisation de l'araignée) à Font d'Urle - photos P. Rias.

Regression of the Locomotion Controlling System in Cavernicolous Carabid beetles

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Abstract

Cavernicolous carabids which have up to now been examined can be grouped according to a preliminary model with 5 stages describing the regression of the control of locomotion. In this model the proportion of periodical components in the patterns of activity decreases successively whereas the proportion of stochastical components increases. - In species with aperiodical patterns of activity special types of stochastical control of activity enable a simple form of time-measuring. Constant mean durations of bursts of activity and pauses of rest can be guaranteed by stochastical control if the probabilities for the transition from activity to rest, and from rest to activity do not change during a larger time span. - From a detailed knowledge of the various stages of the regressive evolution of the chronometrical system, conclusions may be drawn regarding the biological significance and the physiology and genetics of the intact circadian clock.

Zusammenfassung

Die bisher untersuchten Höhlencarabiden können einem vorläufigen FünföStufen-Modell der Regression der Aktivitätskontrolle zugeordnet werden. Der Anteil periodischer Komponenten in den Aktivitätskontrolle zugeordnet werden. Der Anteil periodischer Komponenten in den Aktivitätsmustern nimmt in diesem Modell sukzessiv ab, während der Anteil stochastischer Komponenten zunimmt. Bei den Arten mit aperiodischen Aktivitätsmustern erlauben besondere Formen der stochastischen Kontrolle der Aktivität eine primitive Form der Zeitmessung. Die stochastische Kontrolle garantiert konstante mittlere Längen der Aktivitätsschübe und Ruhepausen, wenn sich die Wahrscheinlichkeiten für den Übergang von Aktivität zu Ruhe und von Ruhe zu Aktivität während einer längeren Zeitspanne nicht verändern. - Genauere Kenntnisse über die verschiedenen Stadien der regressiven Evolution des Zeitmeß-Systems erlauben möglicherweise Rückschlüsse auf die biologische Bedeutung sowie auf Physiologie und der intakten circadianen Uhr.

Introduction

The fact that extreme troglobites have lost the capability of estimating the time of day has been shown by several studies (Ginet, 1960; Deleurance-Glacon, 1963; Gunzler, 1964). But as the circadian system is controlled polygenetically one may suppose that during evolutionary adaptation to life under constant conditions the circadian clock does not disappear abruptly but degenerates gradually as complex organs do. From a deeper insight into such stages of degeneration conclusions might be drawn regarding the biological significance and the physiology and genetics of the intact clock.

The physiological clock can control numerous functions, for example, in man several dozens are known. But in carabid beetles only one periodical circadian function has up to now been measured: the daily change between rest and locomotion. If, under certain environmental conditions the pattern of activity should prove to be structured periodically, one must not directly conclude that the controlling circadian oscillator itself is extinct. Possibly the function has only been separated from the oscillator. Therefore, a valid description about the state of the clock is not possible until the behavior of locomotion has been studied under different environmental conditions. Among these, especially light has an important influence on the expression of the circadian rhythm of locomotion in carabid beetles (Lamprecht & Weber, 1977).

The method of recording the locomotion, and the mathematical evaluations are described elsewhere (Lamprecht & Weber, 1978, 1979). The carabid species tested are listed in Table 1.

Results

The Regression of the Periodicity of Locomotion. The cavernicolous and endogeous carabid beetles, which have been carefully investigated up to now, can be grouped according to a preliminary model with 5 stages describing the regression of the control of locomotion (Table 1).

Stage 1 comprises beetles with intact temperature-compensated circadian clock which controls the distribution of activity in constant darkness (DD) as well as in constant dim light (LL). Examples are the troglophile species Pristonychus terricola and Ceutosphodrus oblongus and the troglobite species Antisphodrus schreibersi (Lamprecht & Weber, 1977, 1979; Weber, in press). The behavior in 12/12 hours light dark cycles (LD) was tested in P. terricola and C. oblongus. Rectangular LD cycles of small amplitude (0/1; $0/10^{-2}$; $0/10^{-4}$ lux) induce a striking "step effect" (sudden increase of activity after "light off"). In P. terricola the influence of the clock becomes visible by weak "time effects": the activity slightly increases in the second half of the light phase independently of "light off" or "light on". Surprisingly such "time effect" could not be observed in the running behavior of C. oblongus. But one cannot call in question, that in LD-cycles the activity of this species, too, is controlled by a synchronized circadian clock. There is an indirect proof for this supposition: in LD-cycles of 4/4 hours the activity of C. oblongus is synchronized to 24 hours.

Stage 2 includes species whose circadian clock controls the activity in dim LL effectively, whereas aperiodical patterns of activity prevail in DD. Examples are the geophile species Duvalius exaratus and the troglobite species Ceutosphodrus navaricus (Lamprecht & Weber, 1977, Weber, in press). A reduction of the precision of the periodicity of locomotion in DD is typical for some dark-active epigeous and troglophile carabid species, too (for example: Carabus problematicus or Ceutosphodrus oblongus). But contrary to the behavior of C. navaricus or D. exaratus, in most animals of these species a periodicity is still evident in DD-conditions. -(The stimulating influence of dim LL must be clearly distinguished from the effect of bright LL, by which the activity is uncoupled from the controlling clock.)

Whether the geophile Duvalius wingelmuelleri and th the troglophile Duvalius boldorii belong to this stage cannot be decided finally, because in these species the circadian excitation is weak in dim LL, too. Under LD-conditions all species show clear "time-effects", by which the influence of the endogenuos circadian clock is demonstrated.

Stage 3 is represented by the eyeless geobite species Typhlochoromus stolzi (Lamprecht & Weber, in press). In DD and dim LL (o, 1 and 1 lux) no periodical components can be identified. However, this species is periodically active in LD, and in most of all specimens the behavior is not a mere reaction on "light on" or "light off". In the first hours of the light phase the activity decreases, but in the second park of the light phase the intensity of locomotion increases again ("time effect"). After a transition from LD to dim LL the animals sometimes exhibit postoscillations, which reflect the LD-activity pattern for 1-2 h hperiods. 14 of 16 specimens reacted to LD cycles of 6/6 hours (0/1 lux) 8 specimens were synchronized to 24 hours by this light dark cycle ("frequency demultiplication") (unpublished results). Obviously, T. stolzi is able to measure the time under LD conditions whereas in constant environment this ability is quickly extinguised.

Stage 4 comprises species without self-sustained circadian rhythms of locomotion and without distinct postoscillations. LD cycles still induce periodical distributions of activity but - contrary to stage 3 - the animals only show "step effects" after "light on". Examples are eyeless species of the genus Duvalius (Lamprecht & Weber, 1979; in press; Weber, in press). The "step effect' is strong in D. jureceki, but weak in D. balazuci and delphinensis.

Stage 5 is typical of aperiodic species which do ot longer react to LD-cycles of small amplitude. In the LL, LD and DD actograms neigher circadian nor ultradian nor infradian periods could be found in the range from 1 to 42 hours. It is only by cycles of temperature that periodical distributions of rest and activity are induced. Examples are the eyeless species of the genera Aphaenops and Geotrechus (Lamprecht & Weber, 1978, 1979, in press; Weber, in press).

Some more cavernicolous arthropods were investigated by other authors. But in a crayfish of the genus Niphargus only, reactions to LL, LD, DD and temperature cycles were tested (Gunzler, 1964). Probably Niphargus has to be assigned between the preliminary carabid stages 3 and 4. It does not show time effects in LD cycles or postoscillations after a transition to constant conditions. But contrary to the carabid species of stage 4, it is active mostly in the dark phase of LD cycles of small amplitude. The crayfish Orconectes pellucidus, investigated for the last time by Jegla & Poulson (1968), seems periodically active in LD cycles. Whether the observed "periods" in the patterns of DD behavior ranging from 14 to 50 (70) hours are really controlled by a clock may be called in question. Perhaps they are conrolled by simple stochastical events. Just the same may be true for the activity pattern of the cavernicolous millepeds Blaniulus lichtensteini investigated under DD conditions by Mead & Gilhodes (1974).

Control of locomotion behavior by simple stochastical regularities. The aperiodical species show clear clear changes between bursts of locomotion and pauses of rest and therewith distinct changes between metabolism of rest and metabolism of activity. Therefore in these species, too, we have to expect control mechanisms synchronizing neuro-muscular activity and metabolic state (for example: release of trehalose from fat body). Since clock mechanisms are not demonstrable we have to look for other mechanisms of internal synchronization.

We may hypothesize two possibilities: 1) the control mechanisms are operating by signals following each other in a stochastical sequence; 2) beyond stochastical signals the patterns of activity and rest are influenced by correlations between the lengths of the pauses of rest (R) and the lengths of the bursts of activity (A). According to these considerations the correlations between the lengths of bursts and pauses have to be investigated at first. From the sequence A_i, R_{i+1}, A_{i+2}, R_{i+3}, etc., we computed the linear correlation coefficients between A_i and R_{i+1}, and between R_{i+1} and A_{i+2}. But in a few cases only, relevant correlations were found. (For a detailed description of the correlative realtions see Lamprecht & Weber, in press). That means that possibility (1) is largely realized. Therewith the probability for the transition to the alternative state can be computed from the frequency distributions of the lengths of the activity bursts and rest pauses. Frequently the distributions can be described by exponential functions of the type $y = a \cdot e^{-r \cdot x}$, in fewer cases by the Poisson or the standard function. In cases of exponential functions the probability for the transition to the alternative state is time-invariable (compare Lehmann et al., 1974). In cases of Poisson or standard distributions are probability for the transition to the alternative state increases continuously with the duration of activity respectively rest (Lamprecht & Weber, 1978).

Discussion

The biological significance of circadian clocks. Our investigations have shown that without any doubt periodicities of low frequencies cannot be demonstrated in the activity patterns of extremely evolved cavernicolous beetles. Apparently under cave conditions there is no selection pressure controlling the genetic fitness of clocks. Therefore we conclude (contrary to Jegla & Poulson, 1968) that internal necessities to stabilize metabolic relations by means of clocks are not existing. Indeed, we had only measured the intensity of activity and not any metabolic reaction. But we feel that it is permissible to conclude from the knowledge of the activity pattern on the temporal organization of metabolism. The change between rest and activity is accompanied by most drastic changes in the metabolic reactions. If stabilizing oscillations in the metabolism really exist, they will comprehend the functions of rest and activity metabolism above all and therefore they will be reflected by the activity patterns.

Our conclusion, is it not refuted by the behavior of the Troblobite species of the evolutionary stages 1 and 2? What selection pressure causes the genetic fitness of their clock? We believe, just the bejavior of Ceutosphodrus navaricus supplies us a fair argument for the conclusion mentioned above. This species is predominantly aperiodic under DD-conditions. That means, periodical organicazion of rest and activity, respectively rest metabolism and activity metabolism is not necessary, perhaps even unfavorable inside the caves. The clock of these species does not remain fit because of internal necessaries but because of the efficiency of external selection. The troglobite species of the stages 1 and 2 prefer entrances of caves. The small diurnal amplitudes of the environmental factors in cave entrances are the factors of selection which prevent the genetic degeneration of the circadian clock in these species. We suppose that clocks are primarily importnat to ecological adaptation. If they should be secondarily effective in stabilizing the metabolic organization of an organism, such a subsidiary effect would not prevent the complete regression of the clock mechanism during the evolution under constant conditions.

Jegla & Poulson (1968) intended to analyse the temporal organization of metabolism by measuring the oxygen consumption. But the "periods" of oxygen consumption in Orconectes pellucidus seem as weak as those of the activity patterns. Experiments with Ceutosphodrus navarcus confirmed our expectation that measurements of oxygen consumption reflect the intensity of activity only. In dim LL the periodicity of oxygen consumption was much more precise than in DD. These differences of the precision correspond to the different precision of the locomotory periodicities in DD and dim constant light. Fettered specimens investigated in DD did not show any periodicity of O_2 consumption (Lamprecht & Weber, in press).

Stochastical control

Stochastical control seems very unbiological. Nevertheless, adaptations to varying environmental conditions could be possible by a variation of the transition probabilities. If the activity must be intensified, for instance because of scarcity of food, then this could be realized by a reduction of the probability for the transition from activity to rest and by a similtaneous increase of the probability for the transition from rest to activity. By this mean length of the bursts of activity would increase and the mean length of the pauses of rest would decrease. In aphaenops we have found that in fact the mean lengths of bursts and pauses are weakly negative correlated with each other (Lamprecht & Weber, 1978). This, stochastical control can be interpreted as a primitive method to measure the time.

Stochastical control of activity and rest was described for the locomotory behavior of crabs of the genus Uca for the first time (Lehmann et al., 1974). But also cockroaches of the species Blaberus fuscus and carabids of the species Carabus problematicus, normally running periodically, frequently show stochastical sequences of activity and rest with time-invariable transition probabilities, when the optic lobes were removed (Lukat & Weber, 1979; Balkenohl & Weber, in press). We assume that stochastical control is realized in epigeous animals, too, but usually superimposed with the control by circadian clocks. Ceutosphodrus navaricus seems a useful subject for investigating the interactions of circadian clocks and stochastically operating mechanisms. Its weakly circadian DD actograms can be simulated by varying the transition probabilities within the circadian period (Weber, in press). Generalizing this finding we assume that in species possessing circadian clocks the fine distribution of spontaneous activity and rest is possibly controlled by stochastically operating mechanisms. Perhpas cavernicolous animals did not evolve a new mechanism to control spontaneous activity and rest, but reactivated that mechanism which was already effective in their epigeous ancestors.

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Table 1. The regressive evolution of the control of locomotion by the circadian clock. DD constant darkness, LL constant dim light, LD light dark cycles (12/12 hours), CW cold warm cycles (12/12 hours).

Binding to DD-Habitats		Species	Eyes	Optical Ganglions	Spontaneous Activity DD	Spontaneous Activity dim LL	Environmental Cycles LD (dim light)	Environmental Cycles CW
increasing binding to DD-conditions ↓	troglophile or geophile	Pristonychus terricola	normal	normal	circadian	circadian	time- a. step-effects	step-effect
		Ceutosphodrus oblongus	normal	normal	circadian	circadian	step-effect	step-effect
		Duvalius exaratus	normal	?	mainly aperiodical	circadian	time-a. step-effects	?
		Duvalius boldorii a. wingelmülleri	a little reduced	?	slightly circadian	slightly circadian	time- a. step-effects	?
		Antisphodrus schreibersi	reduced	?	circadian	circadian	?	?
		Ceutosphodrus navaricus	reduced	reduced	mainly aperiodical	circadian	time- a. step-effects	time-effect
	troglobite or geobite	Typhlochoromus stolzi	lacking	?	aperiodical	aperiodical	time- a. step-effects	?
		Niphargus puteanus[1]	lacking	?	aperiodical	aperiodical	step-effects	step-effect
		Duvalius jureceki	lacking	lacking	aperiodical	aperiodical	step-effect	?
		Duvalius balazuci a. delphinensis	lacking	lacking	aperiodical	aperiodical	step-effect (weak)	?
		Geotrechus orpheus	lacking	lacking	aperiodical	aperiodical	no effect	step-effects
		Aphaenops cerberus a.pluto	lacking	lacking	aperiodical	aperiodical	no effect	step-effects

[1] Investigated by GÜNZLER(1964)
? Not investigated

Présence de Jaera (Isopoda, Asellota, Janiridae) dans le Milieu Cavernicole

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Résumé

D'origine marine, certaines espèces de Jaera sont installées dans les eaux saumâtres, et quelques-unes ont même envahi les eaux douces. Cette invasion du milieu dulçaquicole est généralement limitée aux régions littorales, et toujours restreinte au milieu épigé. Or, des Jaera viennent d'être découvertes dans les eaux libres d'une grotte à plusieurs dizaines de kilomètres de la mer.

L'insertion de ces Asellotes dans les eaux souterraines continentales permet d'imaginer l'origine des Asellidae et le processus de leur colonisation du milieu souterrain.

Abstract

The species of Jaera are of marine origin, certain of them are established in the brackishwaters and a few even invade the freshwaters. This invasion of the freshwater medium is generally limited to the littoral regions and always is limited to the epigean biotopes. Now, Jaera have been discovered in the free waters of a cave located about several tens of kilometers away from the sea. The insertion of these Asellotes in the continental underground waters allows us to imagine the origin of the Asellidae and the process through which they colonized the hypogean biotope.

Les Isopodes vivant dans les eaux douces épigées d'Europe sont désormais bien répertoriés, mais il n'en est pas encore de même pour les espèces des eaux souterraines. On assiste en effet, chaque année, à la découverte de nombreuses espèces souterraines nouvelles; celles-ci appartiennent surtour aux Aselloidea (Asellidae et Stenasellidae) car c'est le seul groupe d'Isopodes totalement inféodé aux eaux continentales et qui constitue une faune ancienne dont l'origine marine est difficile à situer avec précision dans le temps. Tous les autres groupes d'Isopodes aquatiques sont marins et possèdent seulement quelques lignées qui se sont adaptées au milieu dulçaquicole. Le plus souvent, ces lignées continentales sont représentées par des espèces anophtalmes qui vivent dans les eaux souterraines; ce sont soit des formes cavernicoles comme Caecosphaeroma ou Faucheria chez les Flabellifera, soit des formes interstitielles comme Microcharon chez les Asellotes. Cette faune continentale d'Isopodes hypogés est vraisemblablement une relicte de peuplements marins ayant occupé d'anciennes mers. Mais les Isopodes dulçaquicoles apparentés aux espèces marines actuelles peuvent aussi être des formes oculées dont l'installation dans les eaux douces est beaucoup plus récente; ces Isopodes, comme c'est le cas de quelques Janiridae du genre Jaera,n'ont d'aileurs généralement envahi que les eaux épigées littorales et ne semblent pas avoir pénétré dans les eaux souterraines.

Les Janiridae sont des Crustacés typiquement marins bien représentés sur les côtes européennes par le genre Jaera qui vit dans la zone intercoditale sous les pierres et dans les fentes de rochers, quelquefois sur les algues ou dans les moulières. Mais contrairement à Jaera marina (= J. albifrons) par exemple, toutes les Jaera ne sont pas inféodées au milieu marin, et certaines espèces très euryhalines occupent des biotopes de salinité très variable, comme Jaera nordmanni, dont il existe des populations marines, d'autres installées dans des eaux plus ou moins saumâtres et aussi des populations adaptées à des conditions purement dulçaquicoles. Quelques espèces de Jaera sont même devenues des formes exclusivement fluviatiles; ce sont Jaera balearica installée dans les cours d'eau des îles Baléares, Jaera ortizi qui vit dans un petit fleuve côtier du Pays basque espagnol, et Jaera schellenbergi qui se rencontre dans une source du littoral adriatique. Mais, exception faite de Jaera sarsi, véritable relicte ponto-caspienne dont la pénétration dans les eaux continentales est profonde (grands fleuves d'Europe orientale), l'invasion des Jaera dans le milieu dulçaquicole reste toujours limitée aux zones littorales et surtout, toujours restreinte aux eaux de surface. C'est pourquoi, il est intéressant de signaler la découverte de Jaera dans les eaux libres d'une grotte située à plusieurs dizaines de kilomètres de la mer; cette présence montre la possibilité d'une colonisation des eaux souterraines continentales par ces Asellotes.

Cette station exceptionnelle pour Jaera est une grotte des pyrénées espagnoles, la Cueva de las Brujas, située dans la haute vallée de la Nivelle, à proximité de la frontière française près de Zugarramurdi (province de Navarre); les coordonnées géographiques sont les suivantes: Espelette n°7-8, x = 284,5 et y = 115,5 (fig. F). Les galeries les plus profondes de cette cavité sont parcourues par une rivière souterraine qui alimente lors des crues les gours de la grotte (J.H. Stock in litt.); c'est dans l'un d'eux, en pleine obscurité, que furent capturés 2 individus de Jaera, le 19 juillet 1979, par J.H. Stock que je remercie de me les avoir confiés pour identification; ce gour représente sans doute un biotope temporaire, le véritable milieu de vie du Crustacé devant se situer dans la rivière elle-même. Les 2 exemplaires sont pigmentés et normalement oculés, il s'agit d'un prémâle (mâle immature) de 1,1 mm et d'une femelle adulte de 2 mm (fig. A). La systèmatique étant fondée sur les caractères morphologiques des mâles adultes, leur absence dans le lot récolté empêche une détermination spécifique. Mais l'étude de la femelle permet néanmoins de constater que par certaines particularités morphologiques, ces Jaera cavernicoles rappelle Jaera nordmanni, notamment en ce qui concerne la légère concavité du bord distal du pléopode II (opercule) ainsi que la forme, la structure et la chétotaxie des pléopodes respiratoires (fig. B,C,D, et E). Cette ressemblance morphologique est trop insuffisante pour affirmer l'identité des deux formes, mais elle montre sans aucun doute que ces Jaera sont apparentées. Les préférences écologiques de Jaera nordmanni ne sont d'ailleurs pas incompatibles avec l'existence de tels liens de parenté; on sait en effet que l'euryhalinité de cette espèce lui a permis d'émigrer des eaux marines vers les eaux saumâtres, puis de gagner les eaux douces où elle s'est diversifiée, comme en témoignent les formes balearica et ortizi rapprochées maintenant des nordmanni (Lemercier 1960). Ainsi la découverte de ces individus installés dans une grotte nous fait peut-être assister au passage des Jaera de cette lignée dans les eaux souterraines, c'est-à-dire à une nouvelle étape de leur colonisation des eaux continentales.

A 1 km 500 de cette première station cavernicole de Jaera, la grotte de Sare (Pyrénées-atlantiques, France) abrite un autre Asellote souterrain, Proasellus coiffaiti. La présence dans ce biotope de cette espèce endémique, encore oculée et pigmentée, sans lien de parenté avec les espèces épigées actuelles, nous rappelle le problème que pose l'origine des Asellidae et leur colonisation des eaux souterraines. L'invasion des eaux douces par les Janiridae et le passage qu'elles semblent capables de subir du milieu épigé au milieu hypogé nous permettent d'avancer une hypothèse au sujet des Aselles. Les voies d'accès de ces Isopodes aux eaux souterraines continentales ont dû être en effet celles qu'empruntent actuellement les Jaera. Il est donc vraisemblable d'admettre que les Aselles souterrains dérivent d'une forme ancestrale fluviatile euryhaline, dont l'origine devait être marine et littorale comme celle des Jaera.

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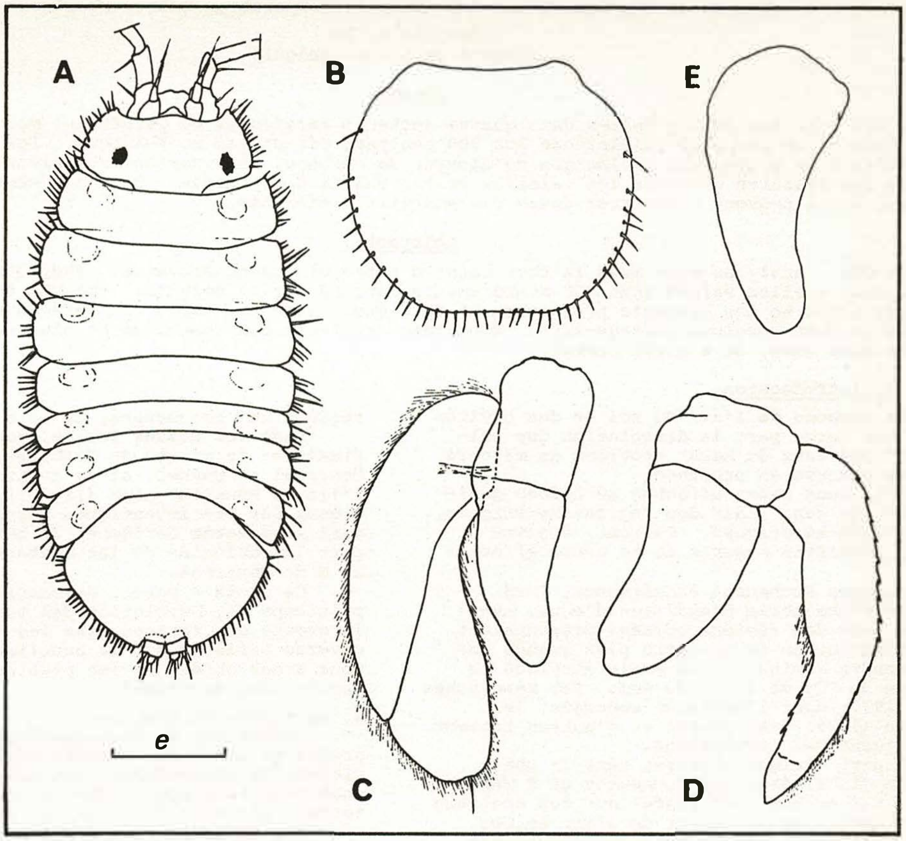

Jaera aff. nordmanni, ♀.

Figure A. vue dorsale, e = 400 μm.

Figure B. pléopode II (opercule) e = 200 μm.

Figure C. pléopode III e = 100 μm.

Figure D. pléopode IV e = 100 μm.

Figure E. pléopode V e = 100 μm.

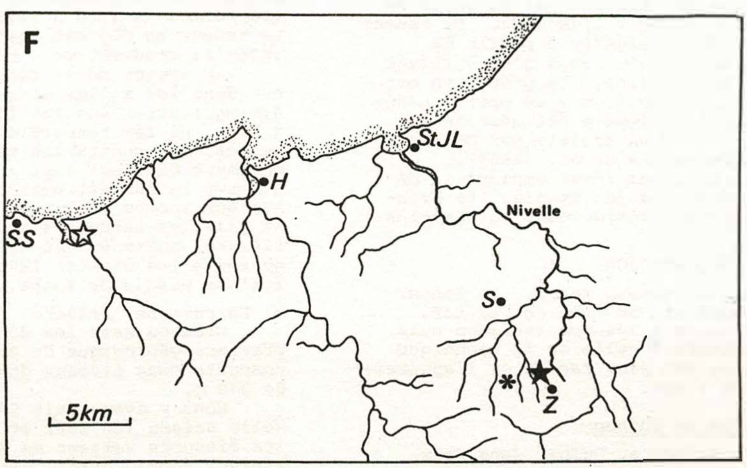

Figure F. carte schématique de la côte basque et du bassin de la Nivelle situant la station cavernicole de Jaera aff. nordmanni (étoile noire), l'aire de Jaera ortizi (étoile blanche) et la station de Proasellus coiffaiti (astérisque). StJ.L = Saint-Jean de Luz; S = Sare; Z = Zugarramurdi; H = Hendaye; SS = Saint-Sébastien.

Mesures de CO_2 Dans L'Air des Grottes: Comparaison Québec-Belgique

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Résumé

Quelque 200 analyses de CO_2 faites dans quatre secteurs karstiques du Québec ont montré en toutes saisons des teneurs un peu plus faibles que les 300 analyses effectuées en Belgique. Les teneurs sont clairement liées à la production biologique de dioxyde de carbone. Les variations saisonnières sont plus marquées dans les fissures que dans les galeries et les salles des grottes. Dans une même moment, des gradients importants peuvent s'observer entre des endroits différents.

Abstract

Some 200 CO_2 - analyses were made in four karstic sites of Quebec Provence. They displayed, in all seasons, somewhat smaller values than 300 measurements carried out in Belguim. The CO_2 content of cave air is clearly bound to the biogenic production of this gas. Seasonal variations are more obvious in fissures than in more spacious passage-ways. Important gradients can sometimes be observed between two points of the same cave, at a given moment.

1. Introduction

Le dioxyde de carbone de l'air du sol et des cavités conditionne pour une large part la dissolution des calcaires, car le CO_2 des eaux du karst provient en majeure partie de la phase gazeuse en présence.

De 1975 à 1980, nous avons effectué au Québec quelque 200 mesures de CO_2 dans l'air des régions karstiques, et surtout des cavités karstiques. Ce sont, à notre connaissance, les premières mesures de ce genre effectuées au Québec.

Dans les Montagnes Rocheuses canadiennes, Ford (1971), à la suite d'une série d'analyses d'eaux, avait déjà noté que les eaux des régions boisées présentaient une capacité de dissolution du calcaire plus grande que les eaux de la toundra alpine, et il avait attribué ce fait à l'influence du CO_2 de l'air du sol. Les recherches de Woo et Marsh (1977) dans l'Arctique canadien, le travail de Roberge (1979) à Anticosti et d'autres travaux confirment et affinent ces conclusions.

Toutefois, à part quelques mesures dans la phase gazeuse par Miotke (1974) dans les Rocheuses et à Terre-Neuve, toutes ces recherches sont basées sur des analyses d'eaux, à partir desquelles la teneur de l'air en CO_2 est calculée, en partant de l'hypothèse de l'équilibre entre l'air et l'eau en présence.

Nos mesures donnent une première image générale des teneurs qu'on peut s'attendre à rencontrer dans les karsts québécois. La comparaison avec un pays de latitude comparable, mais de climat plus océanique, la Belgique, éclaire ces résultats. On ne peut toutefois tirer de nos 200 mesures des données statistiques, vu la grande diversité des sites échantillonnés, dont nous ne pouvons, dans les lignes qui suivent, décrire que les principaux.

2. Méthode et Techniques

Notre méthode de travail a consisté, dans tous les cas, à prélever un échantillon de 100 cc d'air en un endroit choisi, et à mesurer immédiatement sa teneur en CO_2. Nous avons, pour ce faire, utilisé successivement deux techniques d'analyse. Jusqu'en 1978, nous avons procédé, sur le terrain, à des mesures par électrolyse du CO_2 absorbé dans une solution 0,1 de NaCl. La teneur en CO_2 de l'échantillon était calculée à partir de l'intensité du courant utilisé, du temps d'électrolyse et du volume d'air de l'échantillon. La précision est de $\pm$ 0,1 mg CO_2/l. air (soit environ $\pm$ 60 ppm). L'appareillage pèse 10 kg. La technique a été décrite en français par Ek et al. (1968), en anglais par Delecour et al. (1968), et discutée par Ek et al. (1969).

A partir de 1978, nous avons aussi employé le détecteur de gaz Gastec, distribué par Bendix. Le principe de mesure de cet appareil réside dans la réaction du CO_2 avec l'hydrazine:

$$CO_2 + N_2H_4 \rightarrow NH_2 \cdot NH \cdot COOH$$

réaction qui décolore un indicateur redox. La teneur mesurée est lue directement sur un tube de réactif, gradué, avec une précision de $\pm$ 100 ppm (environ 0,18 mg/l), donc un peu inférieure à celle de la technique précédente; mais l'analyse est plus rapide et l'appareillage plus léger (moins de 1 kg).

3. Mesures au Québec

Les mesures ont été faites au Québec dans deux régions naturelles bien différentes: d'une part dans les Basses Terres du St-Laurent, d'autre part sur le Bouclier canadien. Les Basses Terres du St-Laurent ont un substratum de calcaires paléozoïques stratifiés et subhorizontaux et la végétation naturelle y est, pour les secteurs qui nous intéressent, la forêt de feuillus, essentiellement l'érablière. Le Bouclier, composé de roches cambriennes très évoluées, est couvert, dans les régions ici concernées, de bois de résineux.

Dans les Basses Terres, deux grottes ont été étudiées: la grotte de Crabtree, près de Joliette, entre Montréal et Québec, et la grotte de St-Léonard, sur l'île de Montréal même (fig. 1). Deux secteurs karstiques ont été investigués aussi sur le Bouclier: d'une part la caverne Laflèche, au nord de Hull, et d'autre part les dolomies du lac Mistassini, à quelque 700 km au N de Montréal.

Ce choix a permis de comparer, de l'été 75 au printemps 76, l'évolution des teneurs dans deux grottes, la grotte de Crabtree dans les Basses Terres et la caverne Laflèche sur le Bouclier. En particulier, nous avons obtenu là les premières données hivernales recueillies au Canada.

a. La grotte de Crabtree

Présentant un développement d'environ 150 m, la grotte de Crabtree, creusée dans les calcaires ordoviciens de plate-forme, est constituée de deux conduits subhorizontaux confluents et représente un drain souterrain affluent de l'Ouareau (bassin du St-Laurent).

Les 41 analyses qui y ont été faites ont montré ce qui suit: à la fin de l'été, la teneur en CO_2 dans les galeries varie de 1,2 à 1,9 mg/l.air, et est toujours nettement plus élevée au plafond qu'au sol. Dans les fissures, les teneurs varient entre 3,0 et 5,1 mg/l.air. En hiver, les teneurs dans les fissures baissent fortement, les teneurs dans le haut des galeries diminuent un peu, mais, la grotte étant bloquée par la glace, ceci conduit à une homogénéisation des teneurs dans la grotte et, au ras du sol, la teneur, après avoir baissé en novembre, remonte à la fin de l'hiver (moyenne de 3 mesures en avril: 1,6) pour atteindre à peu près les valeurs mesurées au plafond (moyenne de 3 mesures en avril: 1,7).

b. La grotte de St-Léonard

Située dans les calcaires ordoviciens de l'île de Montréal, la grotte de St-Léonard est longue de 35 m (Société québécoise de Spéléologie, 1979). Elle a été fermée de 1968 à 1979 par un épais remblai de terre. La teneur en CO_2 est restée très élevée dans la grotte après sa réouverture. Nous y avons fait 66 analyses.

Au moment de la réouverture en avril 1979, la teneur dans les salles et galeries variait entre 2,9 et 4,6 mg/l.air. Dans les fissures, elle allait de 6,7 à 7,1. Si les teneurs des fissures sont assez habituelles, par contre les teneurs des galeries sont anormalement élevées; sept mois plus tard, après l'été qui a suivi la désobstruction de la grotte, ces teneurs avaient encore augmenté: on mesurait dans les salles et galeries entre 5,4 et 6,5 mg/l. air, et dans les fissures entre 6,7 et 8,1 mg/l.air. Il faut dire qu'entre les visites la grotte est fermée par une épaisse plaque de fonte.

c. La caverne Laflèche

Creusée dans les dolomies précambriennes de la province géologique de Grenville, la caverne Laflèche comporte deux niveaux dont le développement total est de 370 m.

Nous y avons fait 57 analyses. A la fin de la belle saison (en août et octobre), les teneurs dans les fissures varient de 2,1 à 4,7 mg/l, et, à la fin de l'hiver (mars, avril, mai), elles sont comprises entre 2,3 et 3,7 mg/l, marquant ainsi une égalisation des teneurs. Dans les galeries, les teneurs observées ont verié peu: de 0,8 à 1,5 mg/l, en toute saison: la caverne Laflèche a deux entrées, et la circulation de l'air y est franche, toute l'année.

d. Au lac Mistassini

A 51° de lat. N, la lac Mistassini, en pleine fôret boréale, représente un climat beaucoup plus sévère que les sites précédents. Nous n'avons pu y faire nos mesures qu'en été, et le cours d'eau souterrain étudié ne pouvait être atteint qu'à son entrée et à la sortie: les conduits étaient trop étroits pour pouvoir être parcourus.

Nos 20 analyses de juillet 1975 montrent des teneurs en gaz carbonique modérées mais non négligeables. A la perte du ruisseau, dans les fissures moussues où il s'engouffre, les teneurs varient entre 1,7 et 2,4 mg/l. A la résurgence, pourtant, la teneur n'est que de 1,0 à 1,2 mg/l. Une fissure moussue du lapié qui surmonte le cours souterrain fournit 2,1 mg/l, tandis qu'une fissure dans la roche nue ne donne que 1,3 mg/l. A l'air libre, mais sous les arbres de la forêt boréale, la teneur en CO_2 est de 0,9 mg/l: ce chiffre assez élevé nous semble à attribuer à l'activité estivale de la végétation: sous la forêt d'épinettes et de bouleaux, la strate arbustive est dense et recouvre à son tour une strate d'herbes et de mousses abondantes.

Ainsi, les quatre secteurs étudiés au Québec montrent une production de CO_2 non négligeable, surtout à la belle saison, et une variation saisonnière nette comportant en hiver une homogénéisation des valeurs entre les différents points d'une même grotte du fait du ralentissement de la production et de la diffusion du "stock" de CO_2.

4. Comparaison Avec la Belgique et Discussion

Quelque 300 mesures faites en Belgique, et dont une partie ont déjà été l'objet de publications, nous ont fourni une gamme de résultats un peu différente de la série des mesures au Québec (Ek et al., 1968; Delecour et al., 1968; Ek, 1980). Les teneurs de l'air en CO_2 varient également suivant les saisons, mais le minimum hivernal (de décembre à mars) est caractérisé en Belgique par une évasion du CO_2 de la grotte, qui est ainsi appauvrie; à la grotte de Crabtree, au contraire, le confinement hivernal, dû à l'existence d'un bouchon de glace à l'entrée de la grotte, provoque l'accumulation du gaz carbonique dont la teneur s'homogénéise dans la grotte. Cette obturation hivernale par la neige ou la glace est un des traits originaux des cavités québécoises, et des cavités des régions neigeuses en général. En Belgique, d'autre part, les teneurs estivales dans les fissures montent plus fréquemment qu'au Québec au-dessus de 5 mg/l.

La Belgique est à peu près à la même latitude que le lac Mistassini, le secteur le plus septentrional ici étudié au Québec. Mais l'influence du Gulf Stream en fait une région humide toute l'année, et à hivers moins rudes qu'au Québec. C'est ce qui se marque sur la végétation, et par là sur la karstification.

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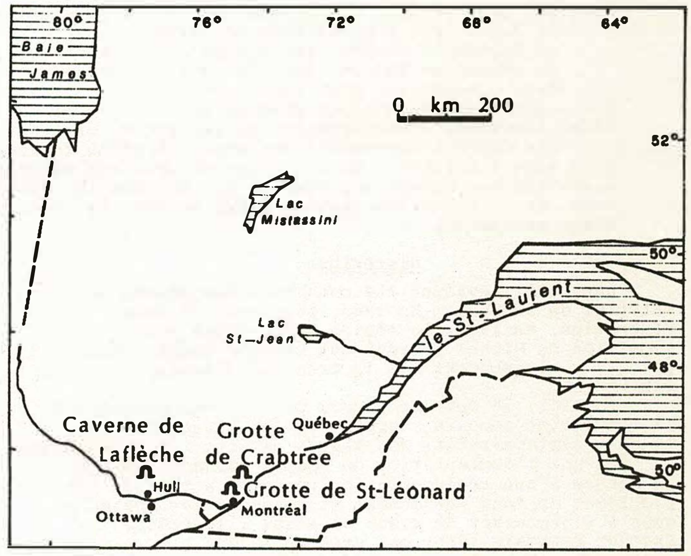

Figure 1. Localisation des 4 secteurs étudiés. Les grottes de Crabtree et de St-Léonard sont dans les Basses Terres du St-Laurent; la caverne Laflèche et le lac Mistassini sont sur le Bouclier canadien.

Le Secours Souterrain En France

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Résumé

En France, les secours généraux sont organisés à l'échelon des départements, sous la responsabilité des Prefets. Une annexe spéléo est prévue dans ceux des départements qui sont karstiques. Ils sont actuellement soixante quatre dotés d'un conseiller technique et de deux adjoints tous membres de la Federetion Francaise de Speleologie.

La politique du S.S.F. est "Efficacite des Secours". Aussi depuis sa création en 1978, il propose aux préfets des conseillers techniques formés, actifs, reconnus par les spéléos qui composent les équipes d'intervention. Ils sont tous des bénévoles requis pour la durée de l'opération.

Depuis 78 a lieu un stage annuel de formation de conseiller tecnique avec Agrement du S.S.F. pour ceux qui sont reçus. Ces stages sont aussi orientés sur la recherche.

Le S.S.F. est composé d'un Directeur nommé par le Conseil Federal.

Le Directeur choisit son équipe de collaborateurs, ils sont pour 1980:

Un Directeur Adjoint qui l'aide et le remplace éventuellement.

Onze Conseillers Techniques Nationaux qui contrôlent et aident un certain nombre de département. Six Conseillers Techniques Spécialisés qui aident la direction dans leur spécialités, enseigement, médicalisation, désobstruction et explosifs, matériel, plongée, assurance.

Les Conseillers Techniques Départementaux forment la structure de base sans qui le S.S.F. n'aurait plus lieu d'exister. En sauvetage ce sont eux qui coordonne et dirige l'opération souterraine, ils demandent les moyens aux Prefets qui demeure le véritable Directeur des Sec. Le S.S.F. se préoccupe aussi de la formation des équipiers spéléos il organise des stages à demande et proposera en 1981 un stage nationale.

Historique

Dès, 1951, avaient été constitué des dépots de matériel de secours. En 1963, naissance de notre Fédération, en 1964, la région Rhône-Alpes sous l' impulsion de Michel Letrone est choisie comme région pilote; ceci débouche sur la création d'équipes régionales.

En 1968, le Docteur Pierre Castin, responsable de la commission secours s'occupe de les structurer sur le plan administratif; des stages nationaux s'organisent.

Devant l'augmentation du nombre des accidents et la menace d'une réglementation de notre activité, les problèmes de fond surgissent et poussent les spéléologues à s'organiser de mieux en mieux : le SPELEO SECOURS FRANCAIS (SSF) est créé en 1977.

Les Secours Speleo Dans L'Organisation Generale Des Secours En France

Les secours sont dans notre pays, organisés sur le plan départemental; chaque département est dirigé par un Préfet qui a la responsabilité de l'organisation et du déroulement des secours dans tous les domaines.

Cette organisation est définie par le plan ORSEC. Une partie de ce plan est consacrée à la spéléologie.

A l'échelon national, la Sécurité Civile essaie d'aider les préfets dans leurs action en leur proposant des attitudes à avoirer l'aide d'un centre opérationnel (CODISC) qui centralise un maximum de renseignements dans tous les domaines.

En matière de spéléologie, les spéléologues ont calqué leur organisation de la même façon, voyons comment.

Le Speleo Secours Francais : SSF

Commission spécialisée de la Fédération dont l' action est:

- la prévention des accidents
- l'organisation des secours

A l'échelon national, le SSF est dirigé par un Directeur élu par le conseil fédéral dont il a la confiance et à qui il rend compte des activités de sa commission. Ce Directeur est chargé d'appliquer la politique des secours définie par le conseil fédéral. En opération, il est le chef du G.I.N.S.S. (groupe d'intervention national en spéléo-secours).

Le Directeur Adjoint, les conseillers techniques nationaux et les conseillers techniques spécialisés constituent la base de travail de cette commission.

1 Nominations:

Le Directeur adjoint:
Nommé par le Directeur parmi les CTN. Le Directeur lui délègue une partie de ses attributions.

Les Conseillers techniques Nationaux (CTN)
Au nombre de 12, remplacés par 1/3 tous les ans.

Les Conseillers techniques spécialisés (CTS)
Au nombre de 5: plongée, médicalisation, enseignement, explosifs et désobstruction, matériel.

2 Les missions:

Nous ne reviendrons pas sur celles du directeur et de son adjoint.

Les C.T.N. forment l'assemblée délibérante du S.S.F.; ils se réunissent au moins une fois par an et font connaitre la politique du S.S.F. par "le haut". Outre les missions particulières sur un thème spécifique, le C.T.N. a une mission permanente sur une aire géographique déterminée: prévention, contrôle, aide juridicotechnique aux C.T.D. Ceci se matérialise par:

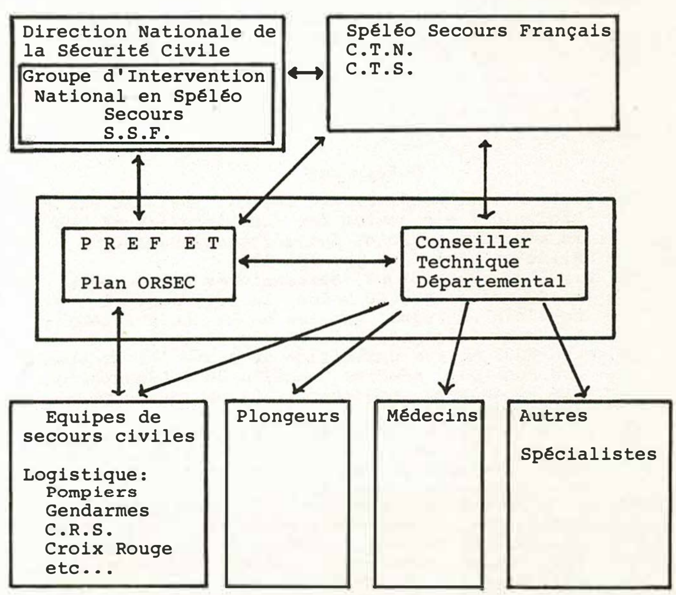
- enseignement, organisation et incitation d' exercice de secours.
- information au niveau de la politique du S.S.F. et répercussion des techniques nouvelles.
- Participation à des opérations réelles dans le but de sa formation et d'assistance au C.T.D. en cas de carence de ce dernier il peut le remplacer.

Les C.T.D. sont des technicien de la spéléologie de haut niveau, hommes de terrain et de relations ils sont la cheville ouvrière du S.S.F.

Ils ont pour mission d'organiser, de former, d' encadrer, d'entrainer les équipes de secours de leur département.

Ils dirigent les opérations réelles sous l'autorité du Directeur des secours ou de son représentant, c'est à dire le Préfet ou son représentant désigné.

Les C.T.S. techniciens de leur spécialité, ils essaient de promouvoir et de former. Ils sont à la disposition des C.T.D. pour toutes opérations aù leur aide est nécessaire.



Fonctionnement de Cette Organisation

1. Les moyens financiers

- Au niveau national, il s'agit du budget alloué par la F.F.S. augmenté des éventuelles participation et subventions de l'administration.
- Au niveau départemental, il s'agit du budget alloué par le C.D.S., augmenté éventuellement d'une participation de l'administration.

2. Le déroulement d'une opération:

- L'alerte

Lors de la survenue d'une accident, le ou les témoins alertent la gendarmerie du lieu ou se trouve la cavité. Cette alerte est transmise au directeur départemental de la protection civile ainsi qu'au conseiller technique (Ce n'est hélas pas toujours le cas) ou l'un de ses adjoints.

- La mise en route de l'opération:

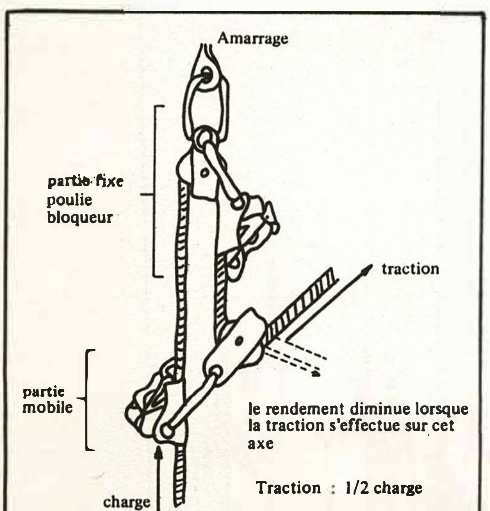
Le conseiller technique, à la lumière des renseignements fournis parle témoin met sur pied ses équipes d'intervention grâce à la liste spélo-secours de son département, par exemple:
équipe de recherche de disparus ou d'attardés
équipe médicale dans le cas d'une victime repérée
équipe de plongeurs
Souvent d'autres équipes seront mises en pré-alerte lorsque les renseignements fournis par les témoins sont approximatifs. Le C.T. met en place le support extérieur:
liaison radios
intendance
service d'ordre
relations avec la presse (Tout ça en relation avec le Directeur des Secours.)

-La technique:

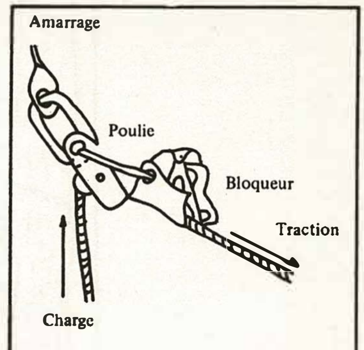
La tendance actuelle est à l'allègement des équipes de secours, l'expérience a montré qu'une petite équipe (6/7) de bons techniciens ayant l'habitude de travailler ensemble est la garantie d'une bonne efficacité dans la sécurité. La matériel utilisé est celui employé couramment, cordes statodynamiques de I0 ou II mm, bloqueurs, poulies, mousquetons en alliage léger. Le treuil a disparu de la panoplie des spéléo-secours modernes. Les amarrages se font avec des chevilles employées habituellement en exploration, les amarrages naturels servent également les difficultés rencontrées ont chacunes un mode de progression particulier et le spéléo sauveteur devra avoir les capacités de les adapter au fur et à mesure de la progression.
exemple: la progression verticale: L'équipement classique est représenté par:

La corde d'équipement habituelle sur laquelle circule les équipiers secours et l'accompagnateur brancard.

2 cordes pour le brancard, une corde assurance, une corde traction, ces trois cordes sont reconnaissables au bas du puits par un code figuré par des noeuds. La traction est réalisée par un palan ex. L'assurance par un poulie bloqueur ex.



PALAN



POULIE - BLOQUEUR
traction : charge

Le brancard.

Depuis 3 ans nous avons essayé de mettre au point un brancard, adaptation du brancard classique à lattes. Celui-ci permet une immobilisation du blessé correcte grâce à un sanglage adapté.
Le blessé est, avant le brancardage emballé dans une combinaison en DACRON, matière isolante et hydrophobe. Ce vêtement grâce à un système de VELCRO peux s'ouvrir et permettre l'accès à l'une ou l'autre partie du corps.

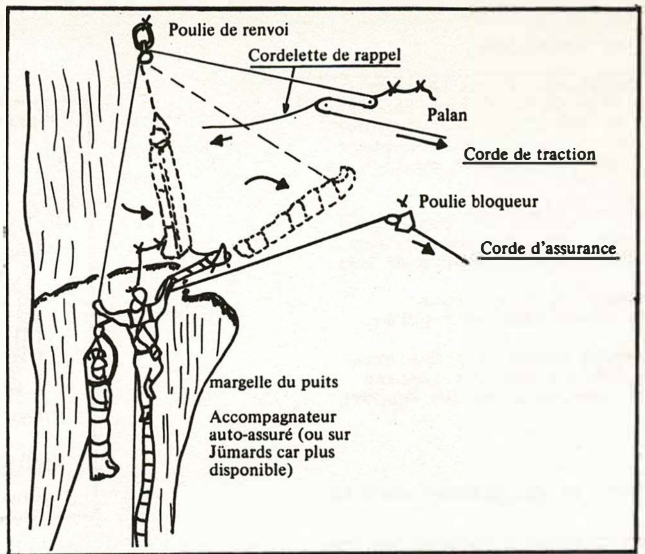
Le réglement administratif:L'assurance :

Une fois le secours déroulé, il reste au conseiller technique une tâche bien ingrate, il faut faire le rapport et le réglement administratif. Les résultats sont transmis au Préfet et au S.S.F.
Les indemnisations des équipes de secours se font par l'administration (Dans le schéma idéal ...) grâce à la convention signée entre notre Fédération et la Sécurité Civile. La victime est prise en charge par l'assurance de la Fédération (Pour les fédérés)

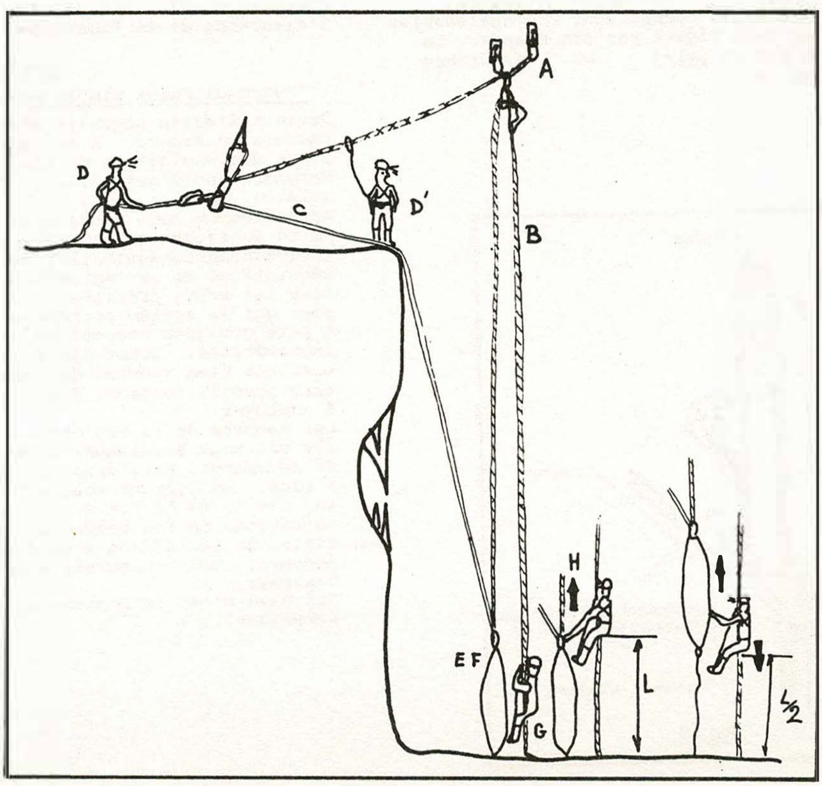
Conclusions

"Pourquoi Faire Simple Quand on Peut Faire Complique"

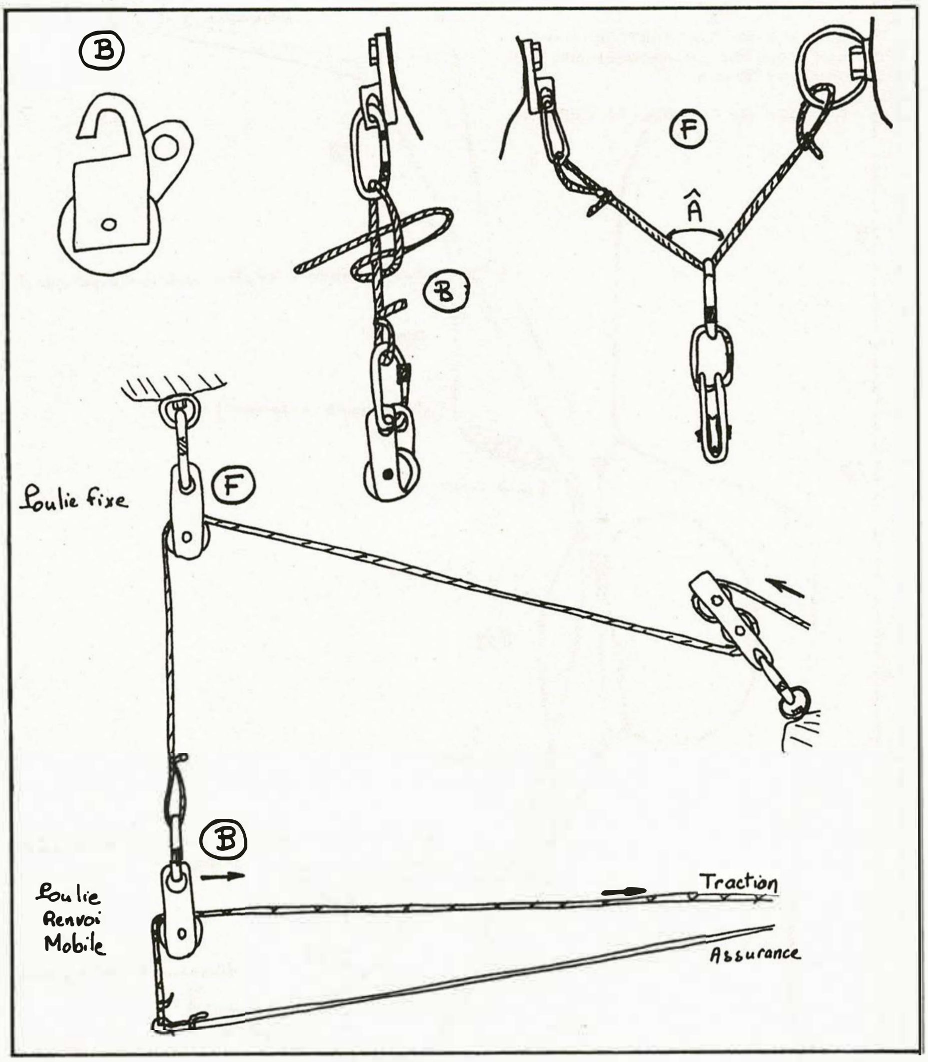
Cette réflexion pourrait résumer l'organisation des secours en France. A la lecture des diagrammes, des plans d'organisation de l'administration, tout semble baigner dans l'huile ...... Pourtant, nous en sommes loin.
Actuellement dans notre pays quatre organismes prétendent faire du sauvetage souterrain il s'agit: des pompiers, de la gendarmerie Nationale, des compagnies républicaines de sécurité et de la Fédération Française de Spéléologie. Pour les trois premiers, il s'agit de professionnels pour qui la spéléo représente un nouveau débouché.
A part quelques exceptions, ils sont dans l'ensemble incompétents. Comme ils sont les premiers prévenus, ils essaient bien souvent de résoudre eux-mêmes les problèmes sans pouvoir toujours évaluer la situation et les moyens à employer.
Les membres dr la FFS détiennent eux, la compétence car ils ont tout simplement la motivation, qualité principale du sauveteur, car, sans motivation, la technique ne sert à rien. La logique voudrait que l'on donne les moyens aux civils de la F.F.S. d'intervenir dans de bonnes conditions en les couvrant, en les dédommageant de leurs frais, en les aidant à se former aux techniques de secours. Cela couterait moins cher aux contribuables français.
Oui mais c'est la logique et on approcherait trop de la simplicité....



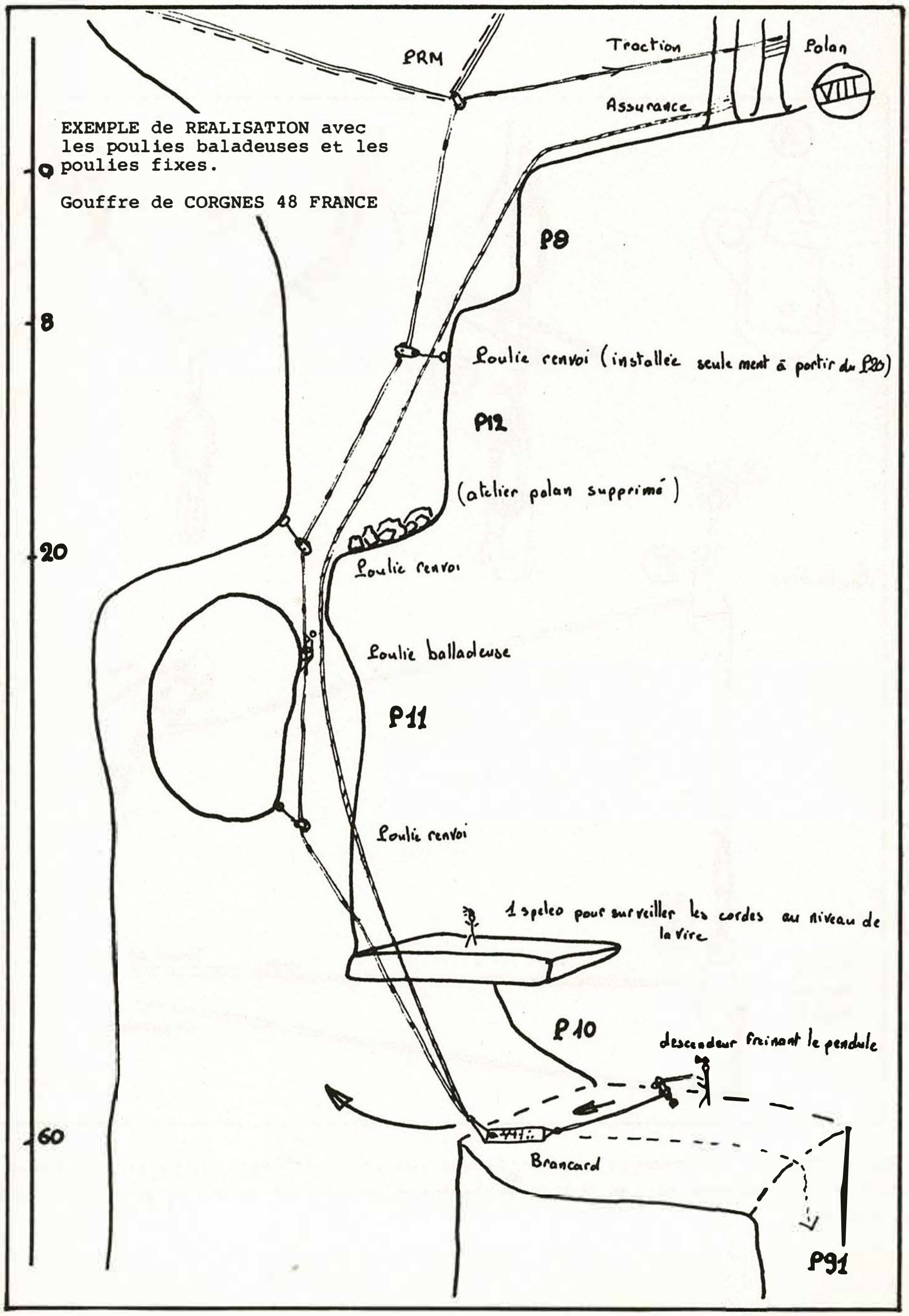
Equipement classique suite — exemple (tiré du manuel du conseiller technique)



Une autre forme d'équipement de verticale est la technique dite du balancier (ex ci - dessous.
Equipe réduite, auto secours.



Pour éviter les frottements nous utilisons les poulies fixes qui seront en place toute la durée de la maneuvre et les poulies baladeuses qui seront enlevées pendant la montée du brancard;



EXEMPLE de REALISATION avec les poulies baladeuses et les poulies fixes.

Gouffre de CORGNES 48 FRANCE

Les Relations entre Technique et Esthetique dans la Photographie Souterraine: la Position des Appareils et des Eclairages

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Résumé

La photographie souterraine, si elle recherche un effet esthétique, dépend essentiellement de deux facteurs: la position des appareils et celle des éclairages. La position des appareils crée partiellement l'ambiance et donne un élan au cliché. C'est l'orientation sur le plan vertical qui est la plus importante (plongée, contre-plongée, etc). Les effets obtenus sont souvent inverses de ceux obtenus en surface et des "seuils" de renversement d'effets apparaissent à partir de certaines inclinaisons. L'éclairage peut être de quatres types: direct, contrejour, latéral, combinaison de plusieurs éclairs. Il est le plus important pour l'ambiance. Les relations appareil-éclairage sont complexes. On souligne l'importance des éclairages anti-naturels (ascendants par ex.) et du maintien de zones d'ombres destinées à laisser libre l'imagination des spectateurs.

Abstract

Underground photography if it is seeking an aesthétique effect essentially depends on 2 factors: the position of the cameras and that of the lighting. The position of the cameras partially creates the atmosphere and gives an "elan" to the photo. It is the direction of the vertical shot that is most important (high-angle shots, low-angle shots, etc). The effects obtained are often the opposite of those obtained on the surface and the threshold at which inversion of the image becomes apparent occurs at different tilts. The lighting can be of 4 types: direct, back-lighting, from the side, combination of several flashes. It is most important for atmosphere. The camera-lighting relations are complex. One underlines the importance of unnatural lighting (upwards for example) and of the maintenance of areas of shadow in the photos destined to liberate the imagination of the audience.

Quelles qu soient les impressions que tente d'exprimer le photographe souterrain, il existe des procédés qui lui faciliteront la tâche. Ils ne servent pas à rendre la "joli" mais le "vrai". Bien que la réalisation d'un cliché soit un "ensemble" que le photographe met globalement en place, on peut, pour des raisons de clarté, distinguer deux phases dans la prise de vues: La mise en place des appareils et la mise en place des éclairages (en général des flashes).

La Mise en Place des Appareils

L'orientation sur le plan horizontal

Que ce soit pour un cliché rapide ou une oeuvre plus élaborée, le photographe, une fois choisi son sujet, va, plus ou moins instinctivement, orienter son appareil sur le plan horizontal et sur le plan vertical.

A l'exception de décors symétriques (galeries régulières, salles rondes, etc) où un appareil placé dans l'axe accentuera cette symétrie, il vaut mieux se décaler légérement par rapport à l'axe du décor. Cela amplifie l'effet de fuite du coté dont on se rapproche qui sera le moins intéressant. C'est également de ce côté que l'on place le premier personnage dans le cas où l'on en échelonne plusieurs sur le cliché. Dans les galeries courbes, on peut rapprocher l'appareil du côté concave afin de mieux voir la suite de la galerie et la courbure de la paroi. Par contre, le personnage se mettra côté convexe afin de se détacher en clair si le fond est sombre, ou inversement, en fonction du type d'éclairage choisi.

L'orientation sur le plan vertical

Elle est en général plus importante que la précédente. Il ne faut pas là confondre avec la pente propre du décor qui peut perturber ou accentuer les impressions dues à la position de l'appareil. En fait, le milieu souterrain englobant va déranger toutes les règles applicables à l'extérieur.

- Les prises de vues horizontales sont souvent plates, sans profondeur, à éviter en général dans les décors horizontaux. On réussit cependant d'excellents clichés avec un appareil horizontal, mais placé en hauteur ou en position basse par rapport à un décor non horizontal. Cela en privilégie les voûtes ou les premiers plans et produit des effets surprenants.

- Les prises de vues en plongée. L'appareil est dirigé vers le bas. En principe un cliché réalisé dans ces conditions donne une impression d'écrasement. Cela peut se faire du haut vers le fond d'une salle, ou du sommet d'une galerie étroite vers le personnage perdu en bas.

Il en est de même dans les puits où les prises de vues du sommet sont impressionnantes, avec une impression d'impuissance des personnages "abandonnés" en bas à revenir jusqu'à nous. La sensation d'écrasement est donc souvent vraie. Par contre les clichés pris selon un angle proche de la verticale donne un curieuse impression d'irréalité, d'annulation de l'espace et de la distance. Dans un puits, même si on saisit intellectuellement la profondeur, le décor semble en même temps s'être raccourci, comme s'il s'était emboité en lui-même de la même manière que les tubes d'une lunette télescopique.

En revanche, dans certaines photos en plongée accentuée, un plafond assez régulier et plan va contrecarrer l'impression d'écrasement en créant un effet de fuite très net. Si les voûtes manquent complétement, surtour dans un vaste décor, l'esprit perd pied, cherche les plafonds et le cliché dévient parfois curieusement aérien, interrogatif, à l'inverse de toutes les idées reçues sur les effets de plongée. Dans le même ordre d'idées, il est souvent préférable, lors d'une prise de vues en galeries de monter sur un bloc ou une banquette pour photographier avec une inclinaison de quelques degrés. Cela augment la perspective: on voit le décor au-dela des personnages. Ici, loin d'écraser, la plongée légére allège le cliché et lui donne sa profondeur.

- Les prises de vues en contre-plongée. L'impression précédente de fuite peut être obtenue en contre-plongée dans des conditions presque inverses. L'appareil placé près du sol est légérement basculé vers le haut, qui semble "couler" vers le bas de l'image pendant que le plafond occupe la plus grande partie de l'espace. La perspective est accentuée, mais de façon moins "naturelle", car il paraît plus logique à l'oeil humain de monter que de descendre.

En principe, les contre-plongées faibles donnent des effets aériens et des images moins oppressantes. Mais le milieu souterrain clos fausse encore une fois la règle du jeu. Si de légères contre-plongées sont en accord avec la théorie, dès que l'appareil est franchement incliné vers le haut ou qu'apparaissent de grandes surfaces de voûtes, l'impression d'écrasement ressurgit plus forte que jamais. Pourquoi ? Parce qu'en contre-plongée accentuée le regard rencontre surtout des parois qui s'élévent, parfois démesurées; il bute sur des voûtes semblant retomber vers l'appareil du fait de l'utilisation de grand-angles accentuant la perspective. Le personnage se trouve écrasé sous ces parois qui montent, montent...

En contre-plongée verticale, il se produit le même phénomène qu'en plongée verticale: les divers plans de l'espace s'emboîtent les uns dans les autres et l'espace est presque aboli. L'esprit attend inconsciemment vers le haut le ciel, la lumière, et il ne rencontre que roche et obscurité. Une voûte en premier plan cachant les plafonds derrière elle, quelques gouttes qui tombent accentuent cette impression car les divers plans sont déformés les une par rapport aux autres, décalés, amplifiant ainsi l'étrangeté et l'irréalité de l'image. Et si un peu de jour apparaît tout en haut, il n'apporte aucun apaisement car il semble innaccessible et factice.

Il se dégage de ces observations une notion de "Seuil", lié a la position de l'appareil, mais aussi à celle du personnage dans le décor. Dans toute "déviation" que l'on peut faire par rapport à la position "normale" d'un appareil, au centre du décor et à l'horizontale, apparaît d'abord une tendance qui se trouve inversée à partir d'un certain "seuil" de cette déviation.

La place du personnage par rapport à l'obstacle intervient également: s'il est dessous ou dedans (puits, cascade), il est écrasé, quelque soit pratiquement l'angle de prise de vues, alors que s'il est dessus, il domine beaucoup plus. Cependant ces impressions ne sont pas absolues et peuvent être contrecarrées par la position de l'appareil.

Ces "seuils" ne sont pas les mêmes sous terre qu'à l'extérieur. Il faut bien les connaître, ou plutôt les "sentir" si l'on veut pouvoir recréer une ambiance souterraine. Il n'est pas possible d'en donner des valeurs angulaires précises car ils varient en fonction des optiques employées et de la topographie. En général, l'angle varie avec la longueur des focales et la proximité des voûtes dont la présence ou l'absence en premièr plan, éclairées ou non, constituent un autre "seuil" important. Ils sont un des facteurs qui rend primordiale la position de l'appareil dans la mise en place d'une image. C'est elle qui donne "l'élan" de la photo, son impression de profondeur ou d'écrasement, par les ruptures ou les continuités dans les lignes de fuite qu'elle introduit.

L'Eclairage et la Lumière

L'appareil une fois placé, le photographe va choisir l'emplacement et l'angle de ses éclairages. Ils influeront eux aussi sur l'ambiance du cliché, en se combinant avec les positions de l'appareil dont ils souligneront ou contrarieront les effets selon les cas.

L'emplacement des éclairages et son influence

- L'éclairage dans l'axe de la prise de vues. A l'exception des photographies "d'action" où la valeur de l'instant fixé l'emporte sur la qualité esthétique, il est préférable de ne pas utiliser, Du Moins Seul, un éclairage situé très près de l'appareil. Le sujet manque de relief, de modelé, les fonds sont sombres. C'est le problème majeur des flashes électroniques à sabot, et même de la plupart des flashes "synchro", à moins d'utiliser de longs cables-allonges peu fiables. Lorsqu'il y a plusieurs sources, un éclairage de ce type est parfois utile: il "débouche" les plages trop sombres proches de l'appareil et permet les synchros des flashes à cellules.

Une place à part doit être faite aux éclairs tirés dans l'axe du cliché, en open-flash, par un personnage placé devant l'appareil. On retrouve alors une ambiance très "spéléo". Cela permet de rendre l'échelle de façon claire et d'intégrer l'homme dans le milieu, le plus souvent en tant qu'entité anonyme. Cela permet de plus "d'économiser" de la lumière car tout l'éclair est utilisé sur le cliché. Il vaut mieux dans ce cas tirer des Ampoules Magnesiques Sans Reflecteurs, à peu près à hauteur de poitrine. Le personnage se découpe bien sur le fond; en l'absence de réflecteur, il ne se forme qu'une ombre derrière lui et il n'est pas nécessaire de tirer un éclair pour le premier plan: en effet la lumière d'une ampoule magnésique diffuse alors sur près de 360°; ainsi les parois sont éclairées En Arrière du spéléologue et son dos et le premier-plan sont débouchés par l'éclairage en contre-jour des parois proches et la réflexion de ces parois. Ltambiance de la progression d'un spéléologue dans la grotte est recrée avec un seul éclair. Seul défaut du procédé: la lumière n'étant pas focalisée, le Nombre-Guide des ampoules diminue considérablement; aussi faut-il utiliser des ampoules puissantes de plus en plus difficiles à trouver.

Comme pour les appareil, il est souvent préférable de décaler légèrement le personnage et son éclair par rapport à l'axe du décor. Dans une vaste salle ou une longue galerie, on peut échelonner plusieurs personnages alternativement à droite et à gauche, chacun tirant une ampoule. Ils ne doivent pas trop se rapprocher de la paroi, ou alors cacher leur éclair et la paroi proche d'eux afin d'éviter de surexposer de trop grandes surfaces.

- Les Contre-jours sont délicats à mettre en place en spéléologie. Ils peuvent donner des résultats remarquables, mais restent aléatoires, même pour un photographe expérimenté. Un léger éclair pour déboucher les ombres les rend souvent plus compréhensibles. Ils peuvent se diviser en deux types:

- Avec la source de l'éclair visible. Les risques de "ratés" sont alors les plus grands: diffusion de la lumière provoquant un halo dû aux particules d'eau en suspension, surtout près des cascades, surexpositions ou images de diaphragmes envahissantes. On peut réduire ces risques en tirant l'éclair le plus possible dans l'axe de l'optique. C'est dans ce genre que l'on peut réussir ses meilleurs clichés d'ambiance où un spéléo "reconnait" certains moments lumineux caractéristiques, quand viennent vers lui ses compagnons aux lampes brillantes alors qu'il est lui-même dans l'ombre.

-Plus fréquemment, la source de lumière n'est pas visible: Soit l'éclair est parfaitement dans l'axe du cliché, dissimulé par une concrétion ou un personnage. Il est difficile de mettre cela en place dans l'onscurité afin d'être sur que le flash ne sera pas visible. Le plus simple est de remplacer le flash par une lampe et de vérifier dans le viseur qu'on ne là voit pas (en espérant que l'opérateur ne bougera pas d'un pouce !).

Soit le flash est légérement décalé par rapport à l'axe du cliché, caché dans le fond. il donne un semi contre-jour, soulignant le luisant des parois lisses ou cupulées, frangeant les concrétions, dessinant les ombres chinoises des personnages. Les résultats sont excellents dans les galeries en courbe, avec un éclair tiré dans le virage, caché par la paroi concave et amenant la question: d'où vient cette lueur?

Dans tous les cas, le Nombre-Guide, et par conséquent le diaphragme, sont très délicats à déterminer, particulièrement en éclair direct. Il ne faut pas trop ouvrir, surtout en couleurs, sous peine de n'obtenir que des noirs, des blancs intenses parfois "baveux" et une photographie "illisible".

- Les éclairages latéraux sont les plus fréquemment utilisés. L'ambiance est encore tributaire de la façon de les disposer, avec les mêmes problèmes de répartition des zones claires (mais pas trop) et sombres (si possibles un peu débouchées). Les possibilités sont innombrables en fonction du sujet, de la topographie et du nombre d'éclairs. Il faut rappeller que tous les éclairages divergents de plus de 110-120 ° de l'axe du cliché sont déja des semi contre-jours.

Pour réaliser ces éclairages, on peut utiliser les rentrants naturels des salles, les anfractuosités des parois, les carrefours de galeries. Ici aussi l'esprit s'interroge inconsciemment: d'où vient cette lumière? Simple rentrant? Suite d'une galerie? L'inconnu demeure.

- Les combinaisons d'éclairages. Les types précédents sont simples. Dans la pratique, il arrive souvent que l'on ~~combine~~ plusieurs types d'éclairages sur les divers plans du cliché: par exemple un premier plan en éclairage semi-direct, un plan moyen en éclairage latéral, un fond en contre-jour; ou un premier-plan en contre-jour et le fond en éclairage presque direct (combinaison donnant de très beaux effets). Ces combinaisons sont innombrables et il en reste un grand nombre qui n'ont pas encore été utilisées.

Reflexions sur l'éclairage

Quel est son rôle dans la photographie souterraine ? Si la position de l'appareil donne "l'élan" du cliché, l'éclairage est l'élément principal de recréation de l'ambiance. Comme on se trouve dans l'obscurité totale et que le décor est "vierge" de tout stéréotype lumineux, tout est permis en ce domaine.

Une des forces de cette photographie, qui charme inconsciemment l'esprit et surprend tant les néophytes, est l'utilisation fréquente d'éclairages Anti-Naturels, par exemples ascendants; on ne les observe jamais dans la nature ou la vie quotidienne. Or l'esprit est imbibé de schémas lumineux; la lumière Doit venir d'en haut, ou sa source Doit être proche de nous, car nous sommes habitués au soleil, aux ampoules électriques suspendues au-dessus de nos têtes ou placées à notre hauteur. Le monde souterrain est ressenti comme étrange par beaucoup, et la façon dont il est éclairé en spéléo joue un rôle dans ce sentiment. Une grotte aménagée dégoulinante de lumière est un milieu tranquille, curieux peut-être, mais guère inquiétant. La même grotte, parcourue à la lueur des frontales, changera totalement, car Tout N'Y Sera Pas Visible.

Dans l'éclairage des photos, cet inconnu, ce "merveilleux" doivent transparaître. Dans les galeries rectilignes, laisser les fonds dans l'obscurité ou utiliser des éclairages d'origine inconnue donnent des impressions. Mais si l'éclairage est le catalyseur de cette ambiance, il existe entre lui et l'élan donné par la position de l'appareil des rapports très importants qui rejailliront sur chaque élément.

Admettons que l'on place l'appareil en plongée ou en contre-plongée. Si l'on donne approximativement le même angle à l'éclairage, la lumière, dans le cliché, épaule les lignes de fuite et la construction s'en trouve consolidée. Mais si on inverse les éclairages, par des contre-jours ou des éclairs en opposition par rapport au décor, les lignes de force de la lumière et de la perspective s'opposent, s'annulent parfois et le cliché change complétement.

Là encore, à partir d'une certaine divergence entre les axes du cliché et des éclairs de flashes, apparaît une "rupture", avec un "seuil" difficilement déterminable. Un éclairage opposé à la position angulaire de l'appareil fait perdre à cette position ses qualités propres et provoque des effets étranges par la réaction de surprise de l'esprit face à cette opposition "anti-naturelle"

Froisser les habitudes lumineuses de l'esprit humain... est une des clefs de la photographie souterraine. Cela peut en particulier être vrai par la recréation d'un "merveilleux" illogique: dans les photographies de lacs et de rivières, il est souvent excellent de tirer un éclair Dans L'Eau!!! Quoi de plus anti-naturel. C'est pourtant presque le seul moyen de rendre perceptible la transparence de l'eau, de mettre en valeur l'élément liquide. Curieusement, cette eau jaune ou verte, irréelle, fera mieux revivre qu'une photo "classique" l'émerveillement devant le cristal liquide et immobile. En fait, ces éclairages "anti-naturels", si l'on n'en abuse pas et si la photo reste lisible, sont peut-être le meilleur, si ce n'est le seul procédé pour rendre l'étrangeté du monde souterrain.

Ceci débouche sur la notion de "manque" d'éclairage comme une irruption de l'inconnu. Laisser des plaques d'obscurité est un des moyens les plus surs d'obtenir une ambiance souterraine. Le problème majeur de la photo spéléo, ce "noir" qu'il faut vaincre tout en la suggérant, devient alors un avantage. Les rapports entre les noirs et les parties éclairées, obtenus par l'emplacement des éclairs de flashes, créent l'ambiance de la grotte ou du moment que l'on veut saisir. Par exemple, la présence d'une bande obscure au premier plan, ou même d'une auréole de noir sont un élément d'iquiétude dans les clichés.

Dans la composition de l'image, ce que l'on ne voit pas est aussi important que ce que l'on voit. Rien que de très logique en cela. La photo doit amener une question et déranger nos habitudes visuelles. Si l'on montre tout d'une galerie ou d'une salle, le spectateur voit un beau document, mais limité dans le cadrage, donc dans l'imagination. S'il subsiste des plages noires apparaît le mystère. Le cadre de la photo est oublié, le cliché n'a plus de limites, le spectateur laisse courrir son imagination qui va chercher à compléter les manques et s'attacher à cette galerie d'où jaillit la lumière, ou désirer saisir l'au-delà de cette plage sombre qui clôt la galerie. Dans ce milieu irréel, comme dans la plupart des domaines esthétiques, suggérer plus que montrer laisse toute liberté à l'esprit du lecteur et permet de passer du document à l'oeuvre d'art.

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Sur Quelques Formes Souterraines Pseudo-Karstiques en France

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Résumé

La comparaison des modalités de creusement de cavités dans des alternances calcaire-marne, des grès à ciment carbonaté ou non carbonaté et dans une lentille schisteuse intercallée dans des quartzites montre que la prépondérance dans les karsts de la dissolution chimique et de l'évacuation sous forme soluble disparaît dans les cavités pseudo-karstiques: l'évacuation mécanique après altération de la roche devient la condition principale de formation des conduits qui acquièrent un profil en long sans contre-pentes. Les conditions de creusement et d'évacuation du matériel sont distinguées, ainsi que les facteurs favorables, essentiellement climatiques, qui ont permis le maintien de ces conduits.

Abstract

A comparison of methods of excavation of holes in the alternations limestone-marl, sandstone with carbonate cement or not and in a schistose lentil embedded in quartzite shows that the preponderance in the karsts of chemical dissolution and excavation in soluble form disappears in the pseudo-karstic holes. Mechanical evacuation after rock weathering becomes the main condition of the formation of galleries which acquire a longitudinal section without reverse slope. The conditions of excavation and evacuation of material are distinguished, as are favorable factors, mainly climatic, which have allowed the maintenance of these galleries.

A partir du schéma habituel des cavités développées dans des carbonates purs, des modifications apparaissent lorsque la lithologie devient moins favorable. Il en résulte d'importantes différences dans les processus, observées dans quelques cavités françaises.

1. Les Formes

A. Les formes souterraines en alternances calcaires-marnes: La source de Champclos (Naves, Ardèche).

Le réseau de la source de Champclos se développe dans l'Oxfordien Moyne (ex. Rauracien-Argovien), constitué d'une alternance régulière de calcaires et de marnes compactes, donnant une stratigraphie très contrastée.

On peur observer sur le plan (Fig. 1) la présence de vastes salles et galeries, et d'étroits conduits. La plus vaste salle, dite du Mont Blanc (d'une circonférence de 150 m) est la seule partie du réseau où les voûtes soient en équilibre. Partout ailleurs, les effondrements sont fréquents dans tous les conduits atteignant une largeur supérieure à 2 ou 3 m.

La disposition de la grotte montre une opposition entre ces vastes salles et conduits et les galeries étroites, souvent en "méandres", qui les joignent. Si l'on compare leurs volumes, cette opposition est encore plus nette, puisque les premiers ont un évidement supérieur à 60,000 m^3, alors que les étroits conduits en représentent deux à trois mille au plus.

Cette opposition peut avoir plusieurs causes: elle peut résulter de différences d'âge entre les formes, les galeries en méandre étant récentes et en cours d'élargissement, puisqu'actives, alors que les grands volumes sont inactifs. Cela peut être interprété comme un nouveau "cycle" d'érosion souterraine dans un réseau complétement figé.

La morphologie rend cette hypothèse improbable: les effondrements y sont l'agent dominant. Les galeries s'obstruent sous les débris de leurs voûtes et les circulations d'eau se trouvent ainsi entravées; le phénomène est favorisé par les insolubles libérés par les marnes. Dans un pareil cas, les eaux passent souvent par d'autres discontinuités au lieu de déboucher la galerie primitive.

Le réseau de Champclos est une application à l'ensemble d'un réseau d'une telle formation exacerbée par la lithologie, avec des formes de raccordement plus ou moins évoluées. L'actuel conduit de l'exurgence est une forme de raccordement, utilisant un joint de stratification, un peu plus ancienne que les méandres allant des grandes salles au réseau des Alauzas (Fig. 1). La galerie des coupes 14-15 est un conduit assez ancien qui était probablement raccordé aux salles plus méridionales et à la grande galerie du réseau des Alauzas. Après sont obstruction, elle a été récoupée accidentellement par l'actuel méandre. On peut dire que l'évolution du réseau se fait par compensation de tous les effondrements par des réseaux parallèles et étroits qui s'élargissement jusqu'à ce qu'ils s'effondrent à leur tour pour être remplacés par une nouvelle galerie.

La seule exception à la régle, la salle du Mont Blanc, aux voûtes en équilibre naturel avec fermeture concentrique des bancs vers le haut, indique qu'une fois dépassé un seuil de dimension, le creusement en alternances calcaire-marnes peut aboutir à des formes presques stables.

B. Les cavités dans les "grès" du Trias ardéchois

Elles se développent dans les épaisses séries triasiques du pied des Cévennes où l'on distingue un Trias inférieur (t_a), un Trias moyne (t_b) et un Trias supérieur (t_c). Dans la région de Largentière, un niveau dolomitique du Trias moyen a permis la formation de l'important réseau de Pézenas, creusé en roche karstifiable au coeur d'une masse gréseuse insoluble. Mais les cavités les plus particulières se trouvent plus au Sud, près des Vans, où des variations latérales de faciès transforment le Trias en une série hétérogène de grès siliceux à lentilles plus ou moins carbonatées.

Dans une lithologie aussi variée, les cavités sont de plusieurs types (tableau I): certaines sont creusées dans des lentilles carbonatées. D'autres sont formées par soutirage dans le grès d'une lentille carbonatée sous-jacente (Aven du Quillard). D'autres sont dues au blocage des circulations verticales par des bancs argilo-marneux qui ont permis des circulations latérales suivies de creusement. Parfois le grès renferme un ciment calcaire (Baume Dupré), parfois ce ciment est argileux ou siliceux (Baume du Luth). D'autres cavités, par contre, ne possèdent pas de bancs argilo-marneux (Fontaine du Pigeonnier, Fontaine de Champetier-Haut). Enfin les cavités les plus vastes, comme la grotte du Vignal, renferment des galeries de plusieurs types.

Il apparaît cependant une unité morphologique dans ces cavités. Les dénivelées importantes sont absentes dans les réseaux, même les plus longs. Les galeries inactives sont rares, encombrées d'éboulis et rapidement obstruées. Les conduits sont étroits et très contournés en coupe, même dans les galeries actives où sont évacués les débris éboulés: chaque variation lithologique donne un redan ou une banquette et les parois sont souvent "bourries" au point qu'on peut les fragmenter à la main.

L'hydrologie est tout aussi dépendante de la lithologie: les débits d'étiage sont minimes et les maxima de crue sont eux-même peu élevés (Tableau I) si on les compare aux débits de cavités creusées dans le calcaire. Dans ces grès, les circulations karstiques sont mineures par rapport aux autres circulations.

C. Une cavité dans les quartzites: la Grotte de Roch-Toul (Fig. 2)

Elle est située dans la commune de Guiclan, près de la ferme de Kerougay, à 3 km au SW du village de Saint-Thégonnec (Finistère Nord). C'est à notre connaissance la <u>seule grotte</u> non marine de Bretagne.

Elle se développe dans un banc de grès quartzites (d^{2b}) intercallés dans les schistes du Coblencien. Sur le site de la grotte, le faciès est extrêmement résistant sur une épaisseur de 15-20m. Il forme éperon au-dessus de la vallée de la Penzé, la couche étant très redressée avec un pendage de 75° vers le Sud et une direction WNW-ESE.

La cavité, sub-rectiligne et longue de 50 m, se divise en une salle d'entrée assez large, peut-être sur une fracture, et un couloir plus étroit (à partir de la coupe B) développé à partir d'un joint de strate.

La formation n'a été possible que grace à l'intercallation d'une lentille schisteuse dans le grès; on en trouve des traces aux voûtes de la cavité. Elle a été altérée, puis a été évacuée par les eaux d'infiltration dont on peut observer une petite arrivée au fond de la grotte. C'est donc un phénomène d'érosion différentielle favorisée par la fracturation de la roche permettant la circulation des eaux et par une remarquable opposition roche dureroche tendre.

II. Essai D'Explication Genetique

L'apparition de cavités dans des terrains inhabituels n'est possible que grace à des facteurs particulièrement favorables qui compensent la faible capacité de "karstification" de la roche.

Les cavités ardéchoises (Champclos, grottes du Trias) bénéficient des précipitation particulièrement abondantes sur les Cévennes (1350 mm/an aux Vans, plus de 1800 mm/an sur les sommets cévenols), et surtour de la violence des précipitations instantanées (parfois plus de 200 mm/24 h), exceptionnelles pour l'Europe et capable de provoquer des effets de chasse dans les galeries, donc de fournir un travail mécanique indispensable, comme on va le voir, pour que se forment ces cavités. Sans ces précipitations, il est peu probable qu'elles aient pu se former. De plus, dans le cas de la Fontaine de Champclos, des apports supplémentaires d'eau provenant du socle cristallin proche ont pu favoriser le creusement.

L'énigmatique grotte de Roch-Toul résulte d'un dégagement probablement fort long, par érosion différentielle, d'une roche tendre dans un encaissant particulièrement résistant.

Moins la roche est carbonatée, plus les modalités de creusement différent de la "classique" mise en solution des carbonates. Dans ces derniers, creusement et évacuation de matière sont intimement liés, puisque la dissolution est essentielle. Dans les autres cavités, il y a lieu, au contraire, de distinguer les processus de formation ou de préparation des conduits "in situ" et les processus d'évacuation du matériel. C'est en ce sens que l'on peut dire qu'il y a une différence de nautre entre les types de cavités décrits (tableau II), car dans chaque type soit le creusement, soit l'évacuation résultent d'un processus particulier.

Dans les alternances calcaires-marnes, le creusement se fait par dissolution et effondrements. Les capacités d'évacuation par les eaux sous forme soluble pour les carbonates et insoluble pour les résidus marneux parviennent ou ne parviennent pas à surmonter ces effondrements successifs qui commandent toute l'évolution des conduits.

Dans les grès, c'est l'altération du ciment qui est la condition essentielle du creusement. Si le ciment est carbonaté, cette action peut s'effectuer par dissolution. S'il ne l'est pas, l'action est plus difficile, plus longue, mais la présence même de cavités montre que cette altération est possible.

Quelle que soit la nature du ciment, la présence de niveaux argilomarneux imperméables favorise l'altération par imbibition de la roche, L'évacuation du matériel, si elle s'effectue partiellement sous forme soluble pour les grès à ciment carbonaté, est essentiellement due aux actions mécaniques de l'eau qui transporte les grains siliceux. Cela rend presque impossible les phénomènes de contre-pente. Seules des circulations plus violentes que celles observées dans les grès pourraient transporter le matériel sous forme solide dans des conduits ascendants. Aussi les écoulements acquièrent-ils un profil en long assez semblable à celui des ruisseaux de surface et toute l'organisation spatiale des cavités s'en trouve modifiée.

Dans la grotte de Roch-Toul, le creusement a été possible grace à une altération différentielle de schistes tendres dans un encaissant siliceux presque inaltérable. L'évacuation du matériel reste assez mystérieuse, une partie des schistes ayant pu disparaître par mise en solution du matériel altéré pendant que l'autre était évacuée mécaniquement par des procédés non déterminés (érosion mécanique ou même solifluxion rendue possible par le perchement du porche au-dessus d'un versant raide).

Lorsque l'on passe des formes karstiques aux formes semi ou pseudokarstiques, le passage d'un creusement par dissolution pure à un creusement par érosion différentielle et d'une évacuation soluble à une évacuation mécanique montrent que les cavités étudiées n'ont en commun que la circulation d'eau, nécessaire au creusement, et une certaine résistance mécanique de la roche, nécessaire pour que les galeries ne s'effondrent pas. Mais les modalités de leur formation sont par ailleurs si variées que l'on en vient à évoquer une convergence de formes plus qu'une véritable similitude.

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CAVITÉS RÉPERTORIÉES	Développement (en mètres)	Dénivellation (en mètres)	Position sur le versant par rapport au thalweg le plus proche	Position sur le versant par rapport à l'ensemble de la serre	Circulation d'eau (*)	Débits en l/s (d'après H. Pascal, 1970)	Étage	Grès	Grès à ciment carbonaté	Roche Carbonatée	Assise Marneuse
1 RIBES	260	–	2/3 sup.	2/3 sup.	++	–	tb			×	
2 CROS	50	+ 3	bas	bas	+	0,1 à 10	tc			×	
3 QUILLARD	–	– 10	haut (10 m du sommet)	haut (10 m du sommet)	–	–	tc tb	× jusqu'à – 5 m		× à partir de – 5 m	
4 DUPRÉ	850	–45	mi-versant de 40 m	Presque sommitale	++	0,1 à 10 à la résurgence de Chalvèches	tc tb	× en aval de la salle	×		× de 120 m de l'entrée au fond
5 PIGEONNIER	240	+2	bas (+10 m) d'un versant en faible pente	2/3 sup.	++	0,05 à 30	tc	×		× dans un affluent	
6 CHORAND	30	+ 1,5	au 2/3 d'un versant complexe de 230 m de dénivellation		++	–	ta	×			×
7 LUTH ou PICONS	350	+ 5	bas	bas	++	0,2 à 50	tc	×			(0,5 m)
8 FONT-BONNE	90	–	bas (+ 25 m) d'un très long versant		++	0,1 à 40	tc	×			
9 CHAMBAJOUR	50	+ 1	1/2 versant	1/2 versant (de 180 m)	++	0,1 à 50	tc tb	×			
10 CHAMPETIER	500	+ 4	3/4 sup.	3/4 sup.	++	0,1 à 30	tc	×			
11 LE VIGNAL	1 900	+ 30	bas (+ 10 m)	sommitale	+	0,1 à 50	tc tb (?)	× en Amont	× en Aval		× (localement)

TABLEAU I Caractéristiques des grottes dans les terrains triasiques.

* ++ Dans toutes les galeries; + présence de galerie sèche; – pas de circulation.

NATURE DE LA ROCHE	PROCESSUS DE CREUSEMENT	PROCESSUS D'EVACUATION DU MATERIEL
CARBONATES	DISSOLUTION	SOLUBLE DES CARBONATES
ALTERNANCES CALCAIRES-MARNES	DISSOLUTION EFFONDREMENTS	SOLUBLE DES CARBONATES
GRES A CIMENT CARBONATÉ	DISSOLUTION DU CIMENT EFFONDREMENTS	SOLUBLE DES CARBONATES (FAIBLE PROPORTION) MÉCANIQUE DES GRAINS SILICEUX
GRES A CIMENT NON CARBONATÉ	ALTÉRATION DU CIMENT, SOUVENT AU-DESSUS D'UN NIVEAU IMPERMÉABLE EFFONDREMENTS	MÉCANIQUE DES GRAINS SILICEUX CHIMIQUE DU CIMENT ALTÉRÉ (?)
SCHISTES ET QUARZITES	ÉROSION DIFFÉRENTIELLE PAR ALTÉRATION DE LA ROCHE TENDRE	(?) MÉCANIQUE OU CHIMIQUE DU SCHISTE ALTÉRÉ

TABLEAU II : TYPES DE GENESE DES CAVITES

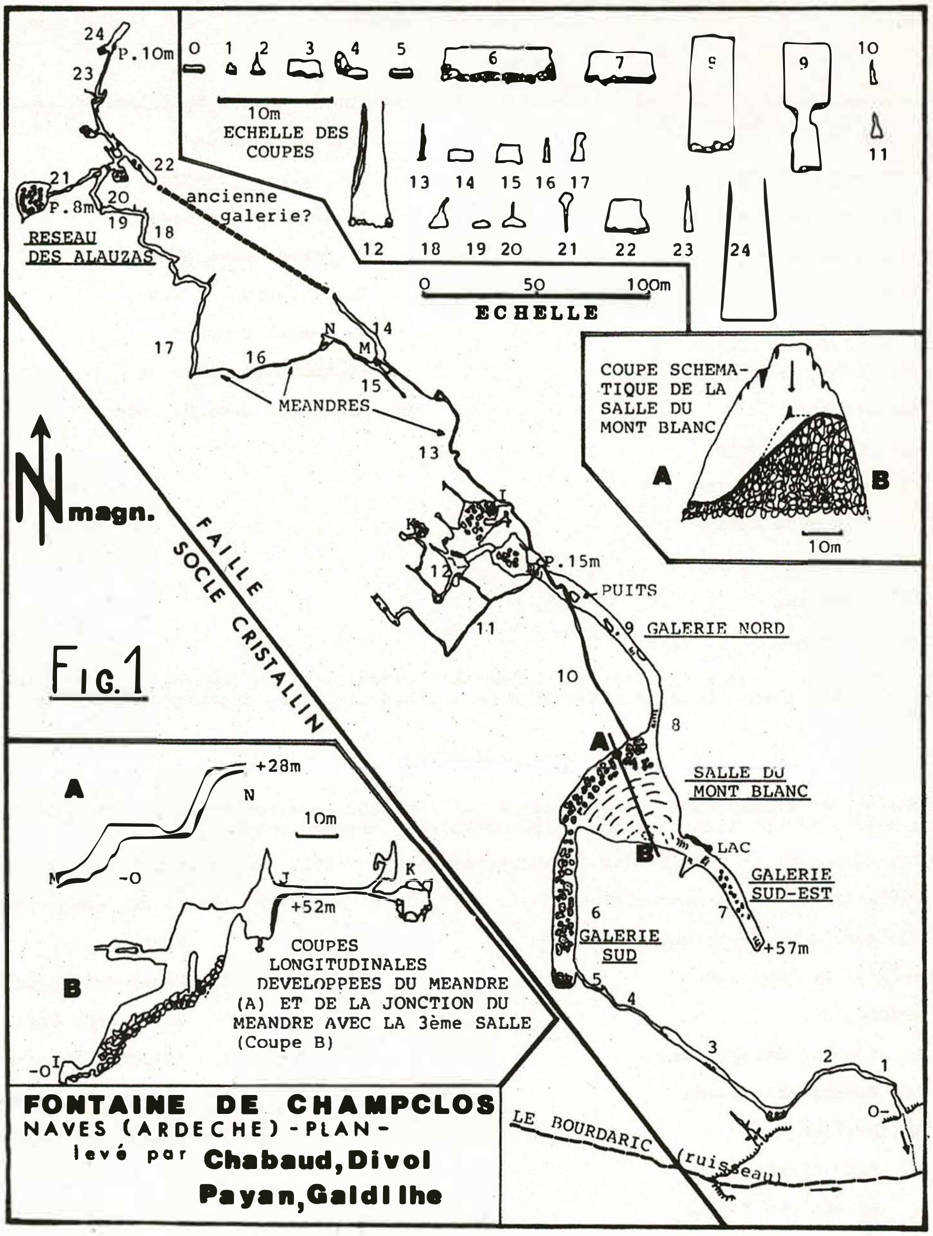

FIG. 1
ECHELLE DES COUPES
10m
ancienne galerie?
RESEAU DES ALAUZAS
P.10m
P.8m
ECHELLE
MEANDRES
N magn.
FAILLE SOCLE CRISTALLIN
COUPE SCHEMATIQUE DE LA SALLE DU MONT BLANC
P.15m
PUITS
GALERIE NORD
SALLE DU MONT BLANC
LAC
GALERIE SUD-EST
+57m
GALERIE SUD
+28m
+52m
COUPES LONGITUDINALES DEVELOPPEES DU MEANDRE (A) ET DE LA JONCTION DU MEANDRE AVEC LA 3ème SALLE (Coupe B)
LE BOURDARIC (ruisseau)
FONTAINE DE CHAMPCLOS
NAVES (ARDECHE) - PLAN -
levé par Chabaud, Divol
Payan, Galdilhe

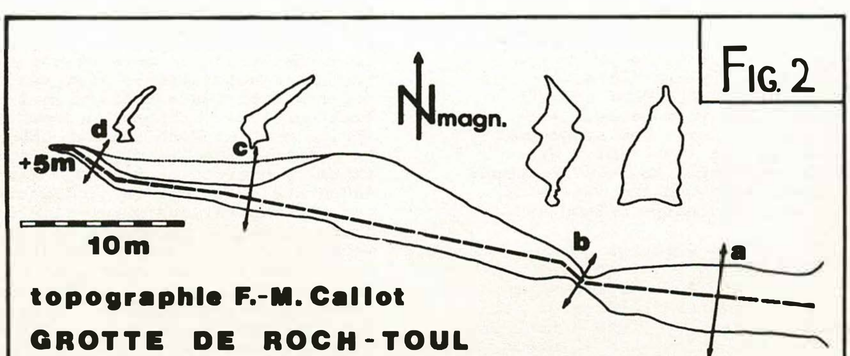

FIG. 2
N magn.
+5m
10m
topographie F.-M. Callot
GROTTE DE ROCH-TOUL

A Functional Classification of Karst

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Abstract

Karst features can be classified by their position and function in a hydrological regime. Such a classification can be outlined:

I. Surficial Karst Features
   - A. Exposed bedrock surfaces
   - B. Mantled bedrock surfaces

II. Interface features
   - A. Insurgences
     1. Diffuse
     2. Confluent
   - B. Resurgences
     1. Gravity spring
     2. Artesian spring
     3. Overflow spring
   - C. Intersection Features
     1. Vertical
     2. Lateral

III. Subsurface Features
   - A. Active cave passages
     1. Tributary passage
     2. Master cave passage
     3. Diversion passage
     4. Tapoff Passage
     5. Abduction passage
   - B. Abandoned cave passage

The placement of a given karst feature within this classification removes explorationally and morphologically biased terminology, and facilitates its hydrological, geomorphological and explorational interpretation.

Zusammenfassung

Karsterscheinungen können nach ihrer Position und Funktion in einem hydrologischen System eingeordnet werden. Eine solche Klassifizierung kann folgendermassen umrissen werden:

I. Oberflächenformen im Bereich der Karsterscheinungen
   - A. Freigelegte Grundsteinoberflachen
   - B. Überdeckte Grundsteinoberflachen

II! "Interface" Erscheinungen
   - A. Anschwellen
     1. Auseinanderfliessend
     2. Zusammenfliessend
   - B. Abschwellen
     1. Schwerkraftquelle
     2. Artesische Quelle
     3. Überflussquelle
   - C. Erscheinungen and Schnittpunkten
     1. Vertikal
     2. Lateral

III. Unterirdische Erscheinungen
   - A. Aktive Höhlendurchgänge
     1. Nebenpassage
     2. Haupthöhlenpassage
     3. Umleitende Passage
     4. "Tapoff" Passage
     5. Ableitende Passage
   - B. Verlassene Höhlendurchgänge

When dealing with landforms that have evolved due to solution of bedrock it can be an advantage to separate the features into two main groups: those formed by surficial solution and those developed through subsurface waterflow. These two groups can be considered to some extent independent of each other. The surficial features form because surface water falls or flows on them. The subsequent destination of the water is not important. Subsurface features can be considered to form independent of surficial features, although the nature of the surface can affect the chemistry, colume and input mode of the water.

I. Surficial features are solution forms found on bedrock surfaces due to local rainfall, snowfall, condensation and runoff, independent of the eventual flowpath of the water (surface or subsurface). An extensive literature exists describing solutional features that form on exposed limestone surfaces (see Jennings, 1971; Sweeting, 1973; Quinlan, 1979), and no attempt is made to further subdivide and classify the wide range of surficial karst features except to note that they tend to fall into two braod categories: features formed on exposed bedrock surfaces and features formed on mantled bedrock surfaces. Exposed bedrock surfaces are in equilibrium contact with the atmosphere and water-flow on and over them is of a free surface, often mechanically energetic, nature. Mantled bedrock surfaces are often not in geochemcial equilibrium with the atmoshpere, and water-flow on and over them is often through a permeable medium and is rarely mechanically energetic. Mantled bedrock surfaces may be covered with an impervious material, and not be in significant contact with water. An exhaustive review of karst features can be found in Quinlan (1979), which classifies karst in terms of cover, rocktype, climate, geologic structure, physiography, hydrology, modification during and after karstification, and dominant landforms. It is improtant to realize that karst features, regardless of the multitude of factors that control their expression and morphology, are a link in the chain of water transport over and through a soluble material. A karst feature's function must be clearly understood for its morphology and history to be explained.

II. Interface features form where the surficial and subsurface environments meet. These are the areas in which water enters the subsurface (insurgences), the areas in which water is discharged from the subsurface environment (resurgences), and areas where the surface environment intersects the subsurface environmnet (intersection features). Because interface features can vary widely in scale and structure, their surface expression can assume a wide variety of morphologies. While the terms insurgences, resurgences, and intersection features readily describe the available hydrologic processes by which the surface and subsurface interact, they do not provide a direct measure of the configuration the surface landscape will assume at these interface points.

As in the discussion concerning surficial karst features, no attmept is made to describe and classify the morphology of karst depressions other than to say they are all, by definition, interface features. Differences in morphology among depressions are a measure of the physical properties of the materials present and the rates at which the karst processes work at them. The basic processes involved, however, are the same -- solutional and gravitational removal of material from the surficial environment in to the subsurface environment.

II.A. Insurgences are points of water input into subsurface conduits from the surface. A great deal of variation can exist in the morphology of an insurgence depending on the structure and lithology of the soluble rock present, the local relief, and the volume of water sinking underground. Sweeting (1973) discusses insurgences and the terminology involved with them, and prefers to call them swallow holes. These features are then subdivided into groups based on morphology. The term swallow hole carries with it a connotation of volume, and implies existence of a cavity or hole into which the water goes. The term insurgences is free of size and volume connotations and describes no specific morphological feature. The subdivisons of Sweeting (1973) are used here with some modifications:

1. Diffuse Insurgence. In this case, water enters the limestone as a series of small, diffuse inputs by percolation (through overburden, if it exists) into small openings in the limestone. The small openings are usually the primary permeability of the carbonate rock, or joints and fracture permeability. Given a large expanse of limestone, the water is seen to enter in approximately equal volume over the entire area. Water concentration takes place in the subsurface environment in the case of diffuse insurgences, not in the surface environment as with confluent insurgences (see below).

2. Confluent Insurgence. In this situation, water enters the limestone after it has been concentrated into identifiable streams which sink into the limestone at one or more discrete points, localitites that can be seen and measured as point inputs.

In many cases, growth and evolution of subsurface conduits and interface features result in abandonment of some insurgences in favor of newly-formed ones upstream. The adjective abandoned can be used to modify those insurgences. Insurgences that are only utilized when insurgences upstream cannot handle the water flow are called overflow insurgences.

Confluent insurgences often tend to cluster. Clusters of confluent insurgences are called a confluent insurgence comples. Given a pre-existing subsurface conduit, insurgences may cluster around its course because the conduit is the drain for water entering the surface area above it. Insurgences may be grouped because hydraulic inefficiencies in one insurgence cause the use of overflow insurgences in times of flood. Insurgences also cluster because the soluble rock may be exposed only in limited areas, so surface water flows to that area to sink.

Confluent insurgence formation is dependent on the presence of some feature, such as impervious lithologies or thick overburden, which provides a surface on which meteoric water can collect as confluent streams. The actual point of contact of the surface stream with the limestone and the conditions existing at that contact (water volume, lithologies, and overburden) control the morphology of the insurgence.

II.B. Resurgences are the interface between the surface and subsurface environments where water that is collected at insurgences and transmitted by solution conduits returns to the surficial environment. Resurgences, or karst springs, are the downstream end members of karst terrains.

1. Gravity Springs. These are resurgences where water under gravity flow leaves the subterranean conduit much like the flow of a surface stream. The actual opening to the surface may be totally or partially blocked by collapse, obscuring the spring and causing local ponding in the conduit behind the spring.

2. Artesian Springs. These springs are those in which water flow from a conduit is due to hydrostatic pressure and not free surface gravity flow.

a) Vauclusian Spring. This is named after the type example at the Fontaine de Vaucluse in France (Sweeting, 1973). Water flows up and out of an ascending solutional conduit under hydrostatic pressure. Ebbings and flowing springs are special cases of Vauclusian springs.

b) Alluviated Spting. Powell (1963) described these springs in which the conduit emerges below local base level into unconsolidated sediment and flushes out an opening to the surface through which the water escapes. Water is under hydrostatic pressure and not gravity flow. Alluviation is usually due to changes in regional base level. A special case is the submarine spring, where the "alluviation" is produced by ponded water (fresh or salt) and the conduit discharges its water into this larger ponded feature below the surface.

3. Overflow Springs. Overflow springs are resurgences which are used only in cases of flood in a cave system when the normal spring is incapable of handling the volume of water transmitted to it. An overflow spring can act as either a gravity spring or an artesian (Vauclusian) spring depending on the morphology of the passages connecting it to the main (low flow) conduit. It can also be seen that under flood conditions, what would normally be a gravity spring can take on the internal characteristics of an artesian spring.

Jennings (1971) and Sweetin (1973) differentiate between resurgences, which they label as the reappearance of sinking streams (confluent insurgences) and exsurgences which is the reappearance of local infiltration of water (diffuse insurgence). Both investigators admit the difficulty in demonstrating a spring to be a resurgence only, an exsurgence only, or a combination of both. Jennings states that almost every resurgence must have some exsurgent input. For this reason, the classification of springs into exsurgences and resurgences is not used. Springs are classified as resurgences, and the term exsurgence can be applied as an adjective to the term resurgence if exsurgent qualities can be demonstrated to be significant.

As with insurgences, maturation of a karst area may result in the abandonment of resurgences in favor of newer ones. In this case, the resurgence classification is used with the adjective abandoned.

II.B. Intersection features, in amny karst areas, connections exist between the surface and subsurface environments that do not relate to appreciable water insurgence to, or resurgence from, a subsurface conduit system. These are called intersection features, and are generally caused by weathering phenomena other than solution, although solution may contribute greatly. After initial formation, an intersection feature may evolve into an insurgence (or resurgence) by capture of water from nearby areas.

1. Vertical intersection, or collapse due to mechanical failure of the roof into a void, is the most common type of intersection. Since the voids are formed by solution, it can be argued that intersection features are solutional in origin; however, their final expression is usually due to other weathering processes.

2. Lateral intersection occurs when retreating cliff lines and slopes uncover pre-existing solution conduits.

III. Subsurface Features. Subsurface solution conduits are best studied when considered as cave systems, parts of the karst hydrological cycle. Individual caves are segments of some active or abandoned subsurface flow path. Cave systems are features that carry)or carried) water from a group of points on the surface to a point or group of points elsewhere on the surface. Solutional cave systems have been classifed in terms of genesis by Ford (1977). White (1977) has looked at cave systems as part of the carbonate aquifer. A functional classification, such as presented here, sidesteps (with conceptual risk) the genetic aspects of the cave system, and treats it as a fait accompli. The function of the various points of the cave system in transmitting water is important to the overall interpretation.

Cave conduits are generally only explored as cave segments, as it is rare that the investigator can travel all the way from the insurgence to the resurgence. A terminology has been developed that describes individual caves in terms of their function with regard to the whole cave system. This terminology does not imply specifically what local conditions (vadose or phreatic) existed at the time of the cave segment formation, or what (structure or lithology) controlled its formation.

The term cave system is used to describe the sum ot the subsurface solution conduits that exist in one subsurface drainage basing. Cave systems, being enclosed in rock, may interact and compete in three dimensions. The individual segments are defined as to function:

III.A. Active Cave Passages. These are passages within a given cave system which carry water from ~~insurgences to resu~~rgences, either permanently or seasonally.

1. Tributary Passage. This is a cave passage entering the cave system which brings water directly from an insurgence(s).

2. Master Cave Passage. This is the primary conduit through which the tributaries discharge their water to the resurgence(s).

3. Diversion Passage. This is a passage which carries water in competition with the master cave.

a) Loop Passage. This is a competing passage which carries water from the same upstream source to the same downstream objective within the cave system as the master cave system.

b) Overflow Passage. This is a passage utilized during flood or high water conditions which carries water past hydraulic constrictions in the cave system to the cave system downstream from the hydraulic constriction(s), or to an overflow spring(s).

4. Tapoff Passage. This is a newly-formed passage (with respect to the rest of the cave system) in the distal portion of the cave system carrying water to a new resurgence by the abandonment of, or competition with, an earlier resurgence.

II.B Abandoned Cave Passages. These are passages eithin the cave system which no longer carry water. Where enough data exist, the past function of the inactive passage can be applied, with the adjective abandoned in front of it.

As with any classification, there is a degree of arbitrariness in the formation and application of it. Sweetin (1973) classifies caves into three main types: phreatic, vadose and vertical. The first two types are based on the apparent genesis of the passage; the last involves an explorational bias. None of the three terms describes the primary function of the cave system, which is to carry water through the subsurface from insurgence(s) to resurgence(s). Jennings (1971) classifies caves as inflow, outflow, thrugh and between, allowing the limits of exploration to determine the cave's classification.

The cave classification used in this paper avoids explorational bias and the need to describe the solutional processes that formed the passage. Problems arise in deciding, at the junction of two equal-sized cave stream,s which is tributary to which. Overflow passages may be difficult to label because they may look like abandoned master caves,utilized only in flood conditions when the cave is inaccessible (an explorational bias). The distinction between tapoff passage and abduction is critical because the former is a common speleological occurrence but the latter is rare. Tapoff formation is commonly the adjustment of a cave stream in the distal portions of the cave system to local base level in response to the influences of surface conditions such as increased jointing and joint gapping, occlusion of resurgences, and intersection by slopes and scarps. It is not to be confused with a total cave system readjustment of passage elevations to a regional drop in base level, with the subsequent abandonment of the higher-elevation passages. Abduction is the capture of water from part or all of one cave system by a pre-existing, competing cave system. The term piracy is used to describe this phenomenon on the surface, but the aspects of three dimensionalism seen in limestone solutional conduits make its rigid application confusing. In the speleologic literature, the term piracy has been used to describe the capture of the water from one cave passage to another, regardless of whether the capturing passage was a meander cutoff, tapoff, overflow route or abduction passage. The term abduction is used because it has no previous speleologic interpretation and therefore can be rigidly defined.

Karst topography is the solutional sculpturing of soluble bedrock material, initiated by placing this soluble material into the domain of the hydrologic cycle. Each individual karst feature forms as part of the water transfer chain or because of interaction with parts of the water transfer chain. Any karst landform can be analyzed as a surficial, interface, or subsurface feature, or some product of their interaction. Cave systems in particular function as water transmitters, collecting water from one area of teh earth's surface and delivering it to another. In discussing karst features, their role as participants in the hydrologic cycle must be considered.

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Glacial Controls of Speleogenesis

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Abstract

Glaciation, because of its global impact, has had an important influence on speleogenesis in three major ways: 1. ice contact effects, involving: a) glacial quarrying of land surgaces, including gradient changes, exposure of limestone surfaces, and removal of limestone surfaces; b) sediment distribution, including burial of recharge and/or discharge areas, and introduction of sediment into caves (tills, outwash, loess, and rhythmites); c) water budget changes, including re-arrangement of surface drainage, and glacial meltwater events; d) chill effects, including freeze/thaw and geochmical changes; 3) isostatic reboudn, including dip and gradient change.

2. Ice proximity effects act at a distance from the ice, but are due to the presence of the ice. These effects include shill effects (periglacial), outwash, loess, and rerouting of major river systems.

3. Global effects are a response to the mass shift from the ocean basins to the continents, with corresponding climate effects. Sea level changes affect mostly coastal areas, but base level changes may occur as a response well inland, Climatic effects are primarily in temperature and precipitation, the latter a key speleogenetic control.

Current glacial environments with serious speleogenetic implications are restricted to alpine ares, and while illustrative of ice contact effects, are not representative of the effects of a global glacial event.

Zusammenfassung

Aufgrund ihrer weltweiten Auswirkung hat die Vereisung einen bedeutenden Einfluss auf die Speläogenesis (Höhlenforschung) gehabt:. 1. Folgen der Eisberührung umfassen: a) Glaziale Auswirkungen auf die Landoberflächen, einschliesslich Veränderungen im Gefälle, Freilegung von Kalksteinoberflächen und Abschleifung von Kalksteinoberflächen: b) Verteilung von Schichtgesteinen, einschliesslich Verschüttung von Aufladeund/oder Abaldegebieten, und die Ablagerung von Geröll in Höhlen (Schuttmassen - Till - geschichteter Trift, Löss und Rhythmiten): c) Veränderungen im Wasserspiegel, einschliesslich Veränderung der Oberflächenentwässerung, und Abschmelzungsvorgänge: d) Auswirkungen der Gefrierverhältnisse, einschliesslich Frieren/Tauen und geochemikalisch Veranderunge: e) Isostatische Ausgleichsbewebungen, einschliesslich Senkungen und Veränderungen im Gefälle.

2. Folgen der Eisnähe machen sich in einiger Entfernung vom Eis bemerkbar, werden jedoch durch das Vorhandensein des Eises verursacht. Diese Folgen umfassen Gefrierverhältnisse (periglazial), Trift, Löss und Verlegung wichtiger Flussläufe.

3. Global Folgen sind eine Reaktion auf die Massenverlagerung von den Ozeanbecken auf die Kontinente, mit gleichzeitigen klimatischen Auswirkungen. Veründerungen im Meeresspiegel wirken sich überwiegend auf Küstengebiete aus: jedoch können Veranderungen im Grunspiegel als Reaktion im Binnenland erscheinen. Klimatische Auswirkungen treten hauptsächlich in Form von Temperatur und Niederschlägen auf, letztere sind eine der wichtigsten speläogeneischen Bedingungen.

Zur Seit bekannte Gletschergebiete, die bedeutende speläogeneisische Begleiterscheinungen aufweisen, sind nur auf Hochgebirge begrenzt, und obwohl sie die Folgen der Eisberührungerklären, sind sie doch nicht kennzeichnene für eine globale Glaziale.

Glaciation has been the most recognizable aspect of the world climate changes of the Pleistocene epoch. Its effect on speleogenesis has been widespread and important, although the results of ice cover have received most of the attention of speleologists. The overall effect of glaciation extends beyond ice contact, it includes changes in areas adjacent to ice covered areas, or ice proximity effects, and global effects, such as climatic change and eustatic sea level fluctuations. The understanding of speleogenesis by the study of current processes and products requires a grasp of all the ways in which Pleistocene climatic variation acted on cave development. The Pleistocene is an extremely anomolous time in earth history, and the landforms that carry over from that time are not reflective of current earth surface processes. The explanation of the effects of glaciation on speleogenesis requires the examination of three major areas: Ice contact effects, ice proximity effects, and global effects.

I. Ice Contact Effects. The aspects of the ice contact can be broken into four basic stages as proposed by Glover (1977):

1. Full Interglacial, or time between major glaciations with ice sheets at or near some minimum cover.

2. Onset of Glaciation, or glacial advance, occuring with increased flooding from the advancing ablation zone of the ice mass. Sediment discharge into caves may be appreciable, and periglacial conitions may occur ahead of actual ice contact. Increased water flow may rejuvenate upper levels in caves, and/or result in the re-establishment of surface water courses.

3. Peak Glaciation, with complete ice cover of the area. Stagnation of water flow conditions in caves, with entombment of surviving karst.

4. Glacial Retreat or withdrawal of the ice cover, with excessive flooding and sediment discharge.

This cycle of events occurred with each major glaciation during the Pleistocene, although often the results of only the most recent glaciation is well preserved by the landforms.

In terms of the description of conditions during a glacial event, this has been msot completely treated by Ford (1977). His major findings can be summarized as follows:

1. Thermo-chemical environment: glaciated terrains do not necessarily display enhanced or depleted solutional activity, although solution potential increases towards the tropics. Water derived from CO_2 depleted ice may saturate at 25ppm wrt calcite at 0^oC, leading to sub-ice precipitation of calcite.

2. Hydrological conditions of ice cover:
   a. Ice base at polar)frozen) condition, no water circulation,
   b. Ice base at temperate (liquid water) conditions, leads to two possibilities:
      1) Pervasive ice sheet cover, resulting in water filled caves and karst under stagnant conditions.
      2) Ice sheet cover non-pervasive, so ice may actually add to the hydrologic gradient, as in some alpine conditions today.

3. Caves are not collapsed by ice loading but surface karst is often quarried or buried.

4. Glacial karst morphology. The karst features in a glaciated area fit into one of four categories:
   a. post glacial forms - formed after ice retreat.
   b. karstiglacial forms - features of glacial origin (scour or deposition).
   c. glacio-karstic forms - features of karst origin, but glacially modified.
   d. pre-glacial forms - pre-date glaciation and unmodified by it.

The above material from Glover (1977) and Ford (1977) gives a framework for, respectively, events and conditions. The results of ice contact involve the shift in mass over a glaciated area. This shift produces a number of effects.

1. Glacial quarrying of land surfaces occurs, which includes gradient increase, limestone exposure or limestone removal. In areas where occupation of valleys by glacial tongues occurred, valley deepening with a subsquent increase in gradient resulted. This has been documented from many areas, with the

Yorkshire, England area being representative (Waltham and Harmon, 1977). In areas where carbonate rocks are the more resistant rocks, glacial quarrying may strip over lying weaker rocks, especially in the areas of flat lying or gently dipping rocks, increasing the surface exposure of the carbonate material. An example involving Devonian clastics and carbonates from New York, USA is discussed in Mylroie and Palmer (1977). Glacial quarrying can also strip off carbonate rocks, especially in areas where the carbonates are the weaker rock material, as in western Newfoundland (Karolyi, 1977). The difference in carbonate expression in a uniformly glaciated area caused by the relative strengths of the carbonate and surrounding rocks is discussed for the Northeastern USA in Cullen, et. al. (1979). The change in limestone exposure and gradient can greatly influence speleogenesis. A variety of karstiglacial or glacio-karstic surface features can form by glacial quarrying.

2. The glacial distribution of sediment on recharge and/or discharge areas causes caves and karst to receive a variety of sediments, including tills, outwash material, loess and rhythmites. Palmer (1977) details the burial of preglacial surface features by variety of glacial deposits. Insurgences can become blocked to a variety of degrees, with till in some cases being intruded directly into cave passages (Mylroie, 1977). Coarse outwash material produced by both advancing and retreating ice sheets is introduced deep into cave conduits, and is well documented from many areas. Fine grained material is also introduced, its source either rock flour or loess. This sediment is often in excess of 50% soluble material, and is variously ascribed to depostion during stagnant, subice conditions (Mylroie, 1978a) or to outwash from nearby glacial fronts (Hladnik and Kranjc, 1977). This material has been called varves, but the term rhythmite is less complicated. Resurgences can be buried by glacial drift, resulting in ponding and over flow passage development in conduits behind the resurgences (Mylroie and Palmer, 1977). Glacial sediment introduction into a karst area directly influences cave conduits and their input and output areas, controlling speleogenesis. Glacial sediment is extremely adept at producing karstiglacial and glacio-karstic features (Mylroie, 1978a).

3. Water budget changes, outside those due to climatic weather patterns are produced by glaciation. Surface drainage is rearranged, by glacial quarrying or sediment deposition, influencing the water budget of the cave system below. While most ice cover conditions are stagnant for continentally glaciated areas, ice advance and withdrawal involves significant water production from the ablation zones of the ice sheets. Catastrophic flooding from glacial lakes is also a factor. Glaciers help control the volume and placement of water input into a cave system, as well as the water's geochemistry and sediment load, and so greatly influence speleogenesis.

4. The local climatic shifts produced by a glacier include enhanced freeze/thaw conditions at input and output areas of caves, and geochemical changes. Ford (1977) discusses geochemical effects, noting that glacially associated water is capable of appreciable solution or, depending on conditions precipitation of calcite. He also comments on the possibility of polar conditions at the ice/ground contact, with cessation of solutional activity.

5. The advance of ice across a land surface, and the quarrying, sediment distribution and lake constriction often associated with it, cause isostatic adjustment in the earth's crust. This adjustment may depress karst areas below base or sea level, inhibiting further development. The rebound of these areas after glacial withdrawal may allow karstification and cave development to begin anew, or for the first time. Cowell (1980) reports an area near Hudson Bay, Ontario, Canada that has developed karst and caves after emerging from the sea only 4400 years BP. Palmer (1977) in New York, USA and Glacek, et. al. (1977) in Central Poland discuss the enhancement of cave development due to joint gapping and motion associated with isostatice rebound. In areas with deep valley glaciations, dip changes may occur due to local crustal depression, with dip reversals possible if depression is local and of enough magnitude. Crustal flexure during and after glaciation can affect rock gradient, dip, and joint stability, with concurrent speleogenetic manifestations.

II. Ice Proximity Effects. Karst areas that are never in contact with ice can still be greatly modified due to the location of an ice mass in an adjacent area. The effect of this ice mass may be dramatic, even over 1000 km from the ice itself.

1. Periglacial effects may often be specifically located near ice mass areas)as opposed to climatically controlled regional periglacial activity). This can influence freeze/thaw effects and water budgets.

2. Glacial sediments, particularly outwash and loess deposits can affect areas far removed from the actual ice mass. Loess covers alarge portion of the midwestern and mideastern U.S., and alters the quantity and nature of the sediment load for cave streams. Outwash deposits can cause graded streams to become aggreding streams at great distances from the outwash source, raising base levels. This can have a major effect on cave systems. The major drain for the Central Kentucky Karst, USA, the Green River, may be back-filled as much as 20 m, flooding the lower levels of cave systems (Quinlan, 1980). The complete shift of major river systems, such as the Teays River in the American Mideast by glacial action (Bloom, 1978) can influence all cave systems in a major drainage basin. Loess deposition can be extremely important as it can travel over long distances and across drainage divides. Outwash if it causes suffiient aggredation, can also cross drainage divides.

III. Global Effects. The global effects of the Pleistocene glaciations fall into two major effects- climatic changes and eustatic sea level changes.

1. Climatic changes may initiate glaciations, but ice masses on the continents and sea level lowering greatly accentuate and perhaps alter the climatic conditions that led up to the glacial event. The climatic changes of the Pleistocene are well documented, and have resulted in changes in rainfall pattern, temperature and evapotranspiration values for many areas. Climate is a key element in speleogenesis. An excellent example of climatic change is the American Southwest. During glacial episodes, the area had a much greater effective precipitation than today (Flint, 1971), with more lakes and rivers than currently exist. The effect on speleogenesis has been improtant, and the return to the present drier climate has reduced cave development (Mifflin, 1979).

2. Eustatic sea level change has a dramatic effect on speleogenesis, especially in coastal areas. The drop in sea level due to glacial ice storage on the continent exceeds 100 m, radically lowering base level along coastal areas. These base level effects can be felt considerable distances upstream in river systems as the rivers adjust to the new, lower base level. Subsequent rise in sea level as the glaciers retreat inundates cave systems that had responded to the lowered base level, resulting in a drowned karst, and submarine springs. Submarine springs are well known from around the world (Sweeting, 1973), and while some are due to structure in the limestone and are unrelated to sea level changes, most appear due to glacial sea level fluctuations. Excellent evidence for this exists in the Bahamas, where flooded vertical shafts up to 140 m deep (Gascoyne and Benjamin, 1977) called "Blue Holes: exist. Horizontal galleries lead off of these shafts and contain numerous speloethems (stalactities and stalagmites) that obviously formed in an air-filled conduit. Still-stands during sea rise and/or fall produced temporary base levels, and cave conduits developed at those horizons.

Sea level has also been higher than at present during the Pleistocene, due to a more complete retreat of glacial ice than at present. Sea levels in the vicinity of 6 to 7 m higher than today have formed well identified cave conduits in the Bahamas (Mylroie, 1978b).

Sea level fluctuations and climatic changes occur over the entire planet, and affect areas distantly removed from ice covered regions. Thes fluctuations and changes can have dramatic effects on speleogenesis.

Study of the current environment with respect to cave development must take into account the wide variety of changes a glacial episode introduces to the planet surface. Even caves that developed post-glacially can be anomalous, due to landscape or geochemical changes produced by a now-terminated glacial event. Current glacial environments with serious speleogenetic implications are restricted to alpine areas, and while illustrative of ice contact effects and perhaps ice proximity effects, are not representative of the effects of a global glacial events.

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Tectonism, Fractures, and Speleogenesis in the Edwards Plateau, Central Texas, U.S.A.

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Abstract

The Edwards Plateau of central Texas, a deeply dissected upland surface developed on Paleozoic and Lower Cretaceous rocks, is one of the largest continuous karst regions of the United States (82,900 km^2). Here, most caves are isolated relict features situated well above valley floors and represent early stages of cavern development. However, where surface streams have incised deeply, base-level caves are characteristic of later stages of development. They are long, well-integrated, and contain active streams.

Most caves have been excavated along bedding surfaces, but passage segments are preferentially aligned along fractures associated with four major regional structural elements: (1) Devils River Uplift (early Paleozoic) in the southwest part of the Plateau, (2) Llano Uplift (Pennsylvanian) in the northeast, (3) San Marcos Arch (Cretaceous) in the southeast, and (4) Balcones Fault Zone (Miocene) along the south and east plateau margins. Distributions of linear cave passage segments and structural lineaments mapped from aerial photographs of the plateau surface agree in orientation, but locally differ significantly in frequency and extent. In many cases, fracture trends not visible in aerial imagery are readily mappable in caves, and under other circumstances cave development is suppressed parallel to prominent surface lineaments. Cave passages are more numerous and extensive along tension fractures, such as the northeast sets of the Devils River and Llano Uplifts, the northwest set parallel to the San Marcos Arch axis, and sets parallel to the Balcones fault zone. Passages are less developed along fractures under compression, such as the northwest set of the Devils River Uplift.

Zusammenfassung

Das Edwards Plateau in Mittel-Texas, ein tiefzerklüftetes Hochlandegebiet, das auf Paleozoic und lower Cretaceous Gestein entstanden ist, ist eins der grössten ununterbrochenen Karstregionen in den USA (82,9OO km^2). Hier sind die meisten Höhlen vereinzelte Reliktgebilde, wesentlich höher als die Talböden gelegen, und repräsentieren frühe Stadien der Höhlenentwicklung. Dort, wo Oberflächenströme jedoch tiefe Einschnitte hinterlassen haben, sind Höhlen auf der Höhe der Grundlinie charakteristisch für spätere Stadien der Entwicklung. Sie sind lang, gut integriert und enthalten aktive Ströme.

Die miesten Höhlen wurden entlang den Bedding-Oberflächen freigelegt, aber Abschnitte von Passagen richten sich vorzugsweise entlang der Bruchstellen aus, die mit vier wichtigen regionalen Strukturelementen zusammenhängen: 1. Devils River Uplift (frühes Paleozoic) im südwestlichen Teil des Plateaus; 2. Llano Uplift (Pennsylvania) im Nordosten; 3. San Marcos Arch (Cretaceous) im Südosten; und 4. Balcones Fault Zone (Miocene) entlang der südlichen und östlichen Grenze des Plateaus. Abalgerungen von Segmenten von linearen Höhlenpassagen und strukturale Lineaments (Verläufe), die von Luftaufnahmen der Plateau-Oberfläche angefertigt wurden, stimmen in ihrer Ausrichtung überein, unterscheiden sich aber westlich in Häufigkeit und Ausdehnung. In vielen Fällen sind Trends zy Erdbrüchen, die nicht aus der Luft sichtbar sind, leicht in Höhlen karthographisch festzulegen, und in anderen Fällen ist die Entstehung von Höhlen parallel zy auffallenden Oberflächen-Lineaments erheblich eingeschränkt. Höhlenpassagen sind in groser Zahl und Ausweitung entlang Tension Fractures vorhanden, wie z.B. die nordöstlichen Verläufe des Devils River and Llano Uplifts, der nordwestliche Verlauf parallel zur San Marcos Arch Achse und Verläufe parallel zu dem Balcones Fault (Erdriss)-Gebiet. Passagen entlang der unter Druck stehenden Frakturen sind weniger entwickelt, wie z.B. der nordwestliche Verlauf des Devils River Uplift.

Introduction

The Edwards Plateau of central Texas is an upland surface underlain by a thick sequence of Early Cretaceous limestone and dolostone in the west and south, and by Paleozoic carbonate and clastic rocks in the northeast. At 82,900 km^2, it is one of the largest continuous karst and cave regions of the United States (Figure 1). Because of its economic importance as a water supply for over 1.25 million people, the Edwards Plateau carbonate aquifers have been extensively studied by the United States Geological Survey and Texas Department of Water Resources (Maclay and Small, 1976; Walker, 1979); yet until recently (Kastning, in preparation), extensive study of karst and cave development have been minimal. This paper discusses the influence of tectonism, structural elements, and fractures on cavern development. Three subareas from the original study are incorporated in the following discussion. They include four maj regional structural elements of the plateau: (1) Devils River Uplift, (2) Llano Uplift, (3) San Marcos Arch, and (4) Balcones Fault Zone (Figure 1).

The interior topography of the plateau is undulating to slightly rolling and moderately dissected by drainage flowing southeast to the Gulf of Mexico. However, the south and east plateau margins are deeply dissected by incision of streams into the Balcones Escarpment.

Geologic Setting and Caves

The area contains a remarkable diversity of bedrock types, ranging from sedimentary units (e.g. limestone, dolostone, marl, chalk, sandstone) to metamorphic and igenous rocks. Several paleogeographic and structural elements have influenced deposition and caused lateral gradations in lithology and thicknesa (Cloud and Barnes, 1946; Stricklin and others, 1971; Rose, 1972). The solubility of carbonate units is variable, and throughout the plateau, caves are generally confined to relatively pure limestone strata or highly porous dolostone beds. In many situations, caves are perched on less soluble beds or are capped by resistant units (Kastning, in press).

Caves in upland areas are generally isolated relict features, consisting of one or more irregularly shaped chambers connected by short passages. They are poorly integrated, and complex or maze caves typically exhibit spongework patterns. In contrast, where surface streams have incised deeply, particularly along the Balcones Escarpment, caves near base level are well-integrated, consist of long horitzontal corridors of rather uniform cross section, and often contain perennial streams.

Of the over 2000 documented caves on the plateau, most are clustered along the deeply dissected Balcones Escarpment (Fiesler and others, 1978, p. 20), suggesting that cavern development has been accelerated through topographic dissection and steepening of hydraulic gradients.

Influence of Structure

The structural framework underlying the Edwards Plateau (Figure 1) has significantly affected cavern development. Where caves have been confined to specific stratigraphic horizons, ground-water flow has been generally down dip, resulting in a predominance of dip-oriented passages. In most cases, control by joints has been overprinted on the dip component, giving caves a slightly angulate pattern, whereby linear passage segments are aligned parallel or subparallel to dip direction. However, in areas of high fracture frequency, and where fractures are of tensional origin, passages are commonly guided by dominant joints sets which may locally prevail over attitudinal control. These effects are illustrated by examining cavern development in areas where fractures are associated with major structural elements.

Devils River Uplift -- The Devils River Uplift in Langtry Area (Figure 1) is an anticlinal structure developed on ~~high-st~~anding Precambrian rocks of the Ouachita System (Flawn, 1959). Uplift occurred during the Paleozoic Era (Webster, 1980) and may have continued during the Cretaceous. The area exhibits a systematic fracture pattern (Figure 2b) consisting of three or four principal fracture sets (Leonard, 1977). Northwest-trending fractures coincide with the northern boundary of the uplift and are related to compressional forces from the late Paleozoic deformation. The northeast sets generally result from contemporaneous tensional forces incurred during extension and faulting along the Balcones Fault Zone and San Marcos Arch to the northeast.

Examined passages from six major caves near Langtry (from maps in Kunath and Smith, 1968) are predominantly oriented parallel to the northeast fracture sets (Figure 2A,B). Note that considerably fewer passage segments are aligned along the dominant northwest fracture set. Differences in fracture influence on caves are attirbutable to the initial openness of fractures following tectonism. Those fractures formed by extension (i.e. the northeast sets) had separated under deformation; however, fractures formed by compression have remained generally closed. Open fractures promoted circulation of ground water and dissolutional enlargement, whereas closed fractures inhibited this process. Analysis of photolineaments, observable on aerial imagery, confirms these relationships (Freeman, 1968; Leonard, 1977). Open fractures are readily visible as lineaments because (1) vegetation (which is sparse in this region) takes root in those fractures with the ability to accumulate moisture, and (2) many lineaments consists solely of vegetal alignments.

Llano Uplift -- Ordovician rocks of the Bend area (Figure 1) are cut by a series of en echelon normal faults striking north-northeast, formed during tensional epeirogenic stresses during the Pennyslvanian Period (Cloud and Barnes, 1946). As a result, carbonate units are well-jointed, with fractures forming conjugate sets in agreement with fault orientation (Figure 2D). Cave passage segements (from maps in Reddell, 1973) agree moderately well with mapped photolineaments (Figure 2C,D). Caves have been selectively excavated along open fractures (formed by extension) that follow the general northward dip and hydraulic gradient to base level. Furthermore, rapid topographic dissection of this area, and concomitant unloading, have further opened existing fractures, enhancing the development of numerous fissure caves.

San Marcos Arch and Balcones Fault Zone -- The New Braunfels Area lies within the Balcones Fault Zone and along the southwest flank of the San Marcos Arch (Figure 1). The San Marcos Arch was raised along its northwest-trending axis during the close of the Early Cretaceous, causing a primary set of extensional fractures to develop parallel to its axis, and two conjugate sets of lessen extent (Figure 2F). Subaerial exposure following uplift resulted in circulation of ground water through fractures and enlargement of primary porosity into poorly integrated cavities (Woodruff and Abbott, 1979). During the Late Cretaceous, the region was again covered by shallow seas which deposited marls, micrite, and clastics above the earlier units.

Regional faulting during the Miocene Epoch, creating the Balcones Fault Zone and Escarpment, allowed ground water to flow southeastward, down dip, and along steep hydraulic gradients. Pre-existing northwest-trending joints were preferentially enlarged along these flowpaths (Figure 2E); however, a significant number of passage segments also developed along extensional fractures parallel to and related to the Balcones faults (Figure 2E,F).

Conclusions

Cave passages develop favorabley along open fractures of extensional origin, in cases where fractures run parallel or subparallel to the dip or in the direction of steepest hydraulic gradient. Speleogenesis is suppressed along closed fractures of compressional origin. True horizontal extents of fractures, as determined from aerial photographs, can easily be underestimated in the case of closed fractures. In many situations dominant orientations and degree of openness of fractures in soluble rock can be more accurately determined from carefully made cave maps than from aerial photography.

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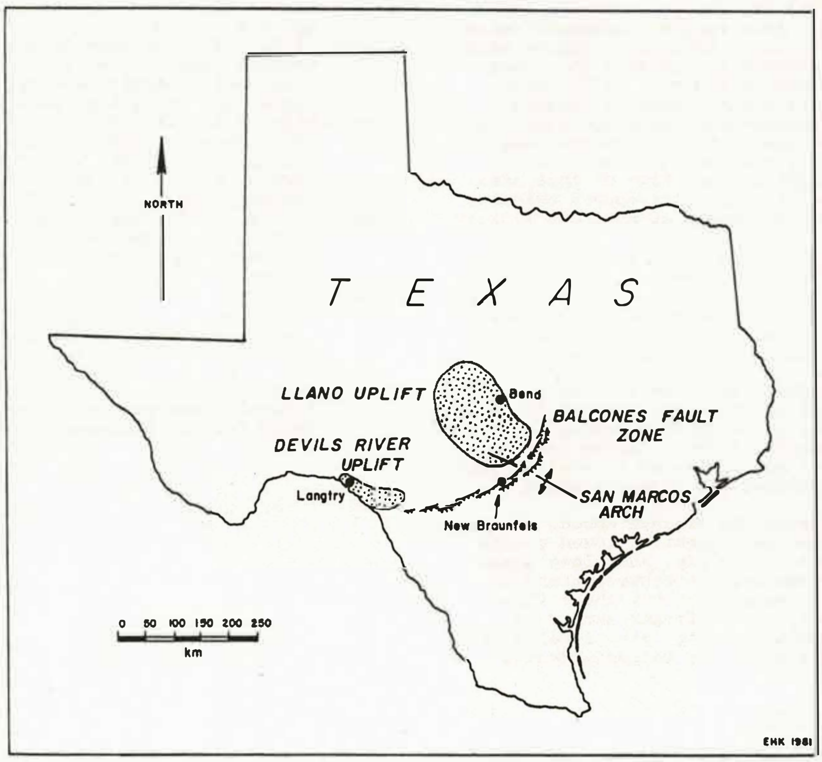

Figure 1: Location Map of Texas Showing Major Structural Elements of Central Texas, the Edwards Plateau Study Area, and the Langtry, Bend, and New Braunfels Subareas.

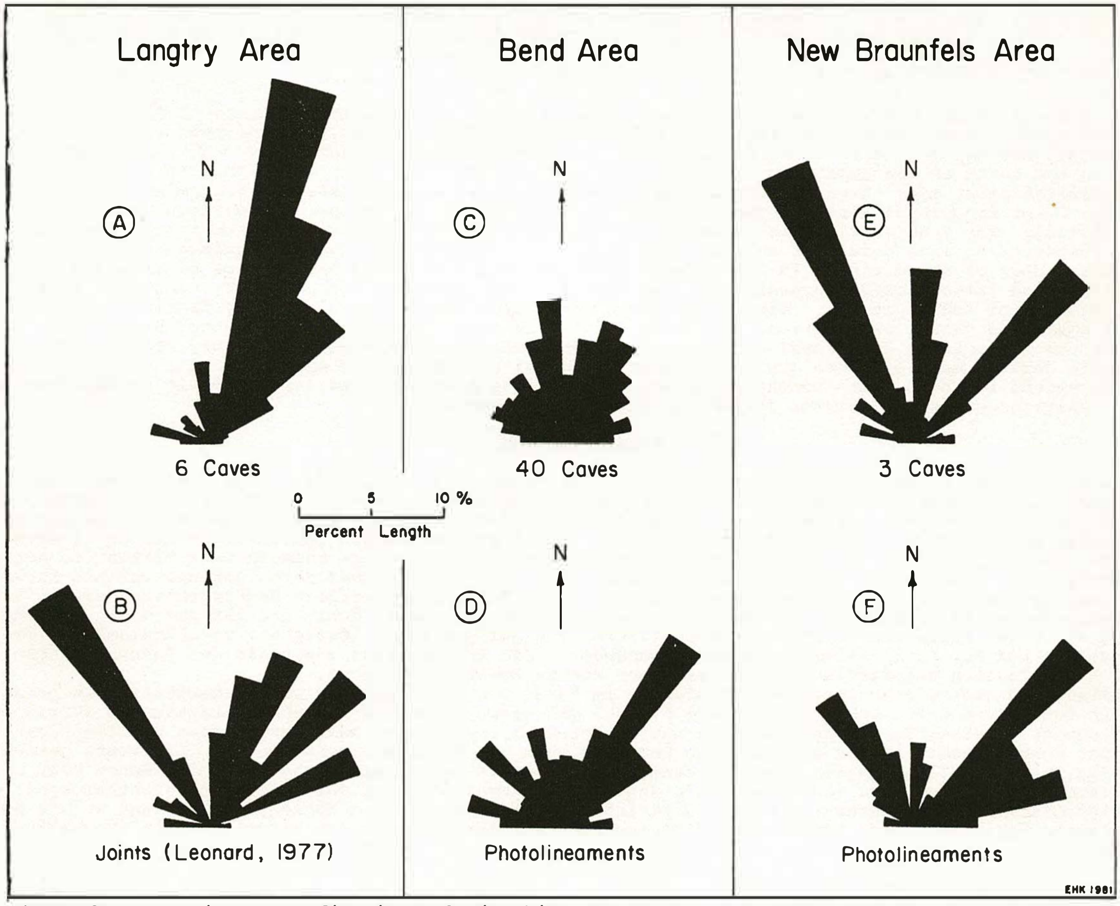

Figure 2: Rose Diagrams Indicating Relationships Between Linear Cave Passage Segments and Mapped Fractures and Photolineaments (Data Summarized from Kastning, in preparation).

Fracture Control of Dolines, Caves, and Surface Drainage: Mississippian Plateau, Western Kentucky, U.S.A.

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Abstract

The western Kentucky karst region (Livingston, Crittenden, Lyon, Caldwell, Trigg, Christian, Todd, and Logan Counties) lies within the Mississippian Plateau physiographic region, a broad belt of limestone terrane that includes two major plateau areas separated by the Dripping Springs Escarpment. The higher Mammoth Cave Plateau to the north of the escarpment is underlain by limestone, sandstone, and shale of the Chester series of Late Mississippian age. Here the topography is moderately to deeply dissected with minor doline development. The lower Pennyroyal Plain to the south of the escarpment is principally underlain by rocks of the Meramec Series. The Pennyroyal Plain is gently rolling and moderately dissected, and it is characterized by a profusion of dolines developed on the higly soluble, relatively pure Ste. Genevieve and St. Louis limestone beds. Much of the drainage in the Pennyroyal Plain is subterranean and surface streams are few.

Dolines and large closed depressions in the western Kentucky karst are generally clustered in broad intefluve areas of modest relief. Lineaments drawn from topographic maps along very distinct doline alignments or preferred doline orientations give rise to the following observations and conclusions: (1) lineaments conform to regional structural elements, (2) lineaments are interpreted as highly fractureud zones or probable faults, many of which are not visible on aerial photography or on the ground, (3) some lineaments correspond to known subterranean water courses and cave passages, and (4) dendritic sinkhold patterns suggest positions of former surface streams prior to karstification.

Zusammenfassung

Das Karstgebiet in West-Kentucky (Livingston, Crittenden, Lyon, Caldwell, Trigg, Christian, Todd und Logan Counties-Grafschaften-) liegt innerhalb des physiographischen Gebietes vom Mississippi Plateau, ein weiter Kalksteingürtel, der zwei wichtige Plateaugebiete umfasst, die durch den Dripping Springs Escarpment (Graben der Tropfenden Quelle) getrennt werden. Kalkstein, Sandstein und Schiefer aus der Chester-Serie des späten Mississippi-Zeitalters bilden die Grundlage für das obere Mammoth Cave Plateau in Norden des Grabens. Die Topographie wird hier teilweise mässig, teilweise stärker durch geringe Dolinen-Entwicklungen zergliedert. Die niedere Pennyroyal Plain in Süden des Grabens enthält hauptsächlich Gestein aus der Meramec-Serie als Unterlage. Die Pennyroyal Plain zieht sich sanft dahin und ist nur wenig zerklüftet; sie wird von einer Fülle von Dolinen charakterisiert, die auf den stark löslichen, verhältnismässig reinen St. Genevieve und St. Louis Kalksteinlagern entstanden. Die Entwässerung innerhalb der Pennyroyal Plain erfolgt hauptsächlich unterirdisch und es gibt nur wenige Oberflächenströme.

Dolinen und grosse geschlossene Vertiefungen im Karst von West-Kentucky werden gewöhnlich in grösserer Anzahl in den ausgedehnten Gebieten zwischen Flüssen mit geringem Relief gefunden. Lineaments (Verläufe), die von topographischen Karten entlang ganz ausgeprägten Dolinentrassen oder bevorzugten Donlinenrichtugnen gezeichnet werden, geben Anlass zu folgenden Beobachtungen und Schlussfolgerungen: 1. Linements passen sich regionalen, structurell bedingten Elementen an; 2. Lineaments werden als h-chst brüchige Zonen oder mögliche Faults (Erdriss) ausgewertet, von denen viele auf Luftaufnahmen oder auf der Erde nicht sichtbar sind; 3. einige Linements entsprechen bekannten unterirdischen Wasserwegen und Höhlenpassagen; und 4. die Anlage dendritischer Seklöcher lässt frühere Oberflüchenströme aus der Zeit vor der Karstifikation (Verkalkung) vermuten.

Introduction

Surface- and subterranean-drainage patterns of the Mississippian Plateau in western Kentucky exhibit various degress of fracture control. These expressions include linear segments of surface streams and cave passages, alignments of dolines and elongate closed depressions, and the presence of sinking streams, karst windows, and springs. A test area was selected for detailed study of lithologic, structural, geologic, and hydrologic controls in an effort to determine variables affecting development of particular karst forms.

The area of study consists of parts of Cobb, Gracey, Cadiz, Caledonia, Johnson Hollow, and Roaring Spring quadrangles (87°49'20" W to 87°39'30" W longitude, 36° 59'30" N to 36°37'40" N latitude) and encompasses nearly the entire eastern half of Trigg County in southwest Kentucky (inset, Figure 1). The town of Caledonia lies in the east part of the study area and the western boundary of the area passes jsut east of the town of Cadiz. This area is located within the Pennyroyal Plain, a division of the Mississippian Plateau physiographic province, and was chosen for study because it has a variety of surface drainage features, ranging from deeply entrenched streams to extensive areas of internal drainage and high doline density. Maximum relief in eastern Trigg County is approximately 140 meters, with elevations from slightly less than 110 meters (where the Little River flows west out of the study area) to 248 meters above sea level (at the top of Buie Knob in the northeast part of the Gracey quadrangle). The topography is generally gently rolling.

Geologic Setting

From Precambrian time until the end of the Mississippian Period, the Mississippian Plateau region received nearly continuous deposition from a shallow sea extending north from the Gulf of Mexico. Later, during regional uplift, structural doming ocurred to the northeast, southeast, and northwest, and a depression formed in the north (Western Coal Basin). Erosion ensued and increased, with continued upwarping from Pennsylvanian to Tertiary time (Brown and Lambert, 1963; Dicken and Brown, 1938; McFarlan, 1943). Major faulting apparently occurred between the Middle Permian and Middle Cretaceous to recent time (Trace, 1974). The southwestern edge of the study area is unconformably overlain by Cretaceous rocks.

The Mississippian Plateau is a broad, arcuate belt of non-glaciated, Mississippian-age, predominantly-limestone rock which forms the west flank of the Cincinnati Arch, a broad, low anticline. The Nashville Basin, a truncated structural dome along the axis of the Cincinnati Arch, lies souteast of the area. Regionald dip is to the north-northeast, at an average of 6 meters per kilometer, toward the Western Coal Basin (Dicken and Brown, 1938). The Jackson Purchase section of the Coast Plain lies west of the Mississippian Plateau, the Blue Grass Region is the the northeast, and the Eastern Coal Field is to the east.

The Mississippian Plateau is divided by the 60-meter-high Dripping Springs escarpment into two major plateau areas. The Pennyroyal plain, below and south of the escarpment, is a rolling plain princiaplly underlain by the St. Louis and Ste. Genevieve Limestones. Above and north of the escarpment is the Mammoth Cave Plateau, which is developed on a cap of Cypress Sandstone lying above the St. Genevieve limestone (McFarlan, 1943). The highly-faulted Fluorspar District occupies the western part of the Mississippian Plateau.

Surface streams on the plateaus are few and drainage is predominantly underground into sinks. Overall, drainage is west-northwest toward the Cumberland River.

Caves and Dolines

Few dolines or caves are located within the area covered by Cretaceous materials. Although most stream beds are dry, topographic analysis shows this area to have the steepest slopes and the greatest density of dissection within the study area (14 to 19 km of stream valleys per km^2) (Kastning, in preparation).

Areas underlain by Ste. Genevieve limestone are predominantly internally drained, with a high density of dolines or enclosed depressions. Interfluve drainage is captured almost immediately and flows underground to springs along the Little River and its tributaries (Figure 1). Interfluve areas located relatively near large surface streams exhibit drainage densities between 8 and 13 km/km^2. Larger interfluve areas, such as the one between Sinking Fork and Steele Branch, were found to have the lowest drainage density within the study area, from slightly-less-than 4 to 7 km/km^2. Methods used in the drainage-density study, and further discussion of the results may be found in Kastning and Kastning (in press) and Kastning (in preparation).

Fracture Analysis

Data for fracture analysis was compiled from a variety of sources, including (1) topographic map measurements of linear stream segments, (2) analysis of published cave maps (Moore and Mylroie, 1979), (3) mapping of photolineaments from black-and-white (1:20,000) and color (1:100,000) aerial photographs, (4) interpretation of alignments of dolines and closed depressions on topographic maps, and (5) field checking of fractures in caves and on the surface.

Evidence for structural control of surface and subsurface drainage is significant. In measurements of linear stream segments ove 0.5 kilometer in length on topographic maps, four dominant joint sets were observed: N 70°-90° W, N 10°-30° E, and N 50°-60° E (Figure 1). Subsurface drainage flows along fractures, as is demonstrated in the eastern edge of the study area (Figure 1). Water entering the system at the Sinking Fork Insurgence has been traced by dye through Pipeline Cave and Boatwright Hole and then to Mill Stream Spring (Moore and Mylroie, 1979).

Previously-mapped faults trend primarily east-west and appear to be the major cause of doline alignments, although dolines are also evident along the other fracture trends mentioned above. Some fractures may be expressed as both linear stream segments and doline alignments.

Ground-water recharge at dolines travels along dominant fractures. Water flowing along fractures, has enlarged them through dissolution, and drainage networks are established as conduits grow and intersect.

Structural Control of Karst and Streams During Denudation

Deposition occurred in eastern Trigg County from Precambrian through Mississippian time. Then, upon regional uplift and gentle regional warping, erosion stripped the youngest rocks, exposing the Highly fractured Ste. Genevieve and St. Louis limestone beds. Subsurface drainage began to evolve. Bedrock lithology and degree of fracturing subsequently influenced the form and rate of evolution of prevalent karst features.

Some fissures were blocked as sediments filled depressions, creating gently-sloping dolines. The depth of dolines is apparently governed by lithology. Many are limited in depth by a series of chert beds within the Ste. Genevieve. Where these beds have been breached, as in the highly-faulted or jointed areas, erosion and stream incision continued, guided by fractures. Rapid entrenchment of flowing streams has preserved many of the original linear trends.

Conclusions

Doline alignments and stream lineaments have been influenced by regional structure such as faults radiating from the Fluorspar District. Lineaments and alignments are expressions of zones of weakness in the bedrock (i.e. along faults or intensely-fractured areas). Most caves of the area exhibit strong fracture control, and passages generally follow dominant fracture orientations along major structural trends. Subsurface drainage also demonstrates fracture control through the alignment of insurgence points, collapse zones, and springs. Varying stages of farst evolution present a means of interpreting the history of surface features. Recently developed dolines may have captured surface streams and formed subterranean cutoffs, leaving abandoned meanders or dry valleys. Elongate closed depressions may be remnants of former linear stream segments and presently indicate the location of subterreanean drainage (Lambert and Brown, 1963).

Acknowledgements

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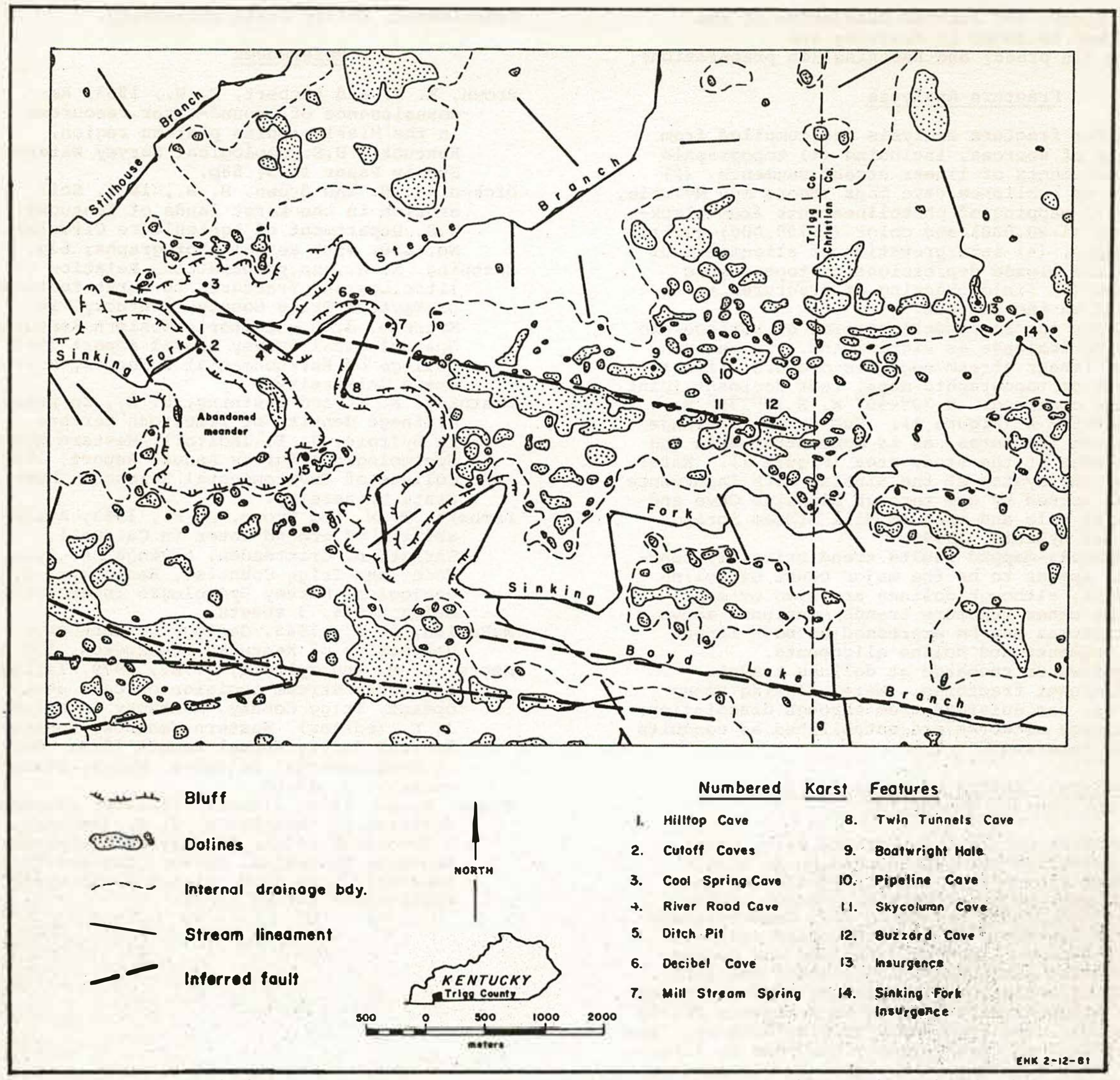

Figure 1. A part of the eastern Trigg County study area, located in the northern half of Caledonia 7.5-minute U.S.G.S. quadrangle. Major caves (from Moore and Mylroie, 1979), dolines, internally drained areas, stream and doline lineaments, inferred faults, and bluffs are indicated. Dye injected at Sinking Fork Insurgence (14) was detected at Pipeline Cave (10), Boatwright Hole (9), and Mill Stream Spring (7) (Moore and Mylroie, 1979).

Un Systeme Karstique Complexe: Le Systeme Sakal Tutan - Değirmenlik - Karapinar (Taurus Occidental, Turquie)

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Résumé

Cette communication décrit un exemple de "système karstique segmenté": les dépressions de Sakal Tutan et du Giden Gelmez Dağ (alt 1600-1700 m) drainent les eaux en direction d'une émergence karstique importante, Su Gözü (alt 1200 m) à Değirmenlik. 3 km en aval de leur source, les eaux disparaissent dans le sol et sont restituées à Karapinar (alt 630 m) dans les gorges de la Manavgat. Elles se perdent une dernière fois dans le lit de la Manavgat, vers 500 m d'altitude, pour être vraisemblablement restituées à Dumanli (alt 60 m). Les sous-unités Sakal Tutan/Değirmenlik et Düdencik/Karapinar contiennent les trois plus profonds gouffres de Turquie connus à ce jour. Ce système karstique est influencé par la présence de niveaux de base imperméables ou pseudo-imperméables, comme le polje de Cevizli où la formation d'un gouffre en mars 1980 a révélé la présence d'un drainage souterrain sous le polje. Il combine les caractéristiques de plusieurs types de karst (haut-alpin et méditerranéen principalement).

Abstract

This paper describes an example of "segmented karstic system": the sinkholes of Sakal Tutan area and Giden Gelmez dağ (elevation 1600-1700 m) drain the waters towards a big spring, Su Gözü (elevation 1200 m) at Değirmenlik village. These waters disappear underground 3 km further and reappear at Karapinar (elevation 630 m, Q = 2 m^3/s ca.) in the gorge of Manavgat river. They disappear again in the river bed itself (elevation 500 m ca.) and are supposed to feed the bigger spring of Dumanli (elevation 60 m, Q = 60 m^3/s ca.). The subunits of Sakal Tutan/Değirmenlik and Düdencik/Karapinar possess the three deepest caves of Turkey which have been explored at the moment. They are strictly controlled by impervious levels and pseudo-impervious levels as Cevizli ovasi where the formation of a pothole in March 1980 has revealed an underground drainage under the polje. This karstic system combines features of several karstic types (alpine and mediterranean karsts mostly).

Une des principales caractéristiques du Taurus occidental est de posséder des émergences et des circulations souterraines dont le moins qu'on puisse dire est qu'elles n'ont pas leur équivalent ailleurs. Il n'est pas rare de voir des sources débitant plus de 10m^3/s à l'étiage et donnant jour à des eaux ayant parcouru sous terre plus de 40 km.

Les plus grandes émergences sont situées dans les gorges de la Manavgat. Elles sont étagées de 30 à 430 m d'altitude et à elles seules assurent à la Manavgat un débit d'étiage de 80 m^3/s (mesurés à son embouchure). Si on connaît maintenant, d'une façon grossière, l'origine des sources de la rive droite (Yedi Miyarlar, Oymapinar,...) et de quelques sources "secondaires" de la rive gauche (Karapinar, Yarpuzlu,...), on ignore toujours d'où viennent les eaux de Dumanli, la plus importante source du Taurus, avec 20 m^3/s à l'étiage et un module annuel d'au moins 50 m^3/s. Aucune des colorations effectuées n'y est ressortie et ce n'est pas lorsqu'elle sera noyée sous 60 m d'eau une fois le barrage hydroéléctrique d'Oymapinar terminé, qu'on connaîtra mieux la provenance de ses eaux.

A l'issue de la campagne spéléologique de 1980, il nous est apparu intéressant de voir comment transitait à travers les masses calcaires une partie des eaux alimentant la Manavgat et, plausiblement, Dumanli.

Les Antécédents Historiques.

C'est en 1966 que les spéléologues (Société Spéléologique de Turquie, Spéléo-Club de Paris, British Speleological Expedition to Turkey 1966, Spéléo-Club de la Faculté des Sciences d'Orsay) ont commencé à s'intéresser à Dumanli, à l'initiative de Temuçin Aygen. Depuis cette date et jusqu'en 1968, des recherches estivales ont été conduites par le Spéléo-Club de Paris, axées indirectement sur le système hydrologique de Dumanli. Des campagnes plus précises menées en 1979 et 1980, avec la collaboration du Club Martel de Nice, ont permis une meilleure compréhension des circulations souterraines intéressant l'organisation karstique du Taurus. C'est un fragment de cette organisation que nous tentons de décrire ici.

Entre Suğla et Dumanli.

Dumanli constitue un point d'interrogation privilégié à partir duquel nous avons tenté de remonter la longue chaîne des événements karstiques et hydrologiques lui ayant donné source. On suppose qu'une partie des eaux de Dumanli vient du lac-polje de Suğla à environ 55 km au Nord, c'est-à-dire de l'autre côté de la chaîne du Taurus. Aucune coloration n'a encore été effectuée en ce sens. Si cette hypothèse se vérifie comme vraie, on aurait alors un transit des eaux entièrement souterrain, perçant dans sa largeur le Taurus, quelle que soit l'hétérogénéité des formations géologiques traversées. Nos explorations ont confirmé, plus modestement, un autre type de transit, plus superficiel, complémentaire du précédent et totalement différent.

Le Giden Gelmez Dağ.

Il s'agit d'un massif calcaire (crétacé supérieur) de bout en bout lapiazé, orienté E-W et situé au Sud du lac de Suğla. D'altitude moyenne de 1700-1800 m, il définit géographiquement et hydrologiquement deux bassins versants: une partie des eaux (fonte des neiges essentiellement) est drainée souterrainement vers Suğla au Nord (alt 1090 m), l'autre vers la Méditerranée au Sud. Nous ne nous intéresserons ici qu'au versant méditerranéen, étant entendu que les eaux du versant septentrional ou anatolien, alimentant Suğla, sont supposées à leur tour passer par voie souterraine du côte du versant méditerranéen.

Le Giden Gelmez Dağ est bordé par une série de dépressions et de poljes d'altitude dont il est remarquable de constater l'étagement régulier: les plus hauts sont tous à 1650 m d'altitude, ceux du second étage à 1550 m. Ils possèdent tous un ou plusieurs ponors alimentant, selon leur position autour du Giden Gelmez Dağ, soit le versant anatolien, soit le versant méridional. Les recherches de 1979et 1980 ont déterminé quelle était la dépression (plutôt que polje ici) située à l'extrême amont d'un système hydrologique segmenté se dirigeant vers le Sud et pouvant avoir comme destination finale Dumanli. Il s'agit de la dépression de Sakal Tutan, à la frontière des provinces de Konya et d'Antalya (pout une fois, la limite administrative correspond à une réalité hydrologique).

Sakal Tutan düdeni - Değirmenlik.

Le fond de la dépression (alt 1650 m) est occupé par un ponor à l'entrée magnifique. Après un puits d'accès de 46 m, une pente à la courbe régulière, entrecoupée de ressauts, conduit gentiment à -303 m où un plan d'eau précède de peu le siphon terminal. L'orientation générale de la perte, N-S sa conformité avec le pendage des couches calcaires lui assignent comme émergence probable l'importante source de Su Gözü à Değirmenlik (alt 1220 m). L'exploration d'un gouffre voisin, Sakal Tutan deliği (-302 m) semblerait confirmer notre hypothèse.

Près des sources, deux cavités servent d'exutoire de trop plein à la fonte des neiges. Leur exploration (1968) a révélé une organisation des conduits karstiques pénétrables différente de celle des circulations souterraines impénétrables. Etant donné son débit (plus du métre-cube seconde), Su Gözü doit être considéré comme l'émergence principale du Giden Gelmez Dağ, versant méditerranéen. Sa présence s'explique par le fait que les calcaires crétacés viennent en chevauchement sur le flysch qui s'est déposé jusqu'au début du tertiaire et qui, pour le malheur du spéléologue, régle toutes les circulations souterraines. Le flysch de la dépression de Değirmenlik-Süleymaniye constitue un niveau de base imperméable commandant le drainage du Giden Gelmez Dağ: il en est de même versant anatolien avec le flysch du lac de Suğla, à une altitude cependant légèrement inférieure (1090 m). Avec le parcours Sakal Tutan düdeni - Su Gözü, nous avons le premier segment de notre système hydrologique complexe.

Değirmenlik - Karapinar.

Nous serons plus discret sur ce second segment dans la mesure où il s'est révélé jusqu'à présent réfractaire à l'investigation spéléologique directe. Les eaux issues de Su Gözü coulent pendant 3 km environ au fond de la dépression et disparaissent dans des pertes impénétrables. Devlet Su İşleri (D.S.İ.) ont coloré ces pertes en avril 1980 et ont ainsi prouvé leur relation avec Karapinar, ou Karamiyar (alt 630 m), source des gorges de la Manavgat, près du village d'Uzümdere. L'été, le débit de l'émergence est sensiblement égal à celui des pertes, laissant supposer que l'apport souterrain est quasiment nul. On connaît toutefois un regard sur ce segment, constitué par Düdencik, perte se terminant sur un siphon à la cote -330 m. Il est à noter que Sakal Tutan düdeni et Düdencik sont à ce jour les deux plus profonds gouffres de Turquie et que ce sont des pertes temporaires. Là encore, une dépression de flysch que traverse la rivière Manavgat vient expliquer l'existence de Karapinar, situé au contact flysch-calcaire crétacé et jurassique.

Gorges de la Manavgat.

Il reste un mot à dire du dernier segment du système hydrologique. Les eaux de Karapinar, c'est la première des grandes sources jaillissant dans les gorges, contribuent à l'alimentation de la Manavgat, mais elles ne parviennent pas directement à la mer Méditerranée distante de quelque 50 km. A 1500 m en aval de Şahap Köprüsü, la Manavgat disparaît, totalement en péroidé d'extrême étiage, dans des pertes impénétrables situées dans son lit même (alt 450 m env.). Que ces eaux réapparaissent à Dumanli (alt 60 m, en rive gauche des gorges) n'est qu'une hypothèse: elles peuvent aussi alimenter un karst noyé allant jusqu'à 110 m de profondeur sous le niveau de base géographique.

Conclusion

Le point de vue que nous avons adopté est purement descriptif. Il ne vise qu'à exemplifier un type de structure karstique déjà pressenti par M. Bakalowicz en 1967 et commandé par le flysch venant coiffer les diverses séries calcaires à différentes altitudes. Celui-ci ruine l'idée de trouver un jour, dans cette partie du Taurus, les cavités gigantesques, à la mesure des circulations souterraines.

Cependant, le flysch, dont l'épaisseur est parfois faible (10 m env.), ne semblerait pas se comporter comme un niveau toujours imperméable. Dans le polje de Cevizli (alt 1050 m) sous lequel passe le segment Değirmenlik-Karapinar, s'est créé en mars 1980 un ponor, Cevizli Gölet düdeni, sous la pression des eaux d'un barrage que D.S.İ. venaient d'édifier, la présence du flysch étant censée assurer sa bonne étanchéité ! Cette mésaventure doit nous inciter à une certaine prudence dans nos interprétations et surtout à mener de front les recherches géologiques, hydrologiques et spéléologiques si tant est qu'elles soient dissociables lorsqu'il s'agit de calcaire.

Il y a dans le Taurus un enjeu karstique considérable.

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Un Exemple de Circulation Karstique: Le Système Hydrologique D'Eynif (Taurus Occidental, Turquie)

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Résumé

Cette communication présente un aspect des recherches spéléologiques entreprises en Turquie depuis 1965 par le Spéléo-Club de Paris et systématisées à partir de 1976 avec l'aide du Club Martel de Nice. En 1967, la coloration d'une émergence temporaire, Akpinar (alt 940 m) a mis en évidence la présence d'un système long de 35 km ayant pour exutoire un "delta" de 21 sources, Oymapinar, à 32 m d'altitude. Ce système passe sous le polje d'Eynif (alt 900 m). A 25 m de profondeur, des cavités rejoignent un niveau d'eau stagnante: à ce jour, aucune circulation active n'a encore été atteinte. Il semblerait que la totalité des eaux emprunte des fissures ou des galeries noyées. Vers l'aval, Tilkiler düdeni doit être considéré comme une grotte-réservoir formée dans les conglomérats burdigaliens, stockant les eaux en période de crue et fonctionnant comme une gigantesque cheminée d'équilibre. Distantes de 34 km, Akpinar et Düden-I sont deux cavités trop-pleins expulsant les eaux que les sources d'Oymapinar ($Q = 8\text{-}10\ m^3/s$) ne peuvent évacuer en période de crue. L'unité du systyme d'Eynif est assurée par la fracturation NNW-SSE des massifs calcaires (séries carbonatées du cretacé et du miocène).

Abstract

This paper presents a view of speleological researches in Turkey undertaken since 1965 by the Spéléo-Club of Paris. In 1967, the dye-tracing of Akpinar, a temporary spring (elevation 940 m) has proved that an hydrological system is draining all the water between Eynif ovasi (elevation 900 m) and the Oymapinar springs (elevation 32 m) which form a "delta" of 21 outlets on the right bank of Manavgat river. This system flows below Eynif ovasi, according to some caves reaching standing water at -25 m: at the moment no underground river has been discovered: it seems that all the water is running through flooded fissures or galleries. Downstream, Tilkiler düdeni is a reservoir-cave formed in burdigalian conglomerate and keeping water during the rainy season, like a big equilibrium-chimney. Notwithstanding the distance (34 km), Akpinar and Düden-I are two overflow caves discharging water that Oymapinar springs ($Q = 8/10\ m^3/s$) cannot evacuate. The unity of Eynif system is due to the fracturation of the limestones ranging from Cretaceous to Miocene.

Le Cadre Géographique et Géologique.

Le système hydrologique d'Eynif est situé dans la partie occidentale de la chaîne du Taurus qui longe la mer Méditerranée au Sud de la Turquie. Le Taurus peut être ordonné en unités historiques (Pamphylie, Lycie..), administratives (Konya, Antalya,...), géologiques (Eynif, Akseki,...) ou hydrologiques (Kembos, Dumanli,...) mais hélas sans qu'il y ait la moindre coïncidence entre elles. En tant que spéléologues, nous avons choisi d'ordonner les cavités découvertes selon leur appartenance (réelle ou supposée) à un système hydrologique et là encore, comme nous le verrons, nous nous heurtons à quelque difficulté.

Ici, le terme Eynif, du polje éponyme, Eynif ovasi, désigne un système hydrologique mis en évidence par colorations en 1967. Il s'étend au Nord de Manavgat (province d'Antalya) et alimente la rivière du même mon sur sa rive droite.

Geologiquement, il traverse les calcaires du crétacé supérieur, passe sous le polje d'Eynif (alluvions quaternaires et flysch): sa direction est déterminée par une faille NNW-SSE. Vers le Sud du polje, un chevauchement le met en contact avec des formations imperméables (flysch) qui contribuent à l'isoler plus nettement des systèmes hydrologiques septentrionaux (Kembos, Yarpuzlu). Puis il pénètre dans un ensemble complexe de calcaires et de conglomérats miocènes (burdigaliens) avant de se terminer dans les gorges de la Manavgat dans et au contact de calcaires paléozoïques. Sa direction NNW-SSE correspond à la fracturation générale des massifs calcaires de la rive droite de la Manavgat et l'exploration spéléologique a confirmé la concordance de la fracturation et des circulations karstiques.

Le Cadre Hydrologique.

Le 6 juillet 1967, l'E.İ.E., administration turque chargée de l'électricité, colore Akpinar (alt 985 m env.) qui est une petite grotte 2-3 km au Nord du polje d'Eynif donnant accès à une circulation souterraine pérenne. Les sources dites de Homa ou Oymapinar (alt 31 et 32 m) restituent le colorant le 9 août, après un parcours souterrain de 42 km (35 km selon d'autres sources: nous ne disposons pas de carte pour trancher entre les deux chiffres). Les sources sont au nombre de 23 (M 1 à M 23) et s'échelonnent du Nord au Sud sur les deux rives de la Manavgat. Leur débit à l'étiage peut être estimé de 5 à 8 m^3/s. Il est à remarquer que trois émergences, les M 4, M 5 et M 6, se trouvent sur la rive gauche. Des colorations plus fines menées par Saydun Altuğ en octobre 1971 ont mis en évidence un système compliqué de circulations souterraines passant sous le lit de la Manavgat, soit dans le sens rive droite-rive gauche soit dans l'autre sens et que le manque de place nous empêche d'analyser ici. Des études ultérieures, menées dans le cadre de la construction du barrage d'Oymapinar, dont l'édification est prévue en amont des exutoires d'Eynif, ont montré que ceux-ci s'ils s'établissaient en coïncidence avec le niveau de base géographique, mominaient en fait de quelque 110 m le niveau de base karstique.

Les Recherches Spéléologiques.

Celles-ci ont commencé peu avant que les études hydrologiques ne révélaient l'intérêt du système d'Eynif. Elles ont surtour été l'oeuvre du Spéléo-Club de Paris et de la Société Spéléologique de Turquie, renforcés la première année (1966) par le Spéléo-Club de la Faculté des Sciences d'Orsay. Elles se sont poursuivies en 1967 puis s'interrompent. Elles reprennent en 1976 jusqu'en 1980, avec l'aide du Club Martel de Nice (1976-1980) et de l'Association de Spéléologie et de Préhistoire de Monaco pour la dernière année, toujours avec la collaboration de la S.S.T. présidée par Temuçin Aygen, le premier à avoir révélé l'importance des phénomènes karstiques de la région. Absence de cartes, rareté des voies de pénétration ont limité les recherches à quelques points privilégiés. De vastes zones restent vierges de toute prospection spéléologique, notamment au Nord d'Akpinar, à l'Ouest et au Sud du polje (Akdağ, Kaklik daği, Cürük dağ, ...).

Nous ferons ici le bilan des recherches et émettront quelques hypothèses. Par souci de clarté, nous décrivons du Nord au Sud cavités et phénomènes karstiques principaux.

De Quelques Cavités et Conclusions Provisoires Q'on Peut Tirer de Leur Exploration.

Akpinar est une grotte de faible développement (16 m; Grottes et Gouffres, 1979 (71) plan) qui avait été explorée par T. Aygen avant notre visite de 1967. Une tentative de plongée a eu lieu en 1978. C'est la seule cavité du système où une circulation d'eau pérenne peut être entendue. En saison pluvieuse, la cavité devient source et l'eau qu'elle déverse va se jeter dans le polje où elle se perd. Il est à noter que ce trop plein échappe au système d'Eynif quand il est émissif puisque son excédent d'eau est restitué par des sources appartenant au grand système voisin, situé au Nord: Kembos (colorations de janvier 1976, Devlet Su İşleri). Ainsi Akpinar a une double appartenance hydrologique, d'où le projet des ingénieurs turcs de D.S.İ. de capter toute l'eau d'Akpinar pour la rejeter en amont du barrage d'Oymapinar (le système d'Eynif échappe à l'alimentation en eau du barrage et constitue du fait de sa position aval un danger potentiel de vidange).

Eynif ovasi (alt 900 m) est un magnifique polje long de 17 km et large de 2 à 3 km. Il possède nombre de pertes et ponors, la plupart impénétrables et supposés alimenter le système de Kembos.

Gürlevik oruğu est un ponor situé en bordure est du polje. Il a été exploré en 1967 (Grottes et Gouffres, 1967 (40) plan). Il appartiendrait de ce fait au système de Kembos. A -22 m, des galeries horizontales, semi-actives, fortement corrodées (régime phréatique), peuvent être parcourues jusqu'à un siphon.

Karaağaçli düden (alt 900 m) est une grotte de hum, explorée en 1980, qui recoupe également une circulation souterraine non pérenne, à la même profondeur: -22 m. En raison de sa position, à l'Est de la faille de direction NNW-SSE, elle doit appartenir au système de Kembos.

Ces deux cavités permettent de dire qu'un drainage s'effectue sous la surface du polje d'Eynif, à au moins 25 m de profondeur et dont une partie échapperait au système hydrologique du même nom.

Les explorations spéléologiques axées plus précisément sur le système lui-même et dans son bassin d'alimentation supposé, c'est-à-dire à l'Ouest de la faille, n'ont révélé que des cavités de faible profondeur, relevant selon nous d'une karstification antérieure aux systèmes actuels. Ainsi, dans les calcaires crétacés se trouvent les deux plus profonds gouffres explorés à ce jour, l'un sur l'Akdağ (alt 1570 m, -92 m) qui est un massif désolé, caractérisé par des "champs" de dolines jointives couvrant les pentes à perte de vue; l'autre plus au Sud, Erkibet dÜdeni (alt 1290 m, -50 m; Grottes et Gouffres, 1979 (71) coupe). Ce sont des cavités fossiles très haut perchées au-dessus des circulations souterraines. Il en est de même des multiples cavités (Çal DÜdeni, Kostak dÜdeni,...) que nous avons explorées de 1976 à 1978 au Nord du village d'Avason dans les calcaires miocènes. Nous avons affaire, à cette altitude (de 1000 à 1300 m) à des lambeaux de karst indépendants des circulations contemporaines qui passent loin au-dessous.

Ces conclusions pourraient être étendues aux cavités situées dans l'axe du système de Kembos.

Tilkiler DÜdeni.

C'est une cavité aveugle (alt 128 m) située à 5000 m env. des exutoires. Elle a été découverte en 1974 lors du creusement d'un tunnel de reconnaissance au contact de la molasse (tortonien) et des calcaires et conglomérats burdigaliens. Un courant d'air puissant s'est créé, révélant l'existence d'une grotte de grande ampleur dans une zone où les recherches précédentes (1966) n'avaient donné que des petites cavités. C'est ce courant d'air qui a motivé la reprise des explorations spéléologiques sur le système d'Eynif à partir de 1976. Elles ont duré quatre ans et se sont terminées sur un développement topographié de 6600 m, faisant d'elle la plus longue grotte de Turquie (Grottes et Gouffres, 1980 (75) plan).

Hydrologiquement, bien que relativement proche des sources, Tilkiler dÜdeni ne recoupe à l'étiage aucune circulation active. En différents endroits, on y observe soit des siphons (2 sûrs à notre avis, à -66 m et -46 m, 3 hypothétiques), soit des lacs ou laisses d'eau mais jamais on n'y rencontre la rivière souterraine souhaitée. En fait, Tilkiler dÜdeni est une cavité semi-active; en hiver et au printemps (fonte des neiges et pluies), les eaux l'envahissent à la façon d'une gigantesque cheminée d'équilibre. Aujourd'hui, la présence du tunnel a modifié cet aspect des choses: ce dernier fonctionne désormais comme trop plein et évacue en période de hautes eaux un torrent atteignant 8 m^3/s ! Ainsi Tilkiler est une cavité qui se fossilise dans ses parties situées au-dessus de la cote d'entrée du tunnel, 128 m (sa dénivellation est de -66 m et +93 m).

Tilkiler se développe dans sa quasi-totalité dans le conglomérat, à l'exception de sa partie sud-ouest (salle du château et au-delà) où on observe la présence du calcaire avec toutefois des passées de conglomérat. Morphologiquement, les galeries creusées dans le conglomérat présentent les mêmes caractéristiques que les grottes calcaires: prédominance du creusement vadose pour la galerie des lacs et du creusement phréatique pour la galerie nord (pour autant que l'abondance du remplissage argileux permette de le dire). Le concrétionnement est parfois riche et en certains endroits il est repris par la corrosion. Il offre une variété de formes à l'égal des grottes du calcaire. Plus remarquables sont les formes créées par la corrosion des galets, donnant aux voûtes et aux parois un aspect parfois peu rassurant.

Météorologiquement, l'existence du courant d'air demeure pour nous un mystère. Très violent à l'entrée de la cavité, il tend à se diviser au fur et à mesure de la progression. C'est lui qui nous a piégés dans la galerie boueuse, s'ouvrant à +34 m et se tirebouchonnant sur 750 m de développement: son exploration s'est étalée sur trois campagnes d'exploration et s'est arrêtée sur des étroitures.

Quand on observe le plan, outre la remarquable parallélisme des galeries, en accord avec la fracturation générale sur laquelle s'est établi le système hydrologique, il faut noter un système secondaire de fracturation qui est grossièrement NE-SW. Tilkiler dÜdeni donne l'impression d'une cavité qui se boucle sur elle-même, faisant avorter nos espoirs de rejoindre un jour, par voie souterraine, le lointain Akpinar. La salle du château et la galerie qui en part vers le SW semblent constituer une barrière à une progression vers les sources. Vers l'amont, hormis la galerie boueuse qui semble une excentricité, tous les passages reviennent en direction de l'entrée ou bien se terminent sur des fissures impénétrables.

Spéléologiquement, l'exploration de Tilkiler est terminée dans ses grandes lignes. Quelques passages étroits sont encore à forcer et de nombreuses escalades à tenter, mais la nature du conglomérat nécessité une technologie qui reste à inventer. Des plongées auraient l'immense mérite de nous dire ce qui est siphon et ce qui ne l'est pas. "Là se trouve la clé vers des prolongements inconnus menant à ce réseau actif qui nous échappe toujours".

L'Aval du Système.

Tilkiler dÜdeni, étant donné l'ampleur des phénomènes considérés et sa proximité relative des sources, fait partie de cet aval. Cependant, il nous faut dire deux mots de DÜden et des sources proprement dites. DÜden (alt 97 m) se développe aussi dans le conglomérat et fonctionne à la fois comme trop plein et comme perte (estavelle). Exploré en 1966, il se termine à -65 m (Grottes et Gouffres, 1967 (40) plan) sur deux lacs, ce qui est en conformité avec l'altitude des sources. L'orientation des galeries est en conformité, elle, avec l'orientation des fractures secondaires dans Tilkiler dÜdeni, c'est-à-dire NE-SW.

Des cavités, dont M 1 mağarasi, découvertes lors du percement de galeries de reconnaissance dans le massif calcaire (paléozoïque, formation de Fatmalar) où est construit le barrage d'Oymapinar, recoupent également une partie des circulations souterraines: elles sont en rapport avec les sources M 1 à M 3.

Les cavités énumérées ci-dessus sont toutes des regards plus ou moins privilégiés sur un système hydrologique de grande envergure et auquel le spéléologue n'a pas encore réussi à accéder. Nous pouvons faire l'hypothèse d'une circulation souterraine totalement noyée mais les grandes diaclases de Tilkiler (leur hauteur moyenne est de 30-35 m), ses salles fossiles, laissent espérer le contraire. L'investigation spéléologique sérieusement poussée dans les environs d'Avason, amorcée autour du polje d'Eynif doit être poursuivie avant de se prononcer. Ce qui est sûr, c'est que nous avons affaire à une spéléologie difficile, ingrate, de longue haleine et que si certains karsts se conquièrent facilement, celui-ci est rebelle à une approche hâtive, superficielle et spectaculaire.

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Etude Statistique des Grandes Cavités Mondiales

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Résumé

On sait que la fréquence F avec laquelle se rencontrent des cavités de dimension D (développement ou dénivellation) peut être mise sous la forme d'une équation telle que:

$$F = \frac{K}{D^n}$$

n et K étant des constantes: n définit la forme de la courbe, et K est fonction de l'échantillon dont on dispose.

En utilisant la liste des grandes cavités mondiales publiées par C. Chabert dans Spelunca, on obtient les valeurs suivantes de n:
- Plus grands développements mondiaux n = 2,4
- Plus grandes dénivellations mondiales n = 3,2

L'examen de la valeur de signification du coefficient n conduit à considérer que l'équation ci-dessus est vraisemblablement de forme trop simple pour le phénomène qu'elle entend représenter.

Abstract

We know that the frequency F with which caves of size D (development or denivelation) occur can be written in the form of an equation such as:

$$F = \frac{K}{D^n}$$

n and K being constant: n determines the shape of the curve, and K is a function of the sample at our disposal.

Using the figures of the greatest caves of the world edited by C. Chabert in Spelunca, we get for n:
- Greatest developments n = 2,4
- Biggest denivelations n = 3,2

Examining the significance of the coefficient n, we must think that the equation presented above is probably written in too simple a way to represent the phenomenon which is involved.

1. But de l'étude

On sait qu'à l'occasion de travaux dont ce n'était pas la finalité première, R. L. Curl fut conduit à chercher la loi liant la fréquence et la longueur de plusieurs lots de cavités pris dans des provinces karstiques des Etats Unis, d'Irlande et d'Autriche.

Utilisant la liste des grandes cavités mondiales publiée par C. Chabert, nous montrons que cette même loi s'applique à cet ensemble de cavités, non seulement en ce qui concerne les développements, mais aussi pour les dénivellations.

A titre de comparaison, nous avons également examiné l'inventaire du département du Jura, dont nous avons assumé la synthèse, et les chiffres fournis par J.P. Besson sur les Pyrénées Atlantiques; les valeurs données ci-dessous sont déduites de ces documents.

2. Relation Entre Fréquence et Dimension

On sait depuis longtemps que la fréquence F d'une dimension D des cavités, telle que le développement ou la dénivellation, peut être représentée par une courbe d'allure hyperbolique; la loi correspondante devrait donc se rapprocher de la formule:

$$D.F. = Cte.$$

C'est du reste ce qu'avait admis, précisément à partir d'un échantillon des Pyrénées Atlantiques (31 avens), C. Mugnier (fig. 1); l'échantillon utilisable étant désormais plus large, cette étude est devenue caduque; mais surtour on doit constater que, dans la généralité des cas, le produit D.F est très loin d'être constant:

En effet, si l'on porte les points définis par D et F sur un diagramme en coordonnées bilogarithmiques (fig. 2 et 3), on observe qu'ils s'alignent généralement de manière très spectaculaire, non pas selon une droite à 45° (cas de l'hyperbole équilatère), mais selon une droite plus pentée, dont l'équation s'écrit donc:

$$n. \text{Log } D + \text{Log } F = Cte.$$

ou, ce qui revient au même:

$$D^n.F = K$$

n représentant la pente de la droite, et K étant une constante fonction de l'échantillon dont on dispose.

Cette analyse, différente dans la forme de celle de R.L. Curl, aboutit au même résultat, puisque notre coefficient n est lié au coefficent ν de Curl par la relation simple (intégration):

$$n = \nu + 1$$

En pratique, pour obtenir la valeur de n, nous écrirons l'égalité du terme $D^n.F$ pour les valeurs extrêmes de D, ce qui revient à faire passer la droite par les deux points connus les plus éloignés.

3. Passage des Valeurs mesurées à la Représentation Mathématique

Dans les tableaux qui suivent, nous avons d'abord groupé les valeurs mesurées en un certain nombre de classes (colonne 1), chaque classe étant définie par sa borne inférieure: ce qui signifie que sur le tableau des grands développements, par exemple, la classe de borne inférieure 3 Km. comprend toutes les cavités comprises entre 3,000 et 3,999 Km., puisque la classe suivante a pour borne inférieure 4 Km.

Pour chaque classe, nous avons déterminé le nombre de cavités contenues dans la classe (colonne 2).

Nous avons ensuite, puisque les bornes ne sont pas à intervalle constant, calculé l'intervalle relatif à chaque classe, que nous avons fait figurer colonne 3 (en Kilomètres pour les développements, en Hectomètres pour les dénivellations).

Nous avons admis (ce qui n'est exact qu'en première approximation) que le point représentatif d'une classe pouvait être pris au milieu de l'intervalle; nous avons nommé D la valeur déterminée de la sorte (colonne 4).

Pour les fréquences, elle ne peuvent être considérées comme représentatives que si elles sont ramenées à des classes d'intervalle constant; nous avons adopté comme intervalles d'homogénéisation 1 Km. de développement et 1 Hectomètre de dénivellation; en faisant le rapport des valeurs contenues dans les colonnes 2 et 3, on obtient la valeur de la fréquence F (colonne 5).

Il résulte de cette définition que le terme F est inférieur à 1 au delà d'une certaine valeur du développement ou de la dénivellation. D'autre part, lorsque la valeur de D est inférieure à 0,5 (cas des développements du département du Jura), puisque l'intervalle d'homogénéisation a pour valeur 1, la valeur de F n'a pas de signification physique (elle prendrait en compte des cavités de dimension négative !).

4. Les Grands Développements mondiaux (fig. 2)

A titre d'exemple, nous donnons ici le calcul de n:

$$300^n \,.\, 0{,}005 = 3{,}5^n \,.\, 196$$

$$\frac{300^n}{3{,}5^n} = \frac{196}{0{,}005}$$

$$n = \frac{\text{Log } \frac{196}{0{,}005}}{\text{Log } \frac{300}{3{,}5}}$$

n = 2,376 arrondi à 2,4

Cet arrondi entraîne, évidemment, que le produit $D^n.F$, calculé pour n = 2,4, n'est pas exactement le même pour les valeurs extrêmes de D.

1.	2.	3.	4.	5.	6.	7.
3	196	1	3,5	196	686	3963
4	97	1	4,5	97	436	3585
5	78	1	5,5	78	429	4666
6	76	2	7	38	266	4055
8	45	2	9	22,5	202	4389
10	66	5	12,5	13,2	165	5664
15	27	10	20	2,7	54	3580
25	27	25	37,5	1,08	40	6473
50	3	50	75	0,06	4,5	1898
100	3	100	150	0,03	4,5	5009
200	1	200	300	0,005	1,5	4406
400	0					
	619 Total mesures					4335 Moyenne

1. Classes (borne inférieure en Km.)
2. Nombre de cavités
3. Intervalle en Km.
4. D
5. F
6. D.F
7. $D^{2,4}.F$

5. Développements des Cavités du Département du Jura (fig. 2)

Les données de l'inventaire du département du Jura conduisent à définir une classe de cavités comprises entre 0 et 20 m. de développement. L'examen des produits D.F permet de se rendre compte que cette classe semble présenter une fréquence insuffisante; on sait que W. Maucci a interprêté un phénomène comparable comme la preuve qu'il n'existait pas de petites cavités; pour notre part, nous pensons simplement que les petites cavités ne sont pas toujours signalées. Si l'on tient compte de cette classe de développements, on trouve n = 1,6; nous avons considéré qu'il était préférable de l'omettre, ce qui donne n = 1, 8 (colonne 7 bis et fig. 2).

1.	2.	3.	4.	5.	6.	7.	7 bis
0	175	0,02	0,01	8750	87,5	5,5	
0,02	85	0,03	0,035	2850	98,5	13,35	6,85
0,05	31	0,05	0,075	620	46,5	9,85	5,85
0,1	28	0,1	0,15	280	42	13,45	9,2
0,2	18	0,3	0,35	60	21	11,2	9,05
0,5	7	0,5	0,75	14	10,5	8,85	8,35
1	2	1	1,5	2	3	3,85	4,15
2	2	3	3,5	0,65	2,5	4,8	6,2
5	0						
	348 Total mesures					8,85	7,1 Moyenne

1. Classes (borne inférieure en Km.)
2. Nombre de cavités
3. Intervalle en Km.
4. D
5. F
6. D.F
7. $D^{1,6}.F$

7 bis $D^{1,8}.F$

6. Les Grandes Dénivellations Mondiales (fig. 3)

La valeur calculée de n est de 4 (arrondi pour 3,97). En fait, comme il était possible de le voir déjà en examinant les produits D.F, il existe deux valeurs, les dernières, qui semblent anomaliques; et l'on voit que pour cette valeur de n, la valeur moyenne de l'expression $D^n.F$ est très différente de celle trouvée pour les valeurs extrèmes de D; ceci est dû pour une grande part, aux deux valeurs en question qui pourraient bien relever d'une loi différente: la dénivellation des réseaux vient forcément "buter" sur la puissance du calcaire karstifiable, qui excède rarement 1000 mètres. En éliminant ces deux valeurs, les points s'alignent bien sur la droite correspondant à n = 3,2.

1.	2.	3.	4.	5.	6.	7.	7 bis
3	143	1	3,5	143	500	21.459	7.877
4	61	1	4,5	61	274	25.014	7.509
5	40	1	5,5	40	220	36.602	9.359
6	24	1	6,5	24	156	42.841	9.584
7	14	1	7,5	14	105	44.297	8.837
8	13	2	9	6,5	58	42.646	7.353
10	2	2	11	1	11	14.641	
12	2	3	13,5	0,67	9	22.254	
15	0						
	299 Total mesures					31.219	8.420 Moyenne

1. Classes (borne inférieure en hectomètres)
2. Nombre de cavités
3. Intervalle en hectom.
4. D
5. F
6. D.F
7. $D^4.F$

7 bis $D^{3,2}.F$

7. Grandes Dénivellations du Département des Pyrénées Atlantiques (fig.3)

La valeur trouvée pour n est 2,5

1.	2.	3.	4.	5.	6.	7.
1	63	0,5	1,25	126	157,5	220
1,5	21	0,5	1,75	42	73,5	170
2	19	1	2,5	19	47,5	188
3	11	1	3,5	11	38,5	252
4	6	2	5	3	15	168
6	3	2	7	1,5	10,5	194
8	3	4	10	0;75	7,5	237
12	0					
	126 Total mesures					204 Moyenne

1. Classes (borne infériuere en hectomètres)
2. Nombre de cavités
3. Intervalle en hectom.
4. D
5. F
6. D.F
7. $D^{2,5}.F$

8. Le Coefficient n

Eventuellement en négligeant certaines mesures pour les raisons que nous avons expliquées, nous avons trouvé:

- pour les plus grands développements mondiaux n = 2,4
- pour les développements du département du Jura n = 1,8
- pour les plus grands dénivellations du monde n = 3,2
- pour les dénivellations des Pyrénées Atlantiques n = 2,5

En ce qui concerne les développements, les résultats obtenus sont cohérents avec ceux donnés par Curl, qui trouve des valeurs de n comprises entre 1,2 et 1,6 pour les cavités américaines, les valeurs pour l'Autriche et l'Irlande se trouvant en dehors de cette fourchette.

De manière plus générale, la dispersion des valeurs de n mérite qu'on s'y arrête; la détermination de ces valeurs parait correctement assurée, malgré un nombre de mesures évidemment faible, si l'on considère la qualité des alignements observés (fig. 2 et 3)

Or, n est représentatif du taux de croissance du nombre de cavités lorsque l'on considère des dimensions de plus en plus faibles; ce coefficient apparaît donc comme pouvant contribuer à caractériser la population des cavités d'une région.

On fera cependant cette réserve que nous ne disposons nulle part d'une population de cavités couvrant une échelle de dimensions réellement large, et il n'est pas certain qu'un coefficient n valable pour les plus grandes cavités d'une région demeure toujours valable pour les plus modestes.

Pour les coefficients n relatifs aux grandes cavités mondiales, ils sont actuellement surtour représentatifs de la zone où les explorations ont été les plus actives, celle des pays tempérés de l'hémisphère Nord: 75 % des grandes dénivellations se situent dans les pays alpins et pyrénéens d'Europe; ces coefficients continueront-ils de s'appliquer lorsque notre information sera mieux répartie?

Mettre en couse la validité du coefficient n dès lors que la population s'élargit, c'est évidemment dire que l'équation utilisée tout au long de cette note est de forme vraisemblablement trop simple pour le phénomène qu'elle entend représenter.

On doit encore préciser qu'il n'y a pas de raison pour que le coefficient n soit le même pour les développements et les dénivellations, puisque des formes de dimensions comparables (galeries et puits) voient leur extension limitée d'une part dans un volume, d'autre part dans une épaisseur de terrain karstifiable.

Conclusion

Le coefficient n mesure une caractéristique du karst profond; et les réserves que l'on peut faire sur les valeurs qu'on calcule actuellement ne sont pas supérieures à celles dont souffrent les autres indices de même nature: densité de cavités, indice de cavernement.

Ces deux indices illustrant des notions finalement peu différentes, l'indice de population n les complète, et rend imaginable une classification purement objective des karsts profonds.

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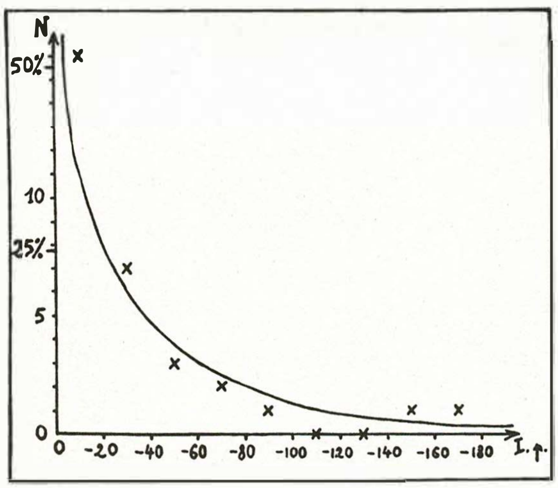

Figure 1. (d'après C. Mugnier): Courbe de fréquence de profondeur des gouffres appartenant à une portion du massif de Ger (Basses-Pyrénées). En abcisse: les intervalles de profondeurs (l.p.); en ordonnée: le pourcentage et le nombre de gouffres (N.) dont les profondeurs sont comprises dans chaque intervalle.

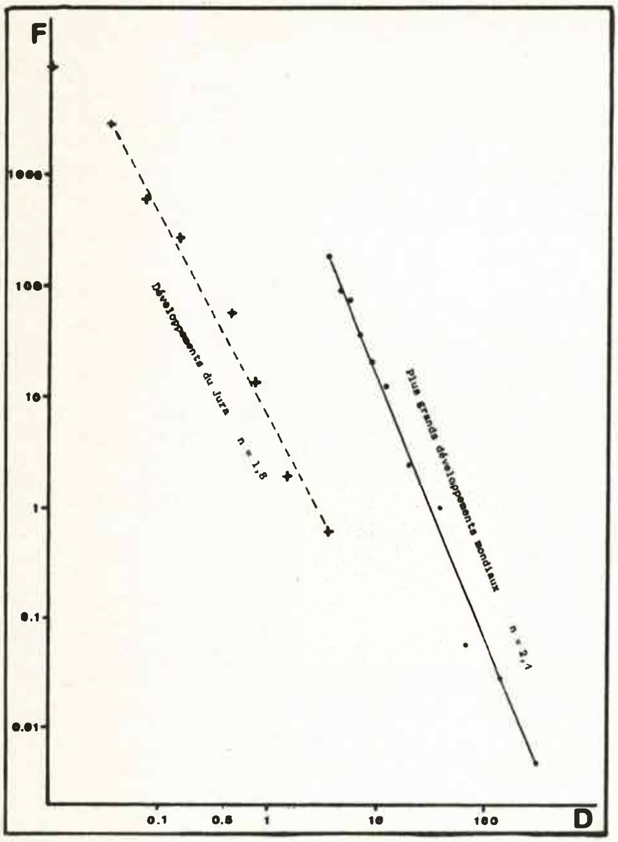

Figure 2. Représentation en coordonnées bi-logarithmiques des développements.

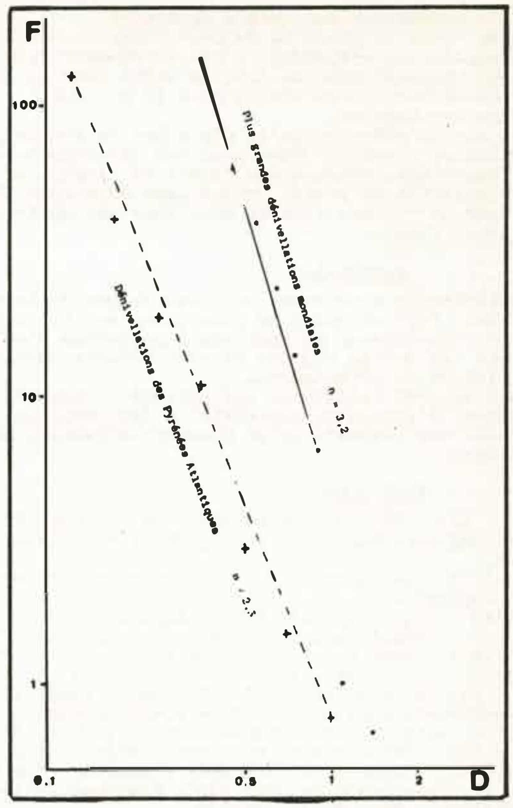

Figure 3. Représentation en coordonnées bi-logarithmiques des dénivellations.

Grottes-Tunnel et Ponts Naturels de la Zone Nord-Méditerranéenne

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Résumé

Les grottes-tunnel et les ponts naturels (compris ici soit comme des grottes-tunnel de faible longueur, soit comme des vestiges de formes plus longues) sont les plus importants phénomènes du karst souterrain dans certains pays tropicaux.

Si l'on considère la zone qui s'étend au Nord de la Méditerranée, on connaît, dans les régions les plus septentrionales de l'Europe, des "ruisseaux à éclipses", phénomène de petite taille lié à l'existence d'un pergélisol.

Et ce n'est que dans la frange nord-méditerranéenne que l'on trouve de vraies grottes-tunnel, bien qu'il s'agisse encore de phénomènes exceptionnels, souvent liés à un recoupement de méandre.

Inversement, plus au Nord, dans toutes les régions d'Europe à climat tempéré frais, les recoupements de méandre n'ont pas abouti à la création de grottes-tunnel.

On peut donc admettre que les grottes-tunnel de la frange nord-méditerranéenne sont liées à un contexte climatique, ou paléoclimatique.

Abstract

The tunnel-caves and natural bridges (understood either as tunnel-caves of small length or as remains of longer sizes) are the most important phenomena of the underground karst in some tropical countries.

If we consider the region stretching in the Nord de la Méditerranée, we know, in the areas of the european far North, some creeks "à éclipses" which are small karstic features linked with a pergelisol.

It is only in the north-mediterranean fringe that real tunnel-caves occur, although they are uncommon phenomena, aften linked with a self-capture across meander spur.

At the opposite, farther in the North, in all the eurpoean areas with a cool tempered climate, the self-captured meanders have created tunnel-caves.

So we can infer that the tunnel-caves of the north-mediterranean area are linked with a climatic, or paleoclimatic situation.

1. Définition

On sait que dans les régions tropicales, la forme majeure du karst souterrain est souvent la grotte-tunnel; il s'agit d'une cavité traversée par une rivière de débit notable, généralement bien supérieur à celui des cours d'eau souterrains connus dans les karsts tempérés. La pente est relativement très régulière; la section est toujours très ample (une à plusieurs centaines de mètres carrés dans les cas habituels), devant évacuer à la période des pluies des débits considérables; cette section est le plus souvent peu variable, l'érosion intervenant certainement pour beaucoup dans le creusement de telles cavités.

Cette section ample fait que les évênements de parcours, tels qu'une confluence, la rencontre d'une zone tectoniquement perturbée, se traduisent par des salles aux dimensions considérables; afin de rétablir l'équilibre mécanique, ces salles ont une grande hauteur de voûte, et il est fréquent que le plafond soit crevé par ce que les spéléologues brésiliens nomment une clarabóia (= oeil de boeuf). Progressivement, la clarabóia s'agrandit dans le sens de la longueur; l'action des facteurs d'érosion externes élargit les bords, et la cavité se trouve interrompue par ce que je nomme une doline-regard, dont le profil est semblable à celui d'un canyon. Bien entendu, le phénomène peut aboutir à la disparition totale de la cavité remplacée par un canyon: c'est un processus fréquemment évoqué dans des régions karstiques très diverses, mais qui demeure totalement hypothétique s'il ne subsiste aucun témoin de la grotte-tunnel.

Ce témoin peut être un pont naturel, phénomène pouvant être défini dans le cas présent comme équivalent à la grotte-tunnel, la longueur étant toutefois du même ordre de grandeur que les autres dimensions. Mais, en français, c'est une définition restrictive, le terme de pont naturel étant généralement employé dès lors que l'on peut voir le jour sous une arche rocheuse; ce terme recouvre donc à la fois ce que W.H. Monroe distingue par les termes de natural bridge (= pont naturel au travers d'une vallée) et de natural arch (= pont naturel qui n'est pas en travers d'une vallée, pouvant être dû, par exemple, à la corrosion différentielle dans la dolomie). C'est donc le premier de ces sens que j'utilise ici, considérant le pont naturel, soit comme une grotte-tunnel de faible longueur, sont comme un vestige de grotte-tunnel.

2. Aire d'Extension dans la Zone Nord-Méditerranéenne

La carte de répartition des grottes-tunnel et des ponts naturels d'Europe et de la Turquie d'Asie est donnée figure 2. Bien entendu, un choix fut nécessaire, fondé sur la présence simultanée des critères caractéristiques: cavité enjambant un thalweg, conduit de grande ampleur et, pour les grottes-tunnel, section peu variable et pente faible.

En particulier n'ont pas été pris en compte les ruisseaux à éclipses, décrits par J. Corbel, dont la relation avec un tjäle paraît assurée, et qui sont de toutes façons de dimensions relativement très modestes. Les quelques phénomènes connus en Irlande du type pont naturel (Marble Arch) ou doline-regard (région de Gort) peuvent très bien trouver leur origine dans une époque où l'Irlande était soumise à un climat de type périglaciaire.

Dans ce choix, qui a été fait, l'on peut évidemment contester la prise en compte de telle ou telle cavité, ou l'omission de telle autre; mais le groupement dans la zone nord-méditerranéenne apparaît de façon claire, la seule exception notable étant le tunnel de Kulna, en Tchécoslovaquie (n° 11).

Bien entendu, je n'ai pas pris en considération des cavités dont le toît est constitué par du tuf calcaire, comme les ponts naturels qui existent dans le Sud de la France, sur l'Argens (Var), l- Siagne et le Loup (Alpes Maritimes), ou le Bitet (Pyrénées Atlantiques). Un site de même nature existe à Yer Köprü, en Turquie.

L'on doit enfin constater la densité du groupement de la péninsule balkanique, où l'on connait 13 ponts naturels dans une zone relativement étroite, soit une densité environ dix fois plus élevée que dans le reste de l'Europe.

Le groupement ainsi observé est loin de recouvrir les principales zones karstiques européennes: si l'on établissait une carte des régions les plus riches en cavités naturelles, elle apparaîtrait bien différente; en particulier, les grands karsts alpins sont dépourvus de phénomènes apparentés à ceux que j'examine ici.

3. Eléments d'Interprétation

Dans les régions tempérées nord-méditerranéennes, grottes-tunnel et ponts naturels ne représentent qu'environ 0,02 % de l'ensemble des cavités (si l'on évalue le nombre de celles-ci à quelques 100.000); ce qui rend généralement peu crédible l'hypothèse du creusement d'un canyon par effondrement d'un phénomène souterrain antérieur.

En fait, beaucoup de grottes-tunnel et de ponts naturels de la zone que j'étudie sont des grottes de recoupement de méandre, ce qui aide à comprendre que la proportion de ponts naturels y soit relativement élevée. Mais celà laisse entendre que les processus karstiques habituels ne sont pas, dans cette zone, susceptibles de provoquer le creusement de grottes-tunnel; du reste, l'Europe possède de nombreuses rivières coulant en méandres dans les régions karstiques; et l'on connaît d'autres systèmes de recoupement de méandre, en Belgique, où le phénomène a été décrit pour la première fois, dans l'Yonne, etc., qui n'ont pas évolué vers la grotte-tunnel caractéristique, confisquant la totalité de l'écoulement subaérien.

Grottes-tunnel et ponts naturels apparaîtraient donc comme des curiosités morphologiques si leur localisation remarquable n'exigeait une explication:

4. Explication Climatique ou Paléo-climatique

S'ils n'ont pas la puissance et la continuité des abats d'eau des régions tropicales, on peut imaginer que les orages caractéristiques du climat méditerranéen puissent façonner des cavités rappelant des formes des karsts profonds tropicaux, quoique généralement de dimensions relativement modestes.

Mais on peut également supposer que ces cavités sont un phénomène relicte témoin de conditions climatiques anciennes plus proches de celles régnant dans les régions tropicales; il reste que ces formes sont vraisemblablement très sensibles au gel (ce qui explique peut-être pourquoi elles ne sont pas plus nombreuses en climat tempéré) et l'on imagine mal que, sous ce climat, elles aient pu se conserver durant de longues périodes tout en demeurant fonctionnelles.

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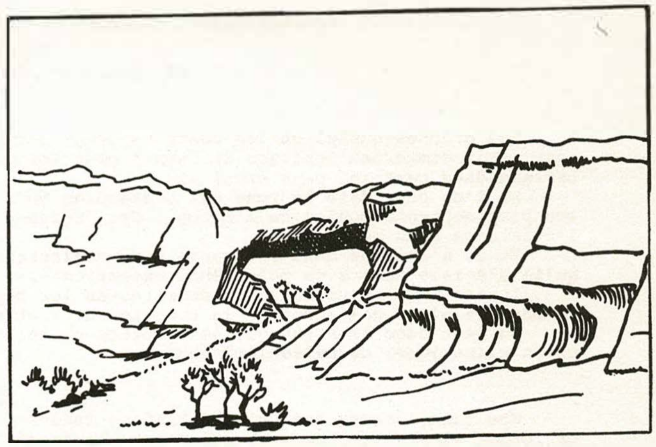

Figure 1. (d'après J. Hazera): pont naturel dans les calcaires turoniens au Km. 17 de la route d'Espinosa à Santelices (Santander, Espagne)

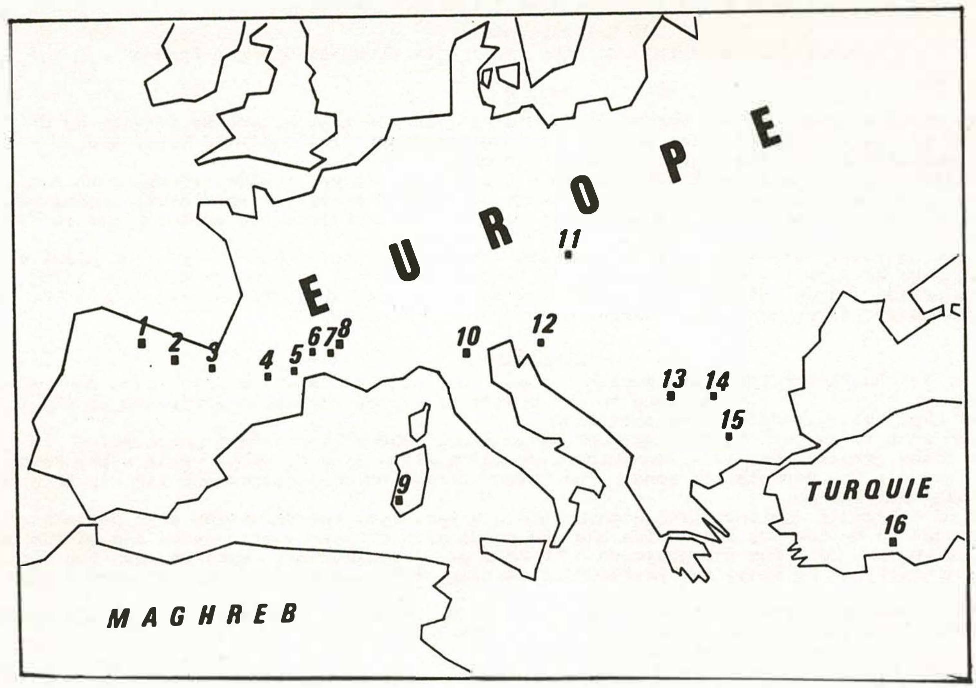

Figure 2. Situation des Grottes-Tunnel et Ponts Naturels de la Zone Nord-Méditerranéenne

Espagne	1. Deboyo (au S.E. d'Oviedo) 2. Grotte-tunnel de Puentedey et pont naturel près de Santelices 3. Tunnels naturels de Zugarramundi (Pamplona)
France	4. Tunnel naturel du Mas d'Azil (Ariège) 5. Tunnels naturels de Minerve (Hérault) 6. Tunnel du Bonheur (grotte de Bramabiau - Gard) 7. Grotte de la Cotepatière (Ardèche) 8. Pont d'Arc (Ardèche)
Italie	9. Grotte de San Giovanni d'Aqua rutta (Sardaigne) 10. Pont de la Veja (Nord de Verona)
Tchecoslovaquie	11. Tunnel naturel de Kulna (Moravie)
Yougoslavie	12. Grand et petit Pont naturel (vallée du Rak) et grotte de Marinic dans la Skocjanska Jama 13. Cinq ponts naturels en Serbie, dont le Lelcki most (J. Nicod - Inédit)
Bulgarie	14. Bogia most, et pont naturel de Prodojna 15. Ponts naturels des Rhodopes (au moins 6 connus)
Turquie	16. Double traversée d'Uzunsu (Antalya)

Les Eaux d'Infiltration dans l'Aquifère Karstique

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Résumé

Des recherches systématiques ont été conduites depuis cinq ans au Laboratoire souterrain du CNRS pour définir le rôle joué par la zone d'infiltration dans le fonctionnement de l'aquifère karstique et dans sa genèse. Un schéma explicatif peut dès maintenant être proposé.

La zone d'infiltration est le siège de deux types d'écoulement. L'un, rapide, s'apparente à un ruissellement. L'autre, lent, est diphasique et fait fonction de "pompe" en entraînant le CO_2 produit dans le sol dans l'ensemble de la zone aérée. Le premier détermine les formes karstiques souterraines et le second les formes de surface.

L'évolution d'un aquifère carbonaté vers un aquifère karstique, c'est-à-dire la mise en place d'une organisation de drainage souterrain, est par conséquent déterminée par la production du CO_2. C'est ainsi qu'interviennent la présence d'un sol ou d'une couverture sédimentaire, le degré de fracturation de la roche, l'existence d'un paléokarst favorisant les échanges gazeux avec l'extérieur.

Abstract

For five years, in the "Laboratoire souterrain du CNRS" systematic researches have been contracted to define the contribution of the percolation zone to the operation of the karstic aquifer and to its formation. Therefore an explanatory model can be proferred.

The percolation zone is subject to two types of water flow. One of them (fast percolation) is like a run-off; the other (slow percolation) is a two-phase flow which works like "a pump" by carrying along the CO_2 from the soil into all the percolation zone. The first brings on the underground karstic forms and the second the superficial morphology.

The formation of a karstic aquifer, from a carbonate aquifer, i.e. the formation of a pattern of voids, is consequently brought on by the CO_2 production and the conditions of water percolation and of the CO_2 transfer. Wherefore we must consider the presence of a soil or of sedimentary deposits upon the surface, the fracturation intensity of the rock, the presence of cavities favoring air and CO_2 exchanges, etc.

La zone d'infiltration des aquifères karstiques n'a retenu qu'exceptionnellement l'attention des géomorphologues et des hydrogéologues. Pour les premiers, elle permet d'observer les formes du karst souterrain qui se sont dévoloppées autrefois dans la zone noyée et qui, abandonnées maintenant par l'activité hydrologique, sont le lieu d'une sédimentation chimique carbonatée. Pour les seconds, son intérêt est limité, du fait de l'absence de réserve d'eau, à l'image qu'elle peut fournir des paléoécoulements.

Cependant, les recherches pluridisciplinaires (hydrogéologie et écologie), menées depuis une douzaine d'années au Laboratoire souterrain du CNRS, ont révélé progressivement le rôle remarquable joué par la zone d'infiltration dans le fonctionnement de l'aquifère karstique, ainsi que dans la mise en place de son réseau de drainage. C'est pourquoi des investigations systématiques ont été entreprises depuis cinq ans sur différents sites expérimentaux. Les résultats et les interprétations proposés ici se rapportent à l'hydrogéochimie uniquement (M. Bakalowicz, 1979).

1. Presentation des Sites Etudies.

Une description rapide permet de présenter le cadre physique de l'étude.

1. 1. La grotte de Sainte-Catherine.

Cette grotte, située à l'aval du système karstique expérimental du Baget (Pyrénées ariégeoises), possède tous les caractères des cavités anciennes dans lesquelles l'eau ne circule plus. A sa partie supérieure, un diverticule se développe à faible profondeur sous la surface (10 à 15 m).

Là, un écoulement quasi permanent de faible débit (jusqu'à 3000 cm^3/mn) a provoqué un important concrétionnement. Un dispositif permet d'enregistrer le débit total des eaux issues des fissures pariétales. La température est également mesurée en continu. Outre les échantillons d'eau prélevés chaque semaine et, lors de quelques crues, chaque heure, des mesures de la pression partielle de CO_2(pCO_2) sont effectuées dans deux forages, l'un dans la zone d'écoulement l'autre dans une zone sèche. Des prélèvements particuliers ont été de plus effectués afin de déterminer la composition isotopique (^{13}C et ^{14}C):

1°) du carbone minéral en solution,
2°) du carbone du CO_2 de l'air des fissures,
3°) du carbone de la roche et des dépôts stalagmitiques.

Cette station des complétée en surface par des sites de mesure et de prélèvement du CO_2 dans le sol à 0,50 m et à 1,00 m. Cette étude a été conduite par M. Fleyfel (1979).

1. 2. L'Aquifère Epikarstique de Gers.

La source de Gers appartient aussi au système karstique expérimental du Baget. Elle draine un petit aquifère superficiel, dont les caractéristiques physiques sont celles de l'aquifère épikarstique (A. Mangin, 1975). Des prélèvements hebdomadaires sont soumis à l'analyse chimique classique, de façon à déterminer, comme pour les eaux de Sainte-Catherine, les paramètres du système calcocarbonique, tels que la pCO_2 équilibrante et l'écart Δ pH entre le pH mesuré et le pH d'équilibre (M. Bakalowicz, 1979, 1980).

1. 3. La grotte de Niaux.

Cette grande cavité pyrénéenne est actuellement l'objet d'une investigation particulière, destinée à prévenir les dégradations de dessins préhistoriques pariétaux par les eaux d'infiltration. La grotte de Niaux est un ancien axe de drainage qui reliait la vallée du Vicdessos à celle de l'Ariège, en traversant le massif du Cap de la Lesse. Plusieurs kilomètres de galeries de grandes dimensions sont actuellement connus. Des écoulements, temporaires ou permanents, toujours de debit très modeste, sont observables soit à proximité de l'entrée, soit plus profondément, là où l'épaisseur de roche sus-jacente peut atteindre 400 m; quelques-uns d'entre eux sont soumis à une surveillance hydrochimique systématique, à laquelle s'ajoutent des mesures régulières de la pCO_2 de l'atmosphère souterraine. Par ailleurs, une étude climatologique détaillée est poursuivie par C. Andrieux (1978).

2. Resultats.

Il n'est évidemment pas possible de décrire en détail l'ensemble des données obtenues. Certaines ont déjà été présentées (cf. M; Bakalowicz, 1979, 1980; M. Fleyfel, 1979). Cependant, une systhèse de l'ensemble peut-être proposée. Elle s'appuie en partie sur l'important travail de A; Mangin (L975, 1978).

2. 1. Dynamique et chimisme des eaux d'infiltration.

Dans la zone d'infiltration des aquifères carbonatés, les écoulements sont soumis à des régimes extrêmement différents selon la dimension des vides qu'ils parcourent. Le long des discontinuités (fractures, joints) d'assez grandes dimensions l'eau s'écoule rapidement, à la façon d'un ruissellement. De ce fait, l'eau d'infiltration rapide possède, dans la zone d'infiltration, des caractéristiques chimiques propres: teneurs en CO_2 souvent élevées, sous-saturation très marquée vis-à-vis des carbonates, teneurs en chlorure et sulfate réduites, fortes variabilité temporelle de ces caractères.

Dans les vides de faibles dimensions, le régime d'écoulement est, au contraire, identique à celui des terrains poreux: l'eau, mêlée à l'air, est alors soumise à un écoulement diphasique. Dans ces conditions, l'eau d'infiltration lente se distingue par des teneurs en CO_2 moyennes, par une saturation systématique vis-à-vis des carbonates, par des teneurs en chlorure et en sulfate plus fortes et, en général, par une variabilité plus modeste. En outre, la grande surface de contact entre l'air et l'eau, due au mélange des deux fluides s'écoulant ensemble, permet un échange continuel entre les deux phases. Ainsi, l'eau d'infiltration lente est particulièrement sensible aux variations de la pCO_2 de l'air de la zone d'infiltration, ce qui se traduit par des variations permanentes du taux de saturation atteignant parfois des sursaturations élevées. En outre, ces échanges imposent aux solutés des caractéristiques isotopiques originales: les teneurs en ^{13}C et ^{18}O et les activités du ^{14}C de l'eau sont voisines de celles de la phase gazeuse (M. Fleyfel et M. Bakalowicz, 1980).

Comme toutes les roches fissurées, les roches carbonatées présentent la particularité de posséder en surface, sur une épaisseur variant de quelques décimètres à quelques mètres, une intense fracturation, sous l'action des phénomènes géodynamiques externes. Cette zone est limitée par une discontinuité généralement bien marquée, qui la sépare de la roche plus compacte où les fractures sont plus rares. Cet imperméable relatif favorise localement l'accumulation d'eau, temporaire ou parfois même permanente comme dans le cas de la source de Gers, et donc la formation d'un aquifère superficiel: l'aquifère épikarstique. L'eau ainsi retenue est soumise à une infiltration différée qui, en fonction des pluies ultérieures, chemine ensuite lentement ou rapidement. Cette eau, stockée parfois longtemps, possède certains des caractères de l'eau d'infiltration lente, saturation vis-à-vis des carbonates notamment. Elle en diffère en général par des teneurs en CO_2 élevées et, surtout, par des teneurs fortes en chlorure et en sodium et très faibles en potassium. En effet, la végétation, qui dispose ainsi d'une ressource hydrique appréciable, consomme l'eau et le potassium qu'elle contient, mais n'utilise pas le chlorure et le sodium, qui se trouvent ainsi reconcentrès par évapotranspiration. Enfin, du fait qu'elles résident à la frontière entre l'aquifère proprement dit et la biosphère, ces eaux d'infiltration différée sont particulièrement sensibles aux variations saisonnières:

- soit directement, car l'augmentation de la fréquence des pluies provoque la diminution du temps de résidence dans l'aquifère épikarstique et tend à rapprocher les caractères chimiques de ces eaux de ceux de l'infiltration rapide.
- soit indirectement, en soumettant l'eau au rythme de production du CO_2 dans le sol.

Enfin, la dernière modalité d'infiltration est celle qui a en général été seule prise en compte: ce sont les apports massifs et localisés dus au ruissellement superficiel aboutissant à des pertes. Dans ce cas, les caractères chimiques des eaux de ce type sont extrêmement variés, puisqu'ils dépendent évidemment de la nature des terrains sur ou dans lesquels ils ont circulé avant de parvenir aux pertes, mais aussi du temps de contact avec ces terrains. Cependant, deux caractères principaux peuvent être retenus: la faible minéralisation due aux basses teneurs en CO_2 dissous et les quantités non négligeables de matières organiques dissoutes ou parcellaires.

Ainsi, l'aquifère karstique se distingue de tous les autres aquifères par la diversité des modalités d'alimentation de sa zone noyée. Cette diversité provoque une extrême hétérogénéité de la qualité chimique des eaux d'infiltration.

2. 2. L'Atmosphère Souterraine.

Que ce soit pour l'hydrogéologue ou pour le géomorphologue, l'intérêt porté au CO_2 est limité au seul fait que sa plus ou moins grande abondance permet une dissolution plus ou moins intense de la roche carbonatée. La plupart des auteurs (A. F. Pitty, 1971; J. N. Jennings, 1971; M. M. Sweeting, 1972; R. S. Harmon et al., 1973; J. J. Miserez, 1975) considère que les eaux d'infiltration acquièrent leurs teneurs en CO_2 dissous dans le sol lui-même, c'est-à-dire dès le début de l'infiltration. Or, les nombreuses données recueillies sur les sites d'observation montrent que la réalité est beaucoup plus complexe.

Tout d'abord, les eaux possèdent le plus souvent des teneurs en CO_2 correspondant à des pCO_2 de la phase gazeuse différentes de celles du sol. Par exemple, en hiver, les eaux de la grotte de Sainte-Catherine possèdent une pCO_2 équilibrante (0,8 à $1,0.10^{-2}$ atm.) nettement supérieure à la pCO_2 mesurée dans le sol au même moment (0,1 à $0,2.10^{-2}$ atm. selon la profondeur). Dans le cas de la grotte de Niaux, la pCO_2 équilibrante des eaux est pratiquement constante au cours des saisons ($0,8.10^{-2}$ atm.). Dans tous les cas, les variations de la pCO_2 équilibrante, quand elles existent, sont toujours corrélées à celles des débits, donc aux vitesses d'écoulement des eaux. Ces faits font considérer la zone d'infiltration dans son ensemble comme un vaste réservoir de CO_2 qui amortit les variations saisonnières de sa production dans le sol.

Ensuite, les mesures directes de la pCO_2 de l'air des fissures, faites dans de petits forages, montrent que l'atmosphère souterraine est riche en CO_2 (0,6 à $1,0.10^{-2}$ atm. pour la grotte de Sainte-Catherine). Cependant la répartition spatiale du CO_2 est profondément hétérogène. En effet, seuls les lieux où circulent les eaux révèlent des pCO_2 élevées, proches de la pCO_2 moyenne annuelle des sols sus-jacents; là où n'existe aucune circulation d'eau, les pCO_2 sont extrêmement faibles, proches de la pCO_2 de l'atmosphère extérieure. En outre, lorsque les fissures sont en relation avec l'extérieur, par exemple par l'intermédiaire d'une grotte, la ventilation naturelle appauvrit considérablement l'atmosphère souterraine en CO_2.

Ces observations confirment donc le rôle de réservoir de CO_2 joué par la zone d'infiltration; elles montrent aussi clairement que l'eau d'infiltration lente est la cause essentielle du transport du CO_2 depuis le sol où il est produit, jusque dans les parties plus profondes de l'aquifère. Dans ces conditions, quelle que soit la saison à laquelle s'infiltre l'eau, celle-ci se charge de CO_2 soit dans le sol lorsque les pCO_2 du sol sont fortes (printemps et automne des régions tempérées), soit plus profondément, en l'absence de production de CO_2 dans le sol hiver). Finalement, dès l'instant qu'existe une couverture végétale, l'eau d'infiltration dispose toujours de quantités importantes de CO_2, nécessaires à la dissolution.

3. Implications.

Dans le schéma fonctionnel de l'aquifère karstique actuellement le plus satisfaisant (fig. 1), les modalités d'alimentation de la zone noyée jouent un rôle déterminant dans l'acquisition du chimisme des eaux souterraines.

Sur le plan hydrogéologique, l'enquête hydrogéochimique sur des sources d'aquifères carbonatés peut révéler non seulement les différents types d'infiltration et leur importance relative, mais surtour l'existence d'une organisation du drainage dans la zone noyée qui conserve, jusqu'à la source, l'information originelle provenant de la zone d'infiltration (M. Bakalowicz, 1977 b). C'est par conséquent un moyen d'investigation qui permet de définir de façon très satisfaisante d'une part l'existence, ou non, d'un drainage karstique fonctionnel, d'autre part son état de développement.

Sur le plan karstologique, les implications sont importantes, car elles permettent de proposer une théorie de la genèse de l'aquifère karstique. J'avais déjà montré (M. Bakalowicz, 1977 a) comment il est possible d'expliquer la dissolution en profondeur, sans faire appel à un grand nombre de mécanismes physiques et chimiques, ni à des mécanismes peu vraisemblables. Compte tenu de la grande rapidité de réalisation de l'équilibre de dissolution-évasion du CO_2 dans l'eau devant la lenteur de l'équilibre de dissociation-précipitation des carbonates, les eaux d'infiltration, lorsqu'elles atteignent la zone noyée, disposent d'un pouvoir de dissolution inversement proportionnel à leur vitesse d'infiltration. L'infiltration rapide déplace donc en profondeur les conditions de dissolution de surface, remplies par l'infiltration lente. Il est par conséquent nécessaire que l'état initial de la roche soit favorable à cette infiltration rapide. C'est là qu'intervient la fracturation, par la création de discontinuités, dont le rôle primordial apparaît lorsqu'une partie des eaux d'infiltration dispose de cheminements préférentiels, conduisant l'infiltration rapide.

Cependant, les conditions d'écoulement dans la zone noyée contribuent aussi à la création des vides karstiques souterrains. En effet, si les possibilités d'évacuation de l'eau sont très difficiles, parce que le lieu d'arrivée de l'eau d'infiltration rapide possède une mauvaise liaison hydraulique avec l'exutoire, dont la position dépend de la morphologie extérieure, la quantité de roche dissoute évacuée sera limitée, par rapport aux endroits où le renouvellement de l'eau de la zone noyée est mieux assuré. Il est évident que ce renouvellement ne doit pas être trop rapide, sinon l'agressivité de l'eau ne contribue pas efficacement à l'élargissement des vides. L'introduction massive d'eau, à partir de pertes d'écoulement de surface, intervient de la même façon que l'infiltration rapide. En effet, bien que pauvre en CO_2, cette eau rencontre l'atmosphère souterraine qui lui fournit le CO_2 nécessaire; le renouvellement efficace de l'eau est assuré par les quantités importantes généralement mises en jeu. Il faut ajouter à cela des facteurs favorables (mais non nécessaires) tels que l'introduction massive de matières organiques qui accroissent l'agressivité de l'eau directement, en complexant le calcium, ou indirectement, en produisant du CO_2.

Par conséquent, lorsque dans un aquifère carbonaté sont réunis les facteurs favorisant l'infiltration rapide et l'exhaure de la zone noyée, comme la structure du magasin (lithologie, fracturation et structure géologique) et la morphologie extérieure, le développement d'une organisation de drainage est possible.

Ainsi, les lieux où l'évacuation des eaux est la plus aisée tendent à s'élargir pour donner naissance à des drains; dès que l'écoulement y devient rapide (quelques certaines de mètres par heure), la dissolution devient moins active. En revanche, les parties drainées où l'eau séjourne plus longtemps, c'est-à-dire les systèmes annexes au drainage, et où arrive l'eau d'infiltration rapide, sont soumises à une dissolution d'autant plus active que le temps de séjour n'est pas trop long. Profressivement, les relations hydrauliques entre certains systèmes annexes et l'axe de drainage s'améliorent, en sorte que, finalement, ils sont intégrés au drainage lui-même. Ainsi, progressivement se constitue un réseau de drainage hiérarchisé, dont la disposition est déterminé, en grande partie, par la position des lieux favorables à l'infiltration rapide et par la position des points déabsorption des écoulements de surface.

Simultanément à la mise en place d'une organisation endokarstique, la surface subit une évolution morphologique. Mais cette évolution est liée essentiellement aux eaux d'infiltration lente ou à l'action des eaux stockées dans les aquifères épikarstiques éventuels. Cependant, dans ce cas aussi, tous les lieux où intervient l'infiltration lente ne possèdent pas les mêmes potentialités; en effet, il est nécessaire que soit assurée une évacuation des matières dissoutes, donc un renouvellement de l'eau. La dissolution en surface est donc, elle aussi, limitée à des lieux privilégiés. C'est précisément ce que prouvent, par exemple, la répartition particulière des dolines, étudiée par de très nombreux auteurs, et le "karst polygonal" de Nouvelle-Guinée (P. Williams, 1972).

Chaque forme élémentaire, résultant de la dissolution par le flux d'eau et de CO_2, prend naissance en fonction des évènements hydrologiques subis par le flux en amont de cet élément; mais sa mise en place, ou son extension, modifie à son tour les caractéristiques physiques et chimiques du flux et prédétermine donc en partie l'évolution de l'aval. En retour, l'évolution de l'aval commande l'évolution des parties en amont; selon que l'évacuation est, ou non aisée, l'élargissement par dissolution est plus ou moins rapide, plus ou moins éloignée de la surface.

Par conséquent, tous les vides creusés et toutes les formes modelées dans un aquifère carbonaté sont liés les uns aux autres par une relation d'interdépendance, que traduit leur hiérarchisation. Mais cette organisation des vides créée par les écoulements s'impose elle-même à ces écoulements par une relation d'interdépendance (A. Mangin, 1978). Les formes de surface et les formes souterraines sont indiscutablement liées. Et cette liaison est en grande partie imposée par les modalités d'infiltration, dès l'origine: l'organisation du karst est, pour l'essentiel, programmée dans la structure originelle de la zone d'infiltration.

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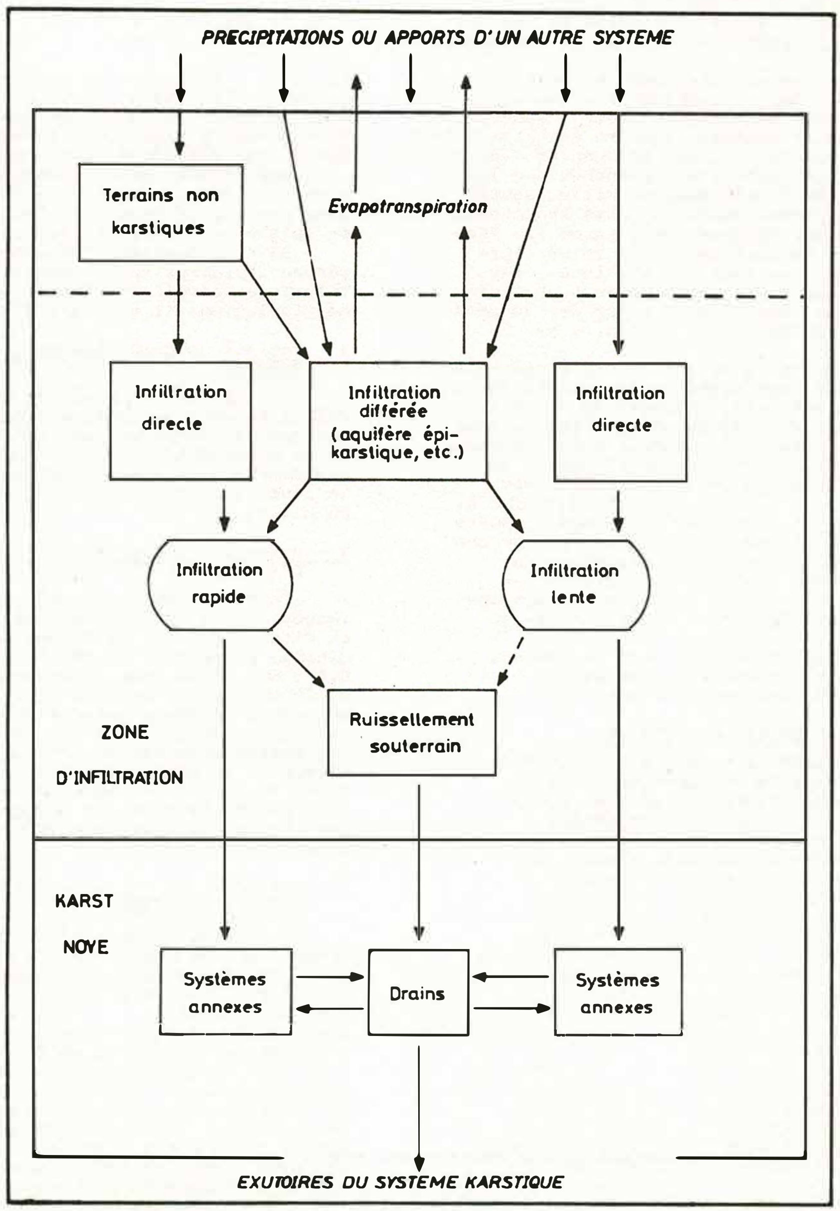

Figure 1. Schéma fonctionnel de l'aquifère karstique.

Sur la Presence d'un Rythme de Reproduction dans le Milieu Souterrain Superficiel: Etude Chez les Coleopteres Bathysciinae

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Résumé

Speonomus hydrophilus espèce souterraine très évoluée vit dans le milieu souterrain superficiel dans lequel les températures varient au cours de l'année de 4 à 13 °C. Des prélèvements de la population ont été faits au cours d'une année et le rythme de l'activité ovarienne mesurée d'après le volume de l'ovocyte en vitellogenèse. Il apparaît qu'un maximum d'activité des ovaires existe à la fin de l'été, période où la température est la plus élevée dans le milieu.

Abstract

Speonomus hydrophilus, a troglobitic species, inhabits the "superficial underground compartment" in which the temperature varies from 4 to 13 °C in the year. Samplings of population were made all along the year and the ovarian activity studied by the mean of the size of the ovocyte in vitellogenesis phase. A maximum of size appears at the end of the summer during which the temperature is maximum.

En zone tempérée les caractéristiques du milieu souterrain permettent, dans la plupart des cas la reproduction des animaux souterrains toute l'année, néanmoins les travaux de nombreux auteurs démontrent la présence d'un cycle ou d'un maximum saisonnier dans cette reproduction. Ces derniers déclenchés par les variations saisonnières de facteurs du milieu souterrain, sont donc des rythmes exogènes. Les inducteurs et synchroniseurs de ces rythmes sont, parmi les facteurs abiotiques, les variations de la température et les crues, et parmi les facteurs biotiques, les variations saisonnières de la quantité de nourriture disponible sous terre. Une mise au point des données disponibles dans la littérature a été faite par C. Juberthie (1975).

Récemment le domaine du milieu de vie souterrain s'est considérablement accru avec la découverte du "milieu souterrain superficiel" (Juberthie et coll. 1980). Celui-ci, qui se développe aussi bien en zone karstique que non karstique, en général sous l'horizon le plus inférieur du sol, est représenté par la zone superficielle de dégradation de la rochemère, par l'horizon d'accumulation fait de cailloux de forme et de taille variées et par le colluvium de bas de pente.

Le milieu souterrain superficiel est très proche de la surface, ses variations de température ont de ce fait une amplitude plus grande que dans les grottes. Il est tributaire, au point de vue des apports énergétiques principalement de la portion de sol qui le recouvre.

Il y avait lieu de rechercher dans ce nouveau milieu l'impact de ses caractéristiques sur la reproduction des troglobies qui y vivent.

1 - Material Etudie et Methode.

Nous avons recherché la présence d'un rythme saisonnier éventuel dans la reproduction chez les femelles d'un Coléoptère Bathysciinae très évolué vers la vie souterraine Speonomus hydrophilus Jeann. qui n'était connu antérieurement que des grottes. Le développement post-enbryonnaire de cette espèce ne comporte qu'un stade larvaire (Deleurance-Glaçon, 1963); elle entre donc dans la catégorie des espèces souterraines les plus évoluées chez lesquelles la contraction du cycle de développement est la plus grande. Les échantillons de population étudiés proviennent d'une station (S6) située en milieu souterrain superficiel non karstique (micaschistes) de la Forêt d'Andronne (Ariège, France); elle est située à une altitude de 1090 m environ, dans le bassin de l'Arget.

La recherche d'un rythme dans la reproduction dans le milieu naturel a été faite par l'observation des ovaires de femelles venant d'être récoltées. Nous savons que chaque ponte n'est constituée que d'un seul oeuf, une ponte ayant lieu en moyenne tous les 25 jours (Delay, communication personnelle) dans les conditions constantes de température (11,5 °C, d'humidité et d'alimentation des élevages. Chez Speonomus hydrophilus, les 2 ovaires sont constitués chacun de 6 ovarioles. Dans le cas général un seul ovule est en vitellogenèse chez la femelle; dans de très rares cas, un ovule appartenant à un ovariole du second ovaire est en début de vitellogenèse; dans ce cas, la taille des 2 ovocytes est très différente, l'un étant en fin de vitellogenèse l'autre en début.

L'activité ovarienne est donnée par la taille des ovocytes; 30 femelles environ sont disséquées à chaque prélèvement d'échantillon de population, les femelles jaune clair qui sont des imagos nouvellement éclos sont éliminées, leurs ovaires ne présentant pas d'ovule en phase de croissance. La taille de l'échantillon permet d'étudier des femelles à tous les stades de la vitellogenèse et l'existence d'un maximum saisonnier de pontes doit se traduire par un nombre plus élevé d'ovocytes de grande taille durant une période de l'année.

Les ovaires sont disséqués dans le liquide de Ringer et les ovocytes mesurés immédiatement dans une lame creuse; en pratique c'est l'ensemble ovocyte et épithélium folliculaire qui est mesuré.

Dans la femelle l'ovocyte est ovoïde; ses 2 axes perpendiculaires L et l sont mesurés et son volume théorique calculé en l'assimilant à un ellipsoïde de révolution; il est égal à $L \times l \times l \times \pi/6$.

2 - Variations Annuelles de la Temperature à la Station Etudiée.

Des relevés mensuels de la température ont été effectués dans la station d'Andronne par B. Delay. Des sondes thermiques ont été placées à demeure à 50 cm de profondeur. Les résultats obtenus (fig. 1) montrent que la température a varié en 1980 de 4 °C en hiver à 13 °C à la fin de l'été; l'échauffement du milieu est lent, son refroidissement est plus rapide.

3 - Variation du Volume Moyen des Ovocytes au Cours de L'Année.

Tout au long de l'année, mis à part les jeunes imagos, il existe chez toutes les femelles un ovule en vitellogenèse. Le volume moyen des ovocytes est minimum en janvier et février où il est voisin de 0,030 mm^3 et maximum en septembre où il atteint 0,170 mm^3; cette moyenne pour les 2 échantillons de septembre présente d'après le test de Fischer une différence statistiquement significative avec toutes les autres moyennes de l'année. L'observation de la courbe de la taille des oeufs au cours de l'année (fig. 1) montre que leur augmentation de volume se fait progressivement et lentement de février à septembre tandis que leur diminution se fait rapidement de septembre à janvier.

4 - Polygones de Frequence de Taille des Ovocytes au Cours de L'Année.

Le volume moyen calculé des ovocytes ne rend pas compte du fait que des oeufs de volume très différent sont présents à une même époque, et surtout que de très petits ovocytes existent dans tous les échantillons de population. Ce cas peut se présenter en effet chez des femelles en début de vitellogenèse et chez des femelles venant de pondre depuis peu.

Pour chaque échantillon de femelles, les ovocytes sont groupés en 9 catégories de taille en progression arithmétique de raison 0,050 mm^3, de 0 à 0,450 mm^3. Les polygones de fréquences ont été construits pour chaque prélèvement (fig. 2). La fréquence des ovocytes dans chaque catégorie au cours de l'année est exprimée en pourcentages dans le tableau suivant:

volume des oeufs en mm^3	janvier	février	juin	septembre	novembre
0 à 0,05	76,19	83,3	38,46	17,07	56,66
0,05 à 0,10	19,04	16,6	23,07	12,19	16,66
0,10 à 0,15			19,23	29,26	6,66
0,15 à 0,20	4,76		7,69	19,51	3,33
0,20 à 0,25			3,84	4,87	10
0,25 à 0,30			3,84	9,75	3,33
0,30 à 0,35			3,84		3,33
0,35 à 0,40				2,43	
0,40 à 0,45				4,87	

Il apparaît que le pourcentage le plus élevé de petits oeufs, de taille inférieure à 0,050 mm^3 est observé en janvier et février (76,19 et 83,3 %). Ce pourcentage, plus faible en juin (38,48 %) atteint son minimum en septembre (17,07 %) pour atteindre une valeur plus élevée en novembre (56,66 %). Par ailleurs, il y a en janvier, 4,76 % des ovocytes qui ont une taille supérieure à 0,100 mm^3, tandis qu'il y en a 38,44 % en juin et 70,69 % en septembre, où les ovocytes les plus volumineux atteignent entre 0,400 et 0,450 mm^3.

On remarque que seules les classes de tailles faibles existent en janvier et février tandis que pratiquement toutes les classes sont représentées en septembre ce qui traduit une activité maximum des ovaires à cette époque: certaines femelles sont prêtes à pondre d'autres sont à des stades différents de la vitellogenèse; certaines femelles en début de vitellogenèse doivent avoir pondu depuis peu.

Discussion

La biologie des animaux cavernicoles peuplant le milieu souterrain superficiel est à peu près inconnue. Nous apportons les premières données concernant la reproduction chez les femelles de Coléoptères.

Chez toutes les femelles de Sp. hydrophilus et tout au long de l'année, un ovule est en phase de vitellogenèse. L'importance de l'activité des ovaires est mesurée par le volume de l'ovocyte qu'il contient; le volume moyen de celui-ci est minimum en janvier, période où la température est la plus basse, et maximum et l'oeuf prêt à être pondu, à la fin de l'été, période où la température est la plus élevée. Il existe donc un rythme saisonnier d'activité des ovaires dépendant de la température. Le fait qu'un ovocyte soit présent toute l'année pose le problème de la nature de ce rythme d'activité. En effet, la vitellogenèse peut soit se produire toute l'année en présentant un maximum saisonnier à la fin de l'été, soit être bloquée en période froide et s'effectuer lorsque la température dépasse un certain seuil. Ce problème de la dépendance de la vitellogenèse vis-à-vis de la température est actuellement à l'étude.

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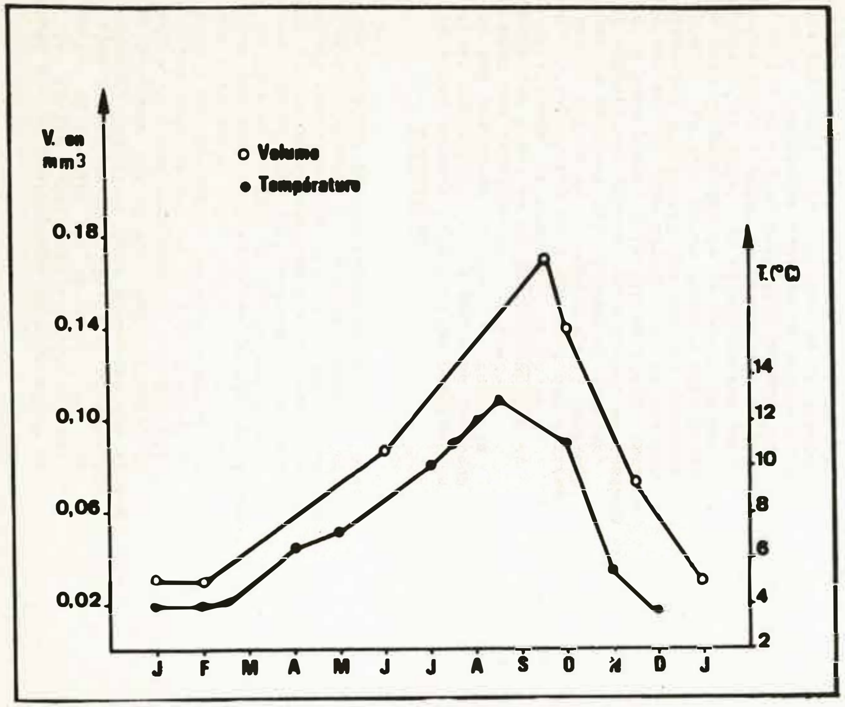

Figure 1. Variations de la température annuelle dans la station de récolte des femelles de Speonomus hydrophilus et variations du volume moyen des ovules en vitellogenèse au cours de l'année.

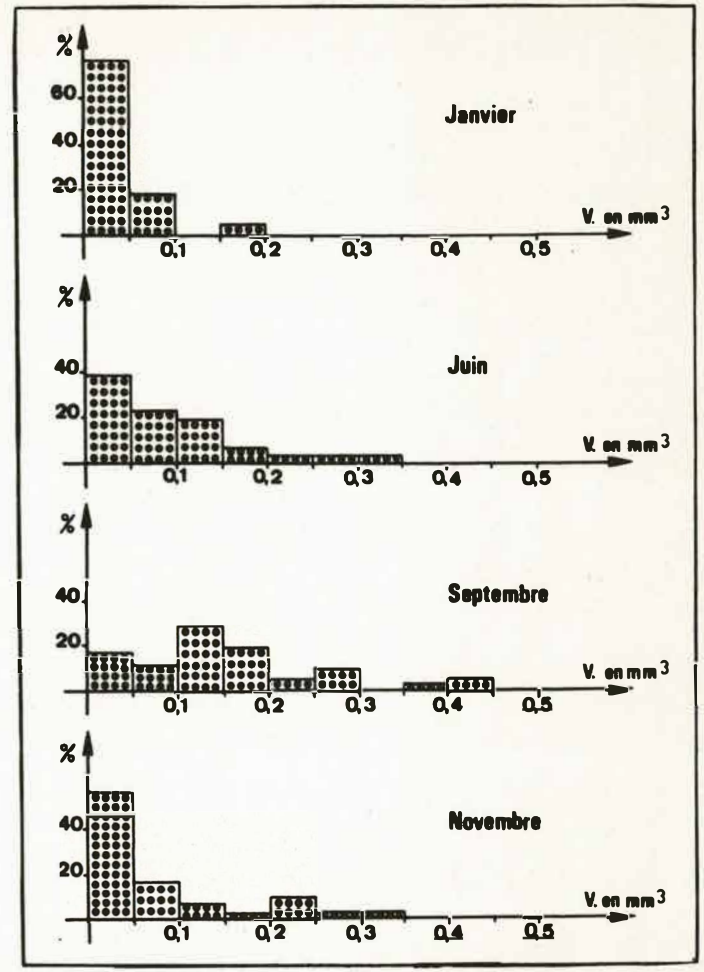

Figure 2. Polygones de fréquence des différentes classes de taille des ovules en vitellogenèse chez Sp. hydrophilus, en janvier, juin, septembre et novembre.

Development of Flow Routes and Cave Passages from Fault Segments in West Virginian Caves

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Abstract

A structural segment is a continuous length of conduit developed along an individual fracture, or along fracture intercepts, such that the fracture(s) can be inferred to have guided flow of ground water during initial stages of the development of the particular flow path. Structural segments formed by minor reverse faults are abundant in Mississippian limestones in West Virginian caves. The faults tend to form ramps with "S-shaped" cross sections. Fault surfaces vary greatly in local strike and in initial fracture widths, due partly to variations in mineral packing. The distinctive geometry and surficial character of the faults exert considerable influence on (1) initial flow routes on fault segments, and (2) the morphology, size, and mode of development of passages enlarged from them, depending on (3) the local hydrologic and stratigraphic settings, and (4) the nature of any fracture intercepts. This study illustrates the most common developmental sequences on fault segments.

Zusammenfassung

Kleine Verwerfungen sind besonders reich in Hoehlen von West Virginia, USA, die in Kalk von dem Mississippian Greenbrier Group (Karbon) entstehen. Die Geometrie, Richtung, und Breite der Flachen der Verwerfungen ueben einen grossen Einfluss auf dem originalen Wege des Grundwassers und auf der Morphologie, Grosse, und Methoden der Vergroesserung des Verwerfungsegments. Die Form dieses Einflusses ist aber auch stark von der lokalen hydrologischen und lithologischen Umgebung abhangig.

Introduction

Minor reverse faults are common in caves developed in the carbonates of the Mississippian Greenbrier Group in eastern West Virginia, USA. This paper discusses some of the more common sequences of cavern development on those passage segments where the initial ground-water flow paths were guided by faults -- fault segments.

Characteristics of Faults

The reverse (or thrust) faults form structural ramps with roughly S-shaped cross sections (Figures 1-3). The larger ramps have a relief of 10-20 m in areas of horizontal bedding, and a lateral extent of 100-500 m. Most faults are bed-parallel in ductile units (shales or argillaceous micrites), but cut bedding at angles up to about 30 degress in the brittle units (purer micrites and sparites). Faults often occur in conjugate pairs "splaying" in opposite directions from a single ductile unit. Many larger faults strike subparallel to the trend of central Appalachian folds (N30E), but tend to die out laterally by breaking up into numerous smaller faults with highly variable strikes (N20W to N60E). The surface character and fracture width of all faults varies considerably due partly to variations in packing by calcite and quartz.

Sequences and Geometries of Passage Development

The characger of passage development on fault segments depends on such factors as (1) fault geometry, (2) the position of introduction of ground water to the faults, (3) the hydrologic setting and changes in it, (4) the thickness of ductile units (which are less soluable than brittle units), and (5) the nature and distribution of fracture porosity on the faults (both are influenced by intercepts with other fractures, or by packing). Some influence of these factors will become evident by carefully considering the following brief, highly generalized accounts of passage development.

Up and Down Conjugate Faults: Fault Loops

Ground water on a bed parting may be re-directed up the dip of a fault only to be returned down by a conjugate fault, thus forming an ungraded loop (Figure 1A). Such a loop most commonly forms below the local "water table." If an upstream piracy causes an abrupt abondonment of the flow path, then the loop may retain early elliptical or circular cross sections throughout (Figure 1F). But if the "water table" drops gradually onto the apix of the loop there results an "isolated vadose trench" (Figure 1C-E,H) similar to those described by Ford (1965) for other structural settings. Distinctive ledges drop with the faults (Figure 1C,D) and usually narrow towards walls near the floor (Figure 1E).

A Set of Strike, Dip, and Strike Patterns

Ground water perched on an argillaceous unit may be discharged into the region of a large ramp near its top (Figure 2). This often occurs within the zone of smaller faults. It is seldom possible to discern the positions and patterns of the original conduits on the separate faults within these zones. But we can note that if the faults are closely spaced, then cross sections are irregular, and blades of bedrock may protrude into the cave (Figure 2A). In such zones wedge-shaped breadkdown is common.

Eventually the ground water may intersect the main fault, where it often takes a strike course. Cross sections become less complex (Figure 2B). At some point a favourable position is reached where flow proceeds down the dip of the fault. If flow then reverts to a strike direction, a distinctive "jog" pattern appears on the plan (Figure 2).

On the dip section several sequences of development are common. If development is phreatic and the upper argillaceous unit is thin (under about .25m), then the dip section may develop elliptical or circular cross sections. These will be retained by an abrupt abandonment of the flow path. If, however, abandonment was not abrupt, or initial development was vadose, then entrenchment occurs. It begins everywhere at the fault and may take several forms. If the upper argillaceous unit is thick then it forms an effective cap rock for a retreating waterfall shaft (Figure 2C) similar to those described by Eddy and Williamson (1968) in Cassell Cave, West Virginia. But if the argillaceous unit is thin, a graded trench will develop (Figure 2D).

A Collapse Pattern

Ground water may be re-directed in its course on a fault intersecting fractures, e.g., joints. In some developmental sequences there then result distinctive collapse patterns. Figure 3 depicts one such sequence.

Ground water entered near the top of the ramp and developed several early anastomotic flow paths under phreatic conditions (3A). One path eventually intersected joing J1; the intersection trends down the fault dip. The increased fracture width provided by the intersection resulted in increased flow relative to surrounding primitive routes. This lead to the local "water table" initiated entrenchment on this conduit (Figure 3C). Floodwaters enlarged the fault plane, widening the upper part of the passage, and exposing joint J2 (Figure 3D). As entrenchment progressed the usual lower argillaceous units (which was omitted from most cross sections for clarity) was reached; it inhibited downcutting (Figure 3E). Thus further dissolution was more effective along the contact with the upper, purer unit. This lead to extensive undercutting of the fault's footwall (Figure 3F), and, facilitated by joint J2, also lead to eventual collapse of a wedge-shaped piece of breakdown (Figure 3G, H).

Conclusion

These are but a few of the possible sequences on fault segments, yet they are among the most common, as shown by reconnaissance study of over 20 caves including Greenville Saltpeter and Laurel Creek Caves in Monroe County, Bone-Norman and Buckeye Creek Cave in Greenbrier County, and Friar's Hole Cave System in Greenbrier and Pocahontas Counties. Work is under way to document these and other sequences in more detail so that a better understanding might be reached on the effects of faults on cave development in West Virginia.

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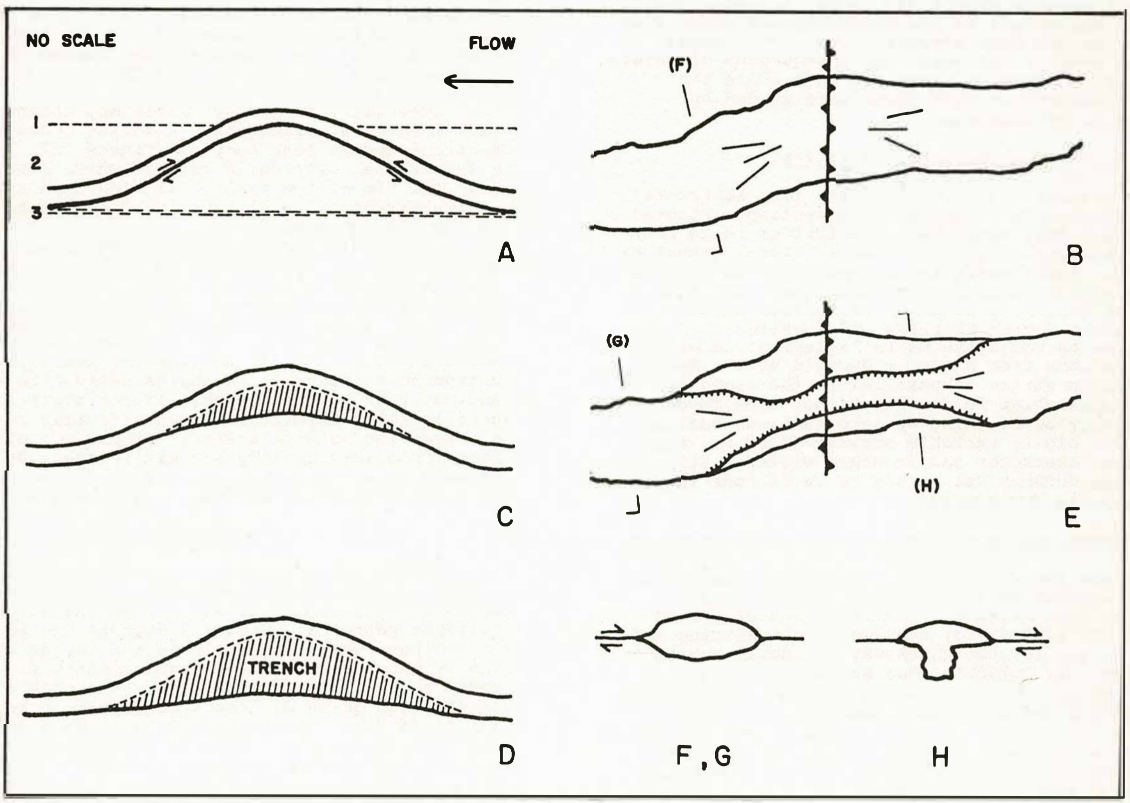

Figure 1. Passage development on conjugate faults. Initial fault loop: (a) profile, (b) plan, (f) cross section. Entrenchment: progression of stages in profile: (c), (d); mature stage in plan: (e), with cross sections (g), (h).

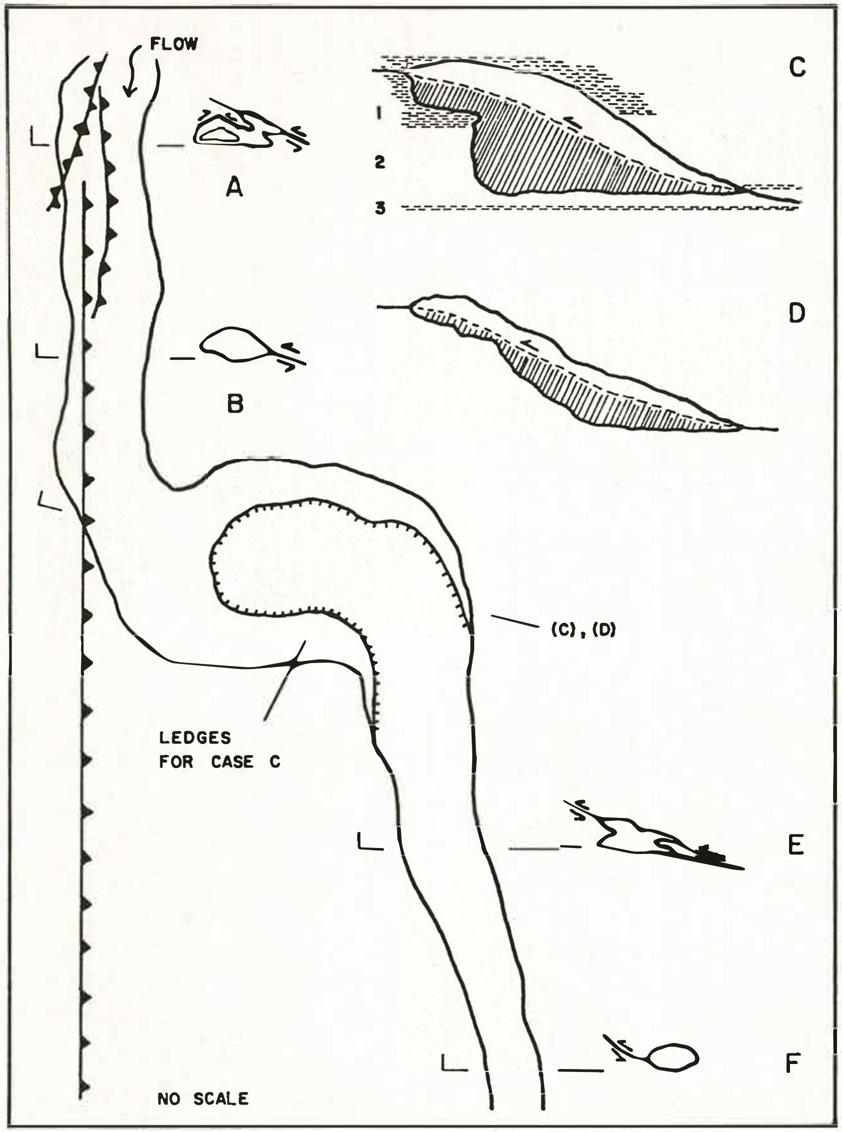

Figure 2. Some strike, dip, and strike patterns. Cross section in zone of smaller faults: (a). Cross section along main fault: (b). Profile of retreating waterfall shaft: (c). Profile of graded trench: (d). Cross sections showing passage leaving faults: (e), (f). 1 = upper ductile unit. 2= central brittle unit. 3 = lower ductile unit.

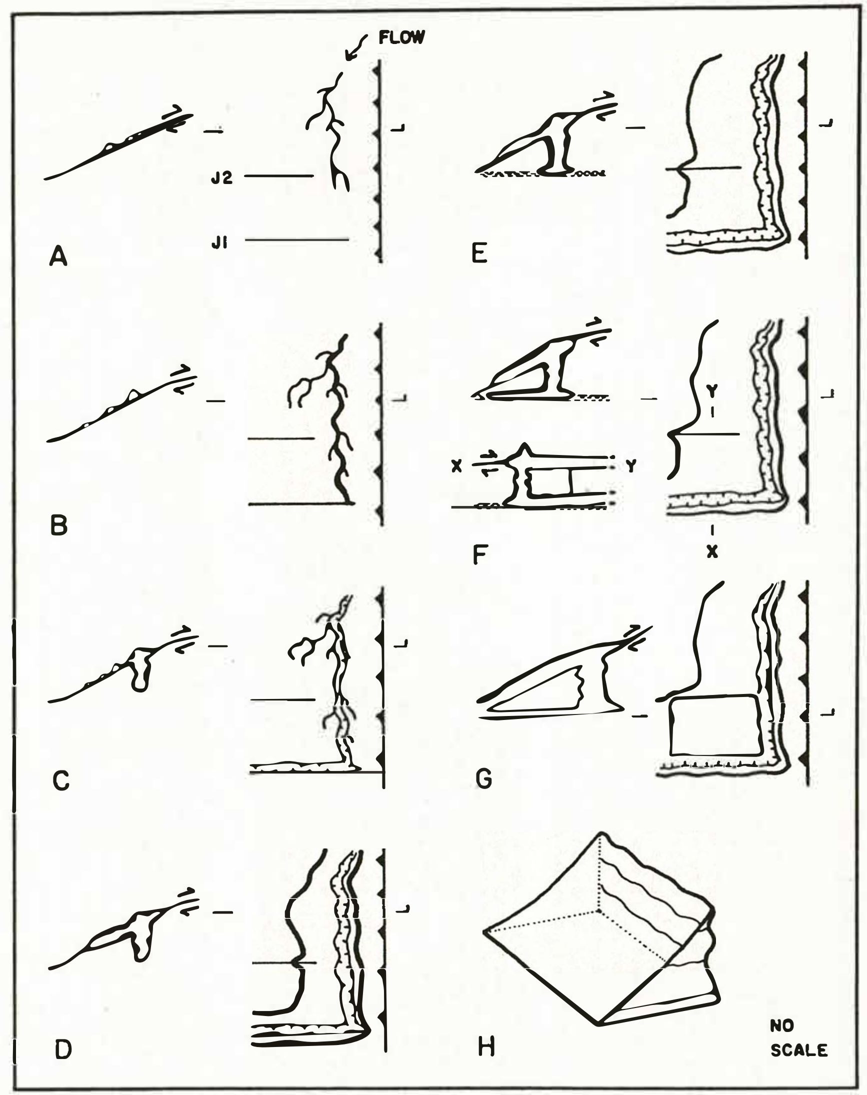

Figure 3. A Collapse pattern involving fault-joint intersections. (a) Early anastomotic paths. (b) Development of principal conduit. (c) Entrenchment of principal conduit. (d) Floodwater widening of fault above trench, destroying most traces of early secondary flow paths. (e) Entrenchment inhibited by impure ductile unit. (f) Extreme undercutting on contact of brittle and ductile units. (g) Position of breakdown in passage. (h) Wedge-shaped breakdown.

Glacier-groundwater Interactions and Quantitative Groundwater Tracing in the Vicinity of Mount Castleguard, Banff National Park, Canada

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Abstract

Contemporary models of glacial hydrology envisage two types of water flow at the ice-rock interface: 1) meltwater flowing in integrated conduits and 2) a closed regelation system involving melting and refreezing of basal ice. Observations around the Rocky Mountains and in Castleguard Cave support this assertion and suggest similar scales of activity in subglacial groundwater flow.

Seeps probably originated as regelation waters at the glacier sole. The tendency for these waters to form speleothems is difficult to explain in terms of conventional hydrochemical mechanisms. However, the unique conditions occurring beneath a glacier may create sufficiently high partial pressures of CO_2 in regelation waters for degassing in the cave to account for speleothem deposition.

Inspection of sinks and springs near Mount Castleguard suggests that some $30m^3s^{-1}$ of resurgent water is unaccounted for by known sinks. Geohydrological and speleological evidence indicate the source of this water to be inaccessible sinks on the Columbia Icefield. The waters are probably supraglacial and reach the bedrock by descending major crevasses in an icefall above a rock step overlying the far reaches of Castleguard Cave.

The karst of the Mount Castleguard area exhibits numerous (>100) springs, relatively few accessible sinks and high seasonal and diurnal variations in flow. In 1979 and 1980 a quantitative tracer program was undertaken, mostly using the fluorescent dye Rhodamine WT. Analysis was made with a Turner Designs Model 10 Series Flurometer capable of continuous flow or discrete sample fluorometry. Twelve-volt snowmobile batteries provided power and resolution was better than one part per 10^{11} Rhodamine. Grab sampling was by automatic water samplers at frequencies of one to six samples per hour.

Basic flow routes were first established. Then repeated tests from selected sinks under different flow conditions were made to test for the presence of underground drainage divides.

All tests were distributary to numerous springs and no true divides found. However, characteristic time-concentration curves allowed functional classes of springs to be identified. Varying multiple peaks in dye output under different flow conditions represent the changing importance of parallel conduits. Some pulses may represent the flushing by the diurnal flood of trapped dye. The tracing results plus a deep recession of the karst aquifer in summer 1980 allowed functional spring clusters to be identified. A simple model for the 4-dimensional network is envisaged.

Résumé

Les modèles contemporains d'hydrologie glaciaire envisagent deux types de coulant à l'interface glace-roc: 1) un flux d'eaux de fusion dans un conduit de type intégré et 2) un système fermé de regélation impliquant la fonte et le regel de la glace basale. Des observations aux environs des Montagnes Rocheuses et dans la caverne de Castleguard supportent cette assertion et suggèrent des échelles d'activité comparables en ce qui a trait aux eaux souterraines sous le glacier.

Une inspection des gouffres et sources karstiques près du Mont Castleguard suggère que les gouffres connus ne peuvent rendre compte de quelques $30m^3s-1$ d'eau de résurgence. L'évidence géohydrologique et spéléologique indique que des gouffres inaccessibles du champ de glace Columbia représentent la source la plus vraisemblable de cette eau. Les eaux sont probablement supraglaciaires et attaignent la rochemère en descendant le long de grandes crevasses. Ces crevasses sont situées dans une chute de glace recouvrant une petite falaise de roc au-dessus du fond de la caverne de Castleguard.

Des infiltrations vont probablement chercher leur origine dans les eaux de regélation au lit glaciaire. La tendance de ces eaux pour former des spéléothèmes est difficile à expliquer en termes de mécanismes hydrochimiques conventionnels. Cependent, les conditions uniques régnant sous un glacier peuvent créer dans les eaux de regélation des pressions partielles de CO_2 suffisamment élevées pour le dégazage dans la caverne explique la déposition de spéléothèmes.

La karst de la région du Mont Castleguard possède plusieurs (>100) sources karstiques, relativement peu de gouffres accessibles, et de fortes variations saisonnières et quotidiennes de débit. En 1979 et 1980, un projet de traçage quantitatif fut entrepris, utilisant principalement le colorant fluorescent Rhodomine WT. Les analyses furent menées à l'aide d'un fluoromètre Turner Designs Model 10 capable d'accomoder des échantillons individuels ou un flux continu. Des piles de motoneige (12 volts) constituaient la source d'énergie et la résolution dépassait une partie par 10^{11} Rhodamine. L'échantillonnage fut mené automatiquement, à une fréquence de un à six échantillons par heure.

On a établi d'abord les trajectoires de flux. A partir de gouffres choisis, des tests furent répétés sous différentes conditions de flux, afin de vérifier la présence de lignes souterraines de partage des eaux.

Dans tous les cas, le traceur fut distribué à de nombreuses sources et aucune véritable ligne de partage des eaux ne fut identifiée. Cependant, des classes fonctionnelles de sources purent être distinguées à l'aide des courbes temps/concentration caractéristiques. Des crêtes multiples variables dans le débit du colorant sous différentes conditions de flux reflètent l'importance changeant des conduits parallels. Quelques pouls peuvent témoigner du rinçage par la crue quotidienne de colorant emprisonné. Les résultats des traçages et une récession profonde de l'aquifère karstique au cours de l'été 1980 ont permis l'identification de groupments fonctionnels de sources karstiques. Un modèle simple pour le réseau en quatre dimensions est envisagé.

Introduction

There are two paradoxical features of the contemporary hydrology of the Castleguard karst: 1) the groundwater discharge is far greater than the sum of sinking streams, and 2) there is active calcite deposition in the cave beneath glacier ice, in which a situation where conventional models involving degassing of biologically derived CO_2 are not applicable. The Columbia Icefield is considered to be the source for both the unknown groundwater inputs and the calcite depositing waters. There is thus strong glacier-groundwater interaction, the elucidation of which is the concern of this paper.

Present day models in glacier hydrology (e.g. Walder and Hallet, 1979; Hodge, 1979) suggest two weakly coupled domains of subglacial water flow: 1) a low pressure, integrated conduit flow, fed by surface meltwater, and 2) a thin, high pressure regelation film within which localised refreezing and melting occur in response to variations in basal pressure.

Basal Meltwaters

Regelation is a cyclical process involving melt on the upstream (stoss) side of obstacles and freezing in the lee where pressure is reduced. On a limestone surface, basal melting is associated with dissolution of the bedrock. Where freezing occurs, the solutes are excluded from the ice and form characteristic subglacial precipitates (Hallet, 1976). Amongst the various forms which such precipitates assume is that of a "subglacial stalactite". These features occur on vertical lee joint faces where hairline cracks exist in the host bedrock. It is supposed that there was a subglacial cavity at these sites and water passed through the hairline cracks, driven by the pressure gradient across the rock step. The release of pressure at the outlet induced freezing and deposition of the small amount of material dissolved in the water. It is thus apparent that there is at least small scale "groundwater" flow beneath temperate ice. There is no apparent reason why the flow need necessarily be localised, since more deeply flowing water can gain heat from viscous dissipation and geothermal sources until its liquid state is no longer pressure constrained. It remains to be shown, however, that such water is capable of precipitating speleothems in the underlying cave.

The hydrochemistry of glacier ice is complex, especially in the basal regelation zone. In general, on freezing the dissolved materials are excluded; solids are precipitated and the gases form bubbles. Consequently, on melting, there is an immediate availability of gases, whilst fresh rock is dissolved.

Measurements of CO_2 in bubbles in glacier ice suggest that a concentration of some 1% is not uncommon (Weiss <u>et al.,</u> 1972). Under an overburden of say 90 m of ice, a partial pressure of 8×10^3 Pa is possible. A normal atmospheric PCO_2 is approximately 30 Pa. While melt does not necessarily occur in equilibrium with such bubbles, the possibility of very high PCO_2 occurring in regelation waters is demonstrated. If the water were equilibrated to a PCO_2 greater than atmospheric, and it reached the cave, having dissolved limestone en route, speleothem production could occur. The failure to observe high PCO_2 in cave drips may exclude this hypothesis, except that such measurements have necessarily been made during the late winter when regelation activity is at a minimum.

Conduit Flow

There are relatively few (~ 10) sinking streams active all summer in the Castleguard area, and most exhibit flows of only a few litres per second. At a maximum these observed inflows total ~ $2 m^3 s^{-1}$. In contrast, some 35 $m^3 s^{-1}$ are estimated to be discharged from the numerous springs found in the Castleguard River Valley.

A study of these springs reveals a marked flow response to temperature fluctuations, including diurnal fluctuations. The water chemistry is characteristic of meltwaters in the region (low dissolved load, some 15 ppm $CaCO_3$, and sub-atmospheric PCO_2). Given these data, and the regional structural and topographic framework, the Columbia Icefield is the only reasonable source.

Meltwaters are believed to reach bedrock by descending crevasses, or from marginal meltwater streams in some situations. In the far reaches of Castleguard Cave numerous dome-pits are found. These are clearly active, although quiescent in winter. On the icefield overlying this part of the cave a marked crevasse zone occurs, developed where ice flows off the massive limestone pedestal supporting Mount Castleguard. Another possible source area is the upper Saskatchewan Glacier, where marginal streams flow against the karst-prone Cathedral limestone.

Given the close spatial association of the present day sinks and springs to the known cave, it is tempting to regard the active hydrological system (Castleguard II) as a close analogue of the cave; that is as a single major trunk system. Although this is speleologically attractive, the conditions under which the original cave formed were very different from those occurring since its abandonment.

The domepits at the end of the cave are invasion features, probably changing in relative importance as the exact locii of crevasses changes from year to year and migrating with progressive erosion of the bedrock step. There has thus not been a single source of input, evolving accumulatively through capture; rather new routes have had to be continuously developed.

Similarly, the close proximity of the outlets to the icefield means that any major of minor ice advances over the 700,000 years since the cave was abandoned would have occupied the Castleguard Valley. The consequent erosional and depositional disruption of the drainage system has left a complex, largely immature drainage system. All of the (approximately 100) active springs are constricted, the lowest level springs extremely so. Abandoned springs are found above the elevation of the presently active springs, presumably having lost their water to more recently developed lower outlets.

Water Tracing

A program of water tracing was undertaken in the region, labelling accessible sinking streams and sampling at the springs distributed over five kilometers of the Castleguard Valley. The size of the system and heavy summer snowfalls limited the extent of the investigation. Plans to make a direct trace from the icefield were thwarted by an unusually cool summer during which no surface melt streams developed in the postulated source area.

The fluorescent dyes Rhodamine WT, Lissamine FF, and Fluorescein were used and collected on activated charcoal detectors or by automatic water samplers. Analysis was on the Turner Designs Model 10 series Fluorometer which features low power demand (24 watts from a 12 volt source), rapid warm-up and stability in inclement environments. The fluorometer was also employed in continuous flow fluorometry and nephelometry. A special rack-mount model was found quite satisfactory and reliable under arduous field conditions. A minor drawback is the delay in changing filters for various applications. The major constraint was in maintaining gasoline generators required for battery charging.

Figure 1 is a greatly simplified summary of the tracing results, showing major zones of sinks and springs. Dye from the Upper Meadows moved directly down dip to springs located around the level of the cave entrance. A weak, delayed link was found to the Big Spring in the valley, 270 m below. A large flood from the cave entrance occurred during a major snowmelt event in the Upper Meadows karst. However, cave floods also occurred during warm weather when there was no water available from this area. Direct upstream extrapolation of the trace encounters the Saskatchewan Glacier, a source of abundant meltwater. This is probably the source of the midsummer flooding experienced at the cave entrance.

Other dye traces were made from the benches flanking the south side of Mount Castleguard. These traces showed water to descend stratigraphically, following major joints through the Stephen shale which elsewhere is an aquiclude. All the traces from the Benches were distributary to every spring monitored in the Castleguard Valley. During high dischrage conditions mean throughflow velocities in excess of 640 m h^{-1} were recorded.

These results initially suggest flow into a major conduit which subsequently distributes to the spring (Figure 2, Model 1). However, the total time concentration of dye is markedly different between springs. There is thus not complete mixing and a model of type II (Figure 2) is suggested.

The form of the time concentration curves varies not only between springs, but also depends on the sink labelled. Two areas with characteristic output forms are identified:

1. The Frost Pot Group: well connected to the Meadows Stream Springs, except under very high flow conditions. A weaker link to Castleguard River Springs.
2. The Benches Group: strongly connected to Castleguard River Springs, a characteristic bimodal time concentration curve at both spring groups.

A possible interpretation of these results is shown in Figure 2, IIIa and IIIb. Although there is no true divide between the two areas there is a functional divide between them.

Repeated tests under different discharge conditions showed that dye behaviour was also strongly flow dependent. The average travel time decreased with increasing discharge. The relative partitioning of Frost Pot water between the two spring groups also reversed its emphasis. (Although the use of a powdered dye may have had an effect in one trace.) Characteristic twin peaks in the dye breakthrough curve in Benches traces varied in a most complex manner. In general, the later peak became further delayed and attenuated as discharge decreased, until it was no longer observed. At low flows, however, the characteristic diurnal discharge increase was accompanied by dye pulses. This may be interpreted as flushing of the dye from routes occupied only intermittently during the day.

The repeated traces demonstrated marked variations in the distribution of dye. Further data processing is necessary before reasonable interpretations are possible.

Conclusion

The hydrology of the Castleguard area is complex, but not significantly different in nature from other karst areas. The rapid transit times, and strongly flow-dependent behaviour appear to be exceptional, however. The two scales of hydrologic activity are considered to be a unique result of contemporary glacier-groundwater interaction. In addition, repeated glacial disruption has created a complex aquifer, the outlets of which are still in an immature state and evolving to lower levels. The intensive quantitative tracer work has confirmed the complexity of the system and the dependence of its behaviour on discharge conditions.

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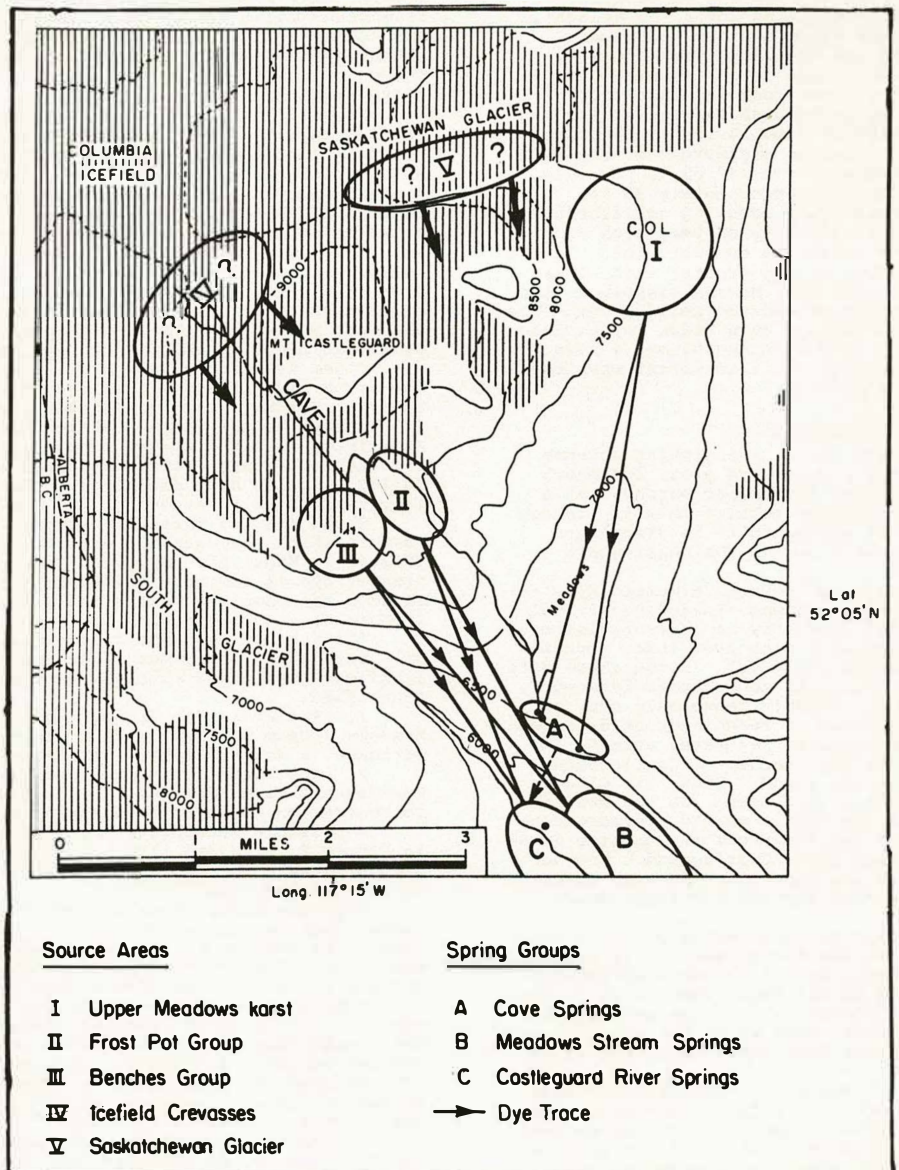

Figure 1. Source areas and spring groups, and dye traces for karst water around Mount Castleguard.

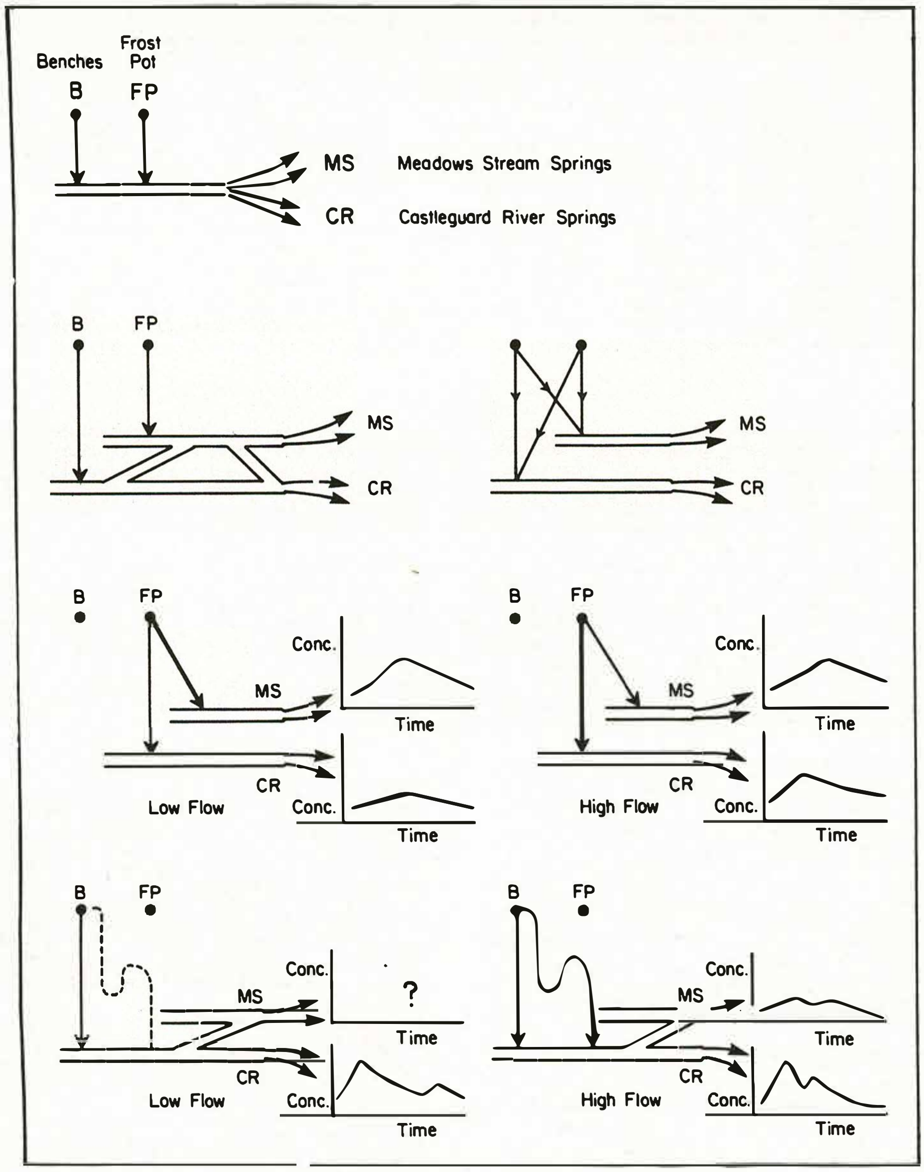

Figure 2. The evolution of karst conduit models form an increasing level of tracer information.

Some Results and Limitations in the Application of Hydraulic Geometry to Vadose Stream Passages

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Abstract

Some apparently-meandering vadose stream passages in Ireland and New Zealand were surveyed as a continuous series of short legs. The data were transformed and inspected for overt structural control. Runs of sign in the curvature (change in direction) series were taken to define 'Individual Bends' of half wavelength. Some unexplained differences exist between right and left bends. A contemporary streamway was compared to an antecedent, high-level meander series. Meanders had migrated downstream without significant change in form.

In terms of wavelength, width and discharge, the data conform to neither conventional hydraulic geometry, nor to previous work in caves. Solutional cave meanders are totally erosional and may only evolve through incision. In some caves, passage height and thus rate of incision decrease downstream. Meanders are correspondingly less well developed downstream. Karst processes are chemical in origin and ultimately reach saturation. Discharge is thus not a straightforward surrogate for erosional activity.

The apparent simplicity of erosional processes in solutional caves suggests a morphologically dominant discharge may be obtained from scallop measurements. This provides a basis for a valid cave hydraulic geometry.

Résumé

En Irlande et en Nouvelle-Zélande, on a arpenté en une série continue de courts segments quelques percées souterraines présentant apparemment des méandres. Les données furent transformées et inspectées en rapport avec des contrôles structuraux simples. Des suites de signes dans la série de courbure furent employées pour définir des "courbes individuelles" d'une demi-longueur d'onde. Les courbes à gauche et les courbes à droite présentent des différences inexplicables. Une percée contemporaine fut comparée à des méandres antécédants de niveau plus élevé. Les méandres avaient migré vers l'aval sans changement significatif dans leur forme.

En termes de longueur d'onde, de largeur et de débit, les données ne se conforment ni à la géométrie hydraulique conventionnelle, ni aux travaux précédants dans les cavernes. Les méandres de solution sont entièrement dûs à l'erosion et ne peuvent évoluer que par incision. Dans certaines cavernes, la hauteur de la percée, et donc le taux d'incision, diminuent en aval. En accord avec ceci, les méandres sont moins bien développés en aval. Les procédés karstiques sont d'origine chimique et s'épuisent ultimement. On qe peut donc pas simplement évaluer l'activité érosionnelle par le débit.

La simplicité apparente des procédés d'érosion dans les cavernes de solution suggère qu'on peut obtenir un débit morphologiquement dominant à partir de mesures de vagues d'érosion. Ceci établit une base pour une géométrie hydraulique valide dans les cavernes.

Introduction

The hydraulic geometry of alluvial river channels is well established (Leopold and Maddoch, 1953). The few studies which have attempted to apply the method to cave streams have shown little departure from conventional geometry (e.g. Deike and White, 1969; Baker, 1973). This is curious considering the diminantly solutional origin proposed for many such passages and the anomalous form of bedrock meanders (e.g. Hach, 1965; Tinkler, 1971). Accordingly, the conservative properties of channel form, width and meander wavelength were surveyed in sample "meandering" cave passages in Ireland and New Zealand in order to investigate whether cave meanders are comparable to alluvial meanders.

Methods and Results

Published cave surveys have been shown to be an unreliable data source (High, 1970) and conventional field survey techniques were considered insensitive. Instead, meanders were surveyed by recording the orientation of a standard 1.5 m leg run along the channel centreline. This was considered to provide a reasonably long and accurate representation of meandering reaches without introducing excessive instrumental error.

Five orientation and passage width series of up to 225 m in length were obtained in Ireland. A second (subsequently subdivided) orientation series exceeding 500 m in length was measured in New Zealand. The orientation data were inspected for structural control. A direct comparison with joint orientations sampled in the cave was not made because the two samples were not independent and the joint data could not be considered homogeneous. One reach exhibiting strong structural control was adapted as a standard. Although streams usually originate from primitive structural elements, only locally was structural control considered important in the reaches studied.

In order to avoid subjective selection of "well-formed" meanders and to provide data comparable to conventional surface studies, "individual bends" were defined by runs of sign in curvature (change in direction). Within this convention right turns would have positive curvature and left turns negative. Other parameters such as stream width and meander wavelength were calculated for each individual bend.

A comparison of right and left bends was made, primarily to test the hypothetical influence of the Coriolis effect on river meanders. The only consistent difference between individual bends was that right bends had lower mean width and higher standard deviation of width than left hand bends. Width data were only available for the Irish caves, but it is hard to account for such a feature in terms of the Coriolis effect. Structural asymmetry may possibly cause such differential erosion. Measurement error is unlikely to be important because not all streams were surveyed in a downstream direction.

Figure 1 shows the plan relationship between an active meandering stream way (Hole-L) and an antecedent series measured at passage centre some two meters above (Hold-H). A comparison of power spectra for the two series showed no significant differences to exist at any frequency.

Meander evolution in this example involves downstream propagation of bends and an increasing complexity in plan form, offset by occasional cutoffs. This is a mode that is consistent with surface meander behaviour (Hichin, 1974).

The relationship between stream width and meander wavelength is shown in Figure 2. The inverse relationship is clearly contrary to previous work. The best-fit relationship cannot be considered representative of an underlying law of behaviour, because the width cannot increase indefinitely at the expense of wavelength. Rather, some underlying assumptions of hydraulic geometry are not being met.

Discussion

The wavelength of meanders of many types has been shown to be commonly related to discharge (Parker, 1976). In rivers experiencing unsteady flow, this is considered to be a response to some "average" or "dominant" discharge. The long relaxation time of meander forms means that a very long term average (or even relict) flow is appropriate. In contrast, flow depth has a negligible relaxation time and will respond very quickly to changes in discharge.

Width in a cave passage is more complex than in a river, for no fluvial mechanism exists for narrowing of a canyon. This is because corrosional cave passages are purely erosional in origin. Width is thus controlled by relative rates of lateral and vertical erosion. In an homogeneous medium, a parallel walled canyon represents an equilibrium between lateral erosion and incision. Structural heterogeneity or an immobile bed of clastic sediments will change the equilibrium form. Caves at or near base-level will not incise rapidly. They assume a para-phreatic character.

The cave meander has been shown to migrate or change position over time. Under conditions of limited incision, this migration will gradually destroy antecedent forms. Where incision is rapid, well formed meanders will be preserved because migration will be accommodated in downcutting and earlier forms will be preserved. This is why narrow, tortuous meandering sections are characteristic of parts of so many alpine caves.

In Country Clare, Ireland, passage height represents the relative rate of incision, because of the simple bedding plane origin of many of the caves. Passage height decreases downstream in many cases. In the reaches surveyed, width also decreases downstream, although the canyon form was maintained. As both height and width decrease downstream, it is clearly not a redistribution of erosional capacity which is taking place, rather an overall depletion. Thus erosional power and discharge are not interchangeable variables and a prime assumption implicit in hydraulic geometry is not met in cave streams.

A meandering passage is thus most likely where caves are above base level, free of clastic load and actively incising. The meanders, however, are likely to become supressed downstream as base level is reached or water approaches effective saturation. The contrary width-wavelength results for the Irish caves ought to be viewed in this context.

Passage-forming Dominant Discharge

The quest for a single equivalent discharge which would produce forms like those created by actual varying flows has not been widely successful. This is partly because of the non-linear superimposition of a suite of processes. A solutional cave passage may provide a relatively simple situation for such an analysis. One definition of dominant discharge is "that flow which removes the most material in solution over a long period" (after Benson and Thomas, 1966). It is not appropriate here, however, since it represents an integration of solutional processes over the entire basin. A more appropriate erosional phenomenon related to discharge is that of scalloping.

Scallops are commonly occurring transverse erosional marks, the scale of which is controlled by boundary Reynold's Number. This allows tentative extraction of a characteristic erosional velocity (Curl, 1974). Where scallops festoon the walls of a cave, they imply that the cave formed at that point in response to that velocity, providing equiligrium conditions exist. It is difficult to calculate discharge for vadose canyons where cross-sectional area is unconstrained. An approximate solution may be obtained using the Manning Equation given a known cross-sectional form, width, slope and a characteristic roughness. The roughness estimate provides the main uncertainty as complex interactions will occur between varying flow and a scalloped surface.

Preliminary results suggest that relatively low flows are 'dominant'. Scallop measurements obtained from different levels above a stream are not markedly different. If flow velocity increases with discharge, then these scallops are relict features. However, the relaxation time of a disequilibrium scalloped surface is unknown, and more detailed mapping of scallop distribution in a channel is required.

Conclusion

Meanders are a characteristic vadose cave form common in conditions of low clastic load and relatively rapid incision. The nature of passage evolution and the solutional process means that great care must be taken in studying cave data in terms of conventional hydraulic geometry. In simple solution-dominated caves, scallops may allow a dominant "passage-forming discharge" to be calculated.

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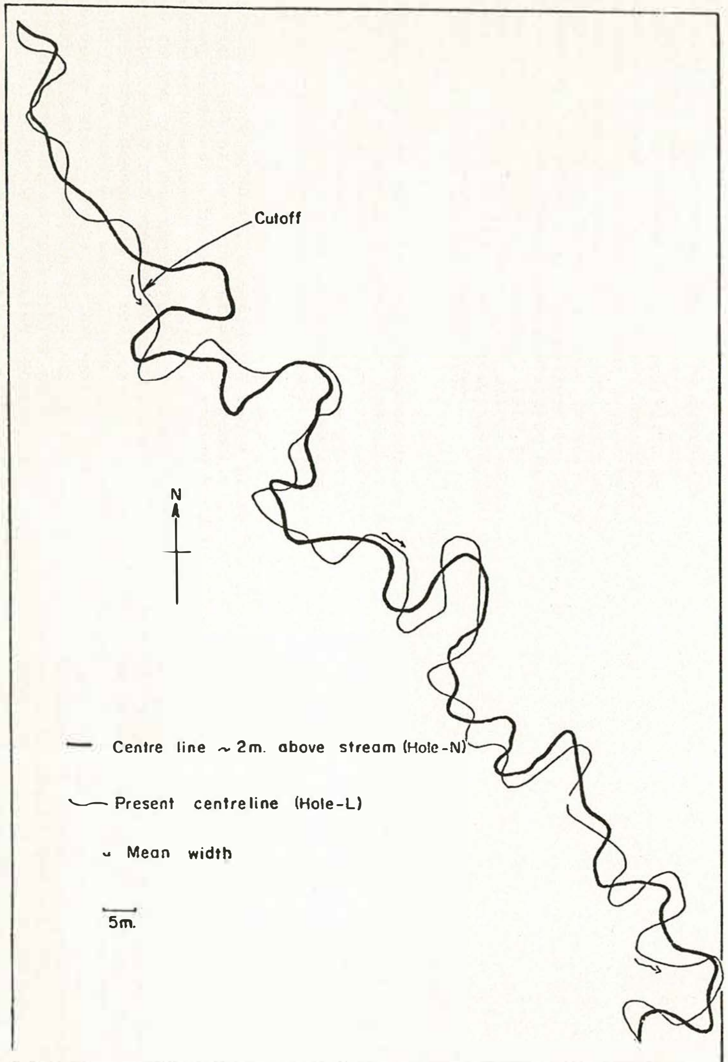

Figure 1. A contemporary meandering cave passage with an antecedent meander form superimposed. Gardeners Gut, New Zealand.

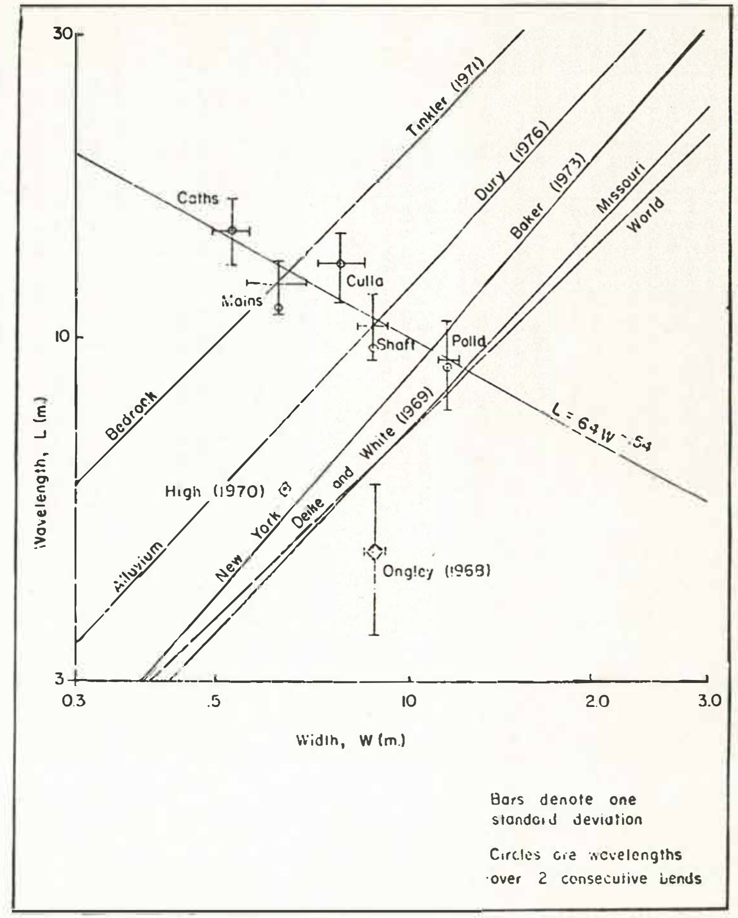

Figure 2. Width and Wavelength relationships from the literature and the present work.

Cavern Porosity Development in Limestone: A Low Dip Model From Mammoth Cave, Kentucky

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Abstract

Aclcite solution kinetics, and the characteristics of primitive pressure fields in limestones of low dip, suggest a model for cavern porosity development with the following characteristics: A rectiliniar tributary pattern of conduits should evolve through a stepwise integration of shorter distributary elements arising from separate inputs. A few of the tributary systems will extend a great distance into the aquifer with expanding width and catchment area while the majority will be of small extent close to the discharge boundary. The levels of Mammoth Cave which actively transmit groundwater appear to match the characteristics of the model.

Résumé

La kinetique des solutions de calcite, et les caracteristiques des champs de pression primitive dans les calcaires trouves dans les pendages peu profonds, suggerent un model pour le developpement des porosites souterraines qui aurait les caracteristiques suivantes: Un disposition tributaire rectiligne des conduits devrait evoluer a travers une integration progressive d'elements de distribution de plus en plus courts, provenant de sources distinctes. Quelques-uns des systemes tributaires s'etendront tres loin dans la couche aquifere, et auront une largeur toujours grandissante, tandis que la majorite seront d'un longueur reduite, pres du bord d'ecoulement. Les niveaux de Mammoth Cave qui transmettent activement les eaux souterraines semblent suivre les caracteristiques du model.

Introduction

Hydrologically significant groundwater conduits in carbonate rocks evolve in response to two fundamental factors, the kinetics of the dissolution reactions and the evolution of the pressure fields within the primitive void spaces. Beyond these factors the geological settings of high and low dip provide two variations. The high dip model with The Holloch (Muotal, Switzerland) as a type example was reported during the previous congress (Ewers, 1978). The present work proposes a low dip model with the lower levels of Mammoth Cave as the type example.

The Chemical Constraints

Basing his calculations upon the calcite solution kinetics data of Berner and Morse (1974), and Plummer and Wigley (1976), White (1977) has shown that groundwater moving through primitive fractures in limestone achieves the bulk of its solution modification of those rocks after traveling only a few meters or tens of meters through the fracture. The kinetics of limestone solution therefore require that the early framework of solution openings in karst aquifers propagate from the inputs toward the discharge boundary. These voids should posess a tapered form in response to the gradual reduction of solvent efficiency as the fluid progresses through the parting. Beyond the point where the kinetics become extremely sluggish the solvent should move to the output without appreciable change. Laboratory solution experiments involving solvent flow along planar partings in soluble media have shown that when the solution kinetics are appropriately scaled, such tapered voids are produced (Fig. 1). Furthermore the experiments show that the flow channelizes to form a distributary pattern of tubes (Ewers, 1966, 1972, 1981). The channeling of the flow has been shown to be a function of the size and distribution of irregularities within the parting (Ewers, 1981).

The Pressure Field Constraints

The rate and direction of propagation of any element of a distributary system of solution tubes developing in a planar parting is controlled by the characteristics of the pressure field in the parting. This, in turn, is a function of the boundary conditions, the distribution of permeability within the parting, and the distribution of any existing solution tubes.

Because of their lower hydraulic resistance, tube networks extend the pressure at their input into the higher resistance parting downstream. Therefore rapidly growing solution tubes produce a continuous distortion of the pressure field. This has two consequences. First, by increasing the pressure gradient beyond the network terminus each increment of growth increases the throughput and propagation rate for that network. Second, adjacent slower growing inputs would experience a continuous decrease in throughput and a commensurate decrease in growth rate. This effect was demonstrated in electric analogues, flow envelope models, and solution experiments (Ewers, 1972, 1981). These effects can be visualized with the help of Figure 2. Note that the flow domain of the longer network (Fig. 2B) becomes broader, discharging along a larger portion of the output boundary, while the reverse is true of inputs 1 and 3. In the situation depicted, input 2 would experience a four-fold increase in throughput and a commensurate increase in growth rate; inputs 1 and 3 undergo a two-fold decrease. A divergent growth competition therefore exists between distributary networks in close proximity to one another. Fast growing networks, or those which begin their growth earlier, become dominant and grow with increasing rapidity at the expense of neighboring recessive networks.

The Low Dip Model

In near-horizontal carbonate sequences, meteoric waters usually have access to bedding planes by way of joints, these may occur at many points over a large area of the rock unit. It is probable however, that not all inputs are active from the beginning.

Resurgences are likely to occur along major stream valleys which truncate the bedding plane at positions lower than the inputs. These may provide continuous linear exposure over great distances. Depending upon the gradient of the stream and minor structural factors, the resurgence may be initiated in a spotty or even a systematically expanding manner.

Figure 3A-E illustrates the development of the low dip linking pattern. In order to simplify the analysis, the following non-essential assumptions are made: 1. two ranks of equally spaced inputs occur in positions parallel to the discharge boundary; 2. input spacing within a rank is 0.5 of the rank spacing; 3. vertical joints communicate between the surface and the horizontal bedding plane; 4. an equal head is present at all inputs (Fig. 3A); 5. all inputs and the total length of the resurgence becomes available simultaneously.

The electric analogue experiments conducted by Ewers, (1981) indicate that under the specified conditions, rank 1 inputs will have initial throughputs eighteen times those of rank 2. The complementary solution experiments (Ewers, 1981) suggest that their growth rates will be in proportion to these throughputs. The electric analogue experiments also have shown that as the rank 1 networks lengthen, the throughput, and therefore the growth rate, of rank 2 networks will decrease (Fig. 3B).

Within rank 1, a growth competition should occur of the type already described. A few rank 1 networks, because of favorable circumstances, will grow rapidly at the expense of neighboring networks. Favorable circumstances would include locally higher bedding plane transmissivity, or the presence of a minor joint near the input, with an orientation parallel to the piezometric slope. These favored networks will establish the initial low resistance connections with the discharge boundary (Fig. 3C).

When a network breaches the bedding plane it may become capable of conducting all of the surface drainage available to it. In such a case, the head throughout the network will fall, approaching the level of the resurgence. This will produce a depression in the hydraulic potential field (Fig. 2C). The two adjacent networks will respond to this change with an increase in their growth rates and with a redirection of their growth toward the low resistance tube. When these establish links with the initial low resistance tube they will become the discharge targets for some of the remaining networks (Fig. 3D).

With the establishment of the first low resistance link between rank 1 inputs and the discharge boundary, the growth of networks in rank 2 will be stimulated. The result should be that networks 3' and 10' will grow rapidly with progressively smaller growth rate changes for rank 2 networks of increasing distance from these (Fig. 3D). The connection of networks 9 and 11 to network 10, and networks 2 and 4 to 3 should further stimulate growth in rank 2. When networks 3' and 10' establish low resistance links with their corresponding rank 1 networks, adjacent rank 2 networks should one by one link to it (Fig. 3E).

Model Summary

The linking scheme for the low dip model can be characterized in the following ways:

1. The number of springs of a given size should be inversely proportional to their drainage area. This is to say that a small number of large springs and a large number of small springs should drain the area.
2. Subsurface drainage basins should be established by the stepwise integration of small distributary subunits into a tributary system.
3. The integration of the system should proceed from the resurgence in a headward direction, the opposite of the direction of the network propagation.
4. The restriction of the scheme to two ranks is quite arbitrary. Additional ranks could be added, but the tendency for the networks which establish initial connections with the output boundary to broaden their influence with increasing distance into the aquifer seems inescapable.
5. The plan form of the conduit pattern should develop in what approximates a rectiliniar trellised pattern. The elements of that pattern oriented at right angles to the discharge boundary predating the elements which are parallel to that boundary.

Mammoth Cave

The dye traces in the Mammoth Cave Region reported by Quinlan & Ewers (1981) support this model. The traces, depicted in Figure 4, are shown as curved lines drawn perpendicular to the equipotential lines of the mapped piezometric surface. They link dye input and recovery points but do not show the actual position of the subsurface conduits.

Basins A & B are of major proportions and conform to the model tributary systems draining through networks 3 and 10. Like their theoretical counterparts, these basins extend laterally in their headwaters and take drainage from upstream of lesser basins C, D, E, F, G, and H. These lesser basins conform to networks 1, 5, 8, 12, and 15 in the model. Basin B1, though partly linked to the main part of basin B, is similar to networks 6 and 13 in the model. Small springs and their basins are not shown in figure 4.

Most of the drainage trunks revealed by dye traceing are unexplorable to an extent that would reveal their actual plan form. One of the exceptions to this statement is the upper reaches of the Turnhole Spring system comprising Parker Cave (Quinlan and Rowe, 1978). Here 11 km of mapped passage reveals five sub-parallel streams with cross connections forming a trellised pattern (Fig. 5).

The correspondence between the theoretical model and the available data from the Mammoth Cave Region are most encouraging. Thus far the five points listed above which summarize the model are met. Further exploration will undoubtedly reveal additional passages with which the model may be further tested. Readers are directed to Ewers (1981) for a more complete analysis of the model and its relationship to Mammoth Cave.

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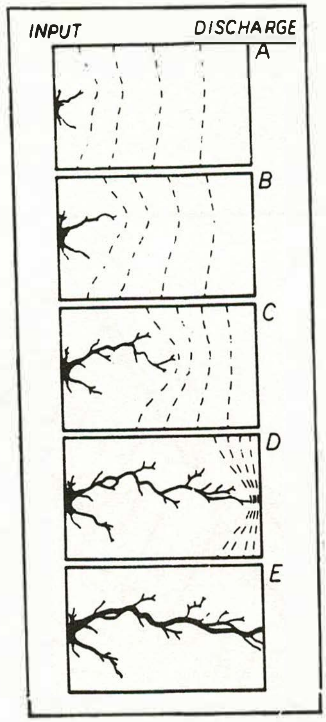

Figure 1. Tube network growth experiment.

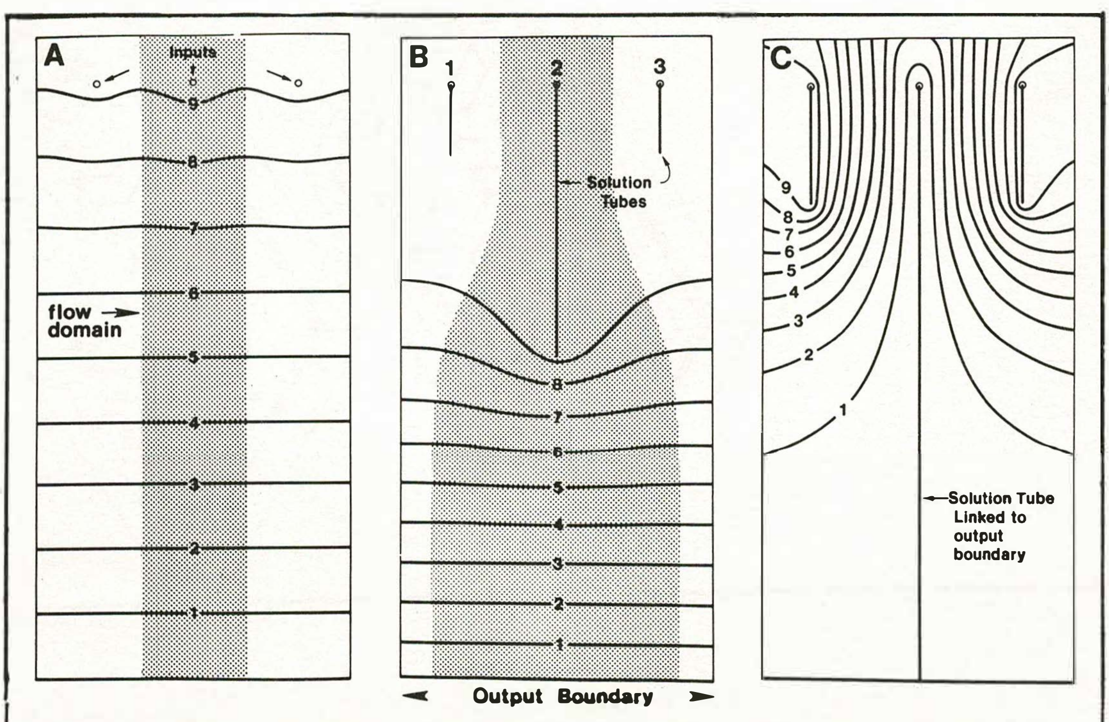

Figure 2. Flowfield surrounding multiple inputs to a common bedding plane.

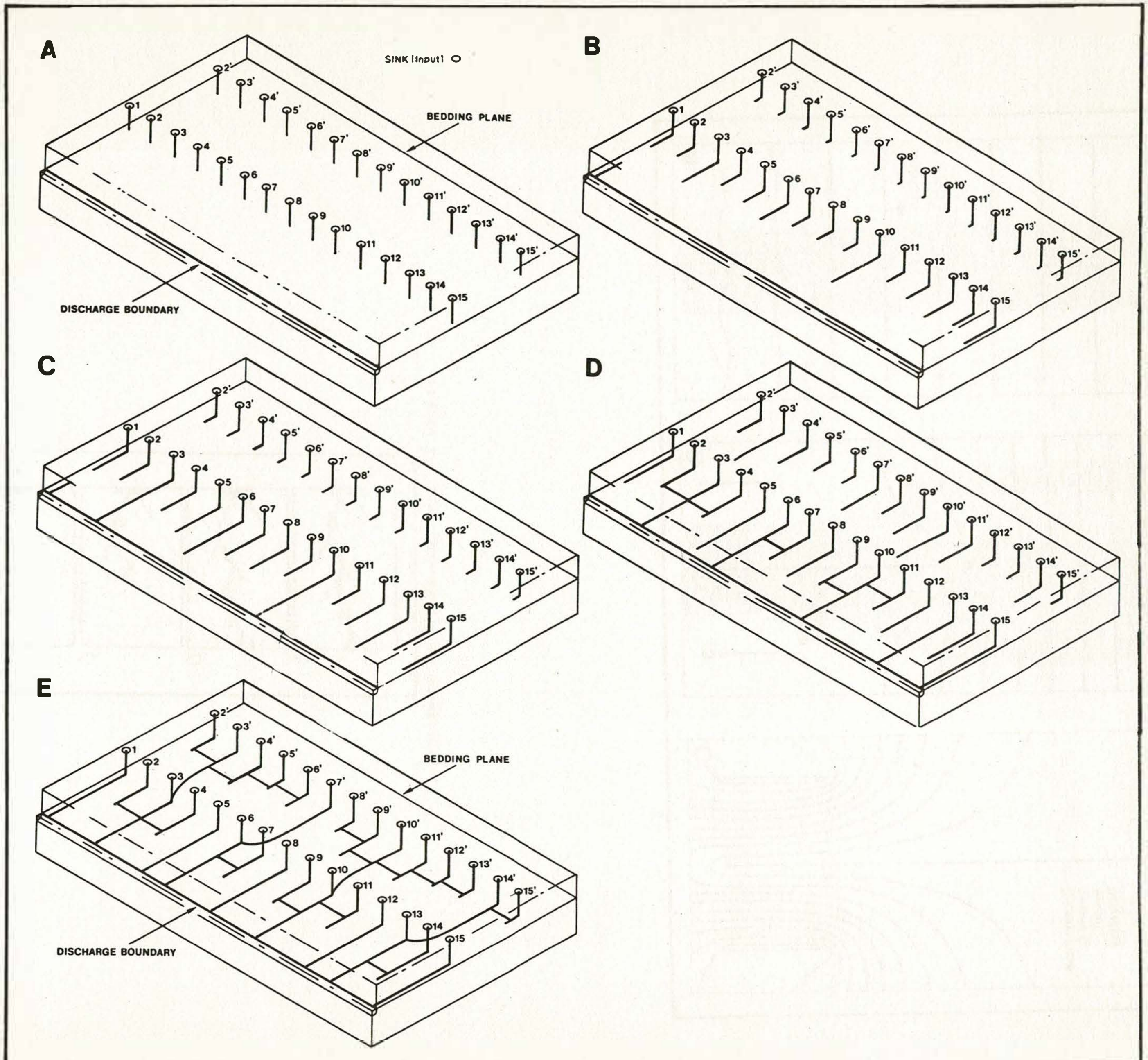

Figure 3. The Low Dip Model

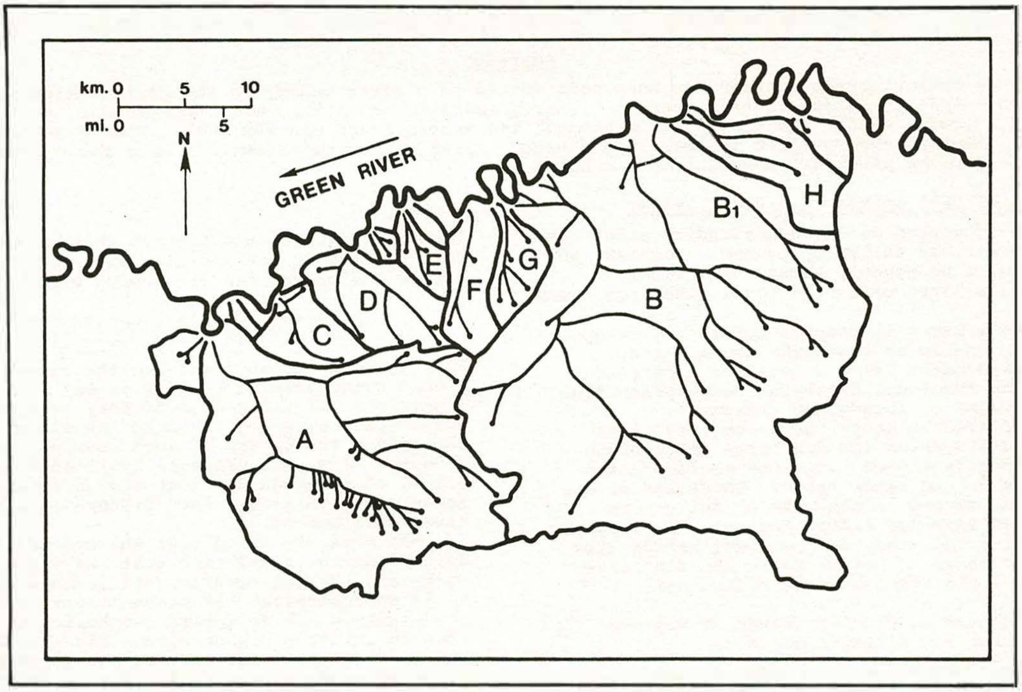

Figure 4. Groundwater Basins
MAMMOTH CAVE REGION, Ky.

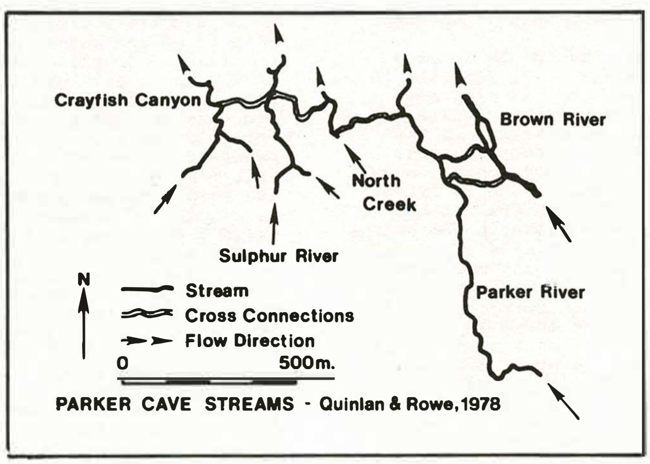

Figure 5.

The Deep Karsts in Wujiang Valley at Wujiangdu Dam Site

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Abstract

A large hydroelectric station has been constructed in a river valley in the karst region in the Southwest China---Wujiandu Hydroelectric Station. Thirty seven karst caverns were found under the lowest river level. The lowest cavern penetrated 220 m beneath the riverbed and was 10m high. The largest cavern penetrated beneath the riverbed and was 34.6 m high. Later thirty-two anomalies were found again under riverbed by radiowave penetration method in boreholes.

Concepts of Deep Karsts in a River Valley

There is still no consensus of understanding about the deep karsts in a river valley up to now. However, several opinions will be roughly summed as follows:

(1) It denotes a karst below the local discharge datum plane;

(2) It denotes a karst in deep circulation zone uncontrolled by the local discharge datum plane;

(3) It denotes a karst below a level at a certain depth under the local discharge datum plane from the standpoint of foundation treatment.

It is difficult to unify the above viewpoints. However, the karsts below the discharge datum plane differ from those developed along the slopes in the vicinity of the ground water table. These karsts are generated and developed in the form of delivering water through an inverted siphon action. This paper deals mainly with the study of the distribution laws and genesis mechanism of karsts below the discharge datum plane from the standpoint of hydrodynamics.

Distribution laws of the deep karst in Wujiang valley at Wujiangdu dam site

The Wujiang River is a 1st-class tributary of the Yangtze River. It runs through the carbonatite regions in Northern Guizhou Province and Southeastern Sichuan Province. During the initial Pleistocene epoch a plateau-gorge type karst geomprphic feature was formed at that time due to widely spreaded intermittent and violent uplifts of the earth's crust as well as deep dissection of the river valley.

The Wujiangdu hydroelectric station is located on main stream of the Wujiang River. The dam site is a transversal valley and the river bed is flat and straight. No crack point and large fault parallel to the river have been discovered. Deep karsts in the river valley possess the following characteristics:

(1) Karsts under the river bed are undeveloped: only 4 small karst holes of 0.1m in diameter and 24 dissolution fissures within a depth of 70 meters beneath the river bed were revealed in 34 exploration coreholes on the river bed. During excavation of the dam foundtion 48 gush points were discovered, the total yield was only 120 liters per minute and the maximum yield was 35 liters per minute which flowed out from a dissolution fissure. No karst cave was found in 210 boreholes (total length=15,000m) of gouting under dam foundation. Only 14 clay-filled fissures were discovered in these bore holes. According to pressure-water-test results on 2,794 sections of bore holes (1 section=5m.), only 16 sections gave out the values of w (unit absorption of water) to be over 0.01 liter per minute. The above data explain fully that karsts under the river bed are undeveloped and only few fissures possess stronger percolation power.

(2) The deep karsts in a river valley are mainly distributed under the slopes of valley and they constitute an inverted siphon which links the mountain divide and bottom of the valley. Deep karsts revealed by bore holes are component parts of such an inverted siphon. The height of the biggest cavern is 34.6m and this cavern is located 35m below the water surface of river. The height of the most deeply buried cavern is 10m and this cavern is located 220m below the water surface of river. 32 anomalies were later discovered again beneath the river bed by radio wave penetration method in the bore holes. The deepest anomaly was located 260m below the water surface of river. (Fig.1).

Both communicating tests and considerable piezometric data in bore holes demonstrated that such deep karsts were all controlled by the local discharge datum plane.

(3) Constituents of the particles of cavern filler vary with the depth of the caverns. Below the dam foundation fillers in caverns and dissolution fissures have distinct properties of zoning. In general these caves are filled by yellowish clay with a little amount of broken stones at elevations above 610m, by sand and gravel with a little amount of clay at elev. from 610 to 540m and all by clay at elevations below 540m. Such a distribution law for cavern fillers gives an important mark to distinguish whether the ground water is free to flow or not and also an important basis for determining the properties of flowing water in these caverns.

Analysis for the genesis of deep karsts in the river valley

(1) The mode of movement and the circulation depth of ground water under the river valley are the important conditions for the growth of deep karsts. As early as in 1930, W.M. Davis had advanced the plutonic water flow theory for the growth of such caverns, later on the model of water flow were proposed by Rhoades and Sinacori. All of them recognized that the underground seepage had taken place in a very deep fissure on the early stage of karst development.

At present, based upon the hydrodynamic sections drawn from the simulation test results of resistance networks and the piezometric data in bore holes (Fig. 2) it is demonstrated that ground water is flowing from the mountain divide toward the bottom of the valley just like an inverted siphon with a big circulation depth. The model display was carried out in homogeneous limestone 1000m below the water surface of the river (below the slopes of valley), moreover, there was still a distinct flow of water.

The mode of movement of ground water under the river valley inevitably affects the distribution condition of karsts. The distribution law of deep karsts under the Wujiangdu river valley coincides with the mode of movement of ground water flow therein.(2) Another important condition for the genesis of deep karsts is the CO_2 source in deeply buried water currents. As is known to all, the ground water absorbs CO_2 from the atmosphere and thus possesses a dissolving power, however, this can not hold for a long distance during the process of its penetration through the deeply buried rock strata. For this reason, it is necessary to solve the problem that the deeply buried ground water could get an approach of possessing an adequate dissolving power at first in discussing the genesis of deep karsts.

The approaches for deeply buried water currents to get dissolving power would include mixed solution, oxidation of sulphurized ore deposits, diffusion and migration of hypogene CO_2 and actions of germs and microorganisms, etc. However, that of most universal significance is the mixed solution and this theory was proposed by A. Bogli who had considered that the deep karst water was saturated by carbonates. However, when one kind of water is blended by another kind of water with different saturability, dissolubility results. Hence dissolution takes place continually in deep interior of the rock mass. The research work of such a theory becomes ripe at present and is generally acceted by karst scholars.

Mixed solution usually occur in areas of intersection of the faults of fractures under the slope of valley. The deep ground water from mountain divide mixes with that infiltrates vertically from slope of valley at this place. Since their moving distances differ greatly and their carbonate saturabilities and temperatures are quite different, so dissolution results and many caverns are formed under the slope of valley,

(3) Caverns under the Wujiang River valley are generally distributed in fault zones and their vicinities, this explains that faults are important factors to control the distribution of karsts, however, what affects the developing depths of karsts are the size of faults and the intersection relations between faults and rivers.

The major fault NO.F 20 on the left bank of the river at Wjuiangdu crosses the slope of valley, thus facilitates the flow of ground water from the mountain divide toward the river valley through an inverted siphon and increases its circulated depth. This current, when mixed with that infitrated vertically through the slope of valley, forms a cavern at a deep position below the water surface of the river. On the right bank although there are two faults of similar sizes, but they are parallel to the river and located at the mid-part of the slope of valley, thus the deep circulation water is intercepted and the deep karst is not developing . From the above descriptions it is clear that faults perpendicular to the river channel are important factors which govern the developing depth of karsts.

Influences of deep karsts upon the Engineering Geology Conditions

First of all is their influences upon the leakage of the reservoir. The deep karsts under Wujiangdu valley are controlled by local discharge datum plane and hence no feasibility for the reservoir water leak out into adjacent valleys far away, however, the inverted siphon below the discharge datum plane could facilitate the leakage of water from the reservoir to the outside and result in leakages under the dam foundation and abutments which would enhance the uplift under the dam foundation. An important problem in studing deep karsts is to determine the lower limit of the grout curtain under the dam foundation.

Based on the characteristics that the constituents of particles of cavern filler vary with the depths of caverns, the karsts beneath the discharge datum plane may be divided into two zones--the upper and the lower and this is of guiding significance in the determination of lower limit of the grout curtain.

Caverns in the upper zone were filled up mainly by gravels and sand. This shows that the caverns belongs to conduit-type flow and it is necessary to take effective anti-seepage measures to cut off any leakage to the outside of the reservoir and also reduce uplift under the dam foundation.

Caverns in the lower zone were filled with yellow mud reflecting that the ground water would flow very slowly. They might be of large size but they are a product of mixed-solution, so they are considered as isolated and suddenly contracted caverns against the flow of ground water. Both the quality of water in these caverns and their permeabilities explain that the ground water inside them belongs to vein crevice water. It is unnecessary to treat these caverns for the time being and the treatment scheme may be determined from the observation information obtained after the filling of reservoir. One year has passed since the initial filling of the Wujiangdu reservoir and all the conditions are favorable.

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乌 江 渡 河 谷 的 深 岩 溶

提　　要

我国在西南岩溶区的河谷上修建了一座大型水电站——乌江渡水电站。在最低河水位下共发现了37个溶洞，最低的溶洞深入河床以下220米，高10米，最大的溶洞深入河床以下35米，高34.6米。后经钻孔无线电波透视，在河床以下又发现32个异常。

本文分四个部份：

(1) 深岩溶的概念

(2) 深岩溶的分布规律与洞穴充填物随深度变化的特征

(3) 深岩溶成因的分析

(4) 深岩溶对工程地质条件的影响。

中国长江流域规划办公室

岩 溶 研 究 组

李 茂 秋

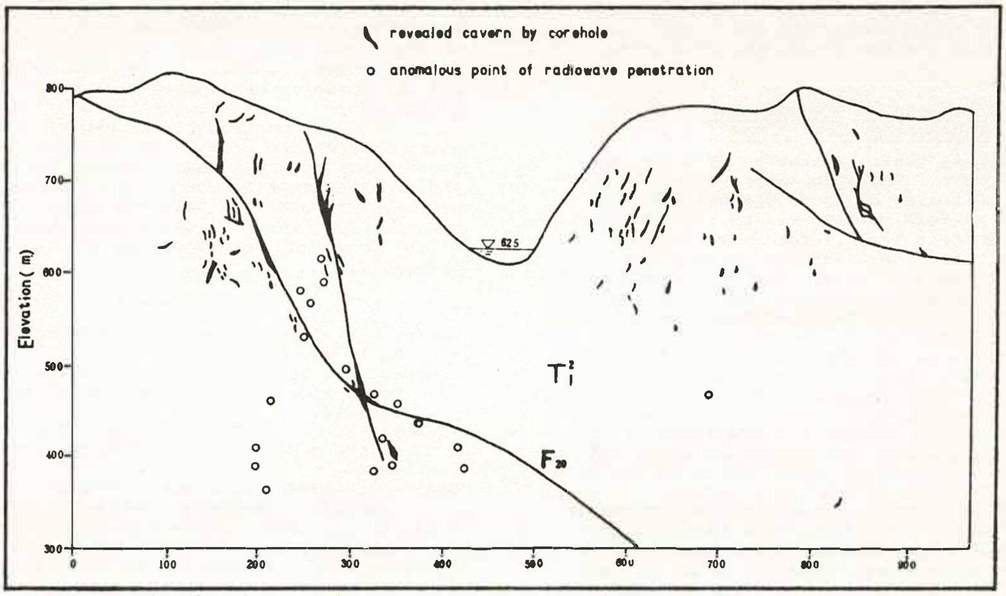

Figure 1. Distributive section of the karst at Qujiangdu dam foundation

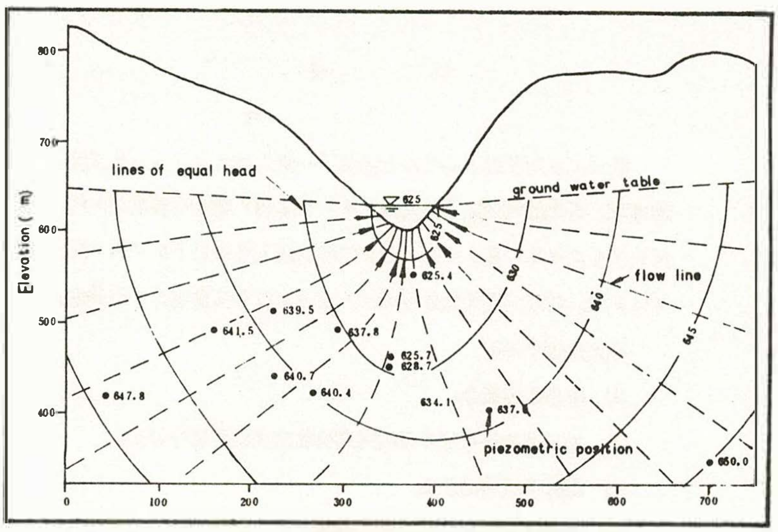

Figure 2. Hydrodynamic section at Wujiangdu dam foundation

Cave Diving in England in the 1950's

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Abstract

The author was active in cave diving in England between 1954 and 1959. Both the techniques and the equipment have improved considerably since then. This paper describes the methods used in the 1950's for the purpose of comparison with those of today.

Résumé

Les techniques et l'équipement de la plongée spéléologique s'étant beaucoup améliorées depuis l'époque ou l'auteur la pratiquait en Angleterre de 1954 à 1959. Nous décrivons ces méthodes anciennes à fin de comparaison.

Cave diving has made some impressive advances in the past few years. I dived in caves on more than thirty occasions in England between 1954 and 1959, and in America four or five times after that. The purpose of this article is to discuss some of the problems as they existed in cave diving in England at that time - NOT for the purpose of putting the clock back - but hopefully so as to encourage present-day cave divers to examine and then to re-examine their underwater techniques and training procedures so as to improve both the effectiveness and the safety aspects of their sport. (These problems have also been discussed by Boon, 1977 and by Farr, 1980.)

Visibility Underwater

Lack of visibility can careat serious problems for the cave diver. There are four stages involved: First, under exceptionally good conditions it may be possible to see for tens or even hundreds of feet, and you may find yourself being lured on and on and ON. Second, when the visibility comes down to five feet or less, you will only be able to see small parts of the walls and floor as they drift in and out of view. Next, comes essentially zero visibility, when the effect of a bright light to illuminate the water with a friendly glow, and when to read the depth gauge requires a bit of an effort. Finally comes total darkness, when you cannot even see a light that is held in front of your mask.

The water is usually clearer on an upstream dive than on a downstream dive, but you cannot rely on it remaining so. Thus, if you are swimming at some distance above the floor, then each time that you flip your foot there might be a puff of muddy water from the floor a second or so later. Each time that you release bubbles there might follow a shower of mud from the roof. A small stone rolling down a mud slope can stir up an amazing amount of mud. Of course, if you are swimming purposefully ahead, then you might not see that this is happening. The discovery that you are in opaque muddy water might therefore come as an unexpected and totally unwelcome surprise. In cave diving, you must always assume that you will not be able to see anything at all on your way out.

Floor or Roof?

Figure 1 has been drawn to emphasise the difference between the roof and the floor. Very often, the roof contains bell chambers and similar solutionally determined forms. The floor will very often consist of small stones, sand and mud that are rearranged by the water flow in times of flood. Indeed, it would sometimes even appear that passages underwater will all be silted up eventually unless they are periodically scoured out in times of flood. From the practical point of view this often means that you can learn more about the water flow by examining the floor than you can by examining the roof.

Figure 1 shows a mud floor sloping down to an opening at the lowest point, and on many occasions you may have to go to the deepest point to find the way on. The water flow in times of flood can determine the shape of the (sandy) passage floor in a horizontal submerged passage also. This can be helpful when exploring under conditions of limited visibility. For example, while walking along a horizontal underwater passage on an upstream dive in Threapland Cave in Yorkshire on 23 June, 1956 with John Buxton, I emerged into an underwater chamber having a height of 4 or 5 feet, and extending sideways beyond the limit of visibility. Such chambers often contain slow whirlpools, and this was no exception, with the mud cloud slowly sweeping across in front of me from the right. What to do? The first priority is to check for cracks in the walls of the passage that can accept the guide wire of the diver who goes straight out into such a place, and cause difficulties on the way out. This I had done. The next priority is to keep ahead of the mud cloud. By advancing at right angles to the ripple marks in the sand on the floor I was able to find the way upstream. I then came to a definite funnel in the sandy floor going downwards at a slight angle under a low archway in the wall. This was the way on. I entered this through a low squeeze, and explored a gently rising passageway in total darkness by the sense of touch for about five or ten feet; at which point it was clearly time to return. Before returning, however, I sat there for a minute or two without being able to see a think, when I had the good fortune to notice that the top of my mask was in air. Dry land was only a few yards away. Later, we made the return trip without being able to see anything. This dive would have failed if I had not studied the floor. (J.S.B. dived in caves for several years before I did and, together with J.A. Thompson and F.G. Balcombe, initiated me into cave diving.)

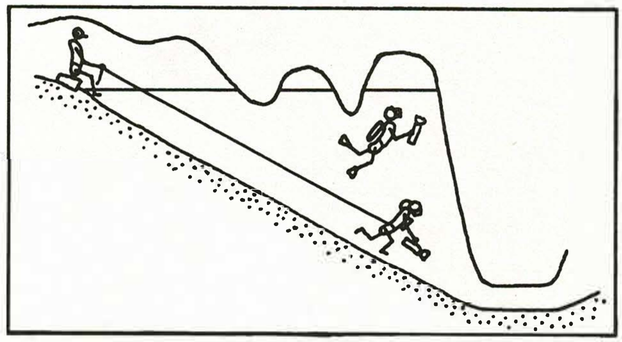

Figure 1. In an underwater cave passage or chamber, the shape of the roof is often determined by solutional effects, while the floor may consist of small stones, sand and mud which are rearranged by the water in times of flood.

Walk or Swim?

Present-day scuba divers are expert swimmers. In the 1950's, cave divers were influenced by the naval practice of those days, which involved the use of both swimming and walking divers (see, for example, Davis, 1955; pp. 290-324). In cave diving, a swimmer can investigate the cavities in the roof and can travel fast (hopefully in the right direction); while a walking diver can only easily examine the floor. It is easier for a walking diver to carry loads, he is less likely to get lost; he is less likely to kick his companion(s) in the face; he is less likely to get his feet tangled in the guide line; but he stirs up the mud faster; he cannot easily examine the roof; and he lives in mortal terror of falling into deep holes in the floor (see also Davies, 1949). In cave diving, the expression "walking" can also refer to a mode of progress when you are horizontal and only a few inches above the floor; bouncing along on your hands, which is not too difficult since you weigh only four or five pounds.

A swimming and a walking diver are shown in Figure 2. The equipment being used by the walking diver is rather simple. It is, in fact, the "bicycle respirator" as used by Graham Balcombe for his exploration of Sump 2 in Swildons Hole on Nov. 22, 1936. (Balcombe founded the Cave Diving Group in 1946 and was its principle organizer and later its President for many years.) This respirator (Balcombe, 1953) was refurbished for the purpose of a demonstration dive (Wells, 1960). Made from part of the seat tube of a lady's bicycle, it was the first self-contained respirator to be used for diving in a cave. The flexible tubes and the mouthpiece, which were missing when Balcombe gave it to me, have been replaced, but the basic configuration is unchanged. With this device, the breathing is controlled by valving the cylinder by hand, while the exhaled air escapes from the blow-off valve by the left shoulder.

Figure 2. Comparison between a swimmer (Jack Sofield) on the left, and a walking diver on the right. The so-called "bicycle respirator" as worn by the walking diver is substantially used by Graham Balcombe for cave diving in Swildons Hole in 1936 - see text. (Photograph by Jim Stark taken on June 21, 1960, using a Rolleiflex camera in a Rollei-Marin waterproof case, with number 5 flashbulb to provide added detail in the foreground.)

In the late 1940's, D.A. Coase and R.E. Davies carried out an extended series of swimming cave dives at Wookey Hole and elsewhere using what were essentially World War II "frogman" techniques. Balcombe (1981) offers the following tribute to Coase: "Coase was a first-class diver and a great companion always, and a steadfast support when I was stressed." Davies (1981) wrote: "Don Coase was a major force in the post-World War II diving explorations associated with the Cave Diving Group in England. He was bold, reliable and always ready to push ahead. His early death during surgery was a great loss."

Swimming is faster than walking. Thus, Davies and Coase covered 360 feet in less than seven minutes of "comfortable swimming" between the Resurgence and Swine Hole in Peak Cavern on June 12, 1949 (>50 feet/min). With Buxton, I walked 900 feet (total out and back) in 28 minutes going fairly hard over easy ground in Clapham Beck Head in Yorkshire on June 6, 1956 (30 feet/min). In the Threapland Cave dive described above we walked 65 feet in 7 minutes (~10 feet/min). In comparison, Statham and Yeadon swam 6,000 feet for the through dive at Keld Head on Jan. 16, 1979 in 150 minutes (= 40 feet/min) (Plant, 1979).

Choice of Respirator

Present-day cave divers have the benefit of greatly improved equipment. In the 1950's, closed circuit oxygen equipment was in used both by naval divers underwater and by fire-fighters on dry land, and it seemed to be a logical choice for cave diving also. The aqualung became available commercially in England in about 1947, but it was between ten and fifteen years before it displaced the World War II equipment obtained by Balcombe as Government Surplus at that time.

The closed circuit oxygen equipment could be used at shallow depths either for walking (which I preferred) or for swimming. The dry suits were generally very satisfactory, with the weakest point being the exposure of the hands of the diver to the cold water. For the exploration of the Fourteenth and Fifteenth Chambers at Wookey Hole at depths down to 65 feet on 6/7 Sept. 1957 and 14 March 1958 with John Buxton, we used the P-Party semiclosed-circuit mixture breathing set (Davis, 1955; p. 300). (Sir Robert H. Davis, who is well-known for his invention of the Davis submarine escape apparatus, was a supporter of cave diving in England for many years. He lent Balcombe the helmet diving equipment that was used for the 1935 Wookey Hole dives. He also donated the two P-Party sets that were used for deep diving in that cave.)

The semiclosed-circuit respirator lasts longer than an aqualung at depth, but the need to keep your soda-lime dry is a constant worry, and you must test most carefully for leaks. The correct operation of the constant-mass reducing valve is critical. The level of exertion must be kept low (which is another reason for walking rather than swimming when using this type of equipment). Here, we cannot do better than to quote from Empleton et al. (1962; p. 105): "Only a very few semiclosed-circuit scuba are in use by sport divers. Most of these are used by former commercial or military divers who have had several years of training and experience in the use of the equipment. The safe use of such equipment requires knowledge, training, and experience under the supervision of a competent instructor. . . . . The many disadvantages and limiting factors encountered in the safe use of closed- and semiclosed-circuit make their use for sport diving both impractical and hazardous."

In retrospect, it is perhaps surprising that the use of open-circuit equipment together with swimming for cave diving in England was delayed as long as it was. One of the pioneers of swimming in caves using open-circuit equipment was R.E. Davies. He obtained an aqualung in 1955 and carried out a number of dives. He had the right idea, but unfortunately he became separated from his fellow divers in Wookey Hole on 10/11 December 1955 (and greatly surprised everyone by reappearing several hours later); so that the use of these techniques did not catch on as rapidly as it should have done. I could have saved him a lot of embarassment on that occasion if I had had the intelligence to hold onto his elbow as he hovered in front of me while trying to untie the end of the line from his reel - but I digress.

Aqualungs were also used for non-CDG cave dives in England by J.A. Thompson in Hurtle Pot in 1956; by R.D. Leakey at Keld Head and at Austwick Beck Head in 1956; and by N. Brindle in New Goydon in 1957. Boon (1977) describes the use of aqualungs in Swildons Hole, starting in 1961. Nowadays, the use of open-circuit equipment with swimming (and caving helmets) is preferred.

Guide Lines for Cave Diving

In the 1940's and 1950's, it was common practice to use ex-army telephone line, with a cloth cover over steel strands and copper strands, as a guide wire for cave diving. This was satisfactory for the short term, but was vulnerable to attack by algae (Round and Willis, 1956). Nylon climbing ropes were also used for hand-held safety lines.

Communication Underwater

A major problem is how to communicate between two divers (especially in muddy water). According to the simplest scheme, if two divers are available, then they should go in together laying a guide line from a reel. The problem is, that as soon as any difficulty arises, then it becomes more or less essential to return to dry land in order to discuss whatever has arisen. (This problem is considerably more serious than it might appear at first sight because of the extraordinary difficulty that is experienced by most of us in summing up an unexpected situation underwater.) So why not leave your supporting diver on dry land with some method for asking him to join you if you would like him to do so? At least, this will free you from any worry about his safety. Besides which, if a real problem should arise, such as your guide line pulling across into a tight-place, then he will be in a far better situation to help you out.

The exploring diver in Figure 3 is on the end of a rope which is being paid out by the "controller" on dry land. How should the exploring diver indicate his wishes to the controller? Giving sharp pulls on the rope according to an agreed code has definite limitations. (I have a colleague that I shall never again invite to be the controller because of the occasion when, for no reason that I could detect, he pulled me out in a muscular manner as I was investigating an underwater tight-place.) Problems can arise, such as the occasion in Bouther Gill in Yorkshire on June 23, 1956 when my belt became hooked onto an underwater spike on the rock.

(The vertical drop that is shown below the air surface in Fig. 3 closely resembles one that exists at Deepdale Rising in Yorkshire. You must be very careful when walking over unknown ground.)

In 1958 I constructed an underwater signalling device in an effort to solve some of these problems. It contained a transistorised oscillator that allowed me to send dot and dash signals along the guide wire to a telephone receiver at base. This gave a "beep" which could be heard for several yards around. In addition, it carried a sound-powered telephone in a waterproof container which could be used if the diver reached dry land. During the dive there were two modes of signalling. For normal operation, the codes were as follows: three beeps for "more line," two beeps for "less line," and one beep for "Stop - everything is splendid." Under these conditions, the line could be paid out or pulled in as required. However, if a walking diver should have the misfortune of walking over the edge of an abyss, then a tighter control would be required. There was a system of signals (which in fact were never needed) to allow for this. This device worked well during the successful passage of Sumps 4 and 5 in Swildons Hole on 13/14 Sept. and 8/9 Nov. 1958, when we used the sound-powered phone from the far side of each of these sumps.

(A telemetry system so that the controller in Fig. 3 could be continuously informed of the diver's depth would be a useful feature if it could be devised.)

Training and Background

Expertise in underwater work is not sufficient for cave diving. Phillip Davies, who was an active cave diver in the 1950's, wrote in response to the first draft of this paper: "It might be useful to add that people involved should be cavers first, using breathing apparatus as a tool to tackle a particular problem, just as they might use explosives under different circumstances. It is wrong to encourage divers to tackle caving problems."

I have saved until last my comments on the subject of commitment. As a one-time cave diver, I am sensitive on the subject of safety. In my active cave diving days I had convinced myself that, if you are willing to take the proper precautions, then cave diving can be a sensible thing to do. So what do we mean by "proper precautions"? The main requirement is to spend enough time underwater every month so as to maintain an adequate level of proficiency. In may types of activity for which a high degree of skill is required (such as flying a private aeroplane, for example) it is necessary to spend at least ten hours a month, every month, to stay competent. (This is in addition to the initial training, of course.) A similar commitment in underwater time is required for yourself and for your friends to maintain proficiency for cave diving. Think about this, please.

Acknowledgments

This article is based on numerous discussions and explorations with many different people at many different times. Certainly, I am grateful to F.G. Balcombe, J.A. Thompson, R.E. Davies and J.S. Buxton for introducing me to cave diving; and to F.G.B., Thomas Cook, R.E.D., Phillip Davies, Derek C. Ford, Warren Hall, Christopher Hawkes and Oliver C. Lloyd for commenting on the first draft of this article - but really, the main acknowledgment must go to the numerous non-diving companions D. Hasell, J. Swithinbank, O.C. Lloyd and many others who located sumps, identified problems, obtained local permissions, discussed points involving safety with the divers; acted as controllers, and generally made the whole thing possible. (Dan Hasell was the controller for cave dives at Wookey Hole for many years. Jim Swithinbank located the sump in Threapland Cave, acted as controller, provided dinner at his home for eleven extra people after the dive described above, and so on. Oliver Lloyd took up cave diving in the 1960's and has greatly influenced the sport.) Why is it that such people are sometimes never even mentioned in cave diving accounts?

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Note Added in Proof

The walking diver in all three diagrams is tied onto a safety line which is held by a supporter on dry land. For longer dives it was common practice to lay lines from a reel. The device being carried by the exploring diver in Fig. 3 is the AFLO (Apparatus For Laying Out lines and underwater nagivation). The line reel is visible in Fig. 3 on this device.

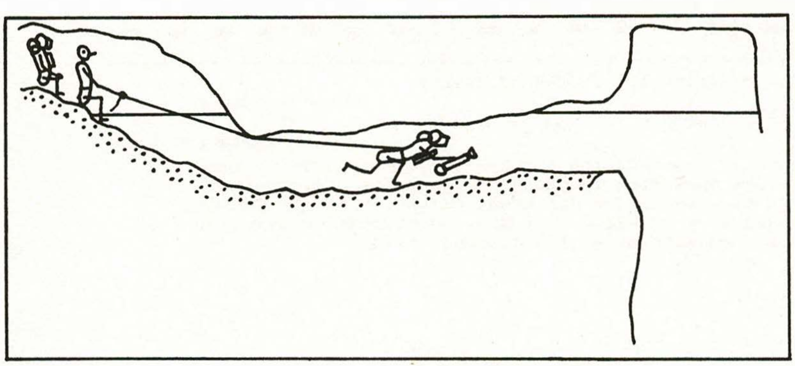

Figure 3. The basic question with a preliminary dive is whether the supporting diver should enter the sump with the exploring diver or whether, as shown here, he should remain on dry land and wait for a signal to go in.

An Analysis on the Palaeogeographic Elements of Karst Development in the Wumin Basin, Guangxi, Southern China

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Abstract

By analysing the distribution of caves and terraces, the lithology of sediments, the ancient vertebrate fossils and sporo-pollens in the Wumin Basin the conclusions may be drawn as follows:

1. During the Tertiary, the Wumin Basin was under erosion-denudation condition. The present peak-top plantion surface of 230-300 m above the sea level represents an old peneplain. In the Quaternary, the basin with its current karst features was gradually developed.

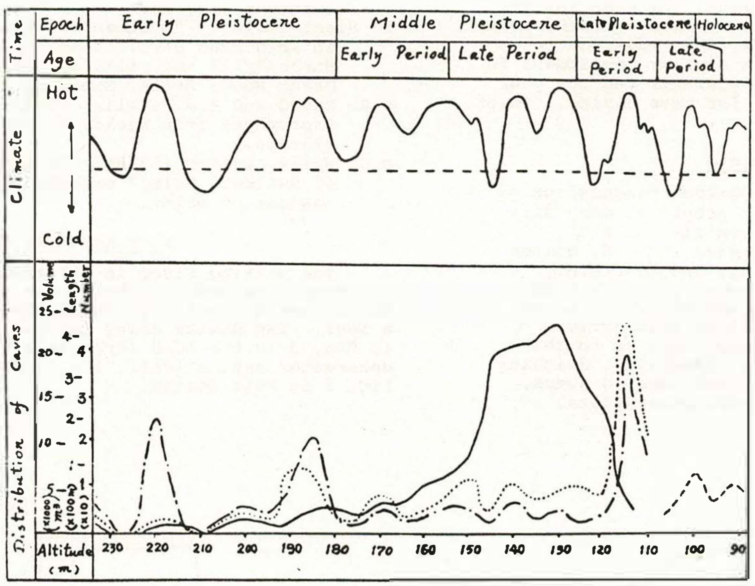
2. In the Quaternary, the paleoclimate experienced several great fluctuations with humid-hot conditions alternating with dry-cool climates. For instance, the accumulation of Gigantopithecus fauna fossils in the Ganxu Cave in the early Middle Pleistocene as well as Elephas maximus fossils and Liquidamber--Polypodiaceae--Pteris--Cyatheaceae monsoon forest sporo-pollens complex in the late period of Late Plesitocene, all reflect a moist-hot environment.

3. The rhythmic variations of the paleoclimate eventually lead to an unbalance of corrosion intensity. In addition, the base-level fluctuations which were resulted from the neotectonic movements and the global paleoclimatic variations resulted in an obvious differentiation of karst development intensity both temporal and spatial. The stratified caves at different level bear evidence to such a process (see figure).

4. As the latitude in the Wumin Basin begin rather low, the duration of humid-hot periods has been longer and, when entering into the dry-cool periods, the amplitude of temperature lowering has been less conspicuous. These are very favorable for corrosion action. For example, the corrosion-denudation intensity in the Elephas-peat accumulated period (about 30000-40000 B.P. as dated by C^{14} and correspondsing to a sub-interglacial stage of Würm glaciation), was more than double that of present day.

Consequently, the "peak-forests" (Fenglin) landscape in the Wumin Basin is a typical tropical karst topograhy, which has undergone repeated humid-hot environments since the Quaternary. To a certain extent, it represents the case nearby the Tropic of Cancer in south China.

From this it may be seen that the palaeogeographic conditions are a basic evidence to study the development of the karst geomorphology and exogenic process, as well as to divide the basic karst geomorphologic types.



The distribution curves of caves:

length — volume — number — relative value

Figure 1. Correlation between the trend curve of temperature variation in Quaternary and the distribution curve of caves along different elevation in the Ganxu--Changan area of Wumin, Quangxi. Distribution curve of caves (modified after Liu Jinrong, 1973).

Sur Le Contour Des Poljes Karstiques

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Résumé

Les levés géomorphologiques montrent bien que les poljés présentent des contours variés, généralement composites, d'où des problèmes de figuré. Ces contours peuvent être:

- rectilignes, traduisant un accident tectonique majeur, faille ou chevauchement: exemples du poljé de Minde (Portugal), de Duvno (Yougoslavie), ou dans les Préalpes françaises du S, celui de Caille.
- à vallées affluente avec souvent un cône de déjection actuel ou hérité à leur débouché dans le poljé (en Provence, partie N du poljé de Cuges), et même des cônes rocheux.
- sinueux, à embayements, et hums: Poljé de Nikšič au Montenegro, de Tripoli au Péloponèse.

Seul, ce dernier type de contour est caractéristique de la prépondérance des processus karstiques, dans des zones de fracturation intense:

- dissolution au contact et sous les alluvions de fond de poljé,
- érosion régressive à partir des ponors,
- tassements dans le poljé, soutirages (dolines),
- effondrements sur la bordure et à proximité (cf. dolines géantes sur le pourtour du poljé d'Imotski (Yougoslavie).

Cette prépondérance des processus karstiques se traduit par un contact brutal entre la plaine et le versant, un Knick net. Ce knick a un caractère ubiquiste: on le trouve aussi bien dans les poljés tropicaux que méditerranéens (cf. les embayements de la basse-plaine de la Neretva) et même tempérés: partie NW du poljé de Sault. Dans ce dernier cas, des versants nus et corrodés dominant les embayements s'opposent aux versants couverts ou de dépôts de pente (grèzes périglaciaires) présents dans d'autres secteurs. Un knick net traduit bien les parties actives d'un poljé.

Abstract

Geomorphological maps show clearly that poljes have various border types; their drawing problem of ten problematic. These borders can be:

- straight, along an important tectonic accident; fault or overthrust: Minde polje (Portugal), Duvno (Yougoslavia), Caille in the French Prealps;
- with affluent valleys showing actual or ancient alluvial cones (in Provence, South of France, northern part of the Cuges (polje), and even sometimes rock fans;
- sinous with embayments and hums Nikšič polje, Montenegro, Tripolic poljé, Peloponese).

Only this last border type is typical of the importance of the karstic processes in the very fractured zones:

- dissolution in contact with the poljé bottom alluvial deposits;
- backward erosion from the ponors;
- underground drainage and collapsing in the poljé (dolines);
- breaking down on the borders and nearly (giant dolines of the preponderance of these karstic processes is shown by a sharp contact between the plain and the slopes, a knick point.

The knick point is omnipresent: it appears equally in tropical (foot-caves) and mediterranean (embayments of the Neretva lower-plain) and even temperate (NW part of the Sault poljé in the Eastern Pyrenees in France). Concerning this last site, bare and corroded slopes dominating the embayments contrast with covered slopes. A sharp knick point really indicates the active borders of a poljé.

Le levé des cartes géomorphologiques à grande échelle (1/20 000, 1/25 000, etc) montre bien le caractère varié et composite des contours des poljés, ce qui pose des problèmes de figuré. Tantôt, ce contour rectiligne ou sinueux s'exprime clairement dans la morphologie, tantôt on en est réduit à fixer arbitrairement la limite du poljé à la plus haute courbe isohypse fermée, indiquée sur la carte topographique, ou à d'autres critères (rupture de pente), laissés à l'appréciation du cartographe.

Types De Contours De Poljes Mediterraneens

En simplifiant, et en fonction de notre connaissance personnelle de nonbreux poljés, 3 types essentiels peuvent être retenus:

1 - Des contours rectilignes traduisant un accident tectonique majeur: faille, ou chevauchement (à forte inclinaison). Ils s'expriment par des escarpements, qui peuvent être perpendiculaires entre eux (SE du poljé de Cuges). Un seul escarpement (Minde, Portugal), correspond à une fracture majeure souvent génératrice de barrage karstique; deux escarpements en vis à vis délimitent un poljé-graben (ex: p. de Cinquemiglia, DEMANGEOT, 1965); un système d'écailles peut donner aussi un escarpement rectiligne (S du poljé de Zafarraya, Andalousie).

L'escarpement rectiligne peut directement être hérité du mouvement tectonique (graben du Val di Diano, Campanie) ou être lié à l'exploitation d'une zone broyée provenant d'un coulissement actif (El Yammouné, Liban). Mais, le plus souvent, c'est le contact structural qui est exploité, et l'escarpement de "ligne de faille" est en partie dans des roches imperméables (Minde), ou semi-perméables (dolomies à Rogues, fig. 1a), qui déterminent le barrage karstique. Dans de nombreux poljés méditerranéens, l'escarpement bordier, déterminé par la fracturation, a été entièrement réglé en période froide par la cryoclastie (Duvno).

2 - Les contours irréguliers, à vallées affluentes sont présents dans de nombreux poljés. Très souvent, des cônes de déjection, actuels ou hérités, se trouvent à leur débouché, et rendent très malaisé la détermination du contour réel du poljé (Cuges, partie N, Fig. 1b). Souvent aussi, il s'agit de cônes rocheux (rock-fans), hérités, qui se raccordent à une banquette ou au niveau de corrosion du fond du poljé (N du poljé de Zafarraya, au débouché des vallons de la Sierra Gorda).

3 - Les contours sinueux, à embayments et hums, sont très caractéristiques des bordures des véritables poljés, au voisinage des ponors et des "estavelles" (inversacs). Le fond plat du poljé dessine une multitude de golfes au pied des versants corrodés, et il est parsemé de hums et de chicots, comme au S du poljé de Cerknica (cf. carte au 1/50 000° de GOSPODARIC'-HABIC' 1978), sur la majeure partie de celui de Nikšič, (fig. 1c). Au voisinage, les plateaux sont affectés d'une multitude de dolines d'effondrement, traduisant des phénomènes karstiques majeurs. Ce type de contour est vraiment caractéristique de l'activité karstique.

Processus En Action Sur Les Contours Sinueux, A Embayments Et Hums Karstiquement Actifs

D'une façon générale, ces portions de poljés, marquées par les phénomènes hydrogéologiques majeurs (ponors et inversacs) correspondent à des zones à haute densité de fractures, comme l'ont bien montré les recherches géotechniques (bordure W du Buško Blato, ROGLIC' 1972). L'inégalité de la fracturation explique d'ailleurs les hums résiduels.

Cette condition étant remplie, 4 processus sont à l'oeuvre:

1 - Les actions hydro-mécaniques au voisinage des ponors, sont en relation avec les variations brutales de charge des circulations karstiques, bien démontrées sur la bordure N et E du poljé d'Imotski par les dolines-lacs jouant le rôle de cheminée d'équilibre. Ces actions peuvent se traduire par des effondrements de bordure, le développement de vallées aveugles, l'apparition, dans le fond du poljé, de dolines d'effondrement sous-alluviales (signalée à Cuges au XIX° siècle), et, surtout au-delà du contour propre du poljé, la formation de grandes dolines et d'ouvalas, dont la coalescence peut préparer l'extension du poljé, suivant le modèle offert par le petit poljé de Njeguši (Crna Gora).

2 - La dissolution de bordure, en surface, est à mettre en rapport avec la nappe d'inondation, ou les marécages semi-permanents qui occupent très généralement ces portions de poljés. Ils sont dépendants des conditions hydrologiques: incapacité des ponors à absorber toutes les eaux (Cuges), multiplicité des sources

(N Moštarško Blato), mise en charge des inversacs et envahissement du fond du poljé par les eaux karstiques comme dans celui de Nikšič, relèvement flandrien du niveau marin (exemple classique des semi-poljés de la basse-vallée de la Neretva).

Dans les poljés montagnards (Pays de Sault, Kuprès), l'existence de tourbières, aux eaux très acides, augmente les possibilités de dissolution des bordures.

3 - La corrosion des bordures, est assurée, en profondeur, sous le niveau du poljé, par les eaux infiltrées dans les alluvions de fond de poljé, et y constituant des aquifères en relation avec les circulations karstiques. Ce type d'aquifère a été bien mis en évidence par les sondages dans le poljé de Zafarraya (LHENAFF, 1978; PEZZI, 1976), et dans ceux de Kestel (GÜLDALI, 1970).

On rappellera aussi l'importance du processus de crypto-corrosion (NICOD, 1975) au contact des argiles fersiallitiques, dans les petits poljés et ouvalas.

4 - L'érosion régressive, à partir des ponors de bordure, joue un rôle antagoniste du processus précédent. En incisant le fond du poljé, le cours d'eau fait apparaître, en les dégageant des alluvions, les surfaces de corrosion réalisées sous la couverture alluviale: ce processus est bien visible au voisinage du principal ponor du poljé de Duvno, où la rivière fait apparaître une banquette de corrosion (ROGLIC' 1972, KAYSER, 1973).

Les Contours De Poljé Et L'Evolution Morphoclimatique

Les contours sinueux, à embayments et hums, offrent une délimitation aisée, suivant un Knick, entre le fond du poljé et ses bordures. Toutefois, plusieurs types existent en fonction de l'évolution morphoclimatique.

1 - L'encoche basale de dissolution (Lösung-unter schneidung) caractéristique des poljés des tropiques humides, dans un contexte général de Kegel ou de Turmkarst, est en relation avec les eaux acides des marécages (Fig. 2a), et se traduit par la multiplicité des demi-grottes à la base des mogotes (Fusshöhle). Trois remarques limitent l'intérêt de cette forme spécifique:

- les demi-grottes sont liées à des sources karstiques à la base des tourelles (à Belize, d'après MACDONALD, 1976), alors que dans les poljés méditerranéens, les formes de corrosion sont principalement au voisinage des ponors;
- l'encoche basale de dissolution n'existe par partout dans les karst tropicaux: dans le Kelifely, à Madagascar, elle est absente, aussi bien sur le versant calcaire du poljé de bordure d'Ambodimanga, que des ouvalas amiboïdes.
- elle n'existe qu'exceptionnellement dans les poljés méditerranéens (cas du Lac des Rives, sur le Causse du Larzac).

2 - Dans les poljés méditerranéens, le Knick se trouve au contact d'une surface d'accumulation, celle du fond du poljé, et d'un versant. Il n'est donc que partiellement karstique.

Ce remblaiement suivant l'altitude et les conditions locales peut être indifféremment fluvio-glaciaire (hauts poljés du Montenegro ou de l'Appenin), périglaciaire (Duvno, Cuges), fluviatile (Popovo), fluviomarin (Basse-Neretva).

Deux cas sont à considérer:

a) le versant est parfaitement réglé (versant "de Richter"), et à peu près nu, comme ceux du Popovo (Fig. 2b), ou du rebord SW du poljé de Duvno. Les matériaux cryoclastiques, corrélatifs de cette morphogenèse, sont piégés dans le fond du poljé, ou ont été partiellement éliminés par la corrosion de bordure. Cela est particulièrement évident dans le cas du poljé de Sault, dans l'Ariège, où les versants sont nus dans le secteur des tourbières, et en partie masqués par des grèzes würmiennes dans une vallée affluente voisine près de Belcaire. Dans le cas du Popovo, le problème est plus délicat, car le remblaiement a un caractère alluvial, mais les versants réglés, ennoyés par lui à la base, sont nécessairement plus anciens.

b) les versants sont irréguliers et corrodés avec des poches nombreuses de terra-rossa, comme c'est le cas en bordure du poljé d'Otočak (Fig. 2d), remblayé d'un matériel lité, où les actions nivales sont plus nettes que l'effet de la cryoclastie. Dans ce cas, le Knick est entièrement karstique, et le fond de poljé, vraisemblablement commandé par le niveau de l'aquifère, s'est étendu aux dépens de la masse calcaire corrodée, et dont les formations résiduelles sont soutirées par le jeu des circulations karstiques au voisinage des ponors. Un tel dispositif témoigne de la continuité des actions karstiques:

- soit en raison de la nature dolomitique des roches formant les versants et reliefs résiduels (les dolomies étant moins gélives);
- soit du fait que la région a connu, au cours des dernières phases froides, une prédominance des périodes nivales sur celles de froid sec.

Les versants des poljés des Causses du Moyen-Atlas (MARTIN, 1977), particulièrement corrodés, correspondent à la conjonction de ces deux facteurs.

La cartographie détaillée des bordures de poljé, en mettant en évidence le rôle des divers processus et les incidences morphoclimatiques, a donc un double but:

- scientifique, en nous éclairant sur la genèse des dépressions majeures du karst;
- géotechnique, en attirant l'attention sur l'incidence de ces processus sur les activités humaines (étanchéité des réservoirs, stabilité des constructions, etc...).

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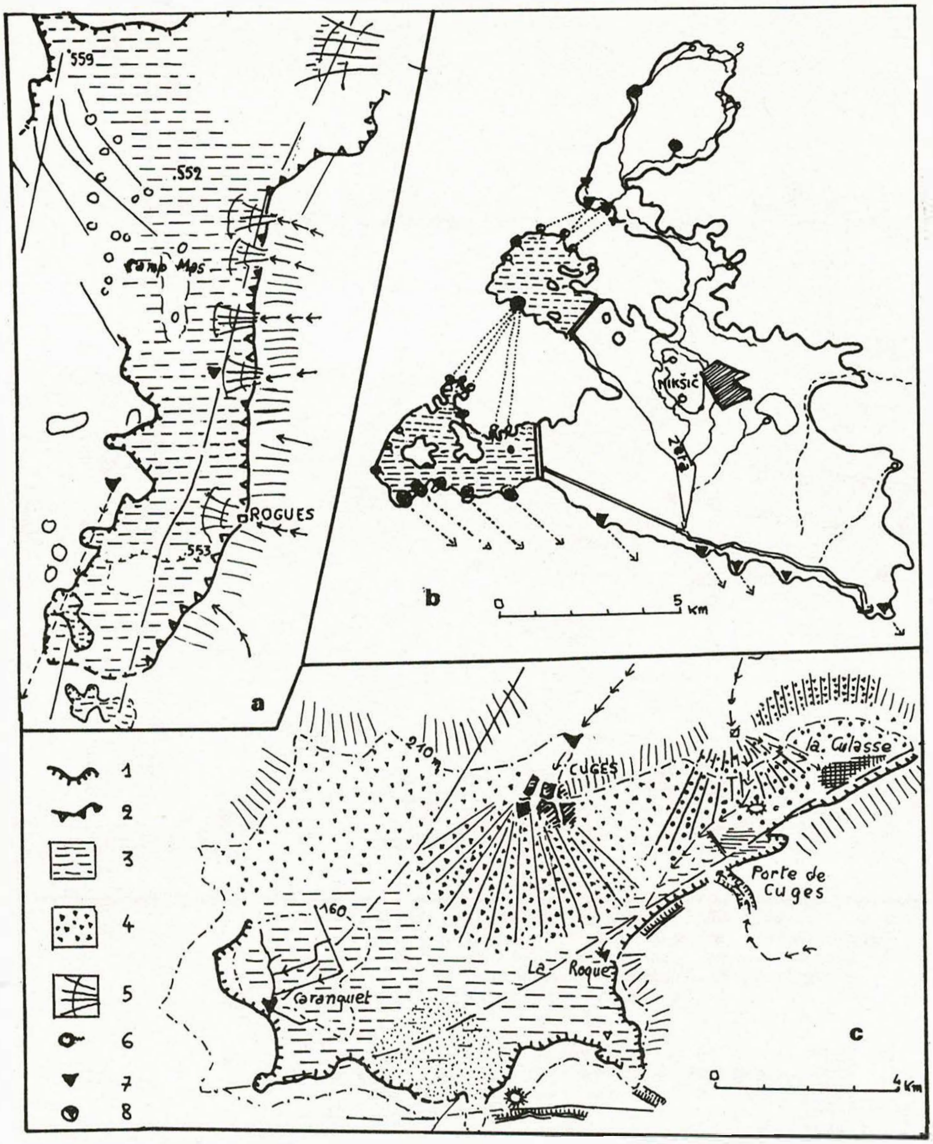

Figure 1. Contour de 3 poljés karstiques - Borders of 3 karstic poljes:
a) Rogues (Causse de Blandas), b) Cuges (Basse-Provence), c) Niksic (Montenegro) (d'après HERAK et RADOJICIC')

1 - Contour de corrosion-corrosion borders; 2 - escarpement tectoniques-tectonic scarp; 3 - terra-rossa; 4 - cryo-clasts; 5 - cône rocheux-rock-fan; 6 - source k.-karst spring; 7 - ponor; 8 - estavelle (inversac).

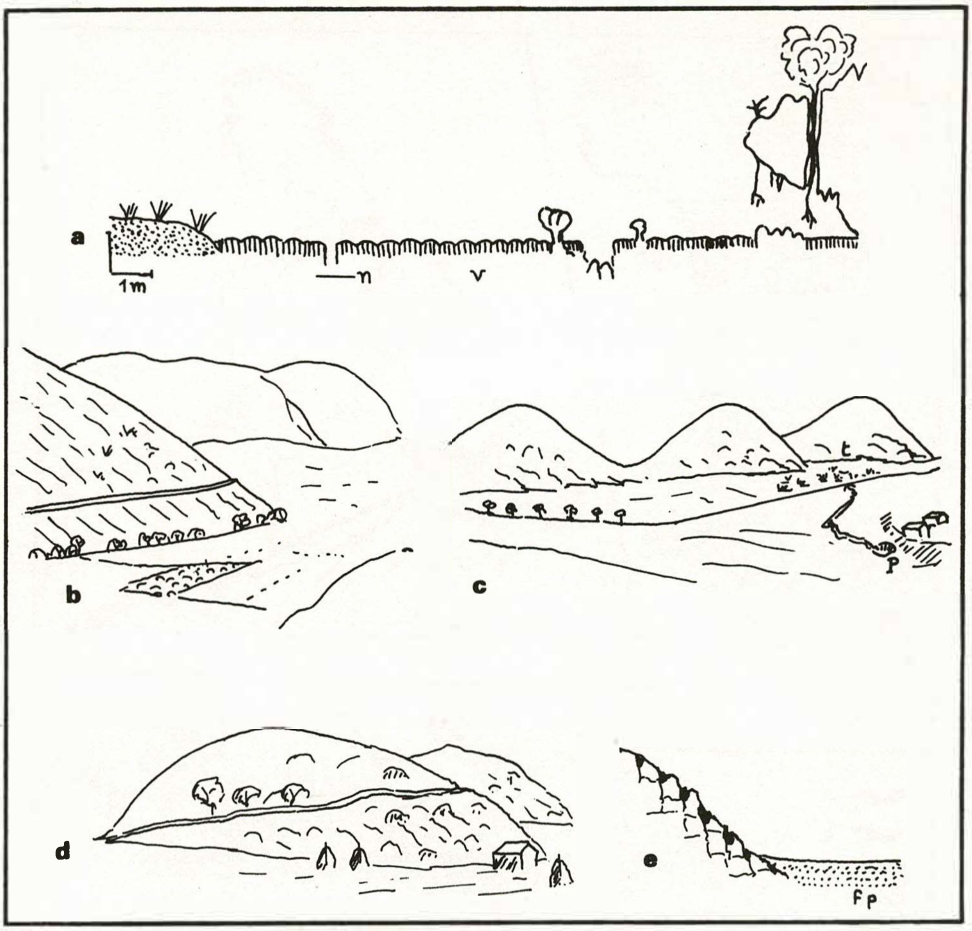

Figure 2. Contact brutal entre la plaine et le versant-
Sharp contact between the plain and the slope.
a) grottes basale foot-caves- dans le poljé d'Amboadoaka, Narinda, Madagascar
n: niveau de la nappe en saison sèche- groundwater in dry season;
v: vertisol
b) knick entre le versant réglé et la plaine alluviale-knick point between regular slope and alluvial plain - Popovo Poljé, Herzégovine.
c) Idem, à l'Ouest - in W border of - du Poljé de Sault (Pyrénées)
t: tourbières, peat-bogs
d) Knick entre un versant corrodé, à poches de terra rossa et la plaine alluviale - Knick point between corroded slope, with terra-rossa pockets and alluviale plain - E du poljé d'Otocak, Croatie.
e) coupe correspondante , fp -fluviatile à éléments périgl. fins

Hydrogeology of the Corchia Marbles (Apuane Alps-Italy): New Data From Water Tracing Experiments

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Abstract

The discovery of a new important cave near the top of the Corchia mountain obliged the authors to make water tracing experiments to discover if it was a part of the Antro del Corchia cave or not.

In the present paper the experimental results and the possible hydrogeological structure for the studied area are reported.

Sommario

Nei marmi del Corchia si trovano sia la grotta più profonda d'Italia (l'Antro del Corchia), che, 200 m più in alto 'Abisso Fighera. In vari punti le due grotte sono molto vicine ma non communicanti.

Nel 1979-80 é stata fatta una campagna di colorazioni che ha permesso di dimostrare che le due grotte fanno parte dello stesso sistema idrogeologico e di difinire per la prima volta le risorgenti del sistema.

Introduction

The Corchia marbles are one of the most important karstic areas of Italy and also here we have the deepest cave of Italy: the Antro del Corchia cave (-950 m), (Selvatici L., 1979).

A few years ago on the top of the Corchia Mountain a new important cave has been discovered and explored: the Fighiera pothole (-830), whose entrance is more than 200 m higher than the highest one of the Antrol del Corchia cave. (g. Badino, 1980).

In many points the two caves are very close to each other (fig. 1), but not connected as yet; moreover they contain several rivers, which seem to be quite independent from each other.

In the borders of the limestones area there are no large karstic, but only several small springs coming from fractures, each of which has a flowrate much lower than those of each of the subterranean rivers of the two caves.

For these reasons the authors decided to do water tracing experiments in the two caves, which were carried out from 1979 to 80.

The experiments showed that the two caves are a part of the same hydrological systems, which has almost all been defined, also it has been possible to define the risings of all the karstic system for the first time.

In the present paper the authors repost the experimental results and then discuss the possible hydrogeological structure for the studied area.

Geological scheme

The formations that constitute the Corchia mountain belong to the Metamorphis autochton unit, which is built up by medium-low rank metamorphism formations (epizone). (Carmignali L., Giglia G., 1977).

The lithologic, hydrologic and karstic features of these formations are summarized in Tab. 1.

Up to day there is not a full agreement about tectonic structure of Corchia M., but it can be stated that it's characterized by a syncline structure with marbles and nodular limestones in the nucleus and apparent dip towards ENE.

Most of the caves are developed inside the marbles; in the "Grezzoni" formation there are several small cavities and also some galleries of the largest ones (Antro del Corchia and Fighiera), which develop as narrow joints or phreatic tubes along bedding joints.

Experimental

3 kg of fluorescent dye was let in the river reaching in a rockfall at -750 m in the Fighiera pothole (fig. 2): to reach this river it was necessary to go down in a large 200m deep joint crossing the "Grezzoni" formation.

Recently polish cavers forced the rockfall and reached a sum at -830 m (807 a.s.l.).

Activate charcoal bags have been put in the Corchia cave rivers and in all the spring around the Corchia marbles (fig. 1), before the dye immission.

The charcoal bags of the external rivers and springs have been analysed two days after the dye immission, while those of the Antro del Corchia cave only a week after owing to a sudden flood due to an intense precipitation which began immediately after the dye immission.

The analyses showed very high dye concentration in the samples from Vianello river and Vidal river inside the Antro del Corchia, in spite of the strong washing undergone.

Of the external samples only those of the Cardoso zone, which were at an altitude equal or lower than 450 m a.s.l., were positive but with very low dye concentration, which can therefore be detected only by means of a spectrofluorimeter.

These results demonstrate that the dye went more than 5 km with a gradient of about 450 m in a time lower than two days.

Discussion

The water tracing experiments showed that the Fighiera pothole and the Antro del Corchia cave are in direct hydrological connection, being a part of the same karstic system with NW-SE flow direction and without any retarding basin.

Moreover owing to the fact that all the positive risings are at an altitude less or equal to 450 m a.s.l., this has to be regarded as the base level for the Corchia karstic system; but, due to the fact that this level it's the same of the Antro del Corchia bottom, it's impossible in this cave to find new galleries deeper than the present ones.

The presence of the base level of the hydrological system at the Antro del Corchia bottom can be explained in two different ways:

1) This altitude still is the actual base level inside the marble formation, and its higher level with respect to the surface one can be justified by the recent rejuvenation of the Apuane valleys.

2) This altitude represents the lowest limit of marble formation, and here the phyllite begins, whose permeability is only due to fractures.

The second hypothesis seems to be more probable: in fact if this altitude would correspond to a karstic base level inside the marble formation, it would be an active or, at least, fossil karstic rising in the zone. But we have only several little springs, suggesting a groundwater circulation which is extremely improbable inside the marble formation.

Moreover at the bottom of the Corchia cave the phillite formation can be seen and this obviously make stronger the presence of a marble phyllite boundary at this level, where, owing to their plasticity at the metamorphic temperature, the "grezzoni" formation has been bended by tectonic processes.

So that the hydrological situation of the Corchia M. can be reconstructed as in Fig. 2.

The Corchia karstic basin is formed by a large syncline with marble at its nucleus.

The two caves (Antro del Corchia and Fighiera) are in hydrological continuity and are parts of a single large karstic system, in which the water flows in NW-SE direction, even if with local deviations.

At the bottom of the Corchia cave there is the water inlet into the fillite and from this point the water circulation becomes phreatic along the tectonic fractures. At the end there are the risings in the Stazzema valley, all below the phreatic level defined by the Corchia cave bottom.

Conclusion

The water tracing experiments carried out in the two largest caves of the Corchia mountain led not only to the definition of the hydrological continuity and risings of the two karstic systems, but also to new informations about the hydrogeological structure of the Corcha marbles.

In fact due to the tracing experiments and the direct speleological observations, the general knowledges on the hydrology and the tectonic structures of all the zone have been largely increased.

Now to reach a complete definition of the hydrological basin it's necessary to control its NE boundaries and this will be possible in the next future, making the same tracing experiments starting from the river inside the "Uomo Selvatico" cave (see fig. 2) which has to be very close to the NE limit of the structure.

Acknowledgment

The authors thank the G. S. Piemontese, G. S. Bolognese, U. S. Bolognese, G. S. Faentino, and all the Speleological Groups of the Speleological Federation of Toscana for the help given during the water tracing experiments.

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Table 1. The Corchia M. formations with their lithologic, hydrologic and karstic features

Formation	Period	Lithologic type	Karstificability	Water circulation
Marbles	Jurassic	Marbles, saccharoidal and nodular limestones	high (large and complex caves)	well developped subterranean karstic rivers
"Grezzoni"	Triassic	weakly recrystallized dolomite	small (few important caves along tectonic structures	small phreatic tubes or large joints partially widened by corrosion
Phyllites	Paleozoic	Phyllites, porphyritic schist	none	small fractures

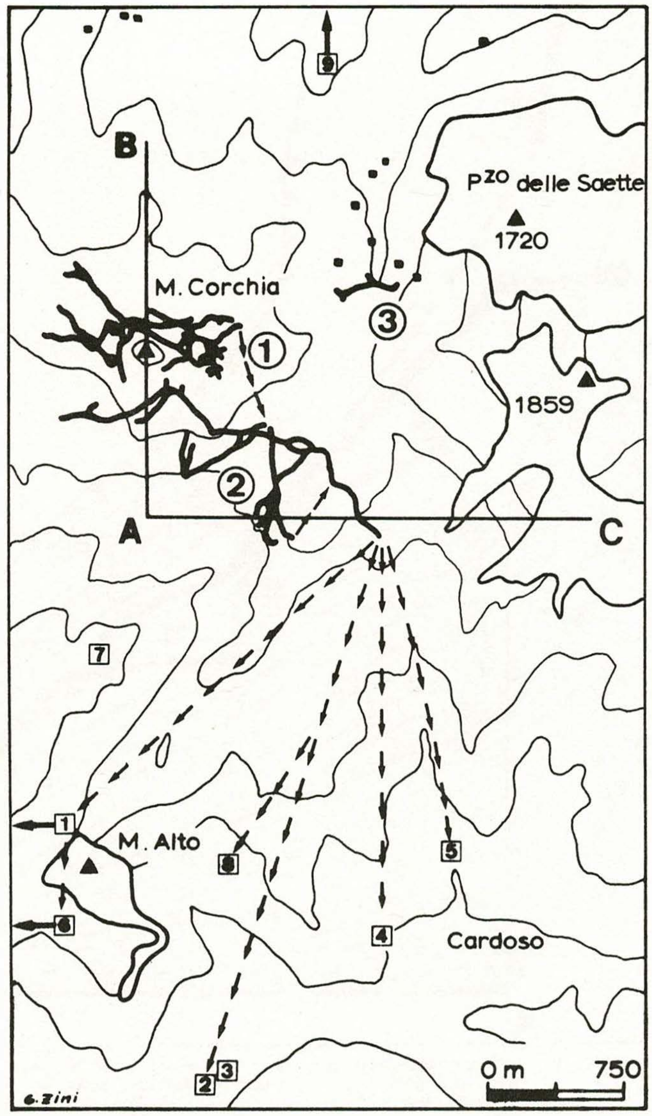

Fig. 1. The Corchia marbles area: 1) Fighiera pothole; 2) Antro del Corchia cave; 3) Uomo Selvatico cave? The risings are indicated by the numbers inside the small squares; the arrows show the dye underground way to the springs. In the Cardoso area only the 7 spring was not reached by the dye due to its altitude higher than 450 m a.s.l.
A-B and A-C are the directions of the section of fig. 2.

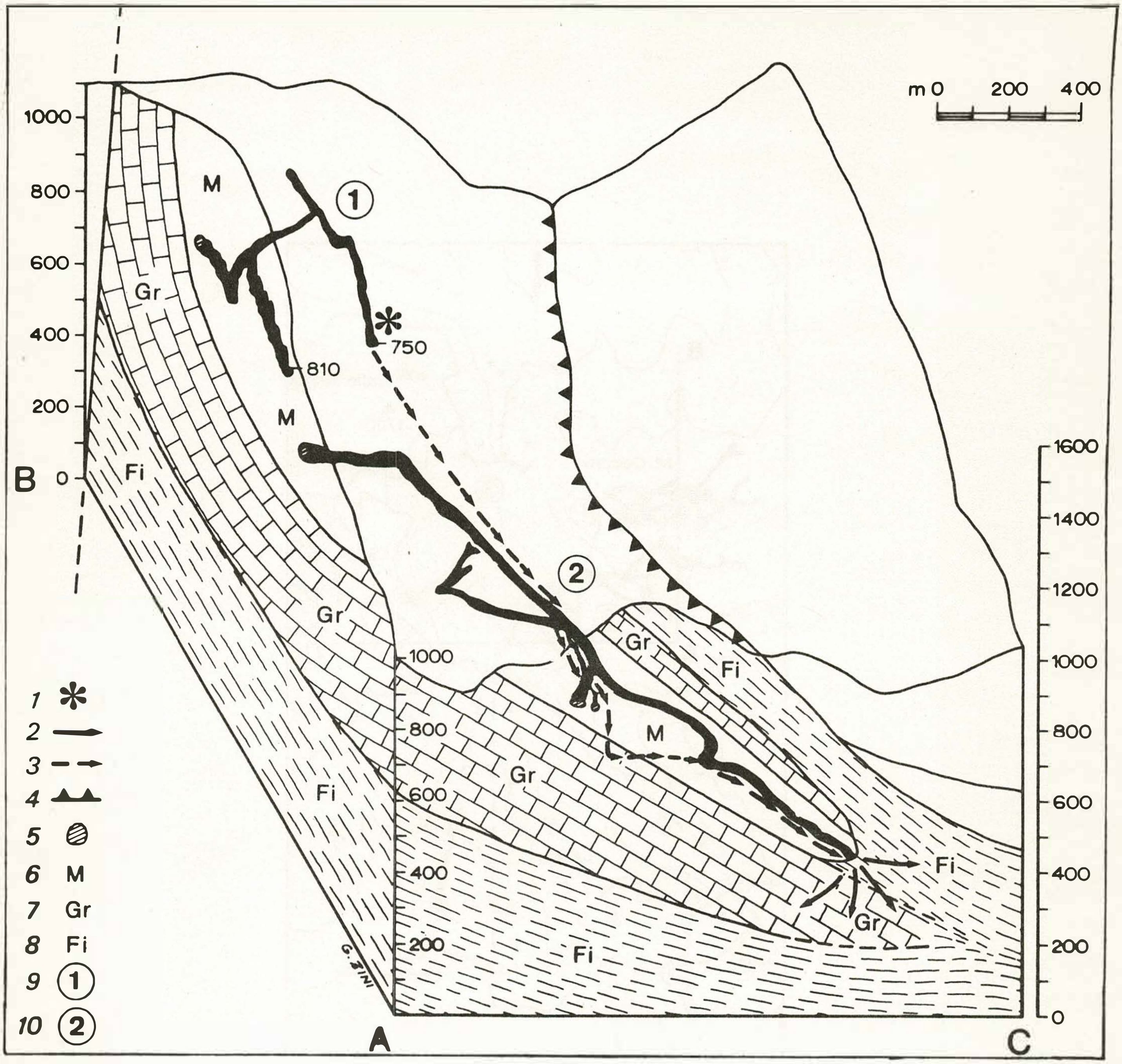

Fig. 2. The hydrologic reconstruction of the Corchia M. A-B and A-C are the same direction that in fig. 1. 1) dye inletting place; 2) dye dispersion after the sump at the bottom of the Antro del Corchia cave; 3) dye underground way 4) Boundary of the Metamorphis autochton unit; 5) sections of cave galleries which cross the A-B and A-C sections; 6) Marbles; 7) "Grezzoni"; 8) Phyllities; 9) Fighiera pothole; 10) Antro del Corchia cave.

Genetical Observations on some Macrocrystal Cave Pearls Found in Two Caves of Lombardia (Northern Italy)

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Abstract

Some small macrocrystal cave pearls were observed in two caves of Lombardia. The laboratory analyses showed that the smallest ones were perfect calcite monocrystals.

In the present paper the authors define the genetic physico-chemical conditions which caused the growth of such unusual cave formations.

Sommario

All 'interno di due grotte lombarde sono state rinvenute alcune pisoliti macrocristalline (0.1-4.0 mm), di cui le più piccole erano perfetti monocristalli di calcite.

Molte di queste ooliti risultavano essere del tutto prive di nucleo.

Nel presente lavoro vengono discusse le condizioni chimico-fisiche che hanno portato alla loro genesi.

Introduction

During a systematic morphological study carried out in the greatest karst cavities of Lombardia (Northern Italy), inside the Forgnone cave (1010 Lo/Bg) several uncommon ooliths (0.1-4.0 mm in diameter) (see fig. 2, A) were observed.

Some of these cave pearls were carried out and analyzed to define their genesis.

In the present paper these analyses are described and the conclusion from the experimental discussed.

Experimental part

The entrance of the Forgnone cave is in the Imagna valley at 750 m a.s.l..

The rocks in which the cave is carved belong to the limestones of Zu(Retic) and are pure limestone, marly limestone and marl, all well stratified from 10 to 18 cm thick.

Owing to the different karstificability of these rocks, the cave passages present several horizontal blades in the walls.

The cave (see fig. 1) is practically a single gallery with an active water flow inside.

There are also some side passages, the most important of which is the "Fossil-230 branch" (A and B in fig. 1); this is an ox-bow in the first part, while in the second there is water circulation, which sometimes partially fill this part as testified by the large mud traces present on the walls.

Just at the end of the 230 branch at 3 m from the floor and 2 m from the ceiling of the gallery there is a small wall pocket (see fig. 1, C) 12 cm deep and inside this cut there was a small amount of sand and mud, both white in colour.

The optical microscope analysis showed that the larger fraction of the sand (1.0-4.0 mm) consists in quite spherical macrocystal ooliths not smoothed or rounded at all (see fig. 2,A).

Their surface is characterized by the juts of the tops of several not eroded calcite crystals (external acicular structure: Ullastre and Masriera, 1973).

Some of these cave pearls (about 50) were sectioned to expose their nuclei, and the thin sections showed that the ooliths are of two different kinds.

The first one (see Fig. 2,B) is the "normal" one, and has a fibrousradial (spherulitic) strucutre with calcite crystals elonged along the Z axis and starting from a nucleus built up by a superficial oolith grown on a non calcareous grain.

The superficial oolith consists of calcite microcrystals while the external part (spherulitic) of large calcite crystals.

The second kind of pearls are quite equal to the first one but has no nucleus (see Fig. 2,C): all its structure consists of calcite macrocrystals, often with concentric impurity layers, which don't interrupt the radial deposition of the crystals (Ullastre and Masriera, 1973).

Some ooliths of the second kind showed an interruption in the crystal growth due to an aphanitic layer of calcite crystals of the surface of a smaller ooliths all over the layer and the radial structure of calcite macrocrystals is repeated.

The smaller fraction of the sand (0.1-0.2 mm) has been analyzed by a scanning electron microscope and consists of rombohedral calcite monocrystals: traces of cleavage are evident and in the center of the faces of the principal rhombohedron there are one or more tops of inverse rhombohedrons with different orientations.

Discussion

The position in which the ooliths have been found is too high to be reached by the river water even when the level changes in the 230 branch.

Moreover they can't be reached by dripping water owing to the fact that the cup, in which the pearls are, is protected by a limestone blade.

For these reasons the only water which can reach the cup is the thin condensation layer ever present on the walls and always in movement more or less on a downward level.

Nevertheless water supply has to be sufficient to avoid the ooliths linkage to the cup floor, but at the same time it has to be not too strong, otherwise the tops of the crystals on the pearls surface have to be smoothed.

So that the growing conditions are those of quiet environment interested by continous supply of water saturated with respect to $CaCO_3$.

The water condensation certainly undergoes periodical (seasonal) and aperiodical variations due to the hydrological conditions of the gallery.

Sometimes there are favorable conditions for water evaporation with consequent supersaturation and then $CaCO_3$ precipitation.

Insulated monocrystal can grow due to the quiet condition existing in the wall pocket; with the crystallization progress in the centre of the faces of the original crystal the inversal rhombohedrons appear and due to the growing process they come in contact to each and form the ooliths without nucleus, if we don't count the rhombohedron which has firstly crystallized as a nucleus.

So that the structure of these ooliths has to be considered primary and not diagenetic.

The aphanitic layers of calcite microcrystals are to be ascribed either to periods in which no crystallization takes place (Gnaccolini, 1978), or more probably to periods in which the water supply was larger than the noraml one, and consequently due to the water stirring inside the cup, microcrystals and not macrocrystals were deposited.

The ooliths with nucleus have the normal origin as described in several other papers; but it's interesting to notice that the length of the crystals grown on the superficial oolith is of the same dimension of those grown on the aphanitic layer in the pearls without nucleus.

This fact seems to test the hypothesis of an higher water circulation for the growth of microcrystals and also demonstrates the occurrence of periods of exceptional water supply which caused the paphanitic layer of the pearls without nucleus, while at the same time, bringing non calcareous nuclei into the cup, give to the "normal" ones the possibility to develop.

Conclusion

The analysis of this particular kind of cave pearls allow us not only to prove the existence of anomalous ooliths in which the nucleus is completely absent, but also demonstrate that the cave undergoes periods of high and low water supply: the first of which is responsible of the growth of the radial macrocrystals and of the monocrystals, while the second of the discontinuities in the crystal growth and of the supply of non calcareous grains, which are utilized as nuclei for the "normal" ooliths.

A short time after the finding of the Forgnone pearls, other similar have been observed in the same zone, inside the Buco del Castello cave (1309 Lo/Br).

This fact clearly indicates that the genetical mechanism as described has to be considered not exceptional and perhaps is quite common but not observed till now owing to the small scale at which it can be noticed.

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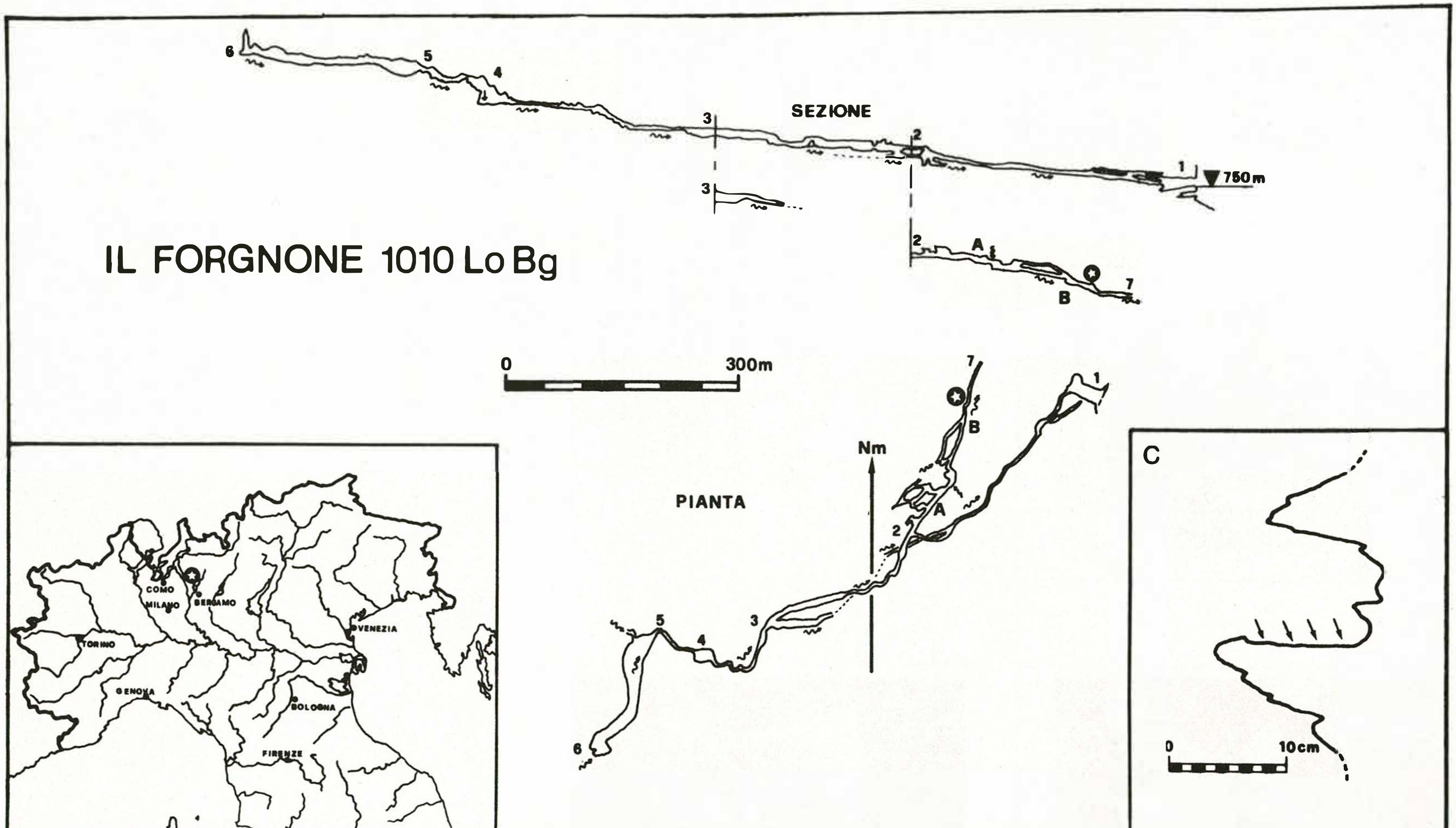

Fig. 1 The Forgnone cave: A-B is the "Fossil-230 Branch"; the star indicates the place in which the ooliths have been found. C: the section of the gallery wall, with the cup

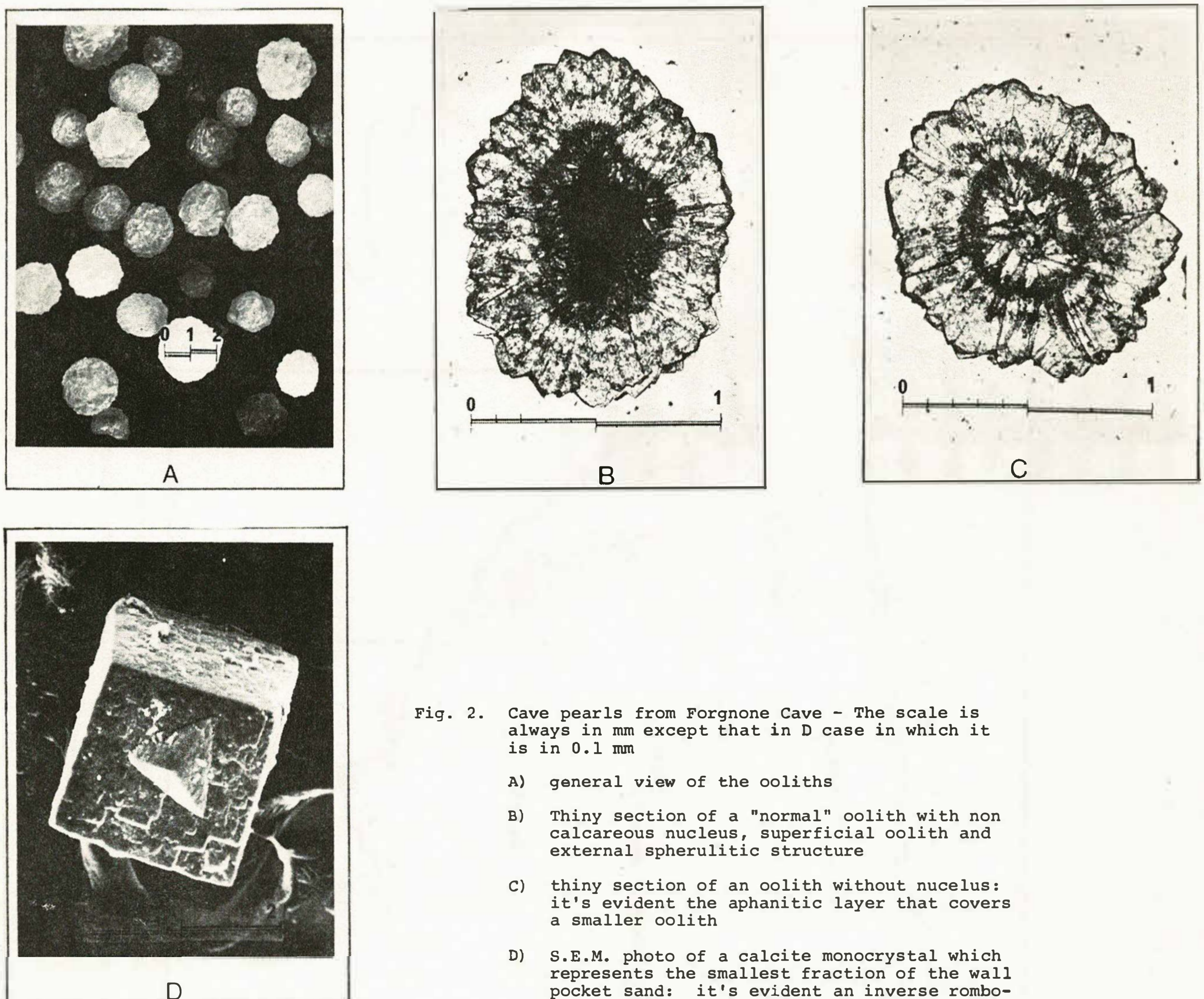

Fig. 2. Cave pearls from Forgnone Cave - The scale is always in mm except that in D case in which it is in 0.1 mm

A) general view of the ooliths

B) Thiny section of a "normal" oolith with non calcareous nucleus, superficial oolith and external spherulitic structure

C) thiny section of an oolith without nucelus: it's evident the aphanitic layer that covers a smaller oolith

D) S.E.M. photo of a calcite monocrystal which represents the smallest fraction of the wall pocket sand: it's evident an inverse rombohedron in the centre of a face of the crystal.

The "Karstic Reactivation" Theory and the Epipalaeolithic Sites of Northern Spain

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Abstract

In the 1950's, the "karstic reactivation" theory developed by N. Llopis Lladó was used by this and other investigators in order to reject the arguments on the stratigraphic position of the Asturian, a local Epipalaeolithic culture, as established by Vega del Sella in the early twenties. The supposed implications of 'karstic reactivation" with the deposition-erosion sequence in Late and Post-Palaeolithic sites is analyzed in this paper. The conclusion points towards the validity of Vega del Sella's depositional scheme, supported by stratigraphic sequences and radiocarbon dating, and the lack of evidence in favour of Llopis' interpretation.

Resumen

En los años cincuenta la teoría de la "reactivación kárstica" desarrollada por N. Llopis Lladó fue utilizada por éste y otros investigadores para rechazar los argumentos sobre la posición estratigráfica del Asturiense, una cultura Epipaleolítica local, tal como habían sido establecidos por Vega del Sella a comienzos de los años veinte. En esta comunicación se analiza la supuesta implicación de la "reactivación kárstica" con la secuencia de depósito y erosión de los yacimientos del Paleolítico Final y Postpaleolítico. La conslusión apunta hacia la validez del esquema de depósito propuesto por Vega del Sella, apoyado por secuencias estratigráficas y dataciones de radiocarbono, y a la falta de evidencia en favor de la interpretación de Llopis.

Resumé

Dans les anneés cinquante la théorie de la "reactivation karstique" développée par N. Llopis Lladó fut employée par celui-ci et par des autres chercheurs pour rejeter les arguments sur la position stratigraphique de l'Asturien, une culture épipaléolithique locale, tels qu'ils ont été établis par Vega del Sulla au début des années vingt. Dans cette communication on analyse les implications supposées de la "reactivation karstique" avec la séquence de dêpot et d'erosion des gisements du Paléolithique final et du Post-paléolithique. La conclusion vise a la validité du schema des processus de dêpot de Vega del Sella appuyée sur les séquences stratigraphiques et les datations de radiocarbone, et au manque d'evidence pour accepter l'interpretation de Llopis.

Historical Background

In 1914 the Count of Vega del Sella dug a test pit in the cave of El Penicial, close to the small village of Neuva (Asturias, Spain), finding a prehistoric industry, unknown in the current archaeological record. The lack of a clear context led him to assign these materials to the Lower-Middle Palaeolithic transition, only on typological grounds (Vega del Sella, 1914).

The systematic research conducted by this archaeologist during the following years in several sites of Eastern Asturias offered him a considerable amount of information about this particular culture, called Asturian, a denomination created by H. Obermaier (Obermaier, 1916, 1924). The most important features of the Asturian were a lithic industry dominated by choppers and, specially, very typical picks made from quartzite cobbles: the "Asturian picks"; and also the association of this industry to shell-midden sites, preferently located on the coastal areas of Eastern Asturias and Santander, in the North of Spain (Figure 1).

These shell-middens, the "concheros", commonly appear in cave mouths or under rockshelters in protected zones, with important concentrations close to the estuaries. The character of this culture has been analyzed in detail in some studies (Vega del Sella, 1923; Clark, 1976; González Morales, 1981).

The Nature of Asturian Deposits

We have said that most of the Asturian sites were shell-middens. Strictly speaking, they are usually the remains of shell-middens. After the accumulation of Asturian deposits at the entrance of caves and rock-shelters there was an erosive phase that affected them, with very few exceptions, destroying the main part of the middens. The evidence we commonly find today is limited to fragments of the original deposits cemented against the walls and/or ceiling of caves and shelters.

As these cemented deposits appeared always over Upper Palaeolithic strata in caves, or Asturian-type tools were found on the surface of some sites, Vega del Sella assigned them to a post-palaeolithic date, and proposed the following depositional scheme (Figure 2):

-Deposit of Upper Palaeolithic layers
-Deposit of Asturian conchero
-Period of partial concretion of the shell-midden
-Destruction of the conchero by the action of water, leaving fragments cemented against the walls and/or ceiling (Vega del Sella, 1923: 9-10).

This sequence of facts was supported by some other arguments: at least in one site (the cave of La Riera), the conchero remained intact, because it was covered by a very thick stalagmite crust and, on the other hand, the cave itself did not seem to have any water circulation (at least of the necessary volume) after the deposition of the shell-midden; the crust sealed a very complete sequence of Upper Palaeolithic levels. At La Riera the stratigraphic position of the Asturian was, therefore, quite clear; in other sites, like the cave of Jonfría (=Fonfría), close to La Riera, the facts were similar (Vega del Sella, 1930).

Vega del Sella's scheme was considered valid until the development of Llopis' theory and its application to this matter.

Llopis' Point of View

In 1953, N. Llopis Lladó and other investigators explored some caves in La Llera, a limestone massif close to Posada de Llanes (Asturias), where La Riera and other caves are located (Llopis, 1953a, 1953b). As a result of these explorations, Llopis suggested the idea that Asturian middens were allochthonous deposits and that there had been an erosive phase before the deposits of Late Palaeolithic levels. In a further development of this theory, Llopis seemed to say that the concheros were redeposited at the entrance of the caves, transported from their original location by the action of the waters (Jordá, 1954:178-179).

In 1957 the problem goes one step beyond; Llopis and other authors formulated the consequence of prior arguments: the great antiquity of Asturian industries and sites, the former opinion justified by their crud aspect, the later one by the arguments cited above, now reinforced by the "demonstration" obtained in the caves of La Cámara and, specially, La Lloseta (Hernández-Pacheco et al., 1957: 23-24).

Llopis applied his ideas about speleogenesis and cycles in the evolution of caves to the problems of the Asturian sites as follows: since the shell-middens have been heavily cemented after their deposition, in the case of cyclical reactivation of Karstic circulation, the waters would destroy the less consolidated Upper Palaeolithic levels, and not the shell-midden.

In the cave of La Cámara, near Meré (Llanes, Asturias), Llopis and his colaborators find what they supposed was a validation for that hypothesis: two fossil resurgence mouths, located at different levels overlooking the Río de Las Cabras (+5 m. and +8 m.); in the upper one there is an Asturian conchero with typical picks; in the lower one scanty remains of archaeological layers are to be seen cemented against the ceiling. These facts were interpreted by Llopis as evidence of several stages of occupation: first, the upper cave was inhabited, while the lower one was still active as a resurgence; after the end of water circulation through this last cave, it was occupied, "maybe in Magdalenian times". On the basis of such evidence a pre-magdalenian date was proposed for the Asturian conchero.

In this interpretation there are several major debatable points. First of all, there is no evidence, as far as we know, for the assignation of the archaeological strata in the lower cave precisely to the Magdalenian. The only thing we can see now at the cave are some cemented patches that include flint and quartzite flakes and fragmented bones which in any case could be considered roughly of Upper Palaeolithic age, without a higher degree of precision. Second, in this cave the erosive destruction of Upper Palaeolithic levels is plainly evident, and the Asturian shell-midden, located at a slightly higher level, was preserved. Third, the Palaeolithic deposits at the lower cave filled it completely, as attested by the remains cemented against the roof; so, any later occupation would necessarily take place in the upper entrance.

The conclusion is that the data available from La Cámara cannot support Llopis' interpretation, the alternative hypothesis (Asturian occupation later than the Upper Palaeolithic one) seeming more probable. In fact, the sequence: "prior Upper Palaeolithic occupation in the lower cave/deposit of Asturian midden in the upper mouth later" is non-contradictory and easier to accept.

Approximately at the same time, F. Jordá developed some consequences of Llopis' theory, applying them again to the problem of the chronology of Asturian deposits. Jordá paid speceial attention to the consolidation or "petrification" of shell-middens, emphasizing the fact of that "petrified" breccias were more resistent to the erosive action of the waters than the "loose" Upper Palaeolithic levels. In his study of the cave of La Lloseta (= de La Moría o del Río), near Ribadesella (Asturias), this investigator developed such argumentation in detail, as a definitive basis for his own hypothesis about the very old chronology for the Asturian industries. About this cave, Llopis even explained that the cemented remains of Asturian conchero were covered by Magdalenian deposits, again a supposedly definitive proof of their point of view (Llopis, 1970: 177-178).

But there were a couple of aspects which seemed to be forgotten. First of all, the idea of the original concheros as petrified masses of shell cannot be supported by an evidence; of course, the shell-middens seemed to have great dimensions in some caves, reaching the roof and walls of cave mouths. But the only cemented parts of these middens were just the ones located in contact with roof and/or walls where a necessary amount of precipitation was present: because of that we very often find fragments of conchero hanging from stalactites or dripstones. The midden itself was loose, even when covered by great travertine formations, like at La Riera, and this mass of shells is very easily eroded by water action.

Second, and more important, at La Lloseta there is in fact a cemented shell-midden deposit on the walls, covered by Magdalenian levels. But it is not an Asturian shell-midden, but a Magdalenian one. In this cave there is evidence of two clearly separated levels of conchero remains on the walls: the lower one correspondes - as faunal remains and C_{14} shows - to the Lower-Middle Magdalenian, and the upper one - not covered, of course, by Magdalenian levels - has been radiocarbon-dated as Late Asturian. In this case it seems evident that the mechanical identification "shell-midden" = "Asturian" led Llopis into a very serious mistake.

Third, at La Lloseta the action of the waters as an erosive agent is very doubtful: in a recent study M. Hoyos concluded that the deposits in the cave collapsed, maybe because of techthonical or gravitational adjustments of blocks in the cave system where La Lloseta is located; so, the actual position of shell-midden remains cemented against the walls is due to such fall, and not the result of hydric erosion (Mallo et al., 1980).

And a final comment on the idea proposed by Llopis of Asturian shell-middens as allochthonous deposits having been transported to cave mouths by the water: recent sedimentological studies of Asturian conchero samples reveal their character of cultural deposits, and there is no evidence of secondary deposition (Butzer and Bowman, 1976).

Conclusions

Briefly, the main conclusion we can retain is the lack of evidence supporting Llopis' points of view about the erosive actions on Asturian concheros supposedly related to ancient cycles or karstic reactivation. As far as we know from recent studies and, specially, radiocarbon dates, the erosion of Asturian shell-middens took place in a quite recent date, maybe during the Subboreal or Subatlantic phases.

The sequence proposed by Vega del Sella in the second decade of this century seems to be the correct one, a more simple and logical interpretation of the facts, and now reinforced by new studies and analyses. The radiocarbon information places the Asturian concheros between 9.000 and 5.000 years B.P., this culture being a long-term coastal adaptation as many others in Mesolithic Europe.

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An Evaluation of the Polaroid Ultrasonic Ranging System as a Tool for Cave Surveying

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Abstract

The ultrasonic ranging system consists of an ultrasonic transmitter/receiver, a pulse detection circuit and a visual display. This device was evaluated in both the laboratory and caves for its usefulness, reliability, accuracy and ease of operation. Its limitations as a cave surveying tool are defined and enhancements are recommended. A new surveying methodology which uses the device's attributes is presented. A cave map produced with the help of this device is shown.

Zusammenfassung

Die Ultraschallmessverfahren-Vorrichtung besteht aus einem Ultraschall-Sender/Empfänge, einem Schwingungsdetektor-Stormkreis and einer Leuchtziffer-Skala. Diese Vorrichtung wurde sowohl in Laboratorium als auch in Höhlen auf Nützlichkeit, Zuverlässigketi, Genauigkeit und Handlichkeit gestestet. Die Grenzen seiner Benützung als Höhlenvermessungs-Hilfmittel werden definiert und Verbesserungen empfohlen. Eine neue Vermessungs-Methode, in welcher die Eigenschaften dieser Vorrichtung zur Anwendung kommen, wird dargelegt. Eine Höhlenkarte, die mit Hilfe dieser Vorrichtung angefertigt wurde, wird gezeigt.

The Hardware

The Polaroid Ultrasonic Ranging System is a range measuring device manufactured by the Polaroid Corporation of Cambridge, Massachusetts, USA. The ranging system, as we implemented it, consists of three basic subsystems: the transducer, the electronics and a mounting system.

The transducer is cyclindrical in shape, about 38 mm in diameter and 8 mm thick. It has a foil stretched over a grooved plate. When the ranging system is activated, the transducer emits a pulse of sound, then waits to receive the echo returning from whatever object the sound pulse has struck. The emitted pulse is a high-frequency, inaudible pulse lasting for 1 millisecond and consisting of 56 pulses of 4 ultrasonic frequencies: 60kHz, 57kHz, 53kHz and 50kHz. Using 4 frequencies overcomes the possibility of a single frequency being cancelled by a target of a particular shape in which case there would be no echo from the target.

The electronics consists of two circuit boards, one to control the transmitting/receiving function and the other to generate a digital display. A digital readout displays measured distance to a tenth of a foot five times each second. Its range is 0.9 to 35 feet (0.3 to 10.7 meters). Polaroid evidently does not manufacture a display circuit for distances in meters. Figure 1 is a block disgram of the electronics.

The mounting system is comprised of a collapsible camera tripod, a protractor and the packaging of the transducer and the electronics. The ultrasonic transducer was mounted in a small metal box which in turn was fastened to the tripod. The box was free to rotate about the protractor indexed to measure the relative change in angle. All the circuits and the batteries were placed in another metal box. The power switch and digital display were positioned on one face of this box. Figure 2 shows how the equipment was arranged.

Cave Mapping with the Range Finder

The range finder's main attribute as a tool for cave surveying is its ability to rapidly measure distances. However, with almost any cave surveying technique, measuring distance is usually musch easier than determing azimuth and inclination. Thus for the instrument to be useful it would have to work much faster, easier or more accurately than the conventional method of stretching a survey tape. T-e range finder is not as accurate (± 0.1 foot) as a tape measure but it could determine the distance to points where a tape could not be carried such as across a pit or to an unreachable ceiling. In addition, because of the speed of taking measurements we could record many more measurements than is normally done. These readings could be used to provide far more detail about the cave than with conventional methods.

A small portion of Greenhorn Cave, a granite cave in California, was used to test the equipment and our procedures. To obtain the floor plan of the cave we set up the transducer on the tripod so it could be rotated about the vertical axis. Measurements were taken every 10 degrees all the way around the axis. The mounting was then rotated 90 degrees so another 36 measurements could be taken in the vertical plane thus recording the cross section of the cave passage. Again the mounting was rotated to take readings in a plane perpendicular to the other two. For each survey station we took 36 measurements in each of 3 mutually perpendicular planes for a total of 108 data points. For each survey station roughly 40 minutes were required to set up the equipment and take the 108 measurements. The survey stations were linked together with conventional methods using a Suunto compass, a Suunto compass, a Suunto inclinometer and a tape.

The polar coordinates of each set of 36 measurements were converted to a 3-dimentional Cartesian coordinate system. Figure 3 shows the type of measurements which were taken at each station.

At each survey station we had the shape of the passage in 3 mutually perpendicular planes. At this point we could have used the data to pick off the plane, profile or cross-sectional views of the cave. We, however, wanted to use all the data in one diagram representing the area surveyed. To do this we wanted to project the cave data as if we rotated the points b y angle Θ about the vertical axis and then viewed the cave from an angle Φ above the horizontal plane. The matrix equation

$$\begin{pmatrix} x^1 \\ y^1 \\ z^1 \end{pmatrix} = \begin{pmatrix} \cos\Phi\cos\Theta & -\cos\Phi\sin\Theta & -\sin\Phi \\ \sin\Theta & \cos\Theta & 0 \\ \sin\Phi\cos\Theta & -\sin\Phi\sin\Theta & \cos\Phi \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

gives the required transformation between the two Cartesian coordinate systems.

The calculations were done on a Hewlett-Packard 9830 desktop computer. Since the H-P 9830 did not have enough memory to handle a hidden line algorithm, the entire figures were drawn out for each plane on the H-P plotter. The final pictures (Figure 4) were obtained by selecting the lines so the mutually perpendicular planes would be shwon. Each orientation of the planes was given a differnet type of shading lines. In addition, 3 sides of a 5x5-foot box were drawn as if viewed from the same vantage point used to view the cave. Figure 4 gives 2 views of the same data from opposite viewpoints. Both are taken as if viewed 25 degress above the horizontal plane.

Evaluation of the Ranging System

The laboratory evaluation consisted of ascertaining the accuracy and effectiveness of the basic principles which we planned to use in the cave. The range resolution of 0.1 foot (0.03 meter) was deemed accurate enough and there was no significant degradation of performance noted using the packaging system we had implemented. The instrument often gave erroneous readings if the transducer was aimed either towards a corner, or so it had a low grazing angle with a flat surface. In these cases the readings fluctuated even though the transducer was stationary.

Caves are usually irregular in shape and the boulder cave we mapped was exceedingly so. As with all line-of-sight measuring devies, some forethought and planning should be exercised to preclude erroneous sampling attributable to overhangs and other obstacles.

In the cave environment the range finder provided to be versatile and easy to use. The speed of operation has already been mentic d. One of us would operate the transducer and call out the readings while the other would record the data. Much more detail can be included in the survey with a significant savings in time.

The range limit of 35 feet (10.7 meters) proved to be no obstacle in Greenhorn Cave. It could, however, be a significant factor if an area had a radius larger than the maximum range of the system.

This system promotes safety since it is no longer necessary to ascend or traverse hazardous areas in order to obtain survey data. Just aim the transducer over the hazardous area, take a reading and record the range.

Any person considering purchasing the Polaroid ultrasonic ranging system should understand that it is necessary to ruggedize and encapsulate the transducer and circuit boards before taking the system into a cave. Even then it must be treated as a delicate instrument.

The booklet provided by Polaroid with the ranging system gives several suggestions on how to adapt the performance of the unit to specific needs, such as how to increase the sampling rate of the transducer but rather of the decoding circuit. A redesigned circuit could greatly enhance the range.

In conclusion, the merits of the system are: 1) ease of operation, 2) rapid smapling rate, 3) operable by one person, 4) compactness, 5) light weight, 6) accuracy, and 7) safety. We believe safety (hazardous areas can be avoided) and the speed of taking measurements are the two most important factors in favor of using this system.

Reference

Polariod's booklet on the Ultrasonic Ranging System. S. Kempe and P. Schneider critiqued the German translation.

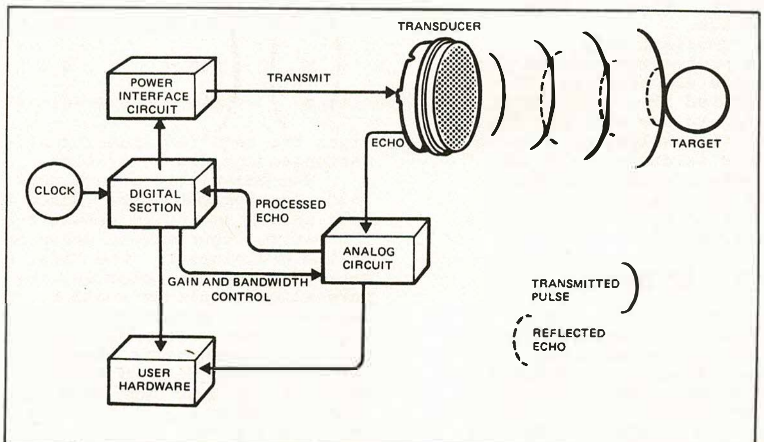

FIGURE 1. BLOCK DIAGRAM – TRANSMITTING/RECEIVING

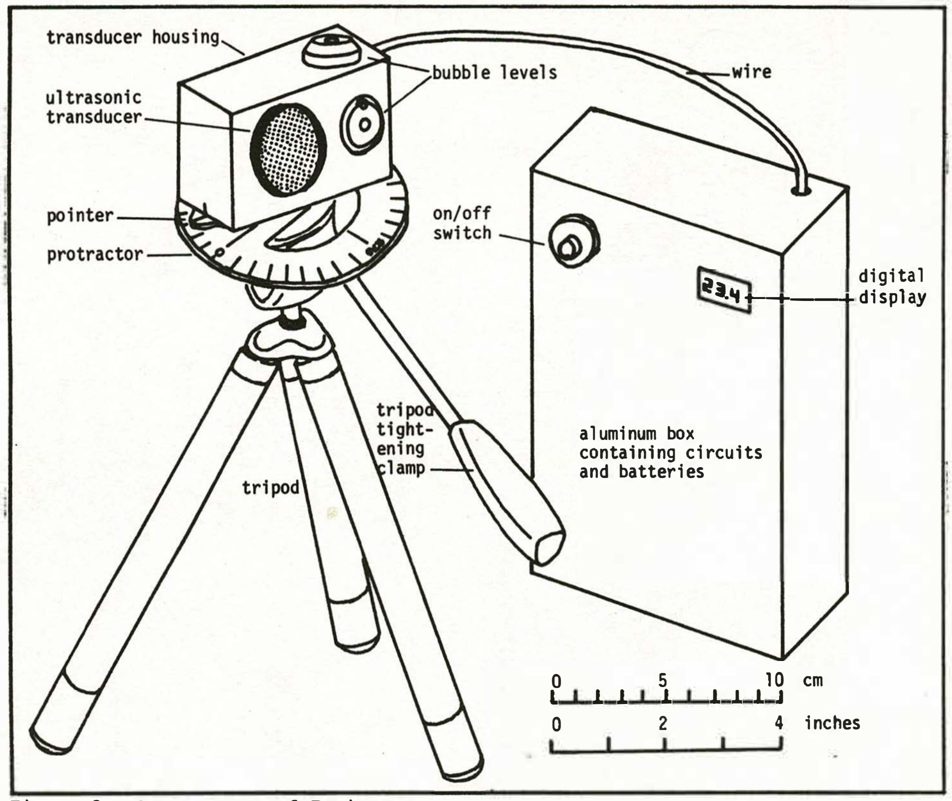

Figure 2: Arrangement of Equipment

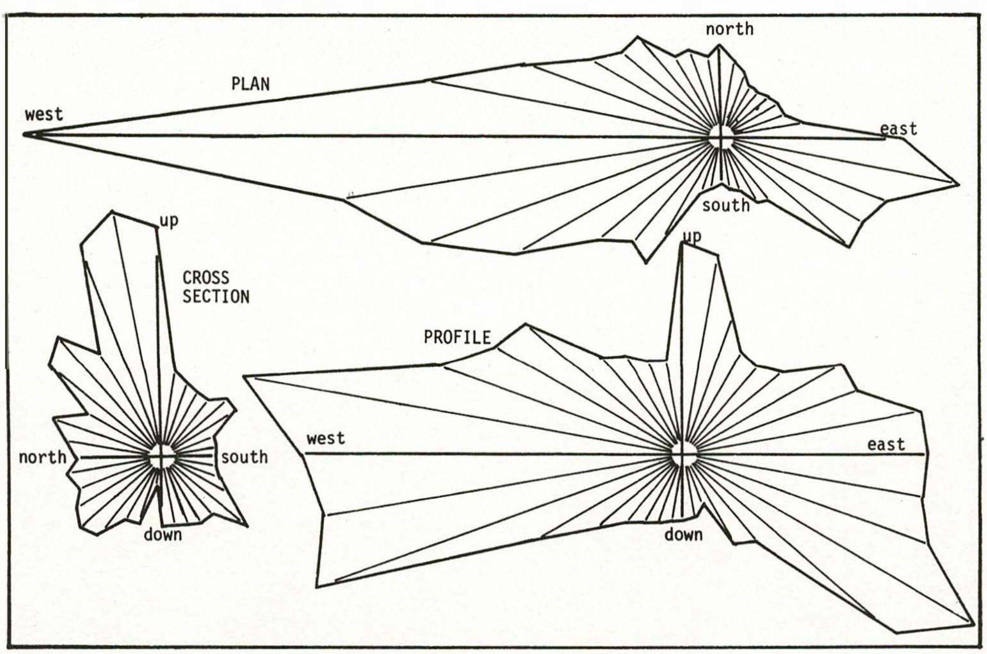

Figure 3: Measurements taken at station 4

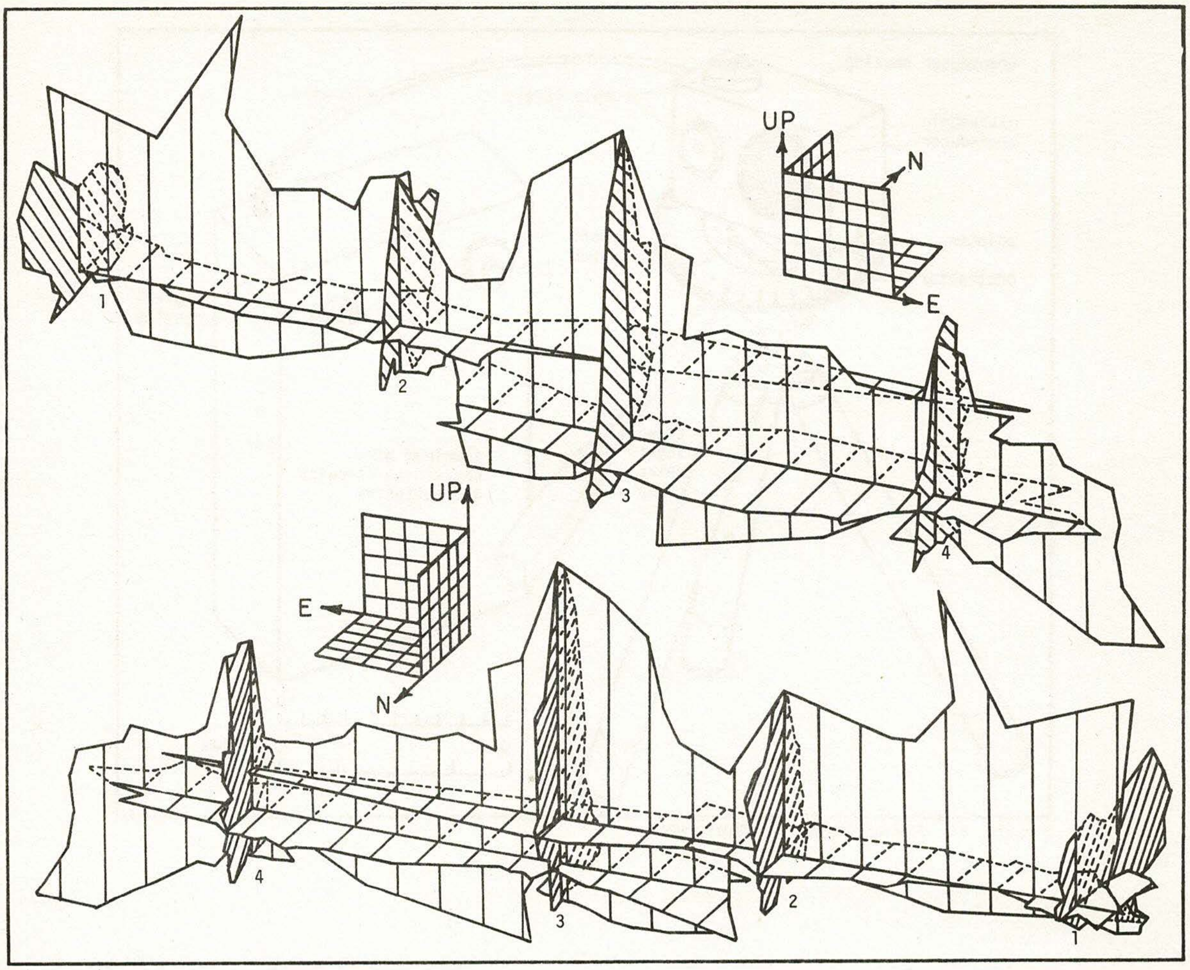

Figure 4: Two views of the same section of Greenhorn Cave

The Shape of "Gypsum Bubbles"

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Abstract

A "gypsum bubble" (Quellungshöhle in German) is a phenomenon of gypsum karst caused by the hydration of anhydrite ($CaSO_4$) to gypsum ($CaSO_4 . 2H_2O$). The expansion of rock during the hydration process forces the superstrata into a hollow, bubble-shpaed dome. A mathematical model for the shape of "gypsum bubbles" is obtained by solving three differential equations of (1) the compressive stress resulting from localized hydration, (2) the effect of gravity, and (3) shear stress. The model predicts that the shape can be expressed as a function of one parameter. Results comparing field measurements with the theoretical model are given.

Zusammenfassung

Eine Quellungshöhle ist ein Phänomen des Gipskarst, das durch die Hydratation des Anhydrits ($CaSO_4$) in Gips ($CaSO_4 . 2H_2O$) verursacht wird. Die Ausdehnung des Gesteins während des Hydratation-Prozesses zwingt die obere Schicht zur Bildung eines hohle, blasenförmigen Dom. Ein mathematisches Modell für die Gestalt der Quellungshöhlen kann durch Lösen von drei Differentialgleichungen für (1) die Druck der Kompression auf Grund der lokale Hydratation, (2) die Wirkung der Gewichtes und (3) Schelirstress aufgestellt werden. Das Modell zeigt, dass die Domgestalt als Funktion nur eines Parameters ausgedrückt werden kann. Resultate, welche Messungen im Feld mit dem theoretischen Modell zeigt, dass die Domgestalt als Funktion nur eines Parameters ausgedrückt werden kann. Resultate, welche Messungen im Feld mit dem theoretischen Modell vergleichen, werden aufgeführt.

Introduction

When water contacts anhydrite ($CaSO_4$) the anhydrite is hydrated to form gysum ($CaSO_4 2H_2O$). The gypsum takes up a much larger volume than the original anhydrite. Estimates of the increase range up to 58%. Anhydrite sometimes occurs at or near the surface of gypsum karst. Surface water causes the expansion of teh rock. The newly-formed gypsum is pushed up from the horizontally-bedded anhydrite into hollow domes which we call "gypsum bubbles". These tend to be round or elliptical when viewed from above.

The earliest description of a gypsum bubble is probably by Stolberg (1923). He described the Waldschmeide in the Harz region of Germany. This "Quellungshohle" was 8 by 7.5 meters across, 2.5 meters high and 0.5 meters thick. Reinboth (1967) has reported its collapse.

In the USA, Myers (1960,1969) briefly described a gypsum bubble in Oklahoma. All the gypsum bubbles measured for this paper were found in the Permian-age gypsum of Eddy County, New Mexico. The biggest gypsum bubbles found in New Mexico were about 2 meters in diameter, stood 0.3 meters high and were 0.1 meters thick. Many had holes or were partially collapsed but this probably happened after they were formed. Figure 1 shows a contour map of two gypsum bubbles. The contour interval was 5 cm. Measurements of its height were made every 20 cm. in a grid pattern shown by +'s in the figure.

Mechanics

In this section we develop a mathematical theory which predicts the shape of teh gypsum bubble. We chose a Cartesian coordinate system with the x-y plane horizontal and at the mid-thickness level of the neighboring gypsum plane. The z-axis points downward through the center of the bypsum bubble. We assume that Hooke's Law describes the strain produced by stresses in the bypsum layer. If we consider a thin slice through the bubble is the x-z plane, the problem of predicting the shape of the gypsum bubble reduces to that of computing the deflection of a prismatical beam (that beam being the cross sectional slice of the bubble). Forces in the y-direction must be in balance or else the bubble would be in motion, hence these forces can be ignored.

Timoshenko and MacCullough (194) give the curvature of the deflection curve of a prismatical beam in bending as

$$\frac{1}{p(x)} = \frac{M(x)}{E\ I} \qquad (1)$$

where: $p(x)$ = radius of curvature at distance x from the origin (cm),
$M(x)$ = bending moment at distance x from the origin (dyne cm),
E = Young's modulus for the material of the beam (dyne cm^{-2}), and
I = area moment of inertia of the cross section of the beam with respect to the neutral axis (cm^4).

Note that the value of E may depend on the direction chosen for the +x-axis. i.e., E amy be a vector. This may be responsible, at least in part, for the noncircular bubbles.

With the assumption that the deflection is small, or more precisely that $(dz/dx)^2 \ll 1$, equation (1) may be rewritten

$$E\ I \frac{d^2z}{dx^2} = M(x) \qquad (2)$$

There are at least three sources of bending moment which must be considered. The principal cause of the deflection is thought to be a compressive stress resulting from the localized hydration of the gypsum layer. This delection is modified by gravitational stress on the bubble. A small additional modification is produced by the shear stress. The principle of superpostion allows equation (2) to be writtne

$$E\ I \frac{d^2z_i}{dx^2} = M_i(x), \qquad z = \sum_{i=1}^{3} z_i \qquad (3)$$

Each source of deflection can thus be considered separately.

Hydration

The localized hydration of the gypsum layer results in a compressive stress in the beam. If the stress is eccentrically applied, i.e. the center of application of the compressive load does not occur at z=0, then a bending moment results. The differential equation of the deflection curve is

$$E\ I \frac{d^2z_1(x)}{dx^2} = M_1(x) = p\ w\ t\left[\varepsilon - z_1(x)\right] \qquad (4)$$

where: $z_1(x)$ = deflection of the beam due to hydration (cm),
p = compressive pressure produced by the hydration (dyne cm^{-2}),
w = width of the beam (cm),
t = Thickness of the beam (gypsum layer) (cm), and
ε = eccentricity of the load (cm).

The geometry of the situation is shown in Figure 2, where the similarity to the situation of an eccentrically loaded thin column should not go unnoticed. Letting $k^2 = (p\ w\ t)/(E\ I)$, equation (4) becomes

$$\frac{d^2z_1(x)}{dx^2} + k^2 z_1(x) = k^2\ \varepsilon \qquad (5)$$

with boundary condition: $z_1(x) = 0$ at $x = \pm r$, and $z_1(x) = -h_1$ and $dz_1(x)/dx = 0$ at $x = 0$.

The solution is:

$$\frac{z_1(x)}{h_1} = \frac{\cos kr - \cos kx}{1 - \cos kr} \qquad (6)$$

where: r = radius of the bubble in the x direction (cm), and
h_1 = height of the gypsum bubble if compression alone were acting on the gypsum layer (cm).

Since we have assumed that the square of the derivative of the deflection curve is small compared with unity, we must have

$$h_1^2 k^2 \sin^2 kx \ll (1 - \cos kr)^2 \qquad (7)$$

The left-hand-side must be small for $x \leq r$, hence $kr \ll 1$. Then expanding equation (7) and ignoring terms higher that the 4th order gives

$$r > 2h_1 \text{ and } kr \ll 1 \qquad (8)$$

as sufficient conditions for equation (2) to be valid. These conditions allow us to expand and simplify equation (6) to

$$z_1(x) = h_1 \left[\left(\frac{x}{r}\right)^2 - 1 \right] \qquad (9)$$

Gravity

Once the compressive stress lifts the beam from its supporting sub-layer the beam is subject to deformation by gravity. The differential equation of the deflection cruve is

$$E\,I \frac{d^2 z_2(x)}{dx^2} = M_2(x) = \frac{g\,\sigma\,w\,t}{2}\; 2 - 2 \qquad (10)$$

with boundary conditions: $dz_2(x)/dx = 0$ at $x = 0$, and $z_2(x) = 0$ at $x = \pm r$.
where: $z_2(x)$ = deflection of the beam due to gravity (cm),
σ = density of the gypsum bubble ($gm\ cm^{-3}$), and
g = accleration due to gravity ($cm\ sec^{-2}$).

Since for a beam of rectangular cross section, $I = w\,t^3/12$, the solution of equation (10) is

$$z_2(x) = \frac{\sigma\,g\,r^4}{2\,e\,t^2} \left[\left(\frac{x}{r}\right)^4 - 6 \left(\frac{x}{r}\right)^2 + 5 \right] \qquad (11)$$

Shear

In addition to the above deflections, the shearing force produces an additional deflection in the form of a mutual sliding of adjacent cross sections of the beam along each other (Timoshenko and MacCullough, 1949). The differential equation of the deflection curve is

$$\frac{d^2 z_3(x)}{dx^2} = - \frac{3\,\sigma\,g}{2G} \qquad (12)$$

with boundary conditions: $z_3(x) = 0$ at $x = \pm r$, and $dz_3(x)/dx = 0$ at $x = 0$.
where: $z_3(x)$ = deflection of the beam due to shear (cm), and
G = modulus of elasticity in shear ($dyne\ cm^{-2}$).

The solution is

$$z_3(x) = \frac{3\,\sigma\,g\,r^2}{4\,G} \left[1 - \left(\frac{x}{r}\right)^2 \right] \qquad (13)$$

Combined Deflection

The combined deflection of the beam, hence of the gypsum bubble cross section, as given in equation (3) and a little algebra is

$$\frac{z(x)}{h} = K \left(\frac{x}{r}\right)^4 + (1 - K) \left(\frac{x}{r}\right)^2 - 1 \qquad (14)$$

where: $K = \frac{\sigma g\ r^4}{2\,E\,t^2\,h}$

h = height of the gypsum bubble (cm).

The dimensionless shape of the gypsum bubble cross section is thus seen to depend solely on the dimensionless shape parameter K, in which we have concealed our ignorance of the physical properties of gypsum. This can be demonstrated by writing out the height of the gypsum bubble in terms of fundamental physical parameters, viz.,

$$h = \epsilon \left[\frac{E\,t^2}{6\,p\,r^2} - 1 \right]^{-1} - \frac{5\,\sigma\,g\,r^4}{2\,E\,t^2} - \frac{3\,\sigma\,g\,r^2}{4\,G} \qquad (15)$$

Incorporated into the above mathematical development is the assumption that the beam (the gypsum bubble cross sectional slice) is freely supported at $x = \pm r$. This means that the cross sections of the beam at the two ends are free to rotate. This, in turn, means that the gypsum bubble should have a well defined edge where the surface of the neighboring gypsum plane meets the surface of the bubble, a feature in agreement with the observations.

We note that it is possible that the shape parameter K is so small that it is quite negligible compared with unity. This would be the case were the bubbles formed in another type of rock, such as limestone. We have here retained all the terms in equation (14) because we do not know the values of Young's modulus or the shear modulus for gypsum. Neither do we know the pressure or the eccentricity of the compressive load.

Field Data

The shapes of actual gypsum bubbles were determined by measuring down from a horizontal beam resting on top of each typsum bubble. Six gypsum bubbles in New Mexico were measured in this manner. Three typical shapes are shown in Figure 3.

Ou model predicts that these shapes should be given by equation (14), a fourth degree polynomial with one unknown I. In order to estimate K, the least squares fit equation was derived for data of the form given by our model. The estimates for K derived by this method were not consistent. Indeed some estimates of K were negative, a physical impossibility since each of the factors making up K is a positive number. K is probably close to 0. Figure 3 shows the modelled shapes of gypsum bubbles of these dimensions if K were 0 or 1.

Several of the gypsum bubbles were unsymmetric. This could have been due to many causes including variations in the thickness of the typsum, Young's modulus not being isotropic, unequal weathering, and damage to the gypsum bubbles during or after their formation. Many of the gypsum bubbles had holes, usually near the edge where stresses caused by the bending are the greatest.

In summary, the fundamental assumption of our model that the strains produced by stresses in the gypsum layer are described by Hooke's Lae, leads to a relatively simple mathematical solution, producing a result (equation(14) easy to compare with the observations. This simple model leads us to believe that gravity and compressive and shear stresses are the dominant forces in determining the shapes of gypsum bubbles. More complicated models involving elastic-plastic theory are probably not warranted in the absence of more detailed information on the time development of the structures.

Acknowledgements

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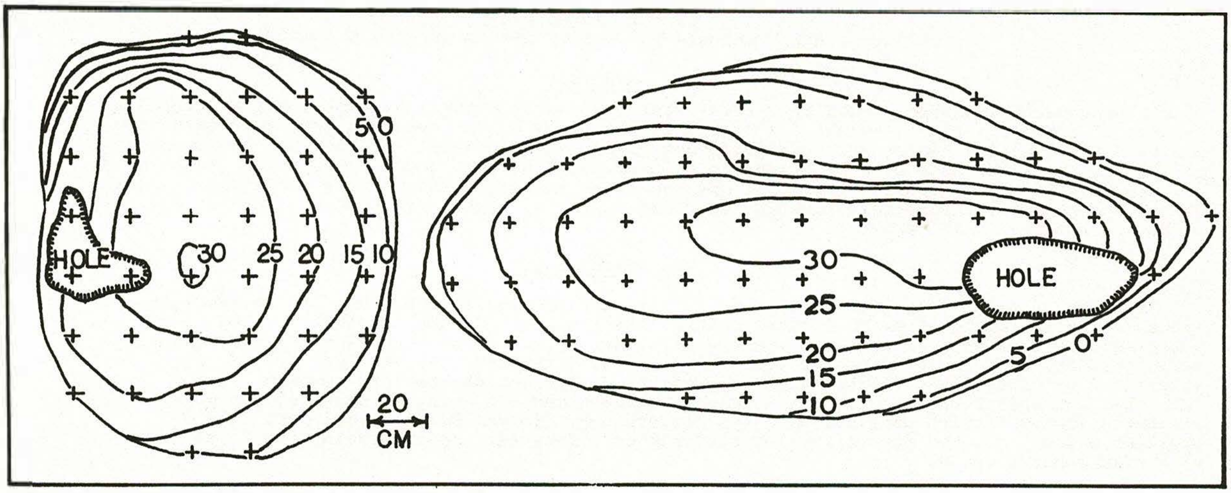

Figure 1: Contour maps of Gypsum Bubbles

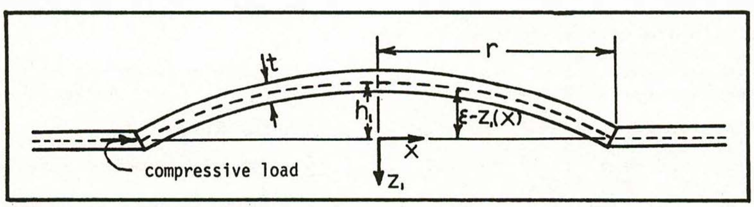

Figure 2: The geometry of a beam under compression. The geometric variables are defined in the text.

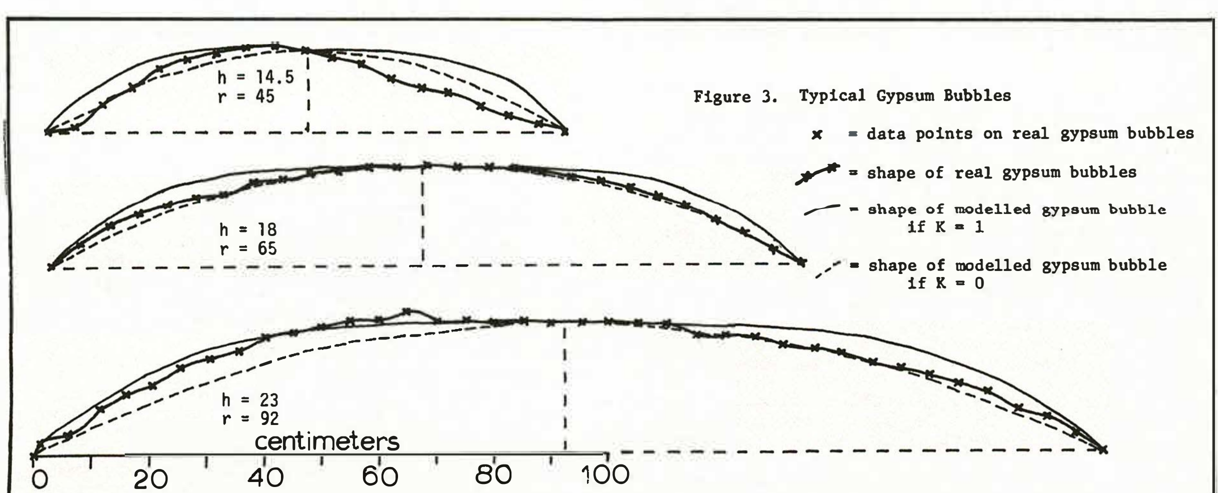

Figure 3. Typical Gypsum Bubbles

A Cupstone Petroglyph of Possible Astronomical Significance from an Early Woodland Site in the Karst Region Jackson County Kentucky

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Abstract

A cupstone petroglyph, found in a karst region of south central Kentucky, may represent a portion of a prehistoric astrolabe. A primitive astrolabe could have been used to observe the position of celestial bodies during significant astronomical events. An accurate perception of the seasons would have been important to an early agricultural group. This type of activity, by Late Archair/Early Woodland cultures, may represent another example of mesoamerican influence. Gypsum speleothems, intensively mined by Woodland cultures, might have been a valuable natural resource utilized in mesoamerica.

Zussammenfassung

Eine ringförmige Felsaufschrift, die in einer Karstregion im südlichen Zentral-Kentucky gefunden wurde, könnte einen Teil eines prähistorischen Astrolobiums darstellen. Ein primitives Astrolobium mag benutzt worden sein, um die Stellung von Himmelskörpern während signifikanter astronomischer Ereignisse zu beobachten. Eine genaue Erkenntnis (Vorhersage) der Jahreszeiten wäre für eine frühe landwirtschaftlich orientierte Gruppe von Wichtigkeit gewesen. Diese Art Aktivität von spätarchaischen/frühen Waldland-Kulturen mag ein weiteres Beispiel für einen mittelamerikanischen Einflub darstellen. Gipsablagerungen, die von Waldland-Kulturen intensiv abgebaut wurden, könnten ein wertvoller matürlicher Bodenschatz gewesen sein, der in Mittelamerika genutzt wurde.

A cupstone petroglyph of possible astronomical significance was recovered from a rockshelter site containing a Late Archaic/Early Woodland component. The coordinates of the Cliff Palace Cave site (see figure 1) are 37°31'30" North latitude and 83°55'30" West longitude, in a karst region of northeastern Jackson County Kentucky. Charcoal recovered from a fire pit feature yielded a radiocarbon date of 1050 B.C. + 75 (Uga-3300).

The cupstone is composed of a very finely grained sandstone with indistinct bedding. The lithic material is from the uppermost beds of the Corbin Sandstone Member of the Lee Formation. Haney and Rice (1978) have found that the unit is exposed in the immediate vicinity of the site. Each flat surface of the artifact is covered with six conical perforations. Measurements of the perforations indicate that they all were made with the same tool or one of similar dimensions. The cupstone has a mass of approximately 1.5 kg.

Thom and Thom (1978) have determined that the cupmarks of Scotland and northeast England (found associated with passage graves and megalithic remains) are set with the megalithic inch. They believe that the designer used a beam compass or trammel with the points set at fixed distances. Designs, then, were identical to those used in setting megalithic rings. Richard Brinckerhoff has noted that cupmarks on top of certain Stonehenge Sarsen Circle lintels still in place may have been used with auxiliary equipment to measure the position of the sun at summer solstice sunrise and lunar position at the northern major standstill (Krupp; 1978, p. 127).

Many varities of cupstones occur in abundance throughout the New World. Converse (1973) defines cupstones occurring in Ohio as conical perforations on rough slabs of clastic sedimentary rocks. Heizer and Baunhoff (1962) described cupmarks as the oldest petroglyph form in the Great Basin area (2000 B.C.-1000 A.D.). Grant, Baird, and Pringle (1968) describe cupstone petroglyphs from the Coso Range of California and consider them to date somewhere between 4000 B.C. and 200 B.C.

Utilization

Cupstone perforations can result from a drilling process, bow drill fire manufacture, and can be used to hold nuts for cracking. Nuts, of course, have been used by many cultures for subsistence.

The cupstone from the Cliff Palace Cave site has, in addition to twelve conical perforations, a circular depression (G) pecked onto the stone's surface (see figure 2). This depression on the stone's edge would not facilitate the holding of nuts, but is a deliberate addition to the geometry of the petroglyph. A groove, formed by percussion flakes, on the side of the cupstone has an angular relationship of 37° with the stone's surface. This is also the angle of latitude for the site area, a fact which of course may be coincidental. However, this angle could have been determined in prehistoric times by sighting the area of the celestrial north pole. Recurrent angular arrangement of the conical perforations (60° and 90°) appear on the cupstone's surface. If we suppose that these angular relationships may have been of some astronomical significance, reexamination of certain site data may provide a clue to their interpretation. At the northernmost portion of the Cliff Palace Cave site an ascending ledge rises over 33 m, allowing easy access to the plateau above (Indian Staircase, see figure 1). This plateau has an elevation of 1,400 feet and is the highest point on the Leighton Quadrangle (USGS, 7.5 minute). This plateau affords a 360° view of the horizon, an important feature for accurate astronomical viewing. For the cupstone date (ca. 1050 B.C.), the obliquity ecliptic would be around 23°48' (Joseph F. Foster: personal communication). This data can be used with the latitude to calculate the rising azimuth of the sun during significant solar events.

Σ - Angle between the earth's equitorial plane and the plane of the ecliptic (1050 B.C. = 23°48')

λ - Latitude (37°31')

h_s - Usual elevation (1°)

Θ - Azimuth (east of north)

Refraction correction = -24'44"

$$\Theta \text{ summer solstice} = \cos^{-1}\left(\frac{\sin 23.80}{\cos 37.52}\right) + \frac{h_s \sin 37.52}{\sqrt{\cos^2 37.52 - \sin^2 23.80}} = 60°18'$$

$$\Theta \text{ winter solstice} = \pi - \cos^{-1}\left(\frac{\sin 23.80}{\cos 37.52}\right) + \frac{h_s \sin 37.52}{\sqrt{\cos^2 37.52 - \sin^2 23.80}} = 121°20'$$

$$\Theta \text{ equinox sunrise} = 90°$$

The ridge directly above the Silver Mine Hollow rockshelter site lies approximately 4.0 km southwest of the Cliff Palace Cave plateau. Solstice alignment could have been observed between the sites ca. 1050 B.C. Now we can see a possible association for the recurrent angles on the Cliff Palace Cave cupstone and certain solar alignments.

If the cupstone was used to determine or record solar alignments, the conical perforations are much too close for accurate alignment. However, the stone may be part of an Astrolabe (a primitive instrument used to observe the position of celestial bodies) used for accurate long distance sighting. If this were true, what would its other components be?

Of all the artifacts of North American prehistory, only the plummet base corresponds to the symmetry of the conical perforations on the cupstone. Plummets are problematical artifacts, described by Converse (1978) as similar in appearance to a surveyor's plumb bob, with a tiny groove or hole near the top. Most are composed of a high grade hematite (a very dense ore of iron). Webb (1968) found that plummets occurred in abundance at the Poverty Point site. Webb and Funkhouser (1928) noted that in Kentucky plummets usually occurred in caches, or in graves, indicating a ceremonial association.

Plummets suspended from a stick would allow astronomical alignment between the plummet strings, or along the stick's surface. The great density of a hematite plummet would pull the crudest primitive string taut and vertical. Plummets used in this manner could be suspended over the conical perforations of a cupstone as shown in fugure 2. A ceramic, stone, or vegetal tube could be added to the stick to increase accuracy. Young (1910) indicates that grooved hour glass shaped tubes composed of steatite and indurated clay up to twelve inches long have been found in Kentucky and might have been used for astronomical purposes.

Plummets were made in abundance by the Poverty Point culture in Louisiana. Webb (1968) has the Poverty Point culture antecedent to Hopewell and Adena cultures and established on the coast and in major valleys between 1500 B.C. and 1000 B.C. Ford has established a sunrise equinox alignment with the ramp and village of the Poverty Point site, and uses this as a Mesoamerican increment.

Cupstones were made in the arid southwest and the karst regions of Kentucky ca. 1050 B.C. Gypsum ($CaSO_4 \cdot 2H_2O$) was a common natural resource. Gypsum occurred in the warm post glacial climate of the southwest as evaporite deposits from Pleistocene playa lakes and in the karst areas of Kentucky as abundant cave deposits (speleothems).

In prehistoric times the caves of Kentucky were intensively mined for gypsum during the woodland period. Watson (1974), working in Mammoth Cave National Park, has found woodland gypsum mining in Salts Cave, Mammoth Cave, Lee Cave, and Bluff Cave. Chert was also found mined from Mammoth Cave in prehistoric times. Watson has concluded that because of the large quantities of gypsum removed, some or all of these substances not only were used locally, but also were traded outside the cave regions.

Approximately 1.6 km south of the Cliff Palace Cave site lie Wind and Big Rat Caves. As in Mammoth Cave, the caves are developed in the Newman Limestone Formation, which includes the chert bearing St. Genevieve and St. Louis Members. Both caves show evidence of prehistoric gypsum and chert mining. Redeposited oleaginous plastic clay also occurs in the caves and would have been a valuable resource in ceramic production.

Conclusion

Mesoamerican cultures used gypsum for frescos and pigment. According to Roglic (1972) the karst areas of the Yucatan and Mexico are characterized by isolated steep hills and vertical development. This woould have limited their accessibility to prehistoric mesoamerican cultures. Gypsum prehistorically mined in the karst areas of Kentucky would have provided a valuable trade item. By 3000 B.C. mesoamerica had nine major cultigens and cultivars including maize, beans, squash, and gourds. These would have been important trade items to the less developed cultures of North America. Determination of important solar alignments would have been important to an early agricultural group. In addition to agriculture, the Mesoamericans had an accurate perception of the seasons based on astronomical events. Ethnography has shown that ideas and concepts, as well as materials can and have been traded. Given our present technology, we should be able to determine at least the regional source area for the calcium sulfate based products of prehistoric mesamerica.

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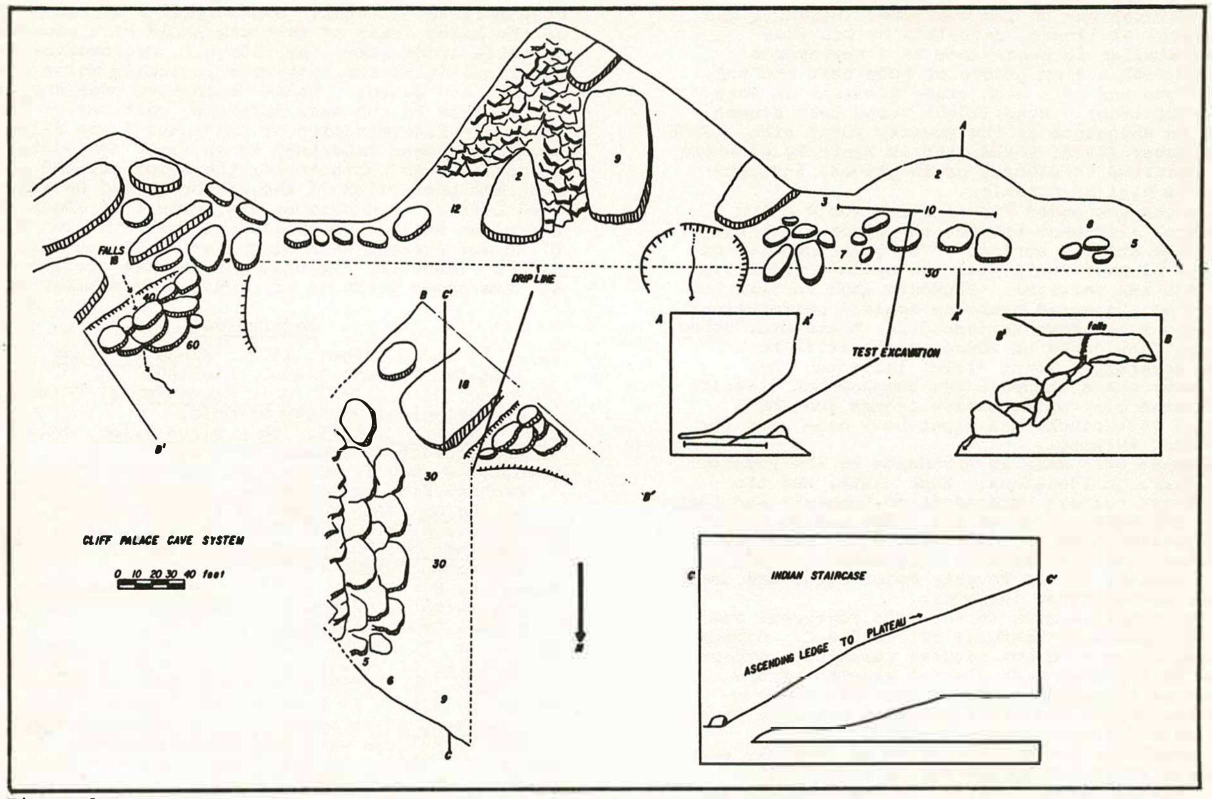

Figure 1: The Cliff Palace Cave site, brunton and tape survey (1978).

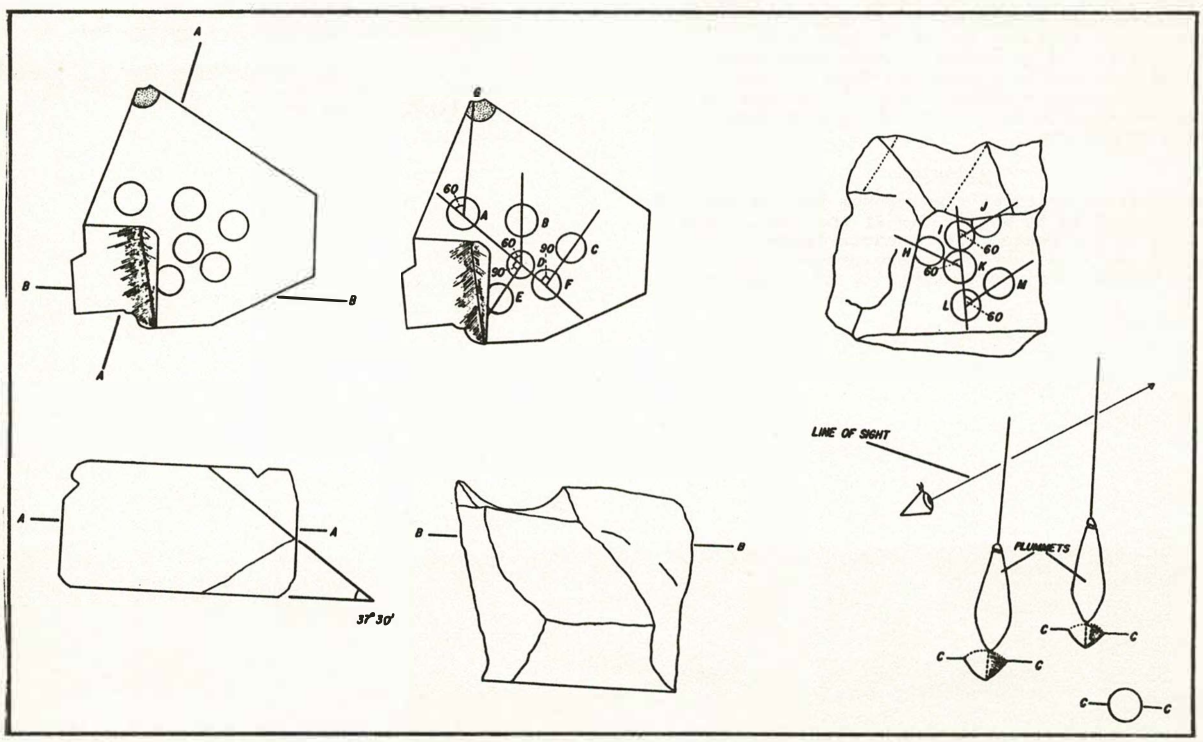

Figure 2: The cupstone petroglyph from the Cliff Palace Cave site, showing the recurrent angular relationships of the conical perforations and their theoretical relationship with plummets.

Karst Flooding in Urban Areas: Bowling Green, Kentucky

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Abstract

Sinkhole flooding is a serious problem for urban areas located upon sinkhole plains. In Bowling Green, Kentucky, homes, streets, apartment complexes, and businesses are affected. The city depends upon the subsurface Lost River and its tributaries to serve as natural storm sewers. Since it is prohibitively expensive to build storm sewers in most karst areas, restricting development in sinkholes which flood by a combination of zoning and stormwater retention basins appears to be the most effective method of dealing with sinkhole flooding. Retention basins are also effective in reducing urban stormwater pollution of karst aquifers.

Introduction

One of the most serious karst-related problems for urban areas located upon sinkhole plains is periodic flooding of karst depressions. Perhaps the most severe problems occur in Bowling Green, Kentucky, where homes, streets, apartment complexes, and businesses are affected (Figure 1). Flooding occurs: 1) during periods of intense rainfall of short duration when the quantity of stormwater runoff exceeds sinkhole outlet capacities and 2) during periods of prolonged rainfall when the Barren River at flood stage has a backwater effect on subsurface streams and/or when subsurface streams at high discharge have a backwater effect on surface runoof attempting to flow underground at sinkholes.

Almost all stormwater runoff in the Bowling Green area flows into sinkholes or drainage wells (over three hundred have been drilled) and thereby into the karst drainage system which includes the Lost River, a major subsurface stream which collects much of the karst drainage from southern Warren County before flowing under Bowling Green to a rising near the Barren River. (Crawford and Beeler, 1980b). Unfortunately, Bowling Green is rapidly growing in a direction that is upstream in terms of the subsurface Lost River; this may increase flooding in the future as increased stormwater runoff from urban and suburban landuse exceeds the capacity of the Lost River Cave system.

Sinkhole Zoning Restrictions

The City-County Planning Commission is attempting to prevent future flooding problems by restricting landuse in sinkholes to the contour which correlates with the capacity of the sinkhole to hold the volume of runoff from a one hundred year probability, three-hour, rainfall event. This will greatly reduce the majority of future flooding problems, but it is not the most conservative estimate of the depth to which karst depressions will flood. Many sinks have springs, often ephemeral, which deliver water to them from areas beyond the topographic divide. Also, many sinkholes are interconnected by way of subsurface conduits into which they normally drain. During floods water may back up behind a constriction (such as a breakdown collapse area) until it has sufficient head to force the floodwater through. This may result in flooding of interconnected sinkholes upstream from the constriction, while those downstream may drain without impoundment even during the largest of floods. The water level in the flooding sinkholes upstream will reach a common level which has nothing to do with the size of each sink. Eliminating a flooding problem in one sinkhole by cleaning out the sinkhole outlet or by the installation of a drainage well may result in increased flooding of other sinks which are upstream from a cave constrictuion and lower in elevation (Figure 2). Some sinks may fill completely and overflow, thus creating flooding problems for other areas.

If two sinks are connected by a common conduit, urban development or other landuse which increases runoff into one sink may result in flooding of the other sink some distance away as water is impounded and flows out of the swallet at the distant sink. Water may or may not flood the sink where the development takes place, depending on its elevation.

Flood Retention Reservoirs

Before approving drainage plans for changes in landuse, the City-County Planning Commission is requiring stormwater retention reservoirs capable of holding the volume of additional runoff directly resulting from the proposed change in landuse which will occur during a three-hour, 100-year rainfall event. Flood retention reservoirs should reduce the rate at which stormwater runoff gets underground at swallets, thus reducing flooding pressure on subsurface streams. Unfortunately, it is standard procedure for developers to drill one or more drainage wells inside the retention basins. This defeats the major purpose of the flood retention basin, that purpose being to retain runoff on site and thus withhold it from the stream so as not to increase the flood stage downstream. Flood retention reservoirs with drainage wells do not withhold runoff water from subsurface streams, instead they deliver water to subsurface streams faster. This may result in flooding of sinkholes which are lower in elevation.

Stormwater Drainage Wells

Over 300 stormwater drainage wells have been drilled in the Bowling Green area. There is direct evidence that several drainage wells have caused subsidence and sinkhole collapse. As the city expands toward the southeast into areas of the sinkhole plain where the depth to bedrock is greater, the danger of sinkhole collapse of residual soil into voids below will probably increase.

Pollution of Karst Aquifers by Urban Stormwater Runoff

Urban stormwater runoff carries pollutants into the caves under Bowling Green. Although oil and grease and some heavy metals are a problem locally, the major concern is with sediment and debris. These contribute to flooding problems by clogging swallets, drainage wells, and cave passages. How does one restore the original capacity of a subsurface stream after it has been reduced by siltation?

Preventing trash, and to a lesser extent silt, from getting into the subsurface drainage system has not been ignored by the city. Trash guards have been placed over all drainage wells and many of the larger swallets. Unfortunately, poorly designed trash guards often contribute to the flooding problem by becoming clogged with debris at the onset of stormwater runoff. (G.R.W. Engineers, Inc. and Daugherty and Trautwein, Inc., 1980).

Stormwater Management Recommendations

In order to facilitate stormwater management decision making in karst regions, an investigation of the complex groundwater system in the Bowling Green area was initiated. Possible correlations between precipitation intensity and duration, stage height of the Barren River, stage height of the subsurface Lost River, elevation of the water table, and the depth and duration of flooding in various karst depressions are being investigated. Eleven stage recorders and four recording precipitation gauges have been erected in the Lost River Groundwater Basin for this study. Underground drainage divides and major subsurface flow routes are being determined by dye tracing. Small quantities of fluoroscein or Rhodamine WT dye are used, water samples are collected by automatic samplers, and a fluorometer is used for analysis.

It would be financially prohibitive for Bowing Green to extend storm sewers throughout the city due to the karst terrain. Even with storm sewers much of the stormwater runoff would still flow into the caves under the city. However, some things can be done which would reduce sinkhole flooding while at the same time help to protect the caves and the water quality of the karst aquifer under the city. The following are some tentative stormwater management recommendations:

1. Restricting development in sinkholes below the contour which correlates with the capacity of the sinkhole to hold the total volume of surface runoff resulting from a one hundred year probability, three-hour, rainfall event should reduce many potential flooding problems. This zoning restriction is presently being enforced by the City-County Planning Commission. Sinkholes which receive water from beyond their topographic divides need to be identified, the one hundred year flood contour calculated, and appropriate zoning applied. The depth of flooding in these sinks is not related to the size of the sink. They include the following:
   a) Sinks with ephemeral springs which deliver water from other areas during and after prolonged or high intensity rainfalls.

b) Sinks draining into subsurface streams that back-flood due to constrictions downstream. The depth to standing water under these inks is usually only one or two meters even during dry periods. Therefore, drainage wells do not drain and flood retention basins are not effective if excavated deeper than the flood level, since the elevation of flooding is determined by the constriction dam on the subsurface stream. A levee built around the sinkhole outlet with a oneway valve to allow water to flow in but not out, might work for some of these sinkholes, but it is probable that in most cases water would rise outside the levee.

c) Sinks and intersink areas which receive overflow from neighboring sinks. This is presently a problem in several areas of Bowling Green where flooding affects houses and businesses which are not even located in sinkholes. In some areas of the sinkhole plain south of Bowling Green long-time residents report that during major floods, such as the flood of 1937, numerous sinkholes overflowed creating wide, slow-moving, surface streams several kilometers in length. These areas need to be identified and zoned accordingly as future urban and suburban development may increase the frequency and severity of this type of flooding.

2. Bowling Green is rapidly growing towards the southeast, upstream in terms of the subsurface Lost River. Urban expansion in that direction will increase the flood crest of the Lost River as more stormwater runoff is directed underground faster. This may increase the depth of flooding in sinkholes downstream, and sinkholes which have not flooded in the past may flood in the future. An intensive investigation is needed of the effects of increased runoff on areas which are lower in elevation and downstream in terms of the flow paths through the karst aquifer upon which the city is built. Flood retention reservoirs to retain increased stormwater runoff resulting from changes in the present landuse as required by the City-County Planning Commission should help to reduce this potential problem.

3. Many of Bowling Green's flooding problems occur because stormwater cannot flow into the Lost River fast enough. Stormwater flooding often occurs on the surface while the Lost River is still at low discharge. A solution to localized stormwater flooding problems in non-karstic areas is to excavate a ditch in order to facilitate the flow of water into a nearby stream. Drainage wells attempt to facilitate the flow of water to underground streams in karst areas and are therefore somewhat analogous to vertical ditches. However, it appears that very few drainage wells actually intersect caves. Most drain through very tight bedding planes. Consequently most wells are not very efficient in delivering large quantities of water quickly to the larger subsurface streams. If the Lost River and its large tributaries could be located by exploration, geophysical techniques and exploratory drilling, perhaps large diameter drainage wells or vertical shafts could be used to direct stormwater into the subsurface streams. Ditches and storm sewers could deliver stormwater runoff from large areas to the shafts. With silt traps and trash guards this technique should be useful for residential areas where pollutants associated with urban stormwater runoff are not a serious problem. Of course if this technique is to be used the consequences of increased sinkhole flooding downstream from the well or shaft must be investigated.

4. In some areas of the city such as low density residential, silt traps and trash guards at swallets and drainage wells may be sufficient to protect the karst aquifer from pollution. Retention basins which let the stormwater filter through the soil should be effective for most other locations. However, in certain areas where urban stormwater runoff is found to carry significant quantities of pollutants into subsurface streams, flood retention reservoirs should be built to prevent the stormwater from flowing underground. The water should then be fed slowly into the sanitary sewer system over a period of days or perhaps treated on site.

5. In areas such as the rapidly growing Greenwood Interchange, which are relatively level and near the drainage divide of the Lost River groundwater basin, perhaps ditches could be excavated which would direct stormwater runoff overland into swallets which drain into nearby Drake's Creek. This would prevent local stormwater flooding while reducing the quantity of water flowing into the Lost River.

6. Where hydrogeologic research reveals that two or more sinkholes drained by the same subsurface stream flood because of a cave constriction downstream, alleviating the flooding problem at one sink should alleviate the problem at the others. In certain cases a storm sewer used to drain one sink would also drain the sinks connected by a common subsurface stream.

7. In the older areas of the city, storm drains and flood retention reservoirs should be used where economically feasible. In some sinkholes earth dikes or concrete flood walls only one or two meters high could be used to protect existing structures by confining the area of flooding. One-way valves might be successful in preventing water from flowing out of some drainage wells.

Conclusions

Restricting development in flood prone areas by zoning, combined with stormwater retention basins (without drainage wells), appears to be the most effective method of dealing with stormwater flooding in karst areas. Retention basins: 1) prevent storm water flooding in the local area; 2) retain stormwater on the surface thereby relieving pressure on the already overloaded subsurface drainage system; 3) provide a means of filtering stormwater through the soil thereby protecting the subsurface drainage system from silt, trash and some other pollutants; and 4) are far less expensive to construct and maintain than storm sewers which are often prohibitively expensive in karst regions.

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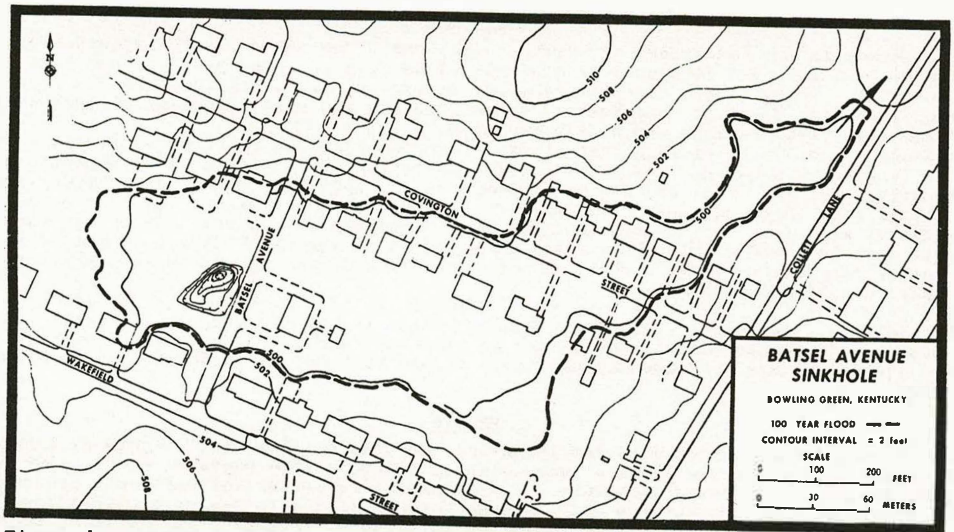

Figure 1. (Source: Booker, R.W., and Associates, Inc., 1978).

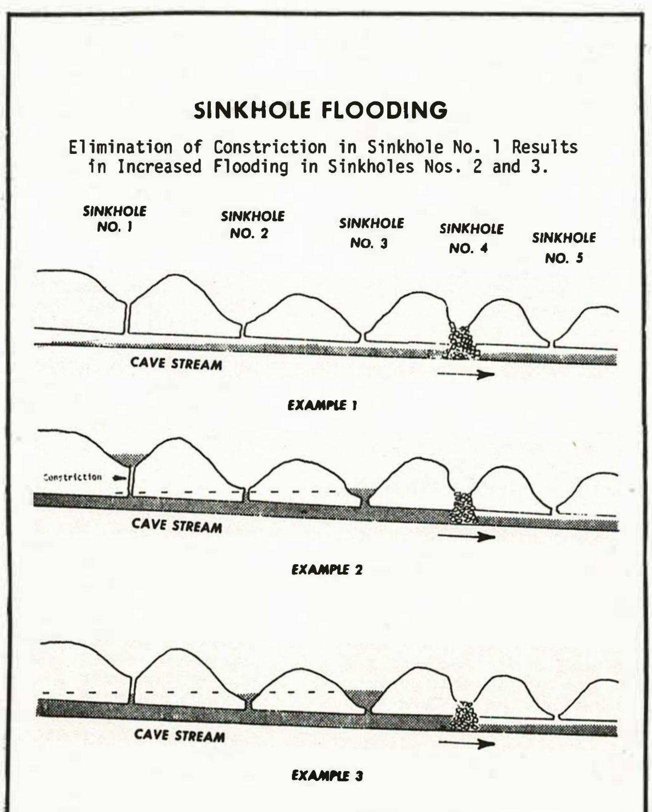

Figure 2.

Pseudo Karst Caves of Arkansas

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Abstract

Caves are common in the sandstones of northern Arkansas. The caves are characteristically a single large room (up to 1000 ft), are developed on a single plane with no side passages, and have large breakdown blocks covering a sandy floor. Speleotherms may be present if carbonate rocks are near the roof of the cave. The Ordovician St. Peter and Everton sandstones are the most important of the cavernous units. These sandstones are clean, friable and poorly cemented.

The sandstone caves can be divided into three categories based on their mode of origin: 1) collapse, 2) piping, and 3) gravity sliding. The first two processes are often difficult to separate and commonly act simultaneously. The St. Peter and Everton sandstones are important confined aquifers in north-central Arkansas. Leakage from these aquifers to underlying carbonate members within the Everton may initiate solution enwidening of joints that allows the piping of sands and/or the collapse of sandstone blocks into the Jasper Limestone member of the Everton, or collapse of the thick Newton or Calico Rock sandstone members into other Everton carbonate members is subsequently followed by upward stoping in the sandstones and downward piping of insolubles.

The least common type of sandstone cave in the Ozarks is that formed by gravity sliding, slumping, and/or joint infilling. The basal sand of the Pennsylvanian Atoka Formation is a massive unit that caps mountains. Wide-spaced joints allow large blocks to break off and slide downward on underlying shales. Breaks between the blocks are subsequently partially filled with colluvium forming caves known to be up to 1200 ft. long.

Résumé

Ontrouve de monbreuses cavités dans les formations de grès situées dans le nord de l'Arkansas. Ces grottes sont caracterisées par une large et unique salle (jusqu'a 1000 pieds de haut), sont developpées suivant un plan unique, sans aucune ouverture sur les parois, et ont un sol sabloneux recouvert par de grands blocks affaisés. Des concrétions calcaires se forment si les roches carbonatées sont proches du plafond de grottes. Les grès de la période "Silurien interieur," situées a St. Peter et Everton sont les plus importantes dans la formation de ces cavités. Ces grès sont purs, friables et peu cimentés.

Les grottes de grès se divisent en trois catégories selon leur origins: 1) Les cavités dûes à un effondrement, 2) Les cavités dûes à une canalisation des eaux, 3) Les cavités dûes à un glissement provoqué par la gravité. The deux premiers procédés sont souvent difficiles à différencier, et contribuent à leur formation simultanément les frès de Peter et d'Everton sont d'importants aquifères captifs, dans le centre-nord de l'Arkansas. Le drainage des ces aquifères vers des formations carbonatées sousjacentes, à Vintérieur de l'Everton, peut favoriser une solution qui e'largit les fissures permettant la canalisation des sables, et/ou l'effondrement de blocs de grès, formant des cavernes à l'intérieur des roches carbonatées. L'effondrement des grès de St. Peter dans les formations calcaires de Jasper qui appartiennant à l'Everton, ou l'effondrement de l'épaisse formation de "Newton" ou de "Calico Rock" à l'intérieur des autres formations carbon atées d'Everton est ensuite suivie par un mouvement d'arret vers le haut, à l'interieur des grès, et par le drainage de substances insolubles vers le bas.

Le type le moins commun parmi les cavités situées dans les grès des Ozarks, est celui formé par un glissement dû à la gravité, à un affaisement ou à une fissure vide. Le sable qui forme le fond de la formation "Pennsylvanian Atoka" est une unité massive qui recouvre les montagnes. Des fissures très es pacées favorisent l'éclatement de larges blocs et leur glissement vers des schistes sous-jacents. Des fissures situées entre les blocs sont ainsi partiellement remplies de colluvium formant ainsi des caves ayant jusqu'a 1200 pieds de long.

Introduction

Caves are abundant in Arkansas. Over a thousand caves are believed to exist, but an accurate count has not been made. This is due primarily to the few number of cave explorers, their lack of organization, and the ruggedness of the terrain. An initial survey has accurately located and filed over 500 caves (David Taylor, personal communication), but few have been mapped. Most of these caves are in limestone and formed by solution, but an important number of caves are in sandstone and have formed by other processes.

Nearly all of Arkansas' caves are located within the Ozark Plateaus Province of the Interior Highlands. Figure 1 shows the three erosional plateau surfaces and the generalized stratigraphy. Most of the caves are found within Mississippian and Ordovician flat-lying carbonate units, but due to unique geologic and hydrologic conditions volumous and lengthy caves occur in sandstones of Pennsylvanian and Ordovician age. Caves in sandstone are known with rooms up to 700 feet long and 30 feet high, and total passage lengths up to 3000 feet. Dolines and natural bridges in sandstone are other occurring pseudo karst landforms. The purpose of this paper is to describe the distribution and origin of sandstone pseudokarst caves of Arkansas.

Application of the Pseudokarst Definition

The origin and occurrence of pseudokarst has not received wide attention in the literature, being discussed primarily as a curiosity. The term "pseudokarst" has been applied by geomorphologists to a diversity of landforms that have evolved in a variety of rock and sediment types, both soluble and insoluble. The term "pseudokarst" has been applied to depressions and caves in glacial, volcanic, and eolian terranes and to features in sandstone, conglomerate, tuff, basalt, unconsolidated sediments, and calcic-rich igneous and metamorphic rocks.

Processes that have formed pseudokarst include solution, piping, suffosion, deflation, collapse, subsidence, differential compaction, and thawing of permafrost. Gravity sliding as a pseudokarst process has almost been ignored in the literature. In Arkansas some sizeable caves and natural bridges have formed exclusively by this process. Werner and Medville (1980) suggest gravity sliding as one of processes involved in the development of caves in the quartzites of southeastern New York.

Sandstone caves similar to those of Arkansas have been described by Halliday (1960), Kastning (1979), Hose and Strong (1979), Cronon (1980), Spong (1980), and Kress and Alexander, Jr. (1980). A geologic roadlog to some pseudokarst areas of north-central Arkansas has been made by Ogden (1980). Select Arkansas caves in sandstone have been described and mapped by Warshaver (1978), Ogden (1979), and members of the Cave Research Foundation (Blore, personal communication).

Since Arkansas' pseudokarst occurs only in sandstone, a review of all the different types of pseudokarst is beyond the scope of this paper. For such a review, the reader is referred to Otvos, Jr. (1976) and the abstracts to the Pseudokarst Symposium held at the 1979 National Speleological Society Convention (Kastning, 1979).

Location and Geology

Pseudokarst is located in two distinct areas of Arkansas with the location dependent on which of the following two processes is dominant: 1) piping or 2) gravity sliding. Caves and dolines formed primarily by piping are located where the Ordovician aged St. Peter and Everton formations crop out on upland surfaces (Figure 2). Where deep dissection has exposed only thin outcrops of St. Peter and Everton in narrow gorges, few sandstone caves are found. The St. Peter and Everton formations crop out in north-central Arkansas and commonly are the surface rocks of the eastward sloping Salem Plateau erosional surface. The Salem Plateau is the lowest of the Boston Mountain erosional surfaces (Quinn, 1958). The rocks dip gently to the south-southwest off of the Ozark Dome which is centered in southeast Missouri. The stratigraphic dip of this asymmetric dome seldom exceed two degrees in Arkansas. Greater dip angles occur in the proximity of the south-southeast dipping (commonly near vertical) normal faults.

The St. Peter and Everton formations are absent or thin in northwest Arkansas, but thicken to the west. The St. Peter sandstone consists of fine to coarse-grained, well rounded, well sorted friable quartz arenite beds. A maximum outcrop thickness of 21_ feet has been reported, but thicknesses of 30 to 50 are more common in Stone and Izard counties where most St. Peter caves are found. The St. Peter sandstone may overlie either a carbonate or a sandstone member of the Everton formation. Sandstone caves have been found only where the St. Peter overlies a carbonate unit. The St. Peter sandstone is a prevalent formation over much of the mid-continent, and a carbonate formation commonly underlies it. In Wisconsin, Cronon (1980) reports on a collapse cave in the St. Peter sandstone where collapse and piping has occurred in the underlying Praire do Chien dolomite.

The Everton Formation of Middle Ordovician age is composed of alternating sandstones, dolomites, and limestones that comprise one of the most important aquifers of northern Arkansas (Ogden, 1979). The Everton ranges in thickness from 350 to 650 ft along the Buffalo River (Suhm, 1970). The sandstones of the Everton are very similar to those of the St. Peter. Where an Everton sandstone member overlies a carbonate member and surface erosion has thinned the sandstone, pseudokarstic caves are common.

Sandstone caves also form in Arkansas by gravity sliding within beds of the Pennsylvanian age Atoka Formation (Figure 2). The Atoka Formation caps the top of the highly dissected Boston Mountain Plateau surface (Figure 1). Where sandstone caves form, the Atoka is over 500 feet thick with rapid thickening southwatd to over 10,000 feet in the Arkansas Valley (Arkoma Basin). In the Boston Mountains, the Atoka consists of three well cemented, massive sandstone separated by thick shales.

Operating Processes

The caves in Arkansas can be classified based on the major formational process. These five primary processes are: 1) solution, 2) piping, 3) collapse, 4) gravity sliding, and 5) slumping. These can be envisioned as end members of a pyramid (Figure 3). There are sandstone caves that form solely by each of the non-solution processes, but most sandstone caves form by piping and collapse aided by solution. Solution is considered here to operate in three manners: 1) cause of a sandstone collapse, 2) removal of carbonate cement between sand grains, and 3) enlargement of joints to aid in the piping process. Therefore, by disregarding those caves formed entirely by solution and solely surrounded by carbonate rock walls, the area marked as "A" on Figure 3 represents how most Arkansas sandstone caves form. A much smaller number of sandstone caves form by gravity sliding, sometimes aided by slumping.

Piping and Collapse

The development of pseudokarst in Arkansas is therefore generally not a function of a single process or rock type, but of a combination of either friable, poorly cemented sandstones overlying carbonates, or of massive sandstones overlying shale beds. In the first situation, piping is the primary process that forms the caves and causes collapse (Figure 4). This is obviously aided by solution of the carbonate cement between the grains and the enlargement of the joints in the underlying carbonate rock. In some instances, there may be direct collapse of the sandstone into a void that formed by solution of the underlying limestone. Even in this case, piping of sand grains is an important cause of enlargement after the collapse (Figure 5). Generally, the collapse can be identified by the lower portion of the cave being in carbonate rock. This may be masked by the sandstone breakdown.

Speleothems are usually absent of sparse in sandstone caves. In some instances, seemingly anomalous, well decorated, sandstone caves have been found. Close inspection has shown that the speleothems occur only where a carbonate unit overlies the sandstone containing the cave. Other factors controlling speleothem development are soil thickness, solubility and thickness of the overlying carbonate unit, wideness of joints, and the surface relief (controlling infiltration vs runoff).

Gravity Sliding and Slumping

Some Arkansas sandstone caves occur even in the absence of any soluble rock. Figure 6 helps to demonstrate how the gravity sliding process forms caves in the Atoka Formation. Deep dissection and differential erosion has left the Atoka sandstones capping ridges in high relief areas. Farther erosion of the shales, expansion of joints due to unloading, and gravity, work together causing massive sandstone blocks to slowly creep down the hillside. Slumping causes the joint face to open at the base of the sandstone block and close off at the surface, thus forming the cave (Figure 6). In rarer cases, caves form where the face joint opens more at the top and is later filled with talus (Figure 6). At Devils Den State Park in Washington County, sandstone caves hundreds of feet long have formed in such a manner. These caves are generally narrow, but passages may be 15 feet high; nearly the thickness of the sandstone blocks.

Summary

Abundant and sizeable sandstone caves occur in northern Arkansas. Two broad classes exist based on the dominant process. Most of the sandstone caves form by piping, aided by collapse and solution. This occurs when there is a carbonate unit under the sandstone. In high relief areas where there are no carbonate rocks, sandstone caves form by gravity sliding commonly involving rotational movement (slumping) of sandstone blocks.

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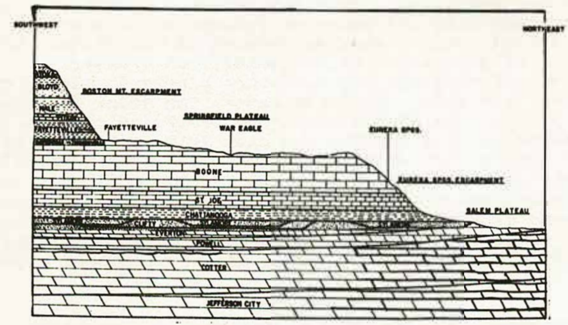

Figure 1. Ozark plateaus, escarpments, and generalized underlying stratigraphy. The St. Peters occurs above the Everton only in north-central Arkansas.

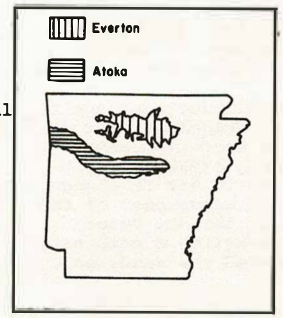

Figure 2. Location of areas in the Atoka and (St. Peter)-Everton formations containing sandstone caves.

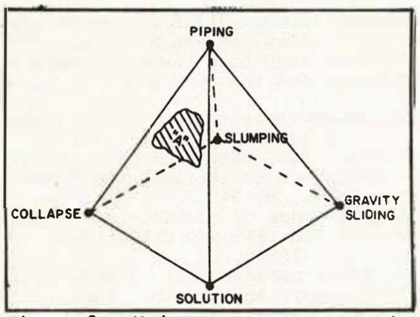

Figure 3. Major processes operating to form pseudokarst in sandstones of Arkansas.

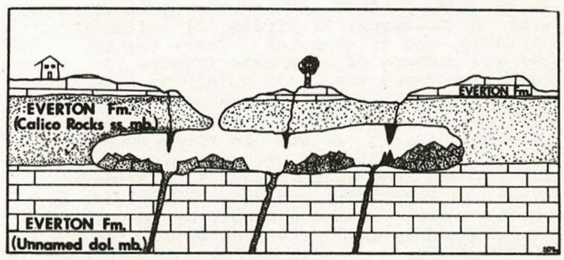

Figure 4. Diagrammatic representation of a sandstone cave formed by piping of sand through solution-enlarged fractures.

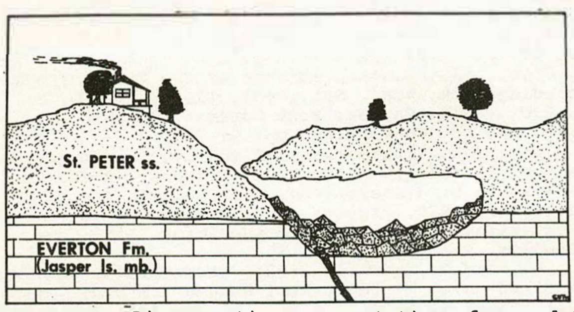

Figure 5. Diagrammatic representation of a sandstone cave formed by collapse into a solution cavity and piping of sand through solution-enlarged fractures.

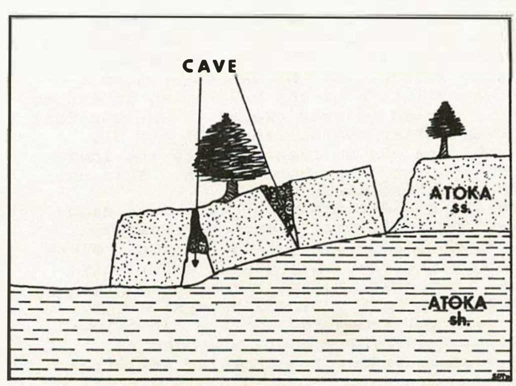

Figure 6. Diagrammatic representation of the development of sandstone caves by gravity sliding and slumping.

Speleogenesis of Arkansas Ozark Caves

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Abstract

Extensive caves are found developed within the Springfield and Salem plateaus of the Arkansas Ozarks. The origin of the caves can be divided into 4 classes: 1) Pocket caves, 2) Perched water-table caves, 3) Confined aquifer or sandwiched caves, and 4)Vadose caves.

A pocket cave is generally a single room that forms in cherty carbonate formation in which chert and limestone beds are not laterally continuous. These caves formed at random depths below the water table and exhibit little or no structural or base level control.

Perched water-table caves formed directly above a perching unit and above present base level. If the perching unit is thick and impermeable, the cave will have ceiling phreatic features. As base level cut below the perching unit, vadose downcutting caused stream entrenchment into the perching formation. Where the perching unit is very thin or semi-permeable (aquitard), leakage caused caves to form above and below the aquitard and generally along a structural weakness. Later breakdown of the aquitard causes integration of the two caves.

Maze caves are found in thinner limestone aquifers that are sandwiched between aquicludes. The confined water exerts a pressure head equally distributed throughout the joints thereby causing a maze pattern.

Vadose caves are common on the sides of steep hills where high gradient surface streams have been pirated to the subsurface through fractures. Fracture enlargement and downcutting give these caves a canyon-passage cross-section and a meandering plan view.

Résumé

De vastes grottes se développent à l'intérieur des plateaux de Springfield et de Salem dans les Ozarks, en Arkansas. L'origine de ces grottes peut se diviser en quatre categories: 1) Les cavernes dites poches, 2) Les cavernes dites plates-formes 3) Les aquifères captifs ou coincés, 4) Les grottes situées au-dessus de la zone de saturation.

Une poche est généralement une simple salle qui se form dans une formation siliceuse et carbonatée dans laquelle les couches de clacaire et de silex noir ne sont ni latérales ni continues. Ces grottes formées a des profondeurs imprevisibles sous la reserve d'eau montrent peu ou pas de controle en ce qui concerne la structure et le niveau de base.

Les grottes "plates-formes" sont formées directment au-dessus d'une unité e'levee et au-dessus d'un niveau de base existant. Si l'unité qui forme une plate-forme est épaisse et imperméable, la grotte aura un plafond aux formes phréatiques. Alors que le niveau de base s'enfonce sous la formation dite "plate-forme," des grottes situées au-dessus de la zone de saturation, en s'enfoncant, provoquent l'installation de cours d'eau dans les formations dites "plate-formes." La, les plate-formes sont très fines ou semi-permeables (aquitards), le drainage provoque la formation de grottes au-dessus et au-dessous de celles-ci, et généralement le long d'une structure faible. Plustard, l-effondrement intègre les deux grottes l'une a l'autre. Beaucoup de grottes ont éte-découvertes dans les aquifères calcaires Moins épais, qui sont coincés entre des "apuicludes" - L'eau captive exerce une pression egalement distribuèe à travers les fissures, causant ainsi l'établissement d'un réseau semblable à un labyrinthe.

Les grottes situées au-dessus de la zone de saturation sont-très répandues sur les pentes abruptes des collines où les cours d'eau dont le gradient est éleve, ont été amenés vers la surface par des fractures. Il elargissement et l'erosion des fractures donnent à ces cavités et à leur profil la forme d'un canyon alors que leur representation sur une carte est sinueuse.

Introduction and Purpose

No accurate survey of caves exists in Arkansas, but members of the former Arkansas Speleological Survey and the present Association for Arkansas Cave Studies (Dave Taylor, personal communication) have estimated that there are over 1000 caves more than a hundred feet in length. Approximately 500 limestone caves have been filed, but few have been mapped due to the low number of organized cave explorers. Detailed geologic investigations of Arkansas caves are non-existant, although Missouri speleologist such as Bretz (1956), Reams (1968), and Vineyard and Feder (1974) have expounded at length on the karst of Arkansas' neighbor.

The purpose of this paper is to discuss in a broad manner, the occurrence and origin of limestone caves in Arkansas. It is not the purpose of this paper to reiterate details of the classical theories of such researchers as Davis (1930), Bretz (1942), Davies (1969), White (1960), and Ford (1965). Most speleologists realize that for every theory of cave origin, there is at least one cave, if not many, that have formed by a particular theory. Therefore, the occurrence of caves will be discussed in a geographical and stratigraphic manner, and their origin will be described with regard to aquifer conditions and lithologic, structural and base level controls.

Location and Geology

The limestone caves of Arkansas are located within rocks cropping out on the Boston Mountain Escarpment and the Springfield and Salem erosional plateau surfaces (Fig. 1). The rocks generally have a south-southwest dip of less than a degree off the asymmetrical Ozark Dome. The stratigraphic dip is occasionally greater in the proximity of nearly vertical, south-southwest dipping normal faults.

The greatest number of caves are found within the cherty Mississippian Boone Limestone and chert-free St. Joe Limestone which together average 450 ft thick (Fig. 2). Ordovician carbonate members within the Kimmswick, Plattin, Joachim, Everton, and Powell formations become important cave formers as they thicken in an eastward direction. These Ordovician formations underlie much of the Salem Plateau which becomes aerially more extensive to the east. Smaller caves are often found in the thin Mississippian-aged Pitkin Limestone and Pennsylvanian-aged Prairie Grove and Brentwood arenaceous limestones. These latter three limestones crop out on the sides of the Boston Mountain Escarpment and are limited in aerial extent.

Origin of Arkansas Caves

The origin of limestone caverns, whether in Arkansas or elsewhere, must be described by means of a group of parameters as shown in Figure 3. It is suggested by this flow chart that the most important parameter is lithology, because without a soluble rock, an extensive cavern will not develop. Minor changes in lithology of the carbonate unit will simply help control the length and volume of caves as demonstrated by Rauch (1972).

To avoid the discussion of the existence of a uniform water table in limestone, the term "saturation" is used here. "Water table" mapping by Ogden (1976) and Quintana (1981) have shown that the water table in limestone exists in discrete "blocks" and that a block with locally confined water can exist next to a block under unconfined conditions due to lateral lithologic or fracture density changes. Likewise, one block may act as an aquifer while the neighboring block may hield little or no water (Fig. 4). This explains how nearby wells may be of different depth and have contrasting static water levels. Caves under these hydrologic conditions may form either above the saturation zone by groundwater with a major downward component (called vadose) or by waters with a major horizontal component of movement (called phreatic).

The formation of caves in the unsaturated and saturated zones is farther controlled by the presence or absence of perching (commonly leaky) layers. Perching layers can be composed of shale, siltstone, chert, or in some instances, massive, limestone with wide-spaced joints. The perching layers are commonly not laterally continuous. Where there are no perching layers, caves may simultaneously form above and below the zone of saturation as shown in Figure 5a. If the perching layer is not continuous, leaky, or sufficiently elevated above base level, a large intergrated cave is unlikely to form (Fig. 5b). Likewise, there will probably be insufficient saturated thickness for water well production. If a thick, impermeable perching layer exists slightly above or below base level, there will be sufficient saturated thickness to enable pocket caves to develop randomly above (Fig. 5) and below the water table (Fig. 4) and large intergrated caves directly above the perching layer. Figure 5c demonstrates how the regional water table can be independent of base level in contrast to the two coinciding in Figure 5d. The largest caves in the Boone-St. Joe aquifer first formed as water was perched above the shaly Northview member of the St. Joe (if present) or the underlying Chattanooga Shale.

It is interesting to note that in checking over 2000 water well records from the Boone-St. Joe aquifer, very few caves were intersected below the top of the zone of saturation. In contrast to this, 67 wells intersected caves far above the zone of saturation. Figure 6 shows the elevation of 14 caves intersected by wells drilled in northern Searcy County. This figure suggests that caves have formed randomly throughout the Boone-St. Joe in response to localized conditions of lithology, structure, and/or perching layers that enhanced solution. Figure 7 shows the elevation of 98 caves in Northwest Arkansas, and also demonstrates that the caves are scattered throughout a thick section of the Boone-St. Joe aquifer. Fewer caves are found in the St. Joe than the Boone, but St. Joe caves are usually longer and occur at discharge points where flow lines are closer together.

Figure 5d also demonstrates how maze caves in Arkansas form. This situation is quivalent to the "sandwich aquifer" described by White (1969). In Arkansas, the Pitkin, Prairie Grove, and Brentwood limestones are sandwiched between shales and have maze caves which are occasionally over a mile in length with several entrances. Under certain idealized geologic and hydrologic conditions, Figures 5a through 5d can be considered an evolutionary sequence. The Pitkin, Prairie Grove, and Brentwood contain the oldest caves in Arkansas, evolving under confined conditions before the dissection of the Boston Mountain Plateau, formation of the Boston Mountain Escarpment, and subsequent erosion of the Springfield Plateau (Fig. 2).

Conclusions

Most of Arkansas caves occur within the Boone-St. Joe limestone aquifer. Relatively young caves have formed in high relief areas high above the zone of saturation. Many small pocket caves are scattered throughout the aquifer indicating lack of base level control and the importance of localized perching layers and fractured zones. Larger, integrated caves occur in the St. Joe Limestone from water perched on the Chattanooga Shale. The Chattanooga acts as base level by controlling the depth of circulating ground waters. Therefore, this "lithologic base level" can be either above or below the elevation of the White and Illinois rivers which drain most of Arkansas' karst lands.

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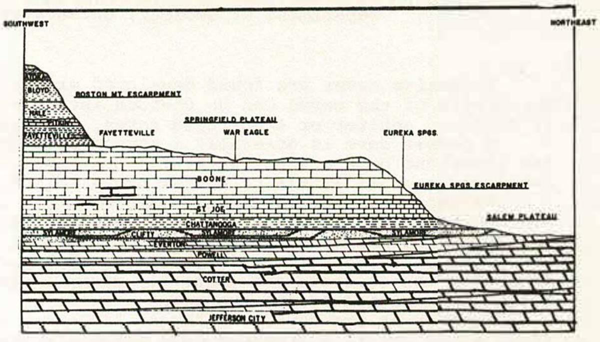

Figure 2. Generalized stratigraphy of the Ozark Plateau Province in Arkansas.

SYSTEM	SERIES	FORMATION	MEMBER
PENNSYLVANIAN		Atoka	
	MORROWAN	Bloyd	
		Hale	Prairie Grove Cane Hill
MISSISSIPPIAN	CHESTRIAN	Pitkin	
		Fayetteville	
		Batesville	Hindsville
	MERA-MECIAN	Moorefield	
	OSAGEAN	Boone	
		St. Joe	
DEVON-IAN		Chattanooga	Sylamore
SILUR-IAN		Lafferty St. Clair Brassfield	
ORDOVICIAN		Cason Fernvale Kimmswick Plattin Joachim	
		St. Peter	
		Everton	
		Black Rock Smithville	
		Powell	
		Cotter	
		Jefferson City	
		Roubidoux	
		Gasconade	Gunter
CAMBRIAN		Potosi-Eminence	
		Bonneterre	
		Lamotte	
PRECAMERIAN BASEMENT ROCKS			

Figure 1. Ozark plateaus, escarpments, and generalized underlying stratigraphy. The St. Peter occurs above the Everton only in north-central Arkansas.

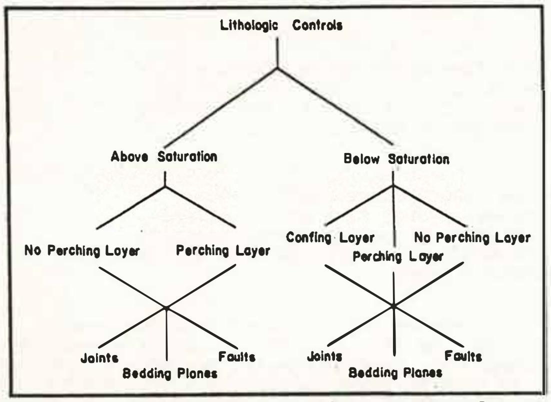

Figure 3. Controls on the development of solution conduits with emphasis on the effect of perching layers.

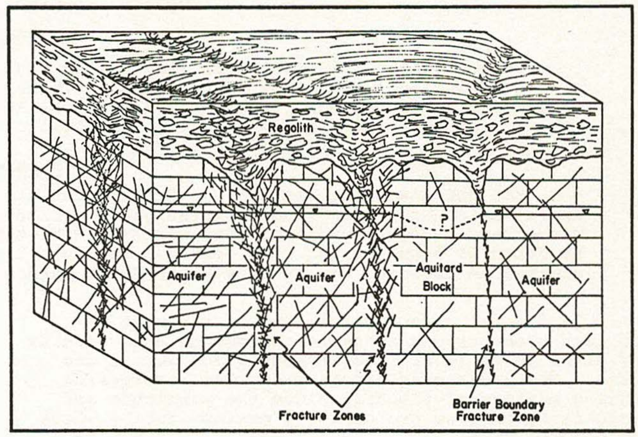

Figure 4. Diagrammatic representation of the "water table" in limestone as explained by adjacent aquifer and aquitard blocks caused by fracture density changes.

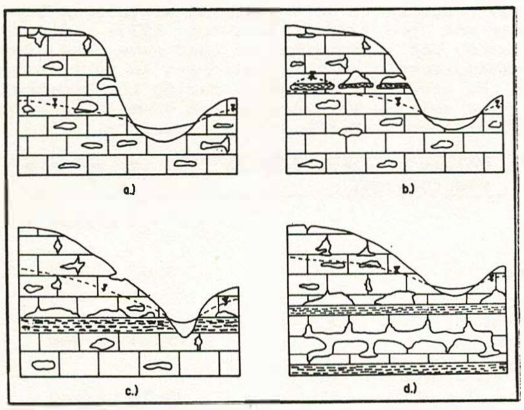

Figure 5a. Top of the zone of saturation corresponding to surface streams in a carbonate containing no perching unit.

5b. Discontinuous perching layers allowing caves to form above the zone of saturation.

5c. Integrated caves forming above a continuous impermeable layer causing the zone of saturation to be above local base level.

5d. Integrated caves forming above a continuous impermeable layer but below local base level; Integrated maze caves are formed sandwiched between impermeable layers.

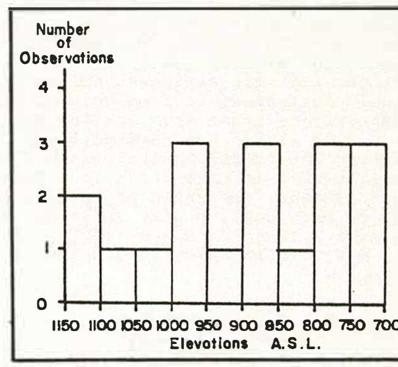

Figure 6. Frequency plot of the tops of caves intersected during drilling in Searcy County, Arkansas.

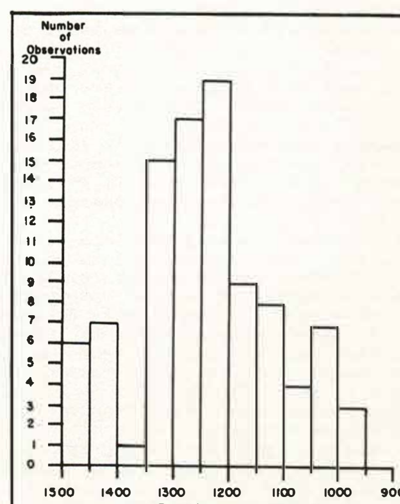

Figure 7. Frequency plot of cave entrance elevations in Northwest Arkansas.

Empirical Confirmation of Curl's (1974) Flow Velocity Calculations

James A. Pisarowicz and R. Mark Maslyn

Abstract

Using scallop data collected from Spring Cave, Colorado, Curl's flow velocity equations were used to calculate water flow during flood. These values were compared to actual flood volumes measured from Spring Cave's resurgences during the 1978 record snow melt. The calculated and measured volumes agreed to within 8.3%, well within Curl's 15% theoretical margin of error

Zusammenfassung

Bei der Anwendung von den aus Spring Cave, Colorado gesammelten Ausbuchtungsangaben, wurden Curls Gleichungen zur Flussgeschwindigkeit gebraucht, um den Wasserandrang bei Flut zu Kalkulieren. Diese Berechnungen wurden mit den wirklichen Flutstärken verglichen, dis während der Schneeschmilze im Jahre 1978 aus Spring Cave gemessen wurden. Die berechneten Grössen stimmten bis zu 8.3% mit den gemessenen überein, was innerhalb von Curls theoretischem Irrtumsfaktor leigt.

In dynamic cave systems, one of the most important observations concerns the volume and velocity of water which flows into, through, and out of the cave. These measures become even more interesting during periods of flooding since the magnitude and velocities of flow are at their maximum during these periods of time.

Flow velocities and volumes may be measured by directly observing the stream itself and the cave's resurgences or by measuring the scalloping found in the passages of the cave. This latter technique tends to only reflect the past history of higher velocity flows through a given cave conduit since scallop patterns develop most rapidly at higher velocities of flow (Curl, 1974). Logically flow volumes that are estimated during periods of flood should correspond to flow columes calculated from measurements taken from scallop patterns.

Curl (1974) has devised a set of equations showing the relationship between flow velocity and scallop size in cave conduits. According to his calculations, the ratio of conduit diameter or width (D) to mean scallop size ($\overline{L_{32}}$) can be used to determine a Reynolds number ($\overline{R_{eL}}$). Mean flow velocity ($\bar{u}$) may then be calculated using the following formula:

$$\bar{u} = \frac{\overline{R_{eL}}}{\rho} \left(\frac{u}{L_{32}} \right)$$

where $L_{32}/u = 21000$ and ρ = density.

The above developments, through intriguing, are supported solely on theoretical arguements set forth by Curl (1974) who also noted a theoretical margin of error of 15% because of assumptions made in deriving these formula. The purpose of this investigation was to collect scallop measures, use these to calculate flow velocities using Curl's equations, and then compare these values to actual cave stream flow. In this regard, data from Srping Cave, Colorado, was used in an attempt to empirically confirm Curl's (1974) flow velocity calculations.

Spring Cave is a river system located on the White River Plateau of north-western Colorado. The cave is wholly developed within the Mississippian Leadville Limestone and contains over 3000 meters of surveyed passage (Pace, 1977, 1979; Pisarowicz, 1978). The cave entrance (elevation, 2380 m) is located at the head of a small tributary of the South Fork of the White River. This stream carries water only during times of very high water when the entrance passage acts as an overflow route for water backed up from the Thunder Road Sump. Nineteen seventy eight was the first year in at least the last twenty that the entrance passage carried water (Davis, 1979).

Initial passage development in Spring Cave correlates with a terrace along the White River 110 meters above modern stream level. The cave shows both phreatic and younger vadose passages developed at this level. Phreatically developed passages exist as upper level segments through the cave, beginning with the section from the double entrance to Thunder Road, a vadose passage carrying the modern cave stream. Thunder Road is one of a network of highly joint-controlled fissure passages with up to 15 meters of relief. Much of this area developed as a result of solution during the backflooding that resulted from ponding at the Thunder Road sump at times of high flow.

Continuing from Thunder Road involves traversing the Butterscotch and Bridge Room passages, both segments of the older phreatic system. This section is followed by 1500 meters of enlarged canyon passage which carries the main cave stream, interrupted midway by Sump One. Several meters overhead this vadose passage is seen to intersect the rounded phreatic tube passage. Throughout the entire section of the cave preceeding Sump One, the main passage development alternates between various joints, but maintains orientation very close to the strike of the Leadville Limestone.

Spring Cave's stream flow, both within the cave and at its resurgences were observed at various times during May and June 1978 (Pisarowicz, 1979) and during the low water ebb in December of that same year (Dowds, 1979). Measurements of the scalloping in various sections of the cave were collected during the December visit. Flow volumes were calculated from the scallop data and compared with the stream flow data.

Table 1: Volume of water flowing from Spring Cave's resurgences.

Entrance	.57 m^3/sec
Overflow Resurgence Group	5.66 m^3/sec
Lower Level Resurgence Group	25.49 m^3/sec
Total	31.72 m^3/sec

On the surface, water from Spring Cave was noted to resurge in three distinct areas--the entrance, an overflow resurgence group (Williams and Pisarowicz, 1979), and the lower level resurgence group (Hassemer, 1976). The flow from each of these resurgences were estimated and totaled in Table 1. The volume of this water was approximately 31.72 m^3/sec.

Flow volumes for the cave passages were calculated using scallop measurements. From Figure 2, the ratio of conduit diameter or width (D) to mean scallop size ($\overline{L_{32}}$) was used to determine a Reynolds number ($\overline{R_{eL}}$). Using the predicted Reynolds numbers derived from Figure 2 in Curl's equation, mean flow velocities for various sections of Spring Cave were calculated (see Table 2).

Table 2: Calculated flow velocities and volumes in Spring Cave.

	Flow Velocities	Flow Volumes
Sump One	1.10 m/sec	32.71 m^3/sec
Flume	1.04 m/sec	36.72 m^3/sec
T Junction	1.82 m/sec	34.31 m^3/sec
Cobble Road	2.10 m/sec	**
Bridge Room	2.05 m/sec	**
Thunder Road	1.98 m/sec	*

Mean = 34.58 m^3/sec

**Flow volumes are not given for Cobble Road and the Bridge Room since both these sections of Spring Cave are overflow routes.

* Thunder Road's flow volumes is not given since this section of the cave is situated within a complex hydrological subsystem of Spring Cave involving not only the Thunder Road conduit but the 17 resurgences of the Overflow Resurgence Group as well.

Concerning these measures, note that the highest velocities occurred in Cobble Road and the Bridge Room. These areas of the cave are certainly high level overflow routes and thus are currently being scalloped only during periods of flood. The Bridge Room may also be showing evidence of older flow patterns as well, before the cave changed from phreatic to vadose.

In Table 2 also note that apparently all the water that flows from the Sump One area is accounted for. The calculations at Sump One, the Flume, and the T Junction all agree within an order of magnitude. The mean flow from these areas is 34.58 m^3/sec.

The calculated volume of water flowing through Spring Cave agrees quite well with the volume flowing from the resurgences. The difference is only 8.26% of the calculated volume. It appears that Curl's theoretic flow velocity calculations from scalloping correctly describe actual cave stream flow.

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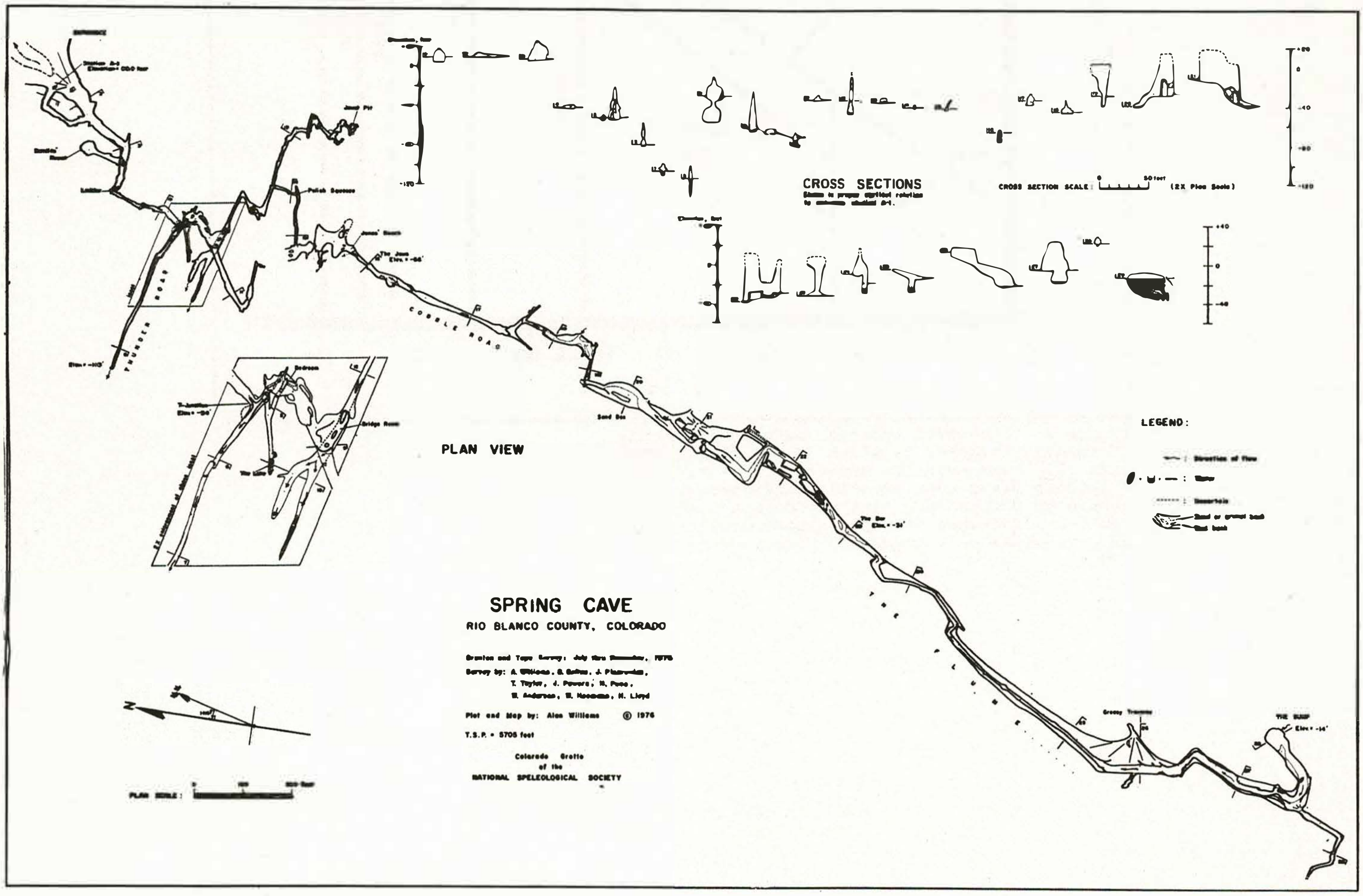
Figure 1: Map of Spring Cave, Colorado



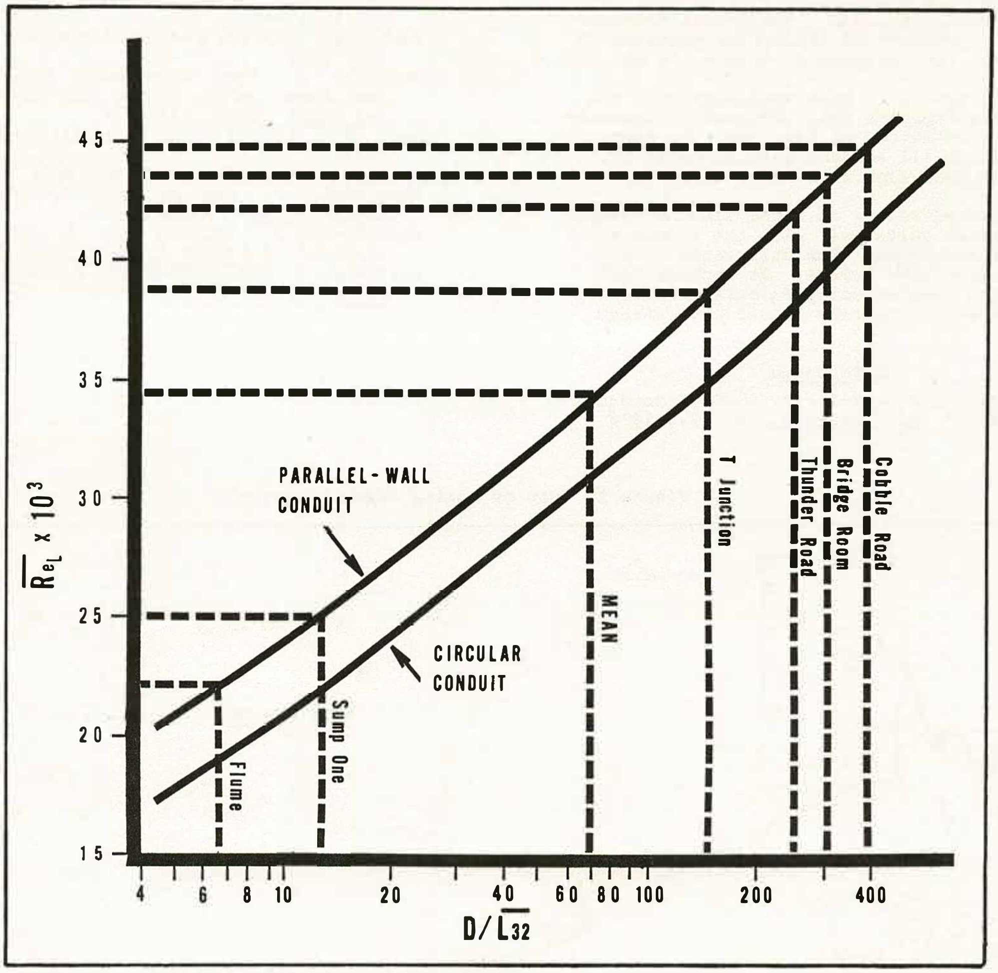


Figure 2: Predicted relation between the ration of conduit diameter or width (D) to mean scallop size ($\overline{L_{32}}$) and Reynolds Number ($\overline{R_{e_L}}$). All calculations based upon Parallel-Wall Conduits. It should be pointed out that the Cobble Road passages could be described as a circular conduit instead of a parallel wall conduit. Figure after Curl (1974).

Classification des Concrétions Calcaires Stratifiées en Fonction des Conditions de Milieu

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Résumé

On peut classer toutes les formes de concrétions, en particulier les concrétions calcaires stratifiées, selon des critères minéralogiques, morphologiques, ou de conditions de milieu.

La classification proposée porte d'une part sur le milieu précis au contact duquel croissent ces concrétions (film d'eau, eau profonde stagnante ou courante, sédiments sableux ou argileux, etc.), d'autre part sur les facteurs qui influent sur ce milieu, en particulier climatiques.

Le choix de ces conditions de milieu est pragmatique, puisque fondé sur l'observation des circonstances dans lesquelles se rencontre tel ou tel aspect morphologique des concrétions considérées; il s'agit donc d'une classification dans laquelle le critère morphologique est en quelque sorte sous-jacent; ce qui semble la condition nécessaire pour que les problèmes de genèse puissent être abordés.

Abstract

We can classify all kinds of speleothems, particularly the stratified calcareous deposits, according to mineralogical, morphological or environmental criteria.

On the one hand the classification depends upon the nearest environment in which these formations grow (film of water, deep standing or running water, sandy or clayey sediments,...) on the other hand it depends upon the agents which have an influence on this environment, particularly the climatic ones.

The choice of these environmental conditions is pragmatic, because it lies on the observation of the circumstances in which occur such and such morphological appearance of the involved speleothems. Thus it is a classification in which the morphological criterion is more or less underlying it seems the necessary condition to handle the problems of genesis.

1. Trois Modes de Classification des Concrétions

La classification des concrétions peut se faire selon divers critères:

- L'un des plus fréquemment adoptés est la nature minéralogique ou, ce qui n'est pas très différent, le processus physico-chimique de dépôt; et l'on distingue alors les concrétions des carbonates, des sulfates, des phosphates, des nitrates, les concrétions siliceuses, les dépôts d'oxydes metalliques, etc.
- On peut aussi tenir compte de la morphologie des concrétions: aux cristallisations définies dans des publications précédentes comme présentant une structure qui résulte essentiellement du mode de croissance cristallin, il convient d'opposer les concrétions stratifiées dont la structure est commandée par un dépôt en couches superposées. A ces deux grandes catégories, on ajoutera les amas de cristaux, beaucoup plus rares; et l'on précisera que le mond-milch a une structure le rapprochant des amas de cristaux, tandis que son mode de dépôt s'apparente souvent à celui des concrétions stratifiées.
- La classification par les conditions de milieu serait la plus satisfaisante dans la mesure où elle livrerait la clef de chaque dépôt, permettant de définir le processus physico-chimique à mettre en cause, et d'expliquer la morphologie. Une telle démarche paraît d'autant plus justifiée que certaines formes de concrétions très semblables sont constituées de minéraux différents.

Mais il est exceptionnel, dans la littérature spéléologique, de voir tel ou tel dépôt de concrétion rapproché objectivement de ses conditions de milieu; de sorte que la classification que je propose est essentiellement la synthèse de mes propres observations.

2. Structure et Consistance des Concrétions Calcaires Stratifiées

Parmi les concrétions du karst profond et superficiel, les concrétions calcaires stratifiées sont, de loin, les plus banales.

Ces concrétions sont constituées le plus souvent de cristaux de relativement petite taille (jusqu'à 2 cm. d'arête environ, comme il est facile de l'ovserver sur certaines coulées stalagmitiques); ces cristaux sont enchevêtrés, certains sont "incomplets" parce qu'ils servent à l'enrobage des autres, de telle sorte que la surface de la formation soit approximativement unie. Certaines concrétions stratifiées sont constituées de cristaux allongés, de faible section, sub-parallèles ou rayonnants (dans les concrétions de forme cylindrique ou sphérique), la structure est alors dite fibroradiée; le plus souvent, la formation est constituée de couches stratifiées à structure fibroradiée, mais il est rare que la stratification ne soit pas au moins marquée par des différences de teintes. On sait que les draperies sont presque toujours à structure fibroradiée; et les concrétions d'aragonite massive ont toujours une structure finement fibroradiée.

Les concrétions stratifiées peuvent présenter trois types différents de consistance, sans que la forme en soit profondément affectée en général:

- les concrétions dures sont les plus connues; en l'absence de précision supplémentaire c'est d'elles que je parlerai;
- les concrétions crayeuses, dont l'aspect microcristallin et la friabilité rappellent les caractéristiques de la craie; elles se rayent à l'ongle; beaucoup sont blanches;
- Les concrétions molles ont une consistance variable, mais elles enfoncent généralement sous la pression du doigt, et certaines sont constituées de mondmilch; une croûte indurée recouvre parfois ce type de concrétion. La décalcification peut rendre molles des concrétions initialement dures.

3. Les Conditions de Croissance

Les concrétions calcaires stratifiées se déposent toujours dans l'eau:

- pour la plupart il s'agit d'un film ou d'une goutte d'eau: stalactites et draperies, stalagmites, planchers stalagmitiques, bords de gours, etc.
- d'autres se déposent dans des eaux plus profondes, animées d'un mouvement plus ou moins rapide; dans ce dernier cas, les formes sont liées au sens du courant (formes "en lanières", "en écailles"). Dans des rivières souterraines mais aussi sub-aériennes, on trouve des dépôts stratifiés érodés par endroits. Certaines de ces concrétions noyées sont molles, qu'elles prennent la forme d'une bande de niveau ou de sortes de choux-fleurs d'un mond-milch grumeleux.
- enfin certaines concrétions stratifiées se déposent en outre au sein d'un autre sédiment, sable ou limon; c'est notamment le cas des bases de stalagmites et de toutes les concrétions se développent sur le sol, qui tendent à englober d'abord les éléments de ce sol, et même à s'infiltrer entre eux (fig. 1); lorsque l'eau quitte une telle concrétion, elle peut, de plus emporter ou déplacer des éléments de ce sol; le vide ainsi formé de comble de concrétion, donnant parfois l'impression d'une véritable injection.

Mais il existe en outre des formes plus spécifiques: certaines concrétions stratifiées banales, enterrées dans un sédiment argilo-sableux vont continuer à croître à l'intérieur de ce sédiment selon des processus comparables à ceux que je viens d'évoquer.

D'autre part, les eaux qui se déplacent à l'intérieur de tels sédiments déterminent des dépôts qui se localisent initialement, en général, selon un plan de stratification du sédiment, plus rarement selon une fissure affectant ce sédiment; il en résulte des formes en poupées tout à fait comparables à celles du loess; ces poupées peuvent finir par se rejoindre et constituer un réseau maillé à deux ou trois dimensions.

4. Les Conditions Géologiques et Géographiques

Il est bien connu que les concrétions se forment souvent au niveau des fissures qui déterminent les arrivées d'eau; si l'arrivée d'eau est importante, la grotte peut se trouver interrompue par une véritable barrière de concrétion. Exceptionnellement, les joints de strate peuvent jouer le même rôle que les fissures dans la localisation des concrétions.

La porosité de certains calcaires permet la croissance de stalactites jointives, surtour quand l'épaisseur du plafond au dessus de la cavité est faible; inversement des calcaires marneux sont peu favorables au dépôt de concrétion.

Par ailleurs, sous un karst nu, la teneur en CO_2 de l'eau est, en principe en équilibre avec celle de l'air extérieur; de sorte que lorsque cette eau parvient dans une cavité souterraine où la teneur en CO_2 de l'air est supérieur (ne serait-ce que par piégeage) à celle de l'air extérieur, elle ne peut dégager du gaz carbonique et déposer des concrétions. Ce n'est que sous un karst couvert, lorsque l'eau peut s'enrichir en CO_2 durant la traversée du sol végétal, que le concrétionnement peut être abondant.

J. Montoriol Pous observe par ailleurs que, dans le cas d'étages de galeries superposés, il y a alternance entre les étages concrétionnés et ceux qui ne le sont pas; pour une part, cette observation peut s'expliquer par le phénomène de décantation du gaz carbonique.

5. Influence du Climat Régional

Comme il est logique, l'influence de ce climat se fait sentir surtour à proximité des entrées.

- dans les régions où le gel est fréquent, les zones des cavités proches des entrées sont généralement dépourvues de concrétions, car les parois sont délitées par le gel. Par ailleurs, dans les régions froides, les concrétions molles sont fréquentes; l'on connaît des concrétions en mond-milch et plus généralement des formes faisant penser à un écoulement de la concrétion par gravité: draperies "en tablier", cascades stalagmitiques présentant des formes très enveloppées " en manteau", stalactites en mamelle. Les zones à climat frais (type Jura) possèdent, dans les zones profondes, les plus beaux groupements de cierges connus (fig. 2).
- à partir des régions méditerranéennes et dans les régions plus chaudes, les dépôts envahissent les entrées et les parois extérieures rocheuses (avec utilisation fréquente des joints de strates), et paraissent liés davantage aux écarts thermiques et à l'évaporation qu'à la simple sursaturation en gaz carbonique; ces concrétions sont de formation rapide, souvent crayeuses et manifestent un pseudo-phototropisme, l'action prépondérante du climat extérieur (et peut-être des actions biologiques) les faisant croître plus vite en direction de la lumière. Bien que le mond-milch n'y soit pas inconnu, les concrétions des régions chaudes ne sont pas soumises à l'écoulement par gravité, et les irrégularités cycliques de surface demeurent bien visibles (fig. 3).

Les concrétions les plus volumineuses qui se forment à l'extérieur, c'est à dire les dépôts de tuf calcaire et de travertin, sont évidemment totalement soumises au climat régional. Mais il semble que le processus de dépôt soit différent selon la température de la source: celles à température ordinaire sont de dureté exceptionnelle, et la précipitation du calcaire parait avoir pour cause l'agitation de l'eau et des processus biologiques, puisque l'on sait que le seul déséquilibre par rapport à la loi de Henry ne suffit pas à expliquer un dépôt rapide; il est probable que la température externe joue un rôle, notamment quand la dureté de l'eau est moins importante, comme dans le cas des barrages de tuf de Plitvice (Yougoslavie); pour les sources hydrothermales, l'évaporation qui se produit à l'émergence est une cause de refroidissement et donc d'accroissement de la solubilité du CO_2, mais en même temps d'augmentation de la concentration en calcaire.

Pour revenir au domaine souterrain, on notera que les indications de J. Corbel concernant la proportion plus ou moins grande de stalagmites par rapport aux stalactites, et le volume plus ou moins important des concrétions selon que le climat est chaud ou froid n'ont guère été confirmées par les observations ultérieures; du reste, les cavités à climat froid prises en compte par J. Corbel sont, d'après ses propres travaux, également des cavités très jeunes; il n'est donc pas surprenant que le volume des concrétions y soit faible. Par contre, l'humidité du climat régional, du reste propice à une couverture végétale, a une action directe sur le volume des concrétions, surtour à proximité des entrées. Quant à la forme de ces concrétions, elle est fonction du débit, ainsi qu'il résulte des mesures de A. Eraso, qui montrent par ailleurs l'influence négligeable de la teneur en CO_2 de l'air (fig. 4).

6. Rôle du Courant d'Air - Les Anémolithes

Parmi les concrétions déformées par un courant d'air, les plus connues sont sans doute les stalactites qui croissent selon une oblique, en direction opposée à celle du courant d'air d'hiver (dans les tubes à vent) (fig. 5).

Mais certaines concrétions, conservant leur morphologie habituelle, se contentent de s'étendre latéralement en direction du courant d'air: stalactites et draperies ornées d'une sorte d'oriflamme, stalagmites en "borne kilométrique".

D'autres concrétions déformées par un courant d'air sont ascendantes: ce sont les "nids d'oiseau", mais surtour les grandes "feuilles" des "stalagmites pomme de pin" ou "en tronc de palmier" (fig. 6); ces formations spectaculaires ne semblent pas, quoiqu'on en ait dit, liées à un contexte climatique régional; mais elles se trouvent toujours à un niveau intermédiaire entre deux dénivellations notables, les formes les plus élaborées ne se rencontrent que lorsque la dénivellation supérieure débouche en surface (fig. 7); ces observations conduisent à penser que des courants de convection sont responsables de ces formes.

7. Cas de Confinement

Avant de décrire les formes liées au confinement, il faut observer que l'influence du climat extérieur s'étend d'autant moins profondément sous terre que ce climat est peu variable: en climat tropical humide, les formes caractéristiques se rencontrent dans des conditions de confinement beaucoup moins sévères que dans un karst européen.

Le confinement est nécessaire à l'élaboration des cristallisations et de ces formes intermédiaires entre concrétions stratifiées et cristallisations que sont les concrétions monocristallines (les plus connues sont des stalagmites monocristallines, notamment à section triangulaire, mais il existe de même des stalactites massives et des draperies monocristallines; ces dernières, précédemment supposées par P. Cabrol, ont été découvertes par moi dans la grotte de Sant'Ana, Sao Paulo, Bresil).

Certains auteurs (W.M. Davis, F. Trombe, etc.) ont cru que l'atmosphère des zones karstiques les plus profondes étant saturée de vapeur d'eau, ou que son taux de CO_2 étant en équilibre avec la teneur de l'eau qui parvient de la surface, le dépôt de concrétion y était impossible. En fait, la décantation (ou sédimentation) du CO_2 se traduit en permanence par un déséquilibre dans le taux de ce gaz dans l'air, rendant parfaitement possible le dépôt de calcaire; il est du reste facile de constater que le dépôt de concrétions stratifiées d'aspect parfaitement classique est souvent très actif même dans des zones bien isolées des influences extérieures.

Si les cristallisations d'aragonite se trouvent en zone confinée, il n'est pas possible d'être aussi affirmatif pour les concrétions massives de cette variété minérale: la plupart se rencontrent, certes, en zone profonde, mais on connaît deux grottes français dont toutes les concrétions, même à relativement faible distance de l'entrée, semblent être en aragonite (les cristallisations y sont en zone profonde); et l'on peut même citer le cas d'une concrétion déformée par un courant d'air, qui est partiellement en aragonite massive (grotte de la Ficelle, Aveyron, France).

8. Observations sur la Méthode

A. Vandel a écrit que "les classifications ne constituent que des artifices destinés à soulager notre mémoire". En morphologie, elles permettent d'aller un peu plus loin:

Les conditions de milieu que j'ai prises en compte résultent de l'observation d'une relation bi-univoque entre la forme et un certain type de localisation.

Dans la mesure où les corrélations mises en évidence apparaissent non contestables, il est clair que ce travail d'inventaire permet de remonter aux conditions physico-chimiques de dépôt, c'est à dire de préjuger des processus.

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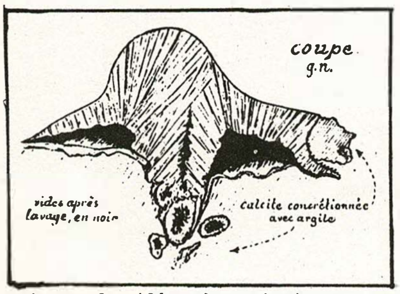

Figure 1. (d'après Prinz): coupe d'une stalagmite ayant englobé des éléments de sol

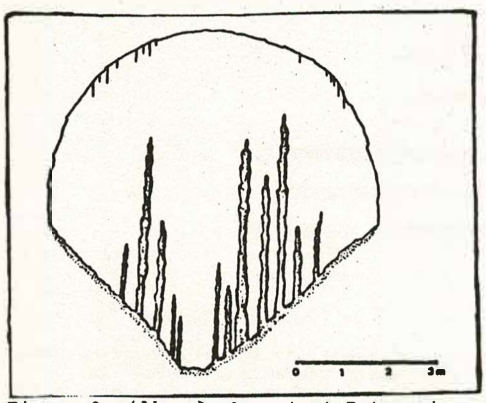

Figure 2. (d'après Aucant et Petrequin - dessin G. Piquard): groupement de cierges de la salle des Mille Colonnes du gouffre de Granges Mathieu (France)

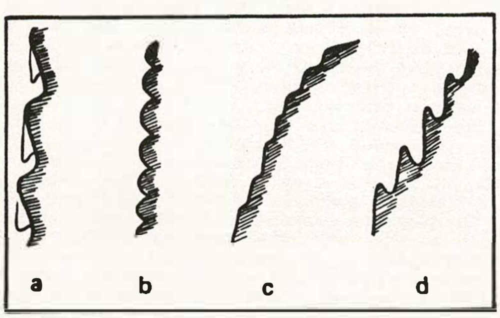

Figure 3. irrégularités cycliques de surface des concrétions stratifiées; a) étages à mini-dais, b) renflements horizontaux jointifs, c) mini-gradins, d) micro-gours

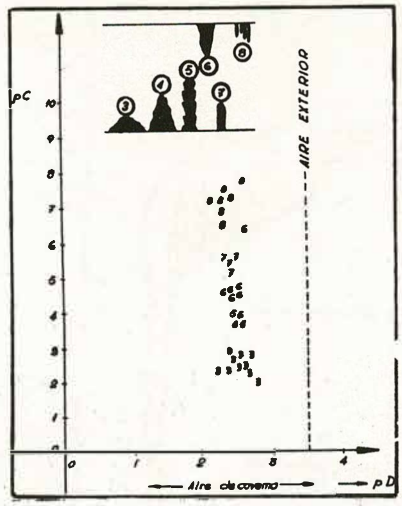

Figure 4. (d'après Eraso): forme des concrétions stratifiées en fonction de pD (= log pCO_2 en atmosphères) et pC (= log débit en litres/sec.)

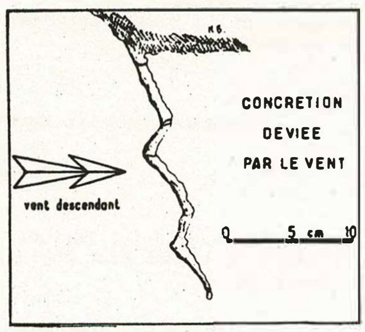

Figure 5. (d'après Bakalowicz): stalactite anémolithe de la grotte de Pinargözü (Turquie); la flèche indique le sens du courant d'air d'été

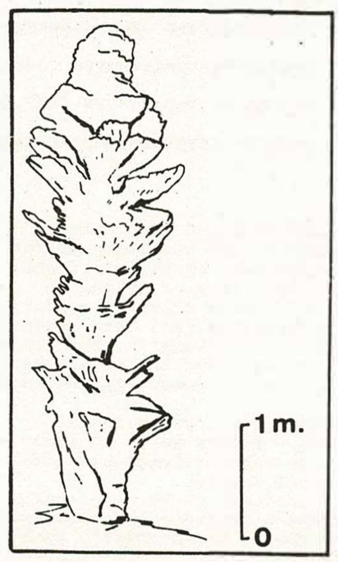

Figure 6. stalagmite en tronc de palmier de l'aven Armand (France)

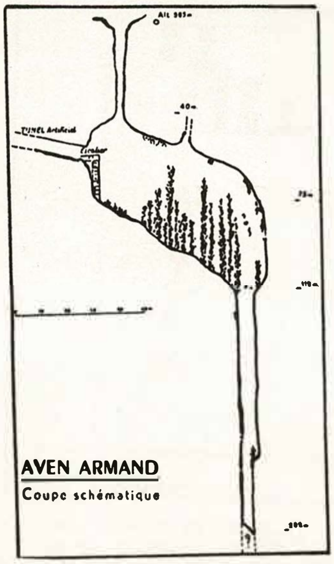

Figure 7. (d'après L. Balsan): coupe de l'aven Armand (France) montrant la localisation des stalagmites en tronc de palmier

Gypsum-Anhydrite Karst on the Territory of the USSR

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Résumé

L'environnement géologique, hydrogéologique, physicogéographique du développement du karst gypso anhydrite sur le territoire de l'URSS sont characterisés. On note aussi les particularités de morphologie du type lithologique donné du karst.

ГИПСО-АНГИДРИТОВЫЙ КАРСТ НА ТЕРРИТОРИИ СССР

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В докладе охарактеризованы геологические,гидрогеологические, физико-географические обстановки развития гипсо-ангидритового карста на территории СССР.Отмечаются также особенности морфологии данного литологического типа карста.

Gypsum and anhydrite are included into hologen formations widely distributed on the territory of the USSR. They occupy the largest area on the platforms and in the foredeeps. The total area of sulphate-bearing hologen formations of stages makes up approximately 10 mln.sq.km. The formations fall into three regions: the East-European, mainly Permian, the East-Siberian, chiefly of Cambrian age, and the Middle-Asian with the prevalence of Jurassic-Cretaceous and Paleogene-Neogen.

The paleokarst and recent karst areas can be singled out of these regions. Recent karst is manifested in the zones of active waterexchangeable artesian basins or hydrogeological massifs.

Depending on the rock composition karst preceeds into gypsum-anhidrite, dolomite-gypsum-anhydrite, limestone-gypsum-anhydrite, gupsum in the terrigene rock mass and saline-gypsum types.

Physical-geographical situations of sulphate karst manifestations are various: arctic (Novaya Zemlya), silvan (the greatest part of the Volga-Kama, Northern Dvina, Pribaltic areas), silvan-steppe (southern part of the Volga-Kama, Pridnestr areas), steppe (the Dnepr-Donetsk area), semidesert and desert (Prikaspian area). Karst of the East-Siberian region develops in the permafrost zone, and in the Middle-Asian region it is formed under desert and highland conditions.

Active gypsum karst is observed at insignificant erosive ruggedness of relief in the lowlands (Pricaspian area), on the plains (the Privolga area), on the plateau (the Kuloysko, Ufimsko), on the slopes of mountain structures (the North Caucasian, Pamirs-Alai).

Usually gypsum-anhydrite massifs due to quick attenuations of jointing with depth differ in less thickness of vertical descending circulation karst water zone and in less depth of karstification comparatively with carbonate ones. The zones adjacent to deep paleovalleys, zones of tectonic joints, contacts of sulphate and carbonate rock masses, where karst is developed at the depth of more than 100 m, represent the exception. Karst waters of high mineralization have sulphate-calcic composition.

Surface karst forms are represented by karren at the sites of exposed and sodded karst, by ponors, karst wells, dolines, the density of which is 500-1000 forms per sq.km, by karst basins, trenches, depressions (of several kilometres across), by karst and karst-erosion ravines, cirques and remnants. Karst ponds, springs and shallow rivers with water mineralization 2-3 gr/l are characteristic of sulphate karst.

Subsurface forms: cavities, channels, corridors or lattice type caves pass along the system of tectonic distribution. The length of separate longest caves in Podoliya achieves 136 km (Optimistitcheskaya Cave).

The regions of active sulphate karst are unfavourable for engineering geology as well as for search for fresh underground waters. But they are perspective for exploration of mineralized waters, hydrosulphuric in particular.

Genetical Observations on Some Natural Cavities of the Masua Mines (SW Sardinia)

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Abstract

The study of the calcite crystals found on the walls of two karstic cavities inside Masua Mine (Iglesias-SW Sardinia) allowed the definition of seven different periods in the cave speleogenesis.

In the present paper the authors discuss the conclusion achieved for the chronology of the observed phenomena.

Sommario

Nella miniera di Masua sono state incontrate alcune cavità carsiche senza diretta comunicazione con l'esterno.

Le pareti di queste grotte sono completamente coperte da grandi cristalli di calcite, corrosi e quindi rigenerati.

Lo studio di questi cristalli ha permesso di definire 7 differenti periodi speleogenetici per le cavità studiate.

Introduction

Mining activities inside the Masua mine (Inglesias-SW Sardinia) came across some karstic cavities without direct communication with the surface.

The walls of these caves were completely covered with large calcite crystals, which were corroded and in a second time partially regenerated.

The study of these crystals allowed the definition of seven different periods in the cave speleogenesis.

In the present paper, the experimental observations and the laboratory analyses are firstly reported, then the authors discuss the conclusions achieved for the chronology of the observed phenomena.

Experimental

In the cambric carbonatic formations of the Masua mine the mining activities came across some karstic cavities without direct communication with the surface.

The lowest caves, called Phaff 1 and 2, are at 42 m b.s.l., much lower than the preexistent water level, which was at 176 m a.s.l., as testified in the "Capstan room cave" (see fig. 1) by a large reempool above which there are vadose concretions, while below there are phreatic formations.

The Phaff 1 cave (see fig. 2) is a large bell shaped room (30X40X40 m) with a dome shaped top of about 60 m; the Phaff 2 cave is quite equal to Phaff 1 but smaller.

The two cavities contain no concretions at all, but their walls are completely covered by large pale yellow calcite disphenoid, which have inside avident layers of more intense colour.

The crystals are quite completely detached from the limestone substratum, being connected only in few places by small rock bridges.

The floor is covered by large boulder choke, and each boulder has only one side, but not necessary the upper one, covered by calcite crystals.

All the crystals are very corroded and then covered by small white transparent or lactescent calcite tabular crystals.

The upper faces of the crystals whether on the walls or on the collapsed boulders are covered by reddish-black clots, which are in turn under layered clay silt: there is a thickness of 2-3 cm over the crystals, while on the floor the thickness is ten times greater.

Discussion

The cavities shape in relation to the cambric rocks bedding and steering clearly indicates that the first speleogenetic stage (corresponding to the vacuum formation) began after the sudetic tectonic phase (middle carboniferous-permian).

Moreover the total absence of calcite sinter is due to the fact that the caves were carved in phreatic conditions by highly aggressive waters.

The second speleogenetic stage is coincident with the growth of the large calcite crystals: these have also been developped in phreatic conditions, but the water composition had to be changed from aggressive to highly supersaturated.

Since the region has been interested by a transgression during the Trias, the variation of water composition can be ascribed to this geological event.

In the third stage the crystals corrosion took place, and again this happened in phreatic condition, because all the crystals inside the caves have involved.

The cause of the corrosion was the H_2SO_4 ingression due to the oxidation of the Pb and Zn sulphides in the top of the ores, which probably is related to a period of an hot climate (Miocene-Pliocene): the product of this reaction, the gypsum, has been completely removed by phreatic waters owing to its high solubility.

The corrosion due to H_2SO_4 rich waters caused also the detachment of the calcite crystals crusts, which are now linked to the walls only by few calcareous bridges. In fact it's more difficult to solubilize the large crystals than the micritic structure of the limestone substratum, which is more rapidly corroded.

Moreover the starting of the forth speleogenetic stage (the collapsing one) is probably to be ascribed to the H_2SO_4 rich waters.

This period is also characterized by phreatic conditions, as it's testified by the cutting edges of the large collapsed blocks and by the fallen crusts of crystals, which normally have not been broken when they fell.

When the H_2SO_4 ingression ended, a new but weaker crystallization phase began, which led to the deposition of small calcite crystals, different in habit and colour from the previous ones, which covered the large and eroded crystals as a thin layer.

This fifth speleogenetic stage is characterized by waters with low mineral content, normal in methoric waters.

This variation in water mineral content is confirmed by the chemical analyses of samples of the crystals, which showed a diminution in Pb, Zn, Fe and Mn content from pale yellow to transparent ones.

The water evolution went on with a progressive lowering of the acidity, when the mineral oxides (mostly ghoetite, but also pyrolusite) coagulation was allowed.

This stage led to the deposition of the black-reddish clots over the second type of calcite crystals; but the Fe, Mn oxides are quite absent under the collapsed boulders and this fact confirms that this period has to be following the previous one.

As in similar cases the oxide coagulation (i.e. the sixth speleogenetic stage) is probably related to strong pedologic variations, which can be ascribed to the glaciations.

The seventh and last speleogenetic stage is due to the artificial lowering of the groundwater owing to mining activities, and brought to the deposition of the clay silt over the upper faces of the wall crystals and on all the boulder choke on the floor.

The outlined genetic schema is also confirmed by isotopic analyses.

The isotopic composition shows an increasing in the $^{18}O/^{16}O$ ratio and at the same time the lowering in the $^{13}C/^{12}C$ ratio from the center to the surface of a single calcite crystal.

For the oxygen the observed trend indicates a progressive temperature lowering of the concreting waters with time and, perhaps, also a variation in water isotopical composition towards ^{18}O negative values (which are to be expected for metheoric waters).

On the other hand the isotopic data for the carbon shows a progressive variation from values characteristic of seawaters to those of metheoric ones.

Therefore the isotopic measurements showed at the same time a lowering of temperature and a chemical variation of the water from those of seawater (connate water?) to those of metheoric ones and this coincides with the difference found in chemical composition of the pale yellow and in the transparent calcite crystals.

Conclusions

The study of the crystals in the karstic cavities of the lowest level of the Masua mine allowed not only the reconstruction of the 7 different speleogenetic stages the studied caves have undergone, but also the definition of the chemical evolution of the circulating waters.

All the first 6 speleogenetic stages have been developped in phreatic conditions, while the chemical composition of water is gradually changed from connate to metheoric type.

Moreover the sulphide oxidation in the top of the ores represents a well defined moment in the geological history of the country.

In the future the karstic studies will be directed to the punctual correlation of the speleogenetic phases with the geological evolution and this will probably be achieved analysing several other caves present in the Monteponi and in the St. Giovanni mines (few km from Masua mine in S direction).

The importance of such studies is to be found essentially in the definition of the general chemical evolution of the groundwaters in the SW Sardinia, where the most important Pb and ZN ores are located.

Acknowledgments

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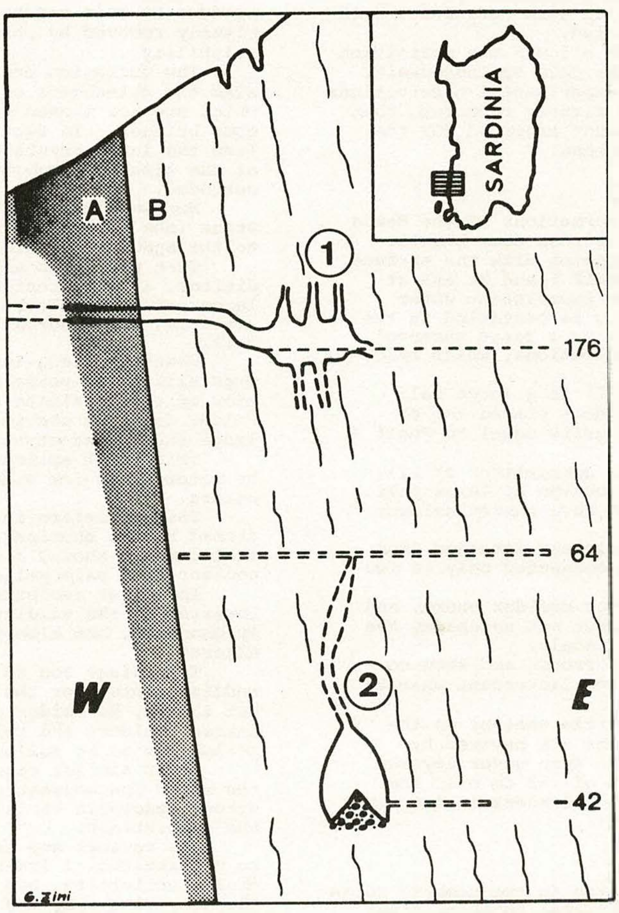

Figure 1. Cross section of the Masua Mine: dot lines represent mine galleries; 1: Capstan room cave with the reempool level at 176 m a.s.l.; 2: Phaff 1 cave; A: schist; B: limestones.

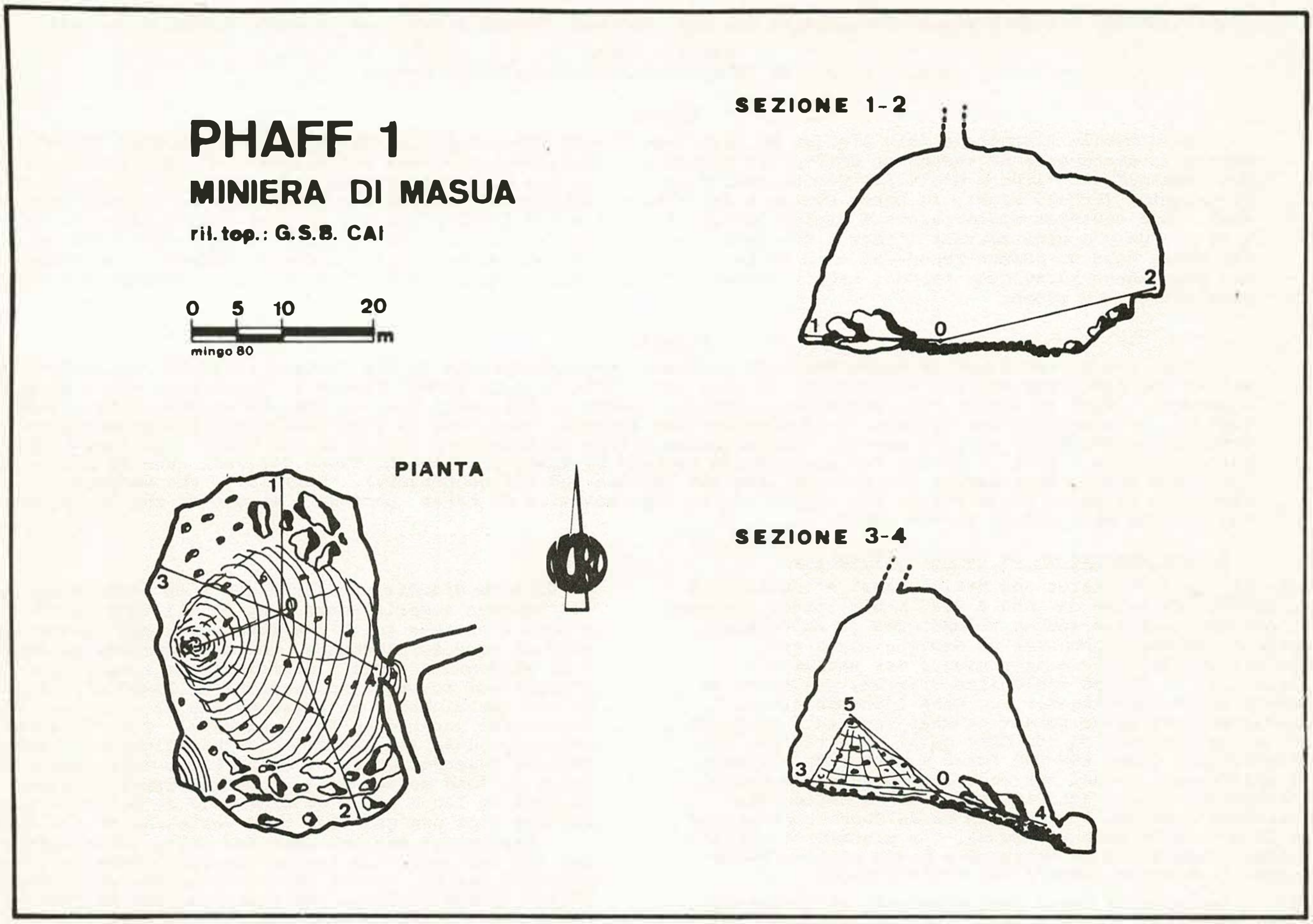

Figure 2. Horizontal projection and vertical sections of Phaff 1 cave

Formation des Grands Systemes Souterrains des Mts. Nakanaï (Nouvelle Bretagne-Paouasie Nouvelle Guinee)

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Résumé

La Nouvelle Bretagne a fait l'objet de deux expéditions spéléologigues de la F.F.S (1978,80). Celles-ci ont permis la découverte de vastes et difficiles systèmes hydrogéologigues dans les karsts à dolines jointives des Mts. Nakanaï (500-1500 m d'alt.). Compte tenu d'une tectonique Plio-Quaternaire très active et d'un climat hyperhumide (P=5-10 m/an), le karst évolue à une vitesse accélérée (dissolution spécifique X= 250-400 mm/1000 ans). Les rivières souterraines à violent débit (15 m^3/s à l'étiage) circulent dans de larges galeries de 40 m x 40 m. On y accède souvent grâce à des dolines-avens géantes de 200 à 400 m de profondeur (Ø 150-500 m). Ces puits hors du commun remontent sans doute au Quaternaire ancien ou moyen. Incontestablement, la démesure des phénomènes karstiques traduit magnifiquement l'hyperactivité de la karstification, certainement une des plus actives du globe.

Abstract

The French Federation of Speleology has organized two expeditions in New Britain (1978,80) which have permitted the discovery and the exploration of huge and difficult underground rivers in the doline karst of Nakanaï Mountains. With an active Plio-Quaternary tectonic (large anticlinal), Miocene limestones very thick (1300-1500 m), an excessive wet climate (5-10 m/year), the karstic evolution is inevitably very quick (specific dissolution X=250-400 mm/1000 years). Subterranean rivers (discharge = 15m^3/s in low water) run inside big galeries (40 m x 40 m). Cavers can reach these systems by giant pitches (collapse dolines) 200-400 m deep and 150-500 m wide.. Such shafts are more or less old (middle and old Quaternary). Certainly, the uncommon dimension of karst phenomena is the result of the hyperactivity of karst processes in one of the limestone regions the most active in the world.

I. Les Conditions de la Karstification:

I-1. Géologie: Le karst des Mts. Nakanaï s'identifie à un plateau calcaire de 1000 à 2000 m d'altitude reposant directement sur les roches volcaniques du Paléogène. Cette formation carbonatée du Miocène moyen est épaisse de 1300-1500 m et présente des variations verticales de faciès (calcaires crayeux, calcaires en petits bancs, argilites...). Dans l'ensemble, ces calcaires sont assez poreux et très tendres. Du point de vue tectonique, on constate qu'il s'agit d'un géanticlinal d'axe WSW-ENE formé à partir du Pliocène. Le soulèvement actuel est encore très sensible comme l'atteste la forte activité sismique de cette côte méridionale située à proximité de la fosse sous-marine de la Mer de Salomon (-7880 m). La plateforme corallienne Quaternaire de cette même bande côtière a été portée localement jusqu'à 300 m d'altitude.

I-2. Climatologie: Cette région connaît un climat de mousson typique. A la station côtière de Pomio, les précipitations annuelles sont de 6541 mm, mais il peut tomber jusqu'à 11000 mm certaines années.

	J	F	M	A	M	J	J	A	S	O	N	D
Pomio	235	151	226	262	449	846	1261	1195	777	463	250	237

Année - 6541 mm

Dans la montagne, la pluviosité est encore plus forte et il faut s'attendre à une moyenne annuelle supérieure à 8 ou 10 m. Au niveau de la mer, la température moyenne annuelle est de 26, 2°C. Malgré la forte évapotranspiration (1500 mm/ an) - la forêt créant ses propres nuages - le volume d'eau disponible pour la karstification demeure colossal, soit 5 m sur la côte.

I-3. Végétation et sols: L'intérieur de l'île est occupé par ce fameux "enfer vert" constitué par la forêt pluvieuse de basse et moyenne montagne. Cette couverture dense et continue détermine avec les pluies surabondantes l'hyperactivité de la karstification. Les précipitations, en traversant les sols en décomposition, se chargent en abondance d'acide carbonique. En surface, dans les mares, les eaux croupies ont des pH acides (6-6,8). Dans les sols, l'acidité est encore plus forte (pH = 5,4 - 5,7). En effet, pluseiurs mesures de la pCO_2 dans les sols ont donné des valeurs 20 fois supérieures à 40 cm de profondeur (pCO_2 = 0,45%) qu'en surface (pCO_2 = 0,02%). Au fond des profondes dolines-avens et dans les grands conduits souterrains, la pCO_2 demeure assez forte (0,15%), soit 6 à 7 fois plus que dans la forêt.

II. Les Systemes Souterrains Géants:

Les Mts. Nakanaï présente un exemple remarquable de karst polygonal à deux dominantes: d'une part un karst à dolines jointives ("Cockpit karst"), d'autre part un fluvio-karst à petits bassins hydrographiques fermés. Grâce aux photographies aériennes, il a été possible de localiser des dolines-avens géantes transperçant comme à l'emporte pièce la surface ondulée des plateaux. Sept de ces cavités phénoménales ont pu être descendues et explorées: elles mesurent 100 à 700 m de diamètre et 150 à 400 m de profondeur, pour des volumes compris entre 3 et 60 millions de m^3. Il s'agit d'énormes puits d'effondrement aux flancs subverticaux ou même surplombants, souvent tapissés de coulées de tufs et donnant accès - du moins dans quatre cas - à d'impétueux torrents souterrains de 15-20 m^3/s à l'étiage. On est certainement en présence des plus grosses entrées de cavités karstiques de la planète. Ces "fleuves" souterrains auxquels les expéditions spéléologiques français se sont heurtées et que l'on aperçoit furtivement par avion au fond de ces puits, s'engouffrent dans des porches de 100 à 150 m de haut pour se poursuivre en rapides dans des galeries très vastes de 40 m x 40 m.

Rien n'est exagéré dans ces pâles descriptions, car ici tout est à la mesure des phénomènes karstiques de cette région. Ainsi en est-il de ce canyon superficiel venant se jeter par crans successifs dans le vaste puits d'effondrement du "Bikbik Vuvu" profond de 160-200 m. Exploré en saison relativement sèche, nous avons pu poursuivre l'exploration dans un véritable canyon souterrain faisant suite au canyon aérien. Là, nous avons rencontré des marmites de géants d'une taille encore jamais constatée sous terre. Certaines sont des marmites-puits de 10-25 m de diamètre et de 10-20 m de profondeur, et que l'on ne peut franchir parfois qu'en escalade artificielle. D'autres, plus évasées, peuvent former des bassins de plus de 30 m de large. Une telle morphologie ne peut s'expliquer que par un torrent débitant 50 à 100 m^3/s en hautes eaux et possédant des crues spectaculaires capables de transporter les plus gros troncs d'arbres jusqu'au siphon terminal situé à plus de 2 km de l'entrée et à 414 m de profondeur. Du point de vue hydrologique, on constate que les grands réseaux souterrains (système de la Matali: -459; système de Naré: - 400; système de Minyé -366; système d'Ora: -260) correspondent à une mosaïque de bassins-versants de taille moyenne mesurant chacun 100 à 200 km^2. Les débits spécifiques sont très élévés: 150-230 $l/s/km^2$. L'émergence de la Matali, d'un débit d'étiage de 20-25 m^3/s, a connu au niveau de son embouchure avec la mer une crue estimée à 1000 m^3/s (en 1977, pont détruit).

III. Formation des Dolines-Avens Géantes:

Les puits géants des Mts. Nakanaï sont des dolines d'effondrement de très grandes dimensions. Comme le montre la planche 6, on remarque qu'il s'agit toujours de la relation entre le plafond d'une grande salle souterraine et le fond d'une grande doline. L'exemple d'évolution le plus simple est fourni par Naré ou Minyé puisque l'on obtient d'immenses puits réguliers, très verticaux, à profil en cloche ou en tube. Dans le cas de Kavakuna, la dissymétrie de la cavité est due au décalage entre la salle et la doline sus-jacente. Pour Ora, on a affaire à une évolution plus complexe donnant lieu à une doline-aven double. Ce sont en fait deux dolines-avens rapprochées sur le point de se réunit en un ouvala puisqu'il ne reste qu'un pont rocheux relativement peu important. Enfin, dans le cas de l'énorme "cratère" de Lusé, il semble qu'on soit en présence d'un ouvala effondré montrant un stade d'évolution plus avancé que celui d'Ora.

Dans quatre exemples sur cinq, on note qu'il existe une relation directe avec une circulation souterraine importante. L'existence de très grandes salles est un fait certain. En effet, pluseiurs vides considérables ont été découverts dans les réseaux de Minyé et de la Matali (KaII). Ainsi, la salle d'Olaipun dans le KaII mesure près de 200 m de haut et présente un superbe profil en cloche (volume 2 millions de m^3). Compte tenu de la vitesse d'évolution de ce karst en général et des dolines, de tels effondrement sont tout à fait logiques. Quant à la datation des phénomènes, on peut avancer quelques hypothèses. Par exemple, l'ouverture de Minyé doit remonter au Quaternaire moyen. En effet, l'éboulis de base, malgré ses 80 m de haut, est bien petit comparé au volume total de la cavité, une grande partie des blocs éboulés ayant été digérés par l'intense dissolution (affaisement progressif in situ et lessivage des carbonates vers la rivière). En estimant le volume de l'évoulis disparu, on peut situer l'effondrement majeur à - 200,000 - 300,000 ans BP environ.

L'importance des dépots argileux en plusieurs points du système de Naré ou de Minyé tendrait à prouver que des mises en charge considérables se sont produites. Il est sans doute probable que l'éboulement massif du plancher suspendu d'une doline ait provoqué simultanément le barrage de la rivière et la remontée consécutive des eaux à l'intérieur de la cavité. Ce phénomène a d'ailleurs déja été signalé à Cuba (cf. Corbel-Muxart, 1970). La genèse des grands collecteurs est étroitement liée à l'important soulèvement Quaternaire de l'île de sorte que ces "fleuves" souterrains ne circulent pas sur un niveau imperméable mais tout simplement dans la masse même de la série carbonatée Oligocène épaisse de plus de 1300 m. Le perchement des émergences au flancs des parois de canyons (ex: Ora, Naré) prouve que le creusement de ces canyons s'effectue plus rapidement, les systèmes hypogés étant loin de leur profil d'équilibre.

IV. Hydrochimie et Dissolution Specifique:

Les eaux souterraines et d'émergences ont une température moyenne de 20 - 21 °C et un pH compris entre 7,2 et 7,8. Leur dureté totale voisine dans une fourchette de 14 à 20°F. Ainsi, compte tenu d'un TH moyen des eaux d'émergences et de rivières de 17 - 18 °F et d'un volume d'eau disponible de 3,5 à 7,5 m/an (lame d'eau écoulée), les taux de dissolution spécifique sont de l'ordre de 230 à 430 mm/ 1000 ans. Il n'y donc pas de doute, la karstification superficielle et souterraine est ici exceptionnellement rapide en raison de l'extrême pluviosité.

Conclusion

A l'inverse de certains karsts tropicaux à longue évolution principalement antéquaternaire comme dans les calcaires primaires de la Chine du SW (Kwangsi) et où la morphologie est celle d'un karst à inselbergs, donc à reliefs résiduels, les Mts. Nakanaï de Nouvelle Bretagne constituent un exemple saisissant de karstogenèse Plio-quaternaire particulièrement accélérée. L'intense dissolution souterraine exercée sur des calcaires tendres explique la formation de vastes salles dont l'éboulement du plafond est à l'origine des grands puits. Ainsi, on observe bien une péjoration de tous les phénomènes naturels: nébulosité, précipitations, couverture forestière, dissolution, volume des cavités, débits des rivières... Sans doute avons-nous là les conditions optimales de la karstification en climat tropical humide.

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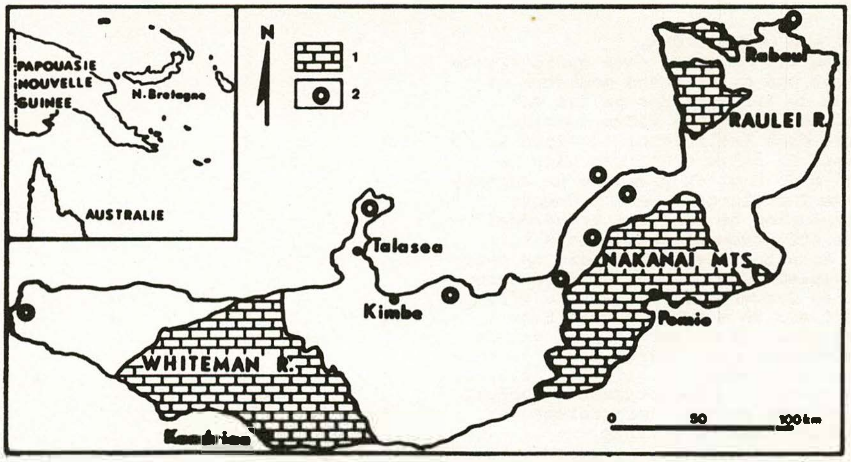
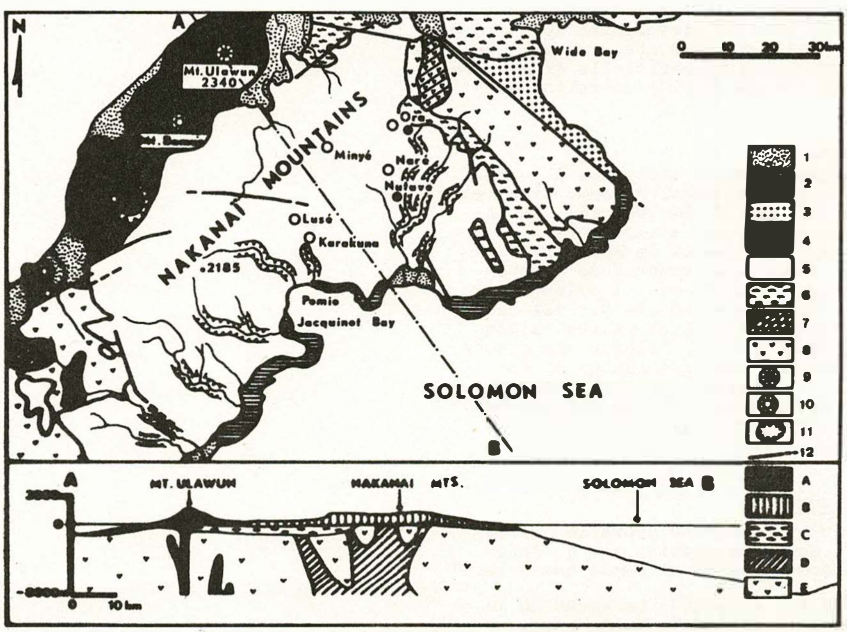


Figure 1: Distribution des karsts en Nouvelle Bretagne (1, Zones karstiques sur calcaire Miocène. 2, volcans actifs et récents).



Figures 2-3: Contexte géologique et coupe géologique des Mts. Nakanaï (Fig. 2: 1, alluvions Quaternaires. 2, calcaires coralliens Quaternaires. 3, conglomérats fluviatiles. 4, volcanisme récent. 5, calcaires de Yalam du Miocène moyen. 6, volcano-sédimentaire de l'Oligocène supérieur. 7, volcanisme sous-marin de l'Olig. Sup. 8, laves basiques de l'Eocène sup. 9, volcans actifs. 10, volcans éteints. 11, caldéra. 12, failles. Fig. 3: A, volcanisme récent. B, calcaires de Yalam. C, volcano-sédimentaire. D, volcanisme sous-marin (Olig. sup.). E, Laves basiques (Eocène sup.).

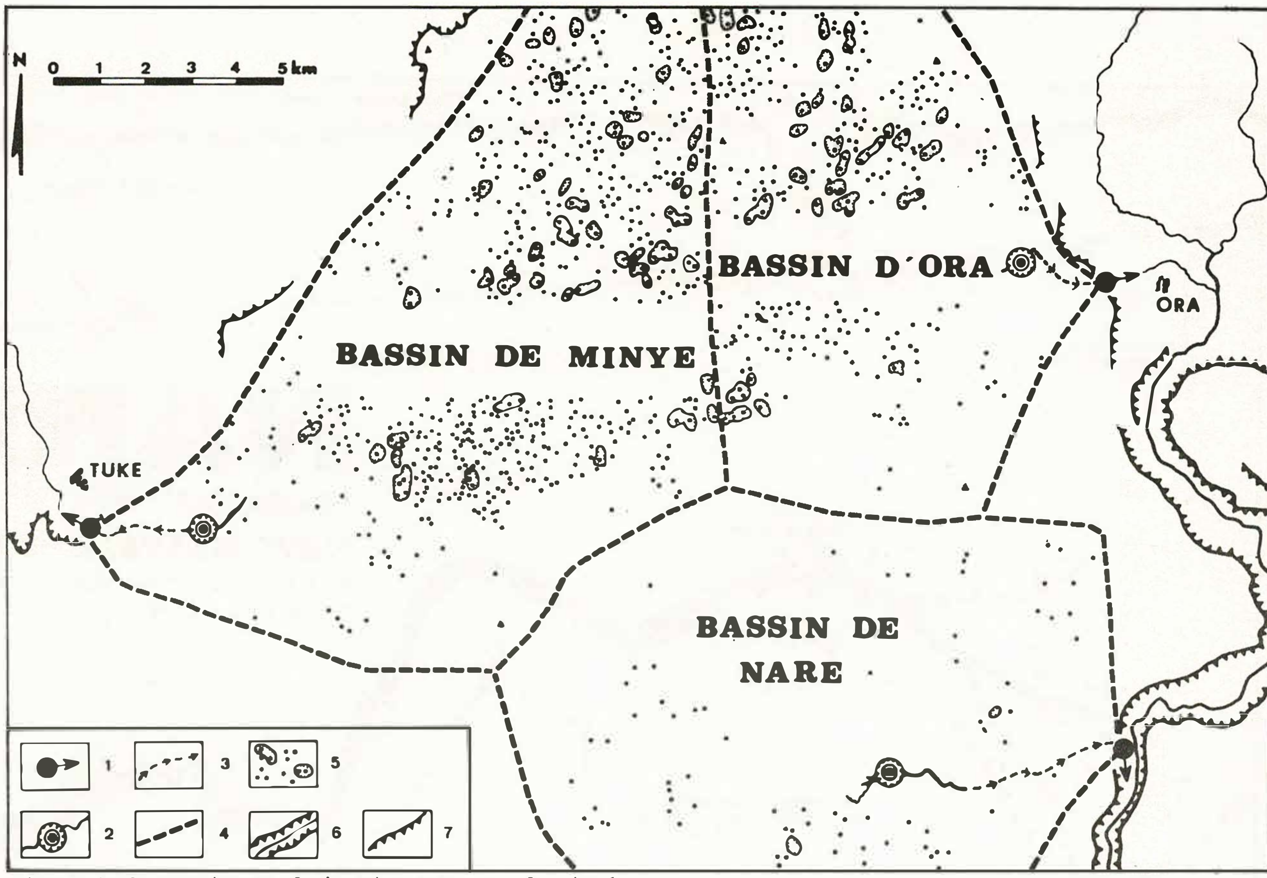


Figure 4: Les trois grands bassins-versants de Minyé, Naré et Ora (Mts. Nakanaï) (1, émergences; 2, dolines-avens géantes et réseaux connus. 3, trajet supposé. 4, limites approximatives des bassins-versants. 5, dolines et grandes dépressions. 6, canyons. 7, escarpements.)

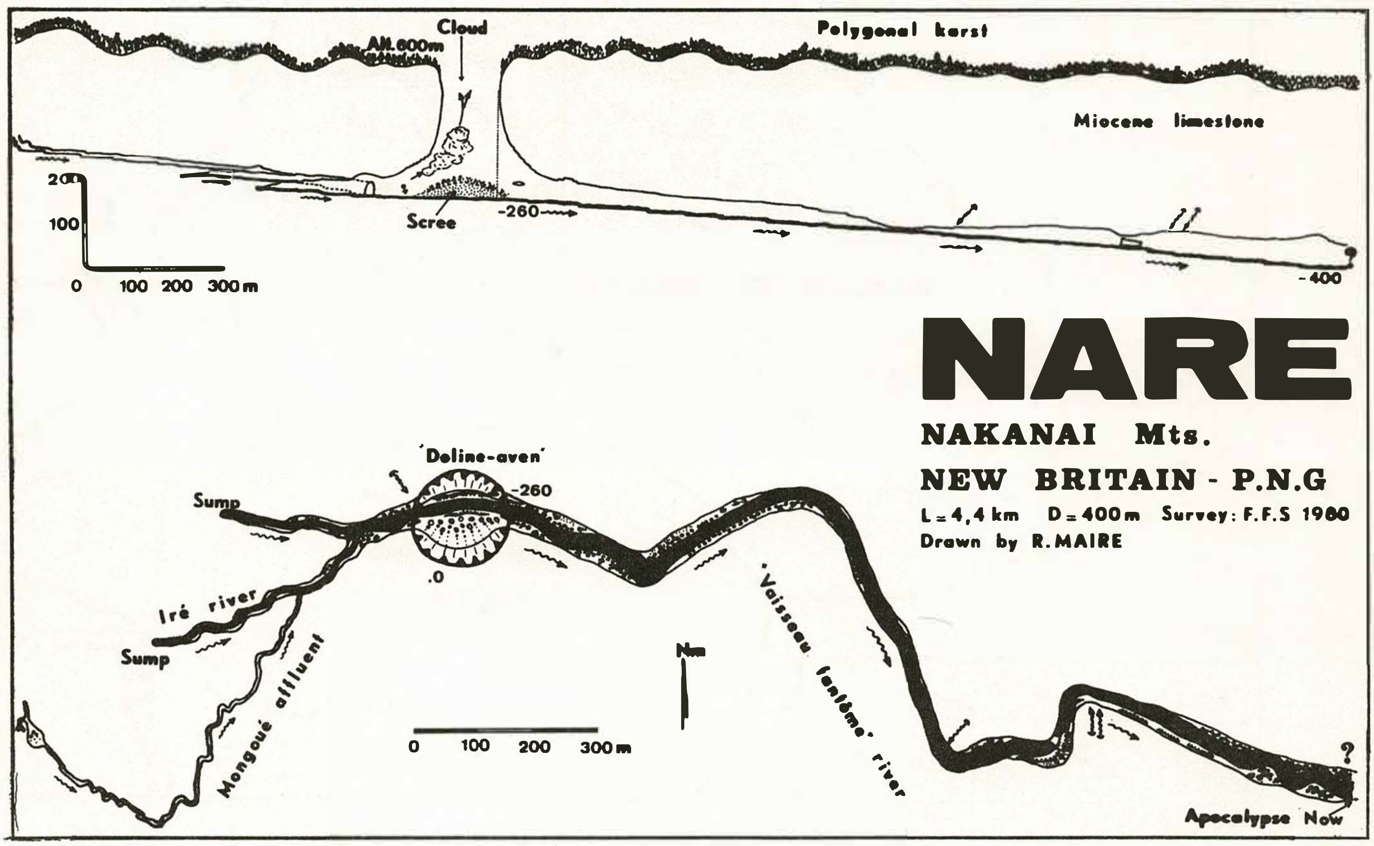


Figure 5: Plan et coupe du réseau de Naré (-400).

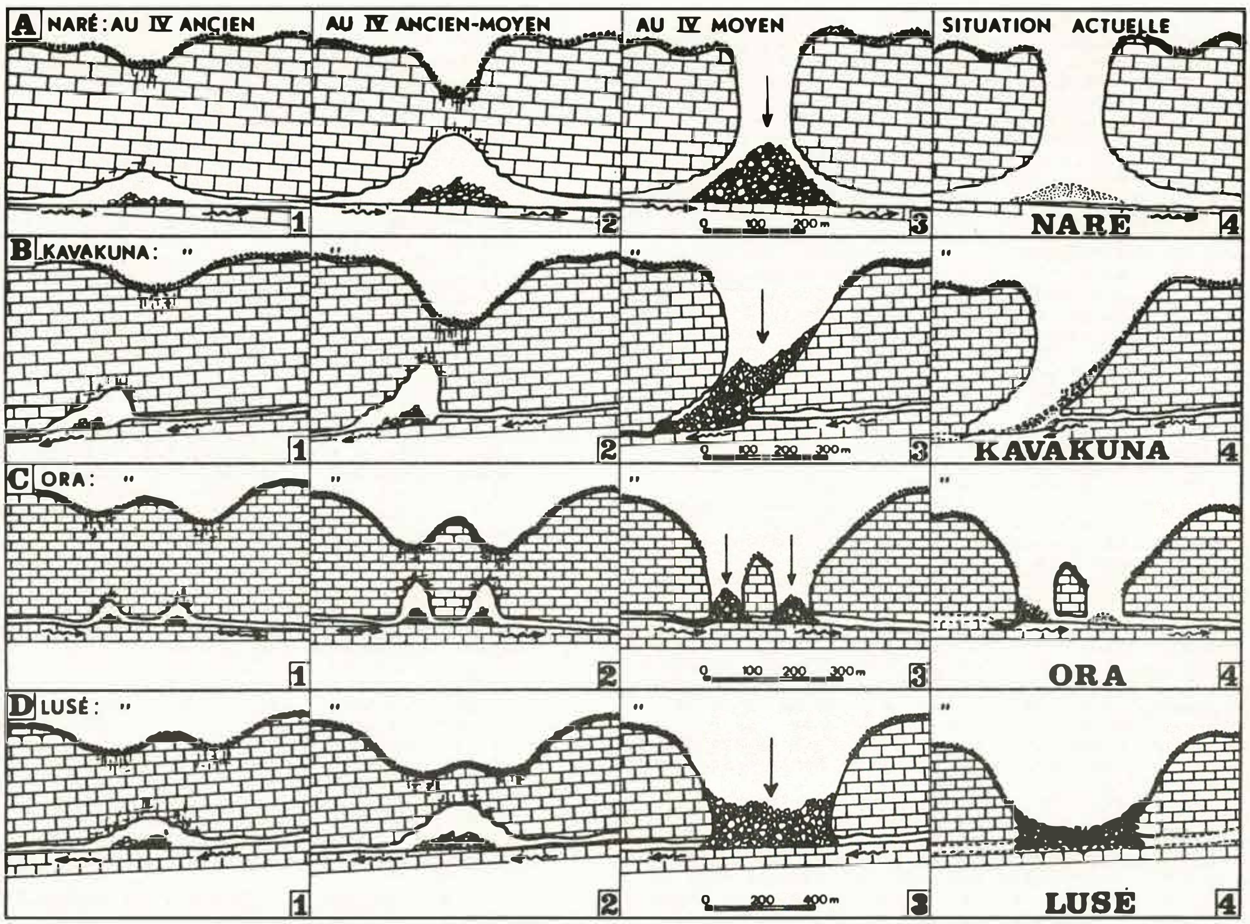


Figure 6: Formation probable des grandes dolines-avens des Mts. Nakanaï.

Les Hauts Karsts Perimediterraneens

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Résumé

Les hautes montagnes calcaires du pourtour méditerranéen renferment un large éventail de karsts d'altitude. En se fondant sur le double critère "précipitations et taux de dissolution spécifique", on peut classer ces régions en quatre types morphoclimatiques: les hauts karsts méditerranéens sub-arides (Espagne du Sud, Atlas marocain, Zagros iranien), les hauts karsts méditerranéens semi-humides (Alpes du Sud, Djurdjura, Taurus...), les hauts karsts méditerranéens humides (Grèce occidentale) et les hauts karsts méditerranéens hyperhumides (Appennin central, Alpes Juliennes, Durmitor).

Abstract

The limestone mountains of the mediterranean periphery contain numerous high altitude karsts. According to the rainfalls and the rates of specific dissolution, it is possible to classify these karst regions into four morphoclimatic kinds: the mediterranean and semi-arid high karsts (Betic ranges, Moroccan Atlas, Iranian Zagros), the mediterranean and semi-humid high karsts (Djurdjura, South Alps, Taurus), the mediterranean and humid high karsts (Western Greece) and the mediterranean and hyper-humid high karsts (Gran Sasso, Julian Alps, Durmitor).

Introduction

Le pourtour de la Méditerranée est caractérisé par la présence de chaînes de montagnes importantes appartenant toutes au système de plissement alpin. Si les karsts de basse et moyenne altitude sont nombreux, les hauts karsts de la zone supraforestière sont également très bien représentés. On trouvera ici une typologie se fondant sur les deux critères essentiels: les précipitations et la vitesse de corrosion (= dissolution spécifique).

Sur un échantillonnage comprenant 34 massifs (cf. tableau hors texte), on remarque que les taux de dissolution spécifique évoluent dans une fourchette de 25 à 108 mm/1000 ans (certaines valeurs sont provisoires). Pour les précipitations moyennes, les hauteurs varient entre 500 et 3000 mm/an. En construisant un graphique mettant en relation les précipitations et la vitesse de dissolution (cf. fig. 3), on constate logiquement que les taux de dissolution sont d'une manière générale directement proportionnelle à la quantité de précipitations. Malgré certains éléments pouvant contrarier localement cette règle (structure, lithologie, altitude, température), la courbe d'augmentation de la dissolution en fonction des précipitations reste impressionnante. On distingue ainsi sans mal quatre types de zones morphoclimatiques:

1. Les hauts karsts méditerranéens sub-arides ($P < 1000$ mm/an et $X = 20\text{-}40$ mm/1000 ans).
2. Les hauts karsts méditerranéens semi-humides ($P = 1000\text{-}1500$ mm/an et $X = 40\text{-}60$ mm/1000 ans).
3. Les hauts karsts méditerranéens humides ($P = 1500\text{-}2000$ mm/an et $X = 60\text{-}90$ mm/1000 ans).
4. Les hauts karsts méditerranéens hyperhumides ($P > 2000$ ans et $X > 90$ mm/1000 ans).

I. Les Hauts Karsts Méditerranéens Sub-Arides:

Le qualificatif de sub-aride ne doit pas prêter à confusion. En effet, les précipitations annuelles sont pratiquement toujours supérieures à 500 mm, mais la sécheresse estivale est longue et intense. La distribution de ces karsts (cf. fig. 1 et 2) fait apparaître deux aires géographiquement opposées: Espagne-Maroc et Liban-Irak-Iran.

I-1.Espagne-Maroc:il s'agit principalement des hauts karsts des chaînes bétiques (Espagne du Sud), du Haut Atlas central calcaire (Maroc) et des parties hautes du Moyen Atlas calcaire (Maroc). Les taux de dissolution spécifiques les plus bas semblent être de 25 mm/1000 ans environ dans le Haut Atlas. Ces hauts massifs renferment une morphologie nivale et glacio-karstique dans un contexte de calcaires marneux du Dogger. Dans le Moyen Atlas, les précipitations sont un peu plus fortes et peuvent atteindre 1000 mm ($X = 31$ mm/1000 ans. Estimation). En Espagne du Sud, les chaînes bétiques possèdent quelques rares karsts d'altitude: Sierra Magina (2157 m) et Sierra Arana (2029 m). Les précipitations atteignent 800-1000 mm/an pour des taux de dissolution voisins de 37 mm/1000 ans. Dans les Pyrénées catalanes, la Sierra del Port del Comte (2332 m) est à la limite climatique des hauts karsts méditerranéens sub-arides et semi-humides avec X estimée à 40 mm/1000 ans pour $P > 1000$ m/an.

I-1. Liban-Iran: ces pays détiennent des karsts de haute montagne sensiblement identiques à ceux du Haut Atlas marocain ~~avec cependant~~ des nuances très spéciales. Au Liban, la grande chaîne côtière du Mt. Liban échappe à cette catégorie en raison des fortes précipitations. En revanche, le Mt. Hermon (2814 m) et l'Antiliban (2659 m) situés en position plus interne connaissent des taux de dissolution spécifique de 33 et 26 mm/1000 ans pour des précipitations de 1000 mm sur les sommets. Dans le Zagros iranien, l'aridité estivale est totale pendant 5 à 6 mois ($X = 25.31$ mm/1000 ans).

II. Les Hauts Karsts Méditerranéens Semi-Humides:

En Méditerranée occidentale, ce type se rencontre en deux régions bien précises. Dans les Alpes du Sud, on connaît surtour l'exemple du Marguareis (2650 m) avec son superbe modelé glacio-karstique et ses gouffres profonds. Les précipitations y sont de l'ordre de 1500 mm pour des taux de dissolution spécifiques de 40-66 mm/1000 ans. Plus à l'Ouest, les massifs du Mounier, de l'Oserot et de la Grande Séolane semblent avoir une vitesse de corrosion plus faible ($X = 35$, 42 et 54 mm/1000 ans). En Afrique du Nord, le Djurdjura (2308 m) est une sorte de "Marguareis algérien" avec des précipitations pouvant dépasser 1500 mm et un taux moyen de dissolution spécifique de 59 mm/1000 ans. Marguareis et Djurdjura se placent d'ailleurs à la limite supérieure du type semi-humide et certaines portions font déjà partie des hauts karsts méditerranéens humides.

En Méditerranée orientale, ce domaine morphoclimatique est beaucoup plus typique. Ainsi, l'immense serie de chaînes calcaires du Taurus (Turquie) contient une belle collection de grands karsts de moyenne et haute montagne. Dans le Taurus occidental, signalons notamment le remarquable massif du Dedegol Dag (3000 m) avec ses petits glaciers résiduels et son modelé nivo- et glacio-karstique exemplaire. Les précipitations sont fortes (1500 mm/an) et $X = 55$ mm/1000 ans. Dans le Taurus central, les massifs culminants du Bolkar Dag (3588 m) et de l'Ala Dag (3734 m) sont par contre de type sub-aride dans la zone qui regarde l'Anatolie (situation sous le vent, $P \leq 1000$ mm/an et $X = 31\text{-}37$ mm/1000 ans). Dans le Taurus oriental et en Arménie, les exemples du Nemrut Dag, du Munzur Dag et de l'Haso-besir-Aluce connaissent une meilleure vitesse de dissolution ($X = 46\text{-}51$ mm/1000 ans) pour des précipitations de 1000-1200 mm/an. Au Liban, le Mt. Liban (3083 m) détient de fortes précipitations dépassant 1500 mm sur les crêtes sommitales ($X = 58$ mm/1000 ans), mais la morphologie est moins belle que dans le Dedegol Dag du fait de la prédominance de calcaires lités du Crétacé.

III. Les Hauts Karsts Méditerranéens Humides:

Cette famille da hauts karsts est parfaitement représentée par les hautes montagnes calcaires de Grèce occidentale. Il y a là de grandes chaînes de montagnes recevant directement les dépressions d'Ouest. Dans le Péloponnèse, le karst est très évolué aussi bien au niveau des grands poljés de moyenne altitude que dans la tranche supraforestière (champs de dolines nivales). Les taux de dissolution spécifique sont de 75-85 mm/1000 ans pour des précipitations de 1500-2000 mm/an. En Crête occidentale, les Levka Ori (2452 m) connaissent une situation identique ($P = 2000$ mm/an et $X = 86$ mm/1000 ans) alors que le Mt. Ida et le Lassithi en Crête centrale et orientale sont en position moins humide.

IV. Les Hauts Karsts Méditerranéens Hyperhumides:

Ces hauts karsts très humides sont tous concentrés sur le pourtour de l'Adriatique: Gran Sasso (2914 m) dans l'Appennin central (Italie), Mt. Canin-Triglav (2864 m) dans les Alpes Juliennes (Italie-Yougoslavie) et Durmitor (2522 m) en Crna Gora (Yougoslavie). En raison des très fortes précipitations comprises généralement entre 2000 et 3000 mm/an et de l'absence d'aridité estivale notamment dans les Alpes Juliennes, ces exemples sont de type haut-alpin. En effet, la dissolution spécifique est voisine ou supérieure à 100 mm/100 ans et s'inscrit bien dans le cadre des hauts karsts tempérés très humides du domaine haut-alpin traditionnel (X = 90 mm/1000 ans dans les Hautes Alpes calcaires franco-suisses).

Dans le massif côtier de l'Orjen (1895 m) situé à proximité de Kotor en Yougoslavie, les hauteurs de précipitations enregistrées sont extraordinaires (P = 5317 mm/an. J. Nicod: com. personnelle) de sorte que le taux de dissolution dépasse 200 mm/1000 ans.

Conclusion

Cette classification des hauts karsts du pourtour méditerranéen permet de mettre en évidence de grandes zones morphoclimatiques comme les domaines sub-arides du Haut Atlas et du Zagros et les domaines semi-humides et humides du Taurus et de Grèce. C'est évidemment au niveau des seuils que l'on rencontre des difficultés de classement d'autant plus que de nombreux taux de dissolution spécifique ont encore seulement une valeur indicative par suite de contradictions entre certains auteurs et aussi de carences en renseignements (chiffres de précipitations imprécis, analyses hydrochimiques peu nombreuses ou absentes, rôle méconnu de la sublimation...). Il est donc nécessaire d'évoluer dans des fourchettes de valeurs en faisant intervenir des taux planchers.

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Tableau 1. Précipitations et dissolution spécifique dans les hauts karsts de la Méditerranée occidentale.

Massifs	Altitude (en m)	Précipitations (en mm/an)	Dissolution spécifique (X en mm/1000 ans et pour une tranche d'alt.	X (valeur moyenne)	Auteurs
1. Djurdjura (Algérie)	2308	1500-1800	56-63 (1700-2300 m)	59	Quinif, 76, Estimation Maire
2. Haut Atlas (Maroc)	4068	700-900	22-31 (2500-3500 m)	26	Couvreur, 78, Estimation Maire
3. Moyen Atlas (Maroc)	2000-2500	700-1100	26-36 (1800-2200 m)	31	Martin, 77, Estimation Maire
4. Sierra Magina (C. bétique, Esp.)	2167	800-1000	36-39 (1700-2100 m)	37	Pezzi, 75, Estimation Maire
5. Sierra Arana (C. bétique, Esp.)	2029	800-900	36-38 (1700-2000 m)	37	Estimation Maire
6. Sierra del Port del Comte (Pyr. catalanes, Esp.)	2332	1000-1400	36-44 (1800-2200 m)	40	Chevrier Magne 74, Estimation Maire
7. Marguareis (Alpes du Sud, Italie-Fr.)	2650	1500	40-66 (2000-2500 m)	53	Julian, 76
8. Oserot (Alpes du Sud,Italie)	3104	1400-1500	49-62 (2000-2500 m)	55	Nicod, 74
9. Mt. Mounier (Alpes Marit., France)	2818	1200	34-36 (2000-2500 m)	35	Julian, 76 Estimation Maire
10. Grande Séolane (Alpes du Sud, France)	2909	1500	48-60 (2500-2800 m)	54	Estimation Maire
11. Gran Sasso (Appennin, Italie)	2914	1500-2000	101-116 (1500-2500 m)	108	Demangeot, 65
12. Mt. Canin (Alpes Juliennes, It.)		3000	94-103	98	Kunaver, 76, Corbel, 57
13. Triglav (Alpes Juliennes, Yougoslavie)	2864	2000-3000	63-128	95	Pulina, 74, Corbel, 65
14. Durmitor (Crna Gora, Yougosl.)	2522	2000-2400	88-109 (2000-2500 m)	98	Nicod, 68, Estimation Maire

Tableau 2. Précipitations et dissolution spécifique dans les hauts karsts de la Méditerranée orientale.

Massifs	Altitude (en m)	Précipitations (en mm/an)	Dissolution spécifique (X en mm/1000 ans et pour une tranche d'alt	X (valeur moyenne)	Auteurs
15. Aroania (Péloponnèse, Grèce)	2341	1800-2000	83-78 (1800-2200)	80	Maire
16. Erymanthe (Péloponnèse, Grèce)	2224	1600-2000	82-85 (1600-2000)	83	Maire
17. Kandyla (Péloponnèse, Grèce)	1935	1500-1700	67-83 (1500-1800)	75	Maire
18. Taygète (Péloponnèse, Grèce)	2407	1800-2200	83-88 (1600-2200)	86	Maire
19. Mt. Ida (Crête)	2456	1400-1800	51-67 (1600-2200)	59	Bonnefont, 71, Maire, 80
20. Levka Ori (Crête)	2453	1800-2200	84-88	86	Estimation Maire
21. Pirin (Rhodope, Bulgarie)	2914	900-1100	47-52	50	Pulina, 74
22. Dedegol Dag (Taurus occid., Turq.)	3000	1400-1600	57-52 (2000-2900 m)	55	Maire
23. Anamos Dag (Taurrus occid., Turq.)	2200	1000-1400	41-60 (1800-2200 m)	50	Maire
24. Bolkar Dag (Taurrus centr. Turq.)	3585	1000-1200	29-33 (2500-3400 m)	31	Maire, 78
25. Ala Dag (Taurus central, Turquie)	3734	1200-1400	33-40 (2500-3500 m)	37	Maire, 78
26. Nemrut Dag (Taurus orien., Turq.)	2100	1000-1200	46-57 (1800-2100 m)	51	Maire, 80
27. Munzur Dag (Taurus orien., Turq.)	3449	900-1100	43-48 (2000-3000 m)	46	Maire, 80
28. Hasobesir-Aluce (Arménie, Turquie)	3503	1000-1100	43-51	47	Schweizer, 75 Est. Maire
29. Ravansar (Zagros, Iran)	2900	600-900	21-28 (2000-2800 m)	25	Maire, 78
30. Parau (Zagros, Kermanshah, Iran)	3300	600-1000	26-36 (2500-3300 m)	31	Maire, 78

31. Zardeh Kug (Zagros central, Iran)	4548	500-1000	22-28 (3000-4200 m)	25	Est. Maire
32. Mt. Liban (Liban)	3083	1500-1700	50-66 (2000-2900 m)	58	Besancon., 73, Hakim, 75 Est. Maire
33. Mt. Hermon (Liban)	2814	1000-1200	28-37 (2200-2800 m)	33	Besancon., 73, Est. Maire
34. Antiliban (Liban)	2659	900-1000	21-30 (2000-2600 m)	26	Besancon., 73, Est. Maire

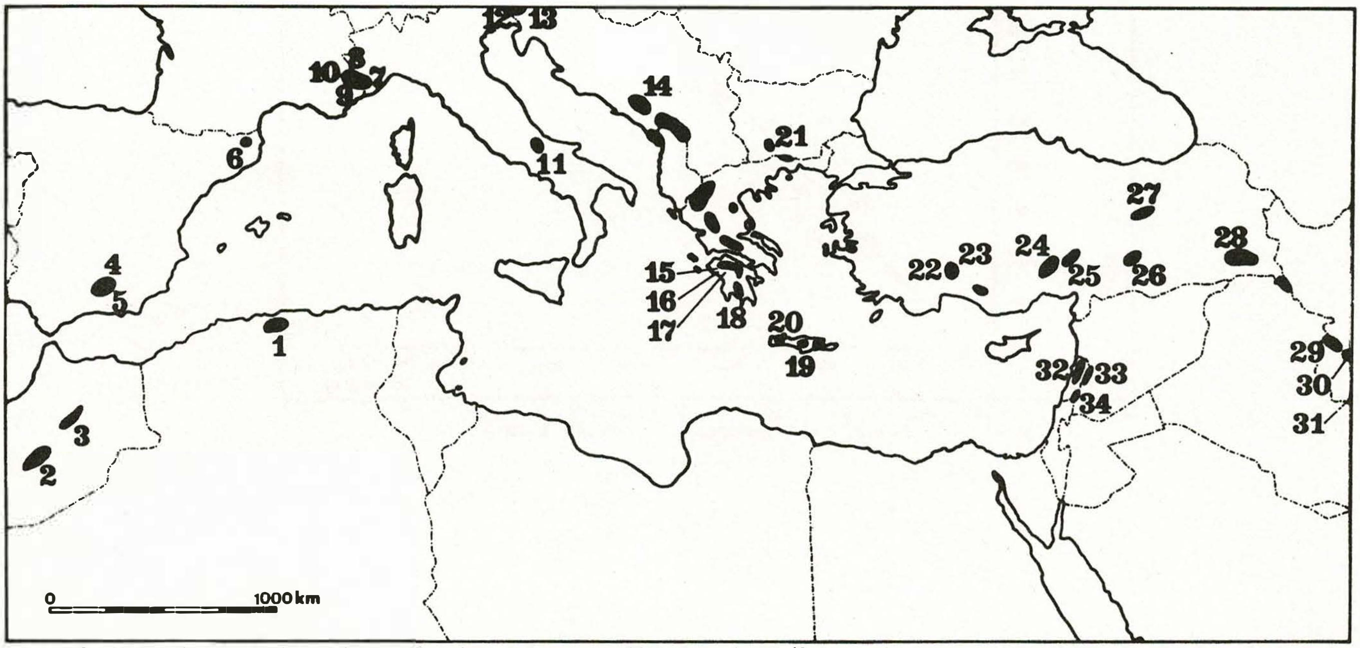

Figure 1: Distribution géographique des hauts karsts méditerranéens (1, Djurdjura. 2, Haut Atlas central calcaire. 3, Moyen Atlas. 4, Sierra Magina. 5, Sierra Arana. 6, Sierra del Port del Comte. 7, Marguareis. 8, Oserot. 9, Mt. Mounier. 10, Grande Séolane. 11, Gran Sasso. 12, Mt. Canin. 13, Triglav. 14, Durmitor. 15, Aroania. 16, Erymanthe. 17, Kandyla. 18, Taygète. 19, Mt. Ida. 20, Levka Ori. 21, Pirin. 22, Dedegol Dag. 23, Anamos Dag. 24, Bolkar Dag. 25, Ala Dag. 26, Nemrut Dag. 27, Munzur Dag. 28, Hasobesir. 29, Ravansar. 30, Parau. 31, Zardeh Kuh. 32, Mt. Liban. 33, Mt. Hermon. 34, Antiliban.)

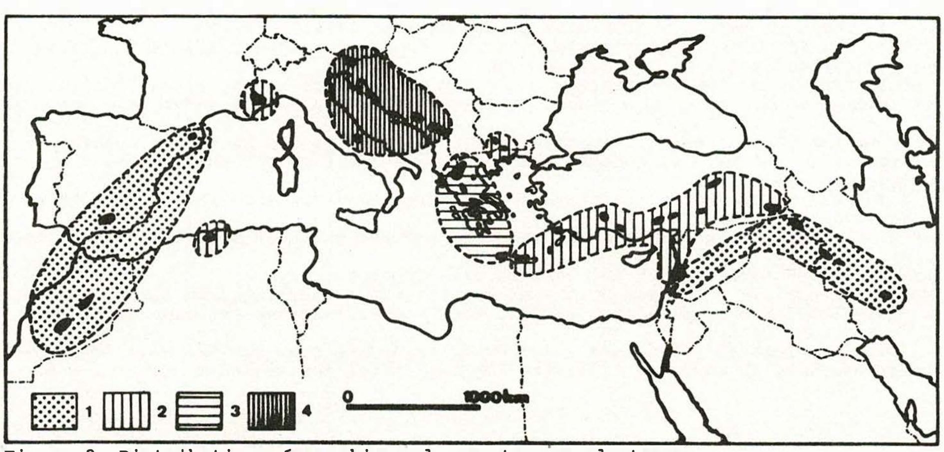

Figure 2: Distribution géographique des quatre grands types morphoclimatiques de hauts karsts méditerranéens (1, type sub-aride. 2, type semi-humide. 3, type humide. 4, type hyperhumide).

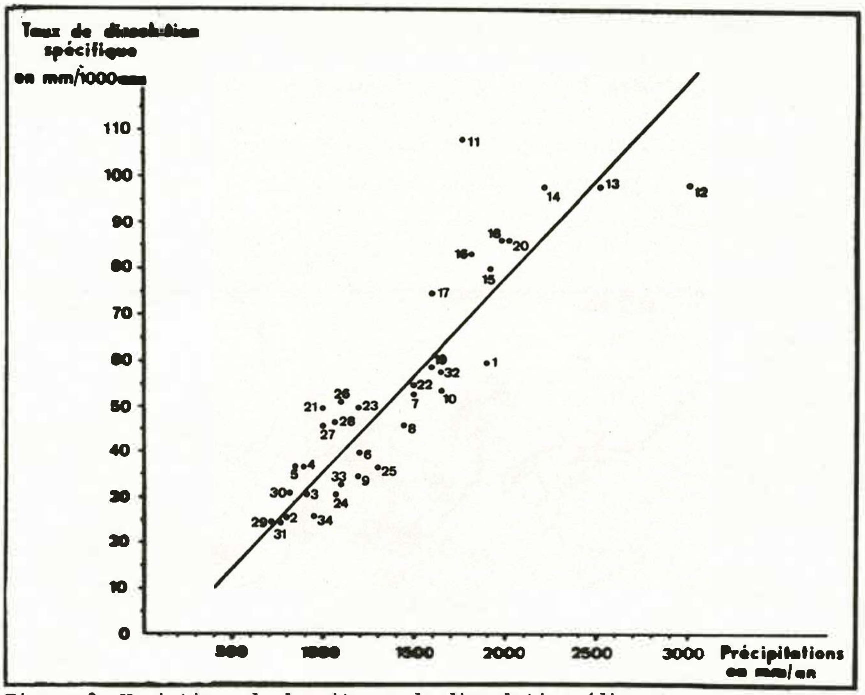

Figure 3: Variations de la vitesse de dissolution (dissolution spécifique) en fonction des précipitations.

On the Hyporheic Hydracarians of Cuba

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The biospeleological expeditions organized by both the Academy of Sciences of Cuba and the Academy of the Socialist Republic of Romania in 1969, 1970 and 1973 suceeded in making evident the exceptional scientific interest of the Cuban subterranean fauna, from both a quantitative and a qualitative point of view.

About 300 new taxa have been described up to now and there is still plenty of material rich in organisms whose study has not yet come to an end.

As concerns the study of the hyporheic hydracarians - living in the alluvial interstices under the water of the rivers - the procinve of Oriente has been in the center of our attention for it was there that we found out several dozens of new species 25 of which have already been described. They belong to 7 new genera some of which we had to introduce into new sub-families.

The first striking characteristic of this fauna is its endemic character, and this is also true for a great part of the underground fauna discovered in Cuba.

Another remarkable feature of the hydracarians is given by peculiar morphological dispositions in the case of several species belonging to the genera of several families, or by completely unknown dispositions, such as:

a) enormous legs in the case of several species of the Kongsbergia and Axonopsis genera.

b) the first coxa having the form of a hook, has a gland, too (!) in the case of the 2 species of the new Crocokongsbergia sub-genus.

c) aberrant - completely different - structure of the first leg tarsus in the case of the 2 representative of the Stygomomoninae, and

d) the morphological peculiarities of the Cladomomonia and the genitals structure in the case of Sibonyacarus sordidus.

All these characteristics have been so far unknown with Hydracarians.

In our work we try to explain these morphological peculiarities starting from the ascertained fact that the island is an isolated center of evolution with many specializations creating new species and even new types within the same group.

In the end the other zoological groups are considered, trying to find certain ways of paleogeographical interpretations (insatisfactory so far) for realistically explaining the island's populating process.

Comparaison du Metabolisme Respiratoire de Niphargus Rhenorhodanensis (Crustace Amphipode Hypoge) Provenant de Deux Systemes Karstiques Differents

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Résumé

La métabolisme respiratoire de Niphargus rhenorhodanensis provenant de deux cavités différentes est étudié. Il n'apparait aucune différence entre les valeurs moyennes de la consommation d'oxygène (720 et 664 µl/gs/h) et des paramètres caractérisant les droites de régression consommation/masse. Ces résultats, comparés à d'autres acquis précédemment pour des Niphargus rhenorhodanensis d'origine phréatique, montrent donc une homogénéité de la consommation d'oxygène de ces animaux souterrains testés à une même température.

Abstract

The respiratory metabolism of Niphargus rhenorhodanensis from two different caves is studied. There is no difference between oxygen consumption means (720 and 664 µl/dw/h) and between the parameters of the consumption/weight regression. Compared to others previously found, these results point out an uniformity of oxygen consumption in these subterranean animals at one and the same temperature.

Zusammenfassung

Der Atemstoffwechsel des Niphargus rhenorhodanensis aus zwei verschiedenen Höhlen wird untersucht. Es gibt keinen Unterschied zwischen den Mittelwesten des Sauerstoffverbrauchs (720 und 664 /gs/h) und Parametern der Regression verbrauch/Masse verglichen mit anderen, früher erhaltenen Ergebnissen über Niphargus rhenorhodanensis phreatischen Ursprungs, zeigen diese Resultate also eine Homogenität des Sauerstoffverbrauchs dieser unteritdischen Tiere untersucht bei gleicher Temperatur.

Dans le cadre de l'étude du métabolisme respiratoire de Niphargus rhenorhodanensis, j'ai été amené précédemment à comparer deux populations de ces Amphipodes souterrains; l'une, karstique, provient de la grotte du Pont des Aniers (Massif du Vercors); l'autre, phréatique, est originaire des canaux de drainage de la forêt de Chassagne, dans la Dombes au nord de Lyon. (Ginet et Mathieu, 1968; Mathieu, 1968; 1971; 1973; 1977; 1980. Morand et Mathieu, 1976).

Malheureusement, la disparition de la population karstique précitée m'a obligé à trouver une autre cavité hébergeant la même espèce de Niphargus et possédant des caractéristiques écologiques relativement semblables, afin de pouvoir terminer ces comparaisons.

C'est le complexe hydrogéologique de Dorvan (Jura mériodinal) (grotte du Cormoran et résurgence du Pissoir) qui m'a permis de récolter des animaux en quantité suffisante pour mener à bien la série d'experiences concernant l'action de la température sur le métabolisme respiratoire, avec des témoins possédant les mêmes caractéristiques que ceux de la cavité précédente.

Dans un premier temps, afin de ne pas perdre les données acquises grâce à la population de Niphargus du Vercors, il était essentiel de comparer la consommation d'oxygène de témoins obtenue avec l'une et l'autre des deux populations karstiques. Ce sont les résultats de ce test comparatif qui constituent l'essentiel de la présente publication.

Materiel et Methodes

Les individus testés appartiennent à l'espèce Niphargus rhenorhodanensis (Schell. 1937); ils ont été récoltés:

1 - dans le ruisseau temporaire de la grotte du Pont des Aniers près de Villars de Lans dans le massif du Vercors (Isère, France) (Ginet et Mathieu, 1968);

2- soit dans le ruisseau souterrain de la grotte du Cormoran, soit à la résurgence de la grotte du Pissoir, ces deux cavités s'ouvrant dans le même massif karstique du Jura méridional situé près de Torcieu (Ain, France) (Gibert et Coll., 1978). Cette similitude m'a amené à faire figurer ces derniers dans l'exposé sous la même dénomination: "grotte du Cormoran".

Dans les deux cas, un certain nombre de facteurs du milieu ont été mesurés; il a été possible de remarquer principalement que la température de l'eau varie peu; la moyenne est située à 9°5 au Pont des Aniers et à 10° pour la grotte du Cormoran (Gibert, communication personnelle).

Les animaux capturés sont transportés au laboratoire et mis en élevage dans des pièces obscures climatisées à 11°C.

L'expérimentation ne porte que sur des individus mâles au stade d'intermue C.

La technique de mesure individuelle de la consommation d'oxygène a été décrite précédemment (Mathieu, 1973, 19). Elle est faite à 11°C.

L'intervalle de temps entre deux mesures consécutives a été de 1/4, 1/2 et une heure pour les individus de la grotte du Pont des Aniers, une heure pour ceux de la grotte du Cormoran. Chaque individus est testé pendant deux heures.

Résultats

Les résultats obtenus sont consignés dans le tableau I, ou représentés sur la figure 1.

Afin d'établir des comparaisons avec des résultats concernant l'influence de la durée entre deux mesures consécutives obtenus précédemment pour des Niphargus phréatiques (Mathieu, 1982), une étude semblable a été effectuée pour les individus de la grotte du Pont des Aniers. Pour ces derniers, les valeurs sont significativement différentes entre "une heure" et les deux autres séries (1/4 et 1/2 heure), que l'on s'adresse à la consommation horaire ou à la consommation ramenée à l'unité de masse (dans ce dernier cas, respectivement: t = 4,4 pour 47 ddl et t = 4,3 pour 33 ddl). Pour ces animaux, il semble donc bien que la durée entre deux mesures agisse sur la consommation d'oxygène, qui diminue (720 contre 1300 µl/gs/h) d'autant plus que cette durée est plus longue. Pour cette population du Pont des Aniers, la valeur témoin retenue sera la plus faible, c'est à dire celle obtenue pour un intervalle d'une heure.

C'est ce résultat, et un soucis d'économie en individus, qui m'ont amené, pour la population de la grotte du Cormoran, a effectuer seulement des expériences dont l'intervalle de temps entre deux mesures est de une heure.

Tableau I. Moyenne de la consommation d'oxygène de Niphargus rhenorhodanensis issus de deux grotte différentes. "1/4", "1/2" et "1" correspondent à l'intervalle de temps entre 2 mesures de la consommation d'oxygène. Les valeurs de cette consommation sont accompagnées de leur intervalle de sécurité. N est le nombre de mesures individuelles; M est la masse moyenne des individus de chaque groupe d'expérience, exprimée en mg.

	Pont des Aniers			Cormoran
	1/4	1/2	1	1
µl/h	5,731 ±0,758	5,090 ±1,284	2,736 ±0,395	3,875 ±0,489
µl/gs/h	1368 ± 319	1272 ± 345	720 ± 86	664 ± 58
N	31	17	18	34
$\bar{M}$ (mg)	5,1	3,8	4,0	6,2

Dans les conditions expérimentales précitées: tests à 11°C avec un intervalle de une heure entre deux mesures, les valeurs témoins de la consommation, ramenées à l'unité de masse, ne sont donc pas différentes entre les deux populations (720 et 664 µl/gs/h : t = 1,93 pour 50 ddl).

Une preuve supplémentaire de cette identité entre les deux populations est fournie par la relation entre la consommation horaire par unité de masse, et la masse des animaux (figure 1). Les pentes des droites et les ordonnées à l'origine ne sont pas statistiquement différentes. On obtient un résultat identique si l'on exprime la consommation horaire en fonction de la masse (figure 1). Ceci apparait en accord avec le fait que la consommation horaire est effectivement différente entre les deux populations (2,736 et 3,875 µl/h : t = 7,36 pour 50 ddl) : la masse moyenne des individus de la grotte du Cormoran est plus importante que celle des autres (6,2 contre 4 mg).

Discussion

Ces résultats rendent à prouver la similitude de la consommation d'oxygène de Niphargus rhenorhodanensis provenant de grottes différentes, mais à caractéristiques écologiques semblables. Les valeurs citées dans ce travail ne sont pas statistiquement différentes. Elles ne diffèrent pas non plus de celles obtenues par Wautier et Troïani (1960) (environ 720 µl/gs/h) avec des exemplaires de la même espèce provenant d'une troisième cavité.

Les valeurs obtenues avec les témoins d'origine phréatique (732 et 684 µl/gs/h : Mathieu, 1982) dans les mêmes conditions expérimentales ne sont, elles non plus, pas différentes de celles exprimées dans ce travail. De plus, les pentes des droites de regression consommation/masse ne sont pas différentes (-0,338 et -0,484 pour les Niphargus phréatiques, -0,382 et -0,437 pour les karstiques).

Les valeurs élevées citées dans Mathieu (1972) correspondent à un intervalle de temps de 1/4 d'heure entre deux mesures. En fait, avec cette condition expérimentale particulière, 1306 µl/gs/h obtenus en 1973 et 1368 µl/gs/h trouvés ici ne sont pas différents.

Les résultats trouvés sur la population phréatique (Mathieu, 1982) et ceux énouncés ci-dessus, confirment que c'est bien la fréquence de l'agitation de l'eau liée à la technique de la mesure, qui provoque des différences de valeurs de la consommation d'oxygène des individus pris comme témoins.

Ainsi, avec les conditions expérimentales amenant à caractériser la consommation d'oxygène de Niphargus témoins provenant du domaine karstique, les paramètres semblent constants: les valeurs globales sont sensiblement les mêmes, ainsi que la relation qui lie cette respiration à la masse. Les comparaisons entre populations provenant de deux systèmes aussi différents que celui des eaux karstiques et celui des eaux phréatiques pourront donc se poursuivre normalement en utilisant désormais les animaux originaires de la grotte du Cormoran.

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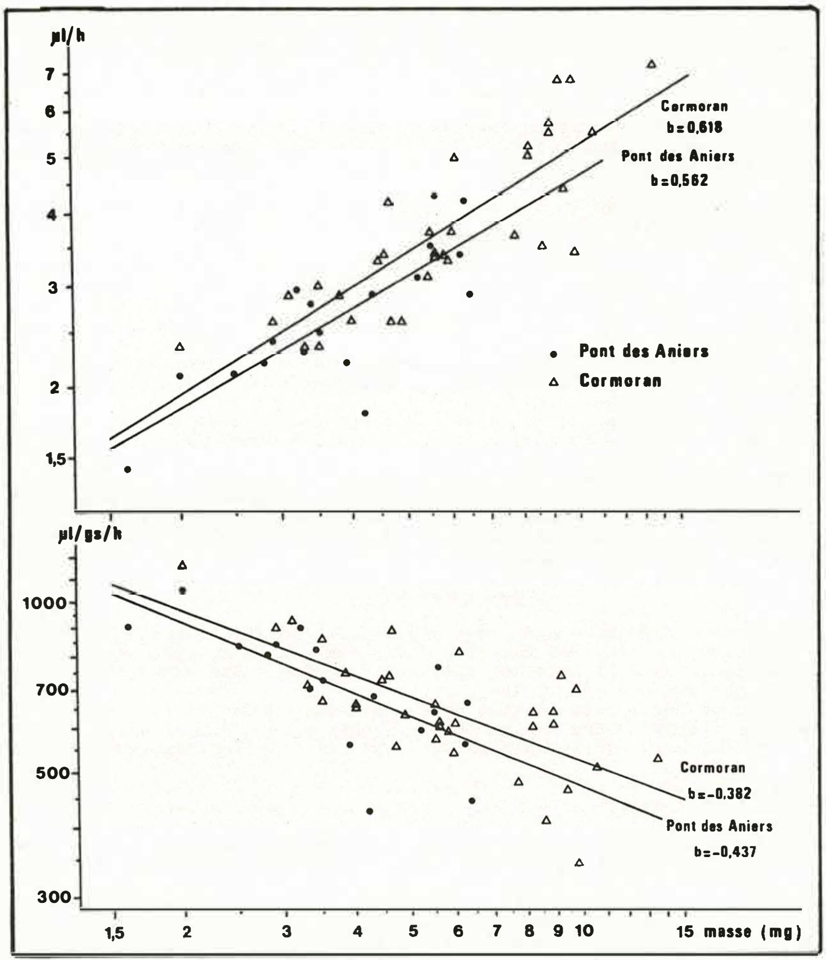

Figure 1. Valeurs individuelles de la consummation d'oxygène en fonction de la masse sèche (en mg) pour les populations de la grotte du Cormoran (+) et de la grotte du Pont des Aniers (•). Coordonnées logarithmiques.

The Activity Controlling Time-System in Epigean and Hypogean Populations of Astyanax Mexicanus (Characidae, Pisces).

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Abstract

The swimming activity in breedings of an Astynax Mexicanusä river population (Rio Teapao, Mexico) and cave population (Cueva de El Pachoa) was studied in artificial light-dark-cycles (LD), in constant darkness (DD) and after light pulses. The activity was registered in two forms: surface (OA) and bottom activity (BA).

Teapao: OA and BA can be entrained by any kind of Zeitgeberprogram. Both phases differ by a shift of 180°. The maximum values of OA correspond to the dark-phases, those of BA to the light-phases of the LD. Cireadian rhythms are superposed in LD with period lengths (T) differing from 24 hours.

In DD the entrained rhythms damp out within one or a few periods. The above mentioned phase-shift between OA and BA is no longer detectable. Freerunning circadian rhythms are obvious.

Light pulses of 6 and 12 hours length switch on a damped circadian oscillation and shift the phase of a freerunning oscillation. Moreover, the 6 h-puls produces damped oscillations of 12 hours length.

Pachon: OA and BA are generally entrainable by any LD in the same way as in Teapao by increasing length intensity in the light-phases. In particular cases, however, there are difficulties in entrainment, if T of LD differs from 24 hours. In general the activity rhythms are not as strong as in Teapao. Circadian rhythms are rarely superposed.

In DD the entrained rhythms disappear at once. An overt freerunning circadian rhythm appears in DD after LD 12:12 h and less strong in DD after LD 8:8 h. In all other cases no significant rhythms can be detected.

The effects of light pulses are weak.

Regarding these results, the river fish seems to possess two types of time measuring systems: a nonlinear circadian one and a passive, linear, strongly camped onw. Effects of both can be observed in the actograms of the cave fish. Thus the cave animals conserved a circadian oscillator, while eyes and pigament are submitted to regressive evolution.

Zusammenfassung

Die Schwimmaktivität von Nachzuchten aus einer Flußpopulation (Rio Teapao, Mexico) and einer Höhlenpopulation (Cueva de EL Pachon, Mexico) des Astyanax Mexicanus ist in künstlichen Licht-Dunkel-Wechseln (LD), im Dauerdunkel (DD) sowie nach Lichtpulsen untersucht worden. Die aktivität wird eingeteilt in: Oberflächenaktivität (OA) und Bodenaktivität (BA).

Teapao: OA and BA werden durch jedes Zeitgeberprogramm mitgenommen. Ihre Phasenlagen sind gegeneinander um 180° verschoben (invers). Die Maxima der OA liegen in den Dunkelphasen, die der BA in den Lichtphasen der LD. In LD mit einer Periodenlänge (T) ≠ 24 Std. ist der Zeitgeberrhythmik eine circadiane Schwingung überlagert.

Im DD geht die Zeitgeberrhythmik nicht sofort verloren. Sie dämpft vielmehr innerhalb von einer bis mehrerer Perioden aus (Nachschwingen). Oa und BA verlaufen nicht mehr invers. Freilaufende circadiana Rhythmen sind nachweisbar.

Durch Lichtpulse von 6 und 12 Std. Länge wird eine ausgedämpfte Rhythmik wieder angestoßen, eine freilaufende in ihrer Phasenlage abrupt verschoben. Der 6-stündige Puls erzeugt außerdem ein 12-stündiges Nachschwingen.

Pachon: Bei erhöhter Belichtungsintensität in den Licht phasen lassen sich OA and BA generell -wie bei Teapao beschriebendurch jedes Zeitgeberprogramm mitnehmen. In LD mit T ≠ 24 Std. treten im Einzelfall jedoch deutliche Schwierigkeiten in der Mitnahme auf. Die Aktivitätsrhythmen sind generell schwächer ausgebildet als bei Teapao. Überlagerungen durch circadiane Rhythmen sind selten.

Im DD geht die Zeitgeberrhythmik normalerweise sofort verloren. Nach LD 12:12 Std. und (abgeschwächt) LD 8:8 Std. zeigt die OA einen freilaufenden circadianen Rhythmus. In allen anderen Fällen ist keine Rhythmik nachweisbar.

Die Auswirkungen von 6- und 12-stündigen Lichtpulsen sind schwach.

Die Ergebnisse lassen vermuten, daß der Flußisch zwei verschiedene Meßsystems besitzt: ein nichtlineares circadianes System und ein passives, lineares, stark gedämpftes System. Auswirkungen beider Systeme lassen sich in den Aktogrammen des Höhlenfisches analysieren, wenn auch in abgeschwächter Form. Es ist erstaunlich, daß die Höhlentiere einen circadianen Oszillator bewahrt haben, während Auge und Hautpigment der regressiven Evolution unterlegen sind.

Cave dwelling organisms are of great interest concerning the investigation of time-measuring systems. The physiological clock is genetically determined and therefore submitted to regressive evolution as well as morphological and ethological structures. To know how the degenerations took place may be a step in revealing basic mechanisms of clock functions. Astyanax mexicanus, a common characid from Mexico, seems to be a properobject for studying the mentioned problems. There are epigean river forms and hypogean cave forms and fertiel crossing is possible! In this work specimens of a river population from the Rio Teapao/Yucatan, subsequently called TEAPAO, and specimens of a cave population from the Cueva de El Pachon/San Luis Potosi, subsequently called PACHON, are compared. Their swimming activity was tested in various ligth-dark-cycles (LD), which were applied as rectangular signals, and in constant darkness (DD). There were two types of LD's: those with period lengths of 24 hours or a harmonie of 24 and those with a period lenghts differing from 24 hours and its harmonies. Furthermore there are two types of activity: called surface and bottom activity.

Results of TEAPAO:

Any kind of LD (for example 16:16 h, 3:7 h, 4.4h) functions as a socalled forcing signal and therefore entrains the activity. The maximum values of the surface activity correspond to the dark phases of the LD, those of the bottom activity to the ligth phases of the LD, i.e. both phases differ by a shift of 180°. There is no phaseangle difference between forcing signal (LD) and forced signal (activity). This form of system answer is called up to now "mascing". Each forcing condition was folloed by DD. The forced oscillations (i.e. the oscillations of entrained activity) don't disappear at once, when LD is finished, but damp out with the frequencey of the forcing signal. These results lead to the conclusion that the basic controlling system is passive and moreover linear because in the tested range the frequency of the output signal (activity) is always like the frequency of the input signal (LD). The damped oscillations of the forced signal characterise the system as passive in contrast to an extremely passive one. Such systems are unable to oscillate but die in an exponential form. Up to no the "mascing" systems were described as extremely passive, but these results show that it is not necessary to suppose so.

If the period length of the forcing signal is a harmonic of 24 hours (for example LD 6:6h, 4:4 h) the activity will show an oscillation of this length and additionally a relatively strong circadian rhythm. If the period length of the forcing signal is no harmonic of 24 hours the additional circadian rhythm will be less stable. In DD a freerunning circadian rhythm with typically unstable amplitude and phase is overt. The rhythm appears only in the surface activity or in the surface and bottom activity at the same time without a phaseangle difference of 180°. Ligth pulses of 6 and 12 hours length shift the phase of a freerunning rhythm and push on a damped one. The 6 hours pulse additonally causes amped oscillations with a period length about 12 hours). The free-running circadian rhythm proves the exictence of a secon activity controlling system. The properties are : nonlinear, selfsustained and circadian.

Results of PACHON

The activity of the cave fish is generally entrainable in the same wasy as in TEAPAO, though the fish itself is less sensitive for ligth signals. To satablise the forced oscillation the amplitude of the forcing signal has to increase. Nevertheless the forced oscillation remaines less strong than in TEAPAO and the forced system reacts less uniform and quick. Effects of ligth pulses are weak. After transition from LD to DD the forced oscillation disappears at once. That means: the passive system of the river fish has developed to an extremely passive one, unable to oscillate, and thus has been simplified. It has remained linear because output signal and input signal ever show the same frequency.

In any LD with a period length differing from 24 hours and its harmonies a circadian rhythm is detectable (LD with a period length corresponding to harmonies of 24 h were not applied). In DD after LD 12:12 hours and less strong in DD after LD 8:8 hours a circadian rhythm is overt. In all other cases the activity is arrhythmic. These results lead to the conclusion that the cave fish has kept a nonlinear, selfsustained, circadian oscillator but its ability of seflsustenance is restricted.

It is notable that the time-measuring systems of the cave fish have degenerated not as quick as several morphological and ethological structures! At this moment only speculations about the reasons are possible because the applied methods of this work don't allow to prove any hypothesis. Perhaps the bats inhabiting the Pachon cave set at least as weak Zeitgebers. Perhaps the possession of a clock is still an advantage in internal regulation, yet unknown.

Dinaric Karst Poljes and Neotectonics

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Abstract

The detailed investigations in the NW dinaric karst regions proved the importance of the geologic setting and neotectonics on the karst poljes morphogenesis, beside erosional, corrosional and collapse influence. In the Postojna and Cerknica regions the neotectonic block movements along the NW-SE directed regional faults, for example Idrija wrench-fault zone, were stated. They reflect in the geologic setting, in faulted quaternary sediments, in the karst relief and in the morphology and genesis of karst caves, specially in water channels between the karst poljes. The typical examples of neotectonic movements and their influence on the polje morphology will be illustrated in the paper.

Résumé

Les recherches du karst détaillées autour Postojna et Cerknica dans la partie NW du karst dinarique ont montré que à part de l'influence d'érosion, de corrosion et d'éffondrement pour la morphogenèse des poljés karstiques sont importantes surtout la structure géologique et la néotectonique. Le long de failles orientées dans la direction dinarique ayant le caractère régionale, comme par example la zone de faille d'Idrija il y sont constatés les mouvements quaternaires et même récents de blocks de differente taille dans la région de Cerknica et Planina poljés. Ces mouvements reflètent dans la structure géologique, dans la fracturation de roche entre les sédiments quaternaires, dans le relief karstique le long de poljés et sur eux mêmes et aussi dans la distribution et dévelopement de cavernes souterraines, surtout de grottes actives dans le karst de soutirage entre les poljés karstiques.

Dans la communication les examples caractéristiques de mouvements tectoniques récents et leur influence sur la formation de poljés seront présentés.

Sensation Seeking and Locus of Control in Spelunkers: Further validation of these personality constructs

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Abstract

The personality of spelunkers was investigated by means of a mail-survey to a random sample of National Speleological Society members. Demographic variables, amount and intensity of caving activity, sensation-seeking and internal-external locus of control scores were obtained for each subject. Results showed spelunkers to be a heterogeneous group with sensation-seeking and locus of control scores not significantly different from the general population. Amount and intensity of caving activity, however, did correlate significantly with sensation-seeking, with the most active cavers being higher in sensation-seeking. Locus of control scores only showed significant correlations with certain types of spelunking. Males and females showed no significant difference in caving activity.

Résumé

Une enquête sur la personnalité de spéléologues était faite au moyen d'un sondage par poste d'un échantillonage au hasard des membres de la Société Nationale de Spéléologie. Les variables démographiques, la quantité et l'intensité de l'activité spéléologique et les comptes (les scores du sensation-seeking (recherches-sensation) et du locus de control interne-extérieur ont été obtenus pour chaque sujet. Les résultats ont indique que les spéléologues sont un groupe homogène dont les comptes du locus de control et du sensation-seeking ne diffèrent pas d'une manière trop significative de la population générale. La quantité et l'intensité de l'activité spéléologique, cependant, se trouvent en corrélation avec sensation-seeking. Les spéléologues les plus actifs sont supérieurs vis-à-vis l'aspect sensation-seeking. Les comptes du locus de control ne révèlent des corrélations significatives qu'avec certaines catégories de spéléologie. Les mâles et les femelles ne révèlent pas de différences significatives d'activité spéléogique.

Why do some people like to crawl, walk or climb in cold, dark holes in the earth? What type of person chooses to be a spelunker? This study was designed to investigate the relationship of certain personality dimensions to amount and nature of caving activity. The dimensions on which the study focused were sensation-seeking and internal versus external control of reinforcement.

Sensation seeking, as conceived by Zuckerman, can be conceptualized as curiosity, exploratory drive or a need for stimulation. The total concept of sensation seeking comprises four distinct subscales: thrill and adventure seeking, boredom susceptibility, disinhibition, and experience seeking. Experience seeking is the need to try a wide-variety of new and different experiences, whereas thrill and adventure seeking is the desire to attempt activities which most would consider exciting, or even dangerous, not just different. Boredom susceptibility and disinhibition are self-explanatory. Research has shown wide-spread individual differences in this trait which may be biologically-based. (See Zuckerman, 1978 a & b for a more detailed discussion of this construct and a review of the research literature.)

The concept of internal vs. external control of reinforcement was developed by Rotter (1966 & 1971) from social learning theory to describe the degree to which individuals perceive reinforcements contingent upon their own behavior. Internal control refers to individuals who regard the locus of control to be internal (self-generated) while external control refers to individuals who believe reinforcements are not under their personal control but are under the control of external forces (e.g., luck, chance, fate, powerful others). Both sensation seeking and belief in internal or external control are measured by a forced choice test where the subject selects which of 2 choices best describes him or her.

Since sensation-seeking has been shown to be higher in those involved in physical risk taking, such as sky-diving, race car driving, snowmobiling and underwater diving (Zuckerman, 1978 a, p. 519), it was hypothesized that spelunkers also would show high sensation-seeking scores. Previous research (Joe, 1971, p. 632) also suggests a relationship between internal-external control and risk-taking behavior. Internals are more cautious and conservative than externals in riks-taking situations in an attempt to control events. Zuckerman (1978, p. 508) also reports a correlation between a belief in external control and various aspects of sensation-seeking. Thus, it was hypothesized that cavers would be high both in sensation-seeking and belief in external control. A random sample (n = 200) of members from the National Speleological Society (NSS) was selected from the NSS 1978-1979 membership list. These subjects were sent: (1) a cover letter explaining the research project; (2) a Background Data Sheet, to ascertain demographic variables and the amount and intensity of caving activity; (3) a modified version of Rotter's Internal-External (I-E) Locus of Control scale (Rotter, 1966); and (4) Form V of the Sensation-Seeking scale (Zuckerman, 1971). Subjects were asked to complete the questionnaires, and return the answer sheet, anonymously if they preferred, to the researchers.

Seventy-nine questionnaires were returned, yielding a 40% response rate. Sensation-seeking scales (SSS) were scored for Thrill and Adventure Seeking (TAS), Experience Seeking (ES), Disinhibition (Dis) and Boredom Susceptibility (BS), as well as a total score (TSS). The I-E Locus of Control scale was scored for the amount of belief in external control, with high scores indicating high external orientation, low scores indicating high internal orientation.

The frequency and intensity of caving activity was scored by tabulating responses to various items on the Background Data Sheet. Three scores were derived in the following manner: (1) "Group" caving indicated the amount of participation in group meetings, cave projects, society newsletters, group caving, and cave conservation projects; (2) "Sport" caving indicated the extent of involvement in actual spelunking, vertical caving, and cave diving; (3) "Carousing" indicated the extent of involvement in partying at NSS conventions, extra and premarital sexual activities, and consumption of marijuana and alcohol.

Histograms were constructed to observe the patterns of scores, and Pearson product-moment correlations computed to explore the relationship between background variables, caving activity and the scores on the personality measures.

Statistical analyses showed that spelunkers as a whole are a heterogeneous group. Their mean scores on the Sensation-Seeking scales did not differ significantly from those found in the standardization sample (See Zuckerman, 1971). However, the degree of Carousing, Sport and Group caving all correlated significantly ($p < .05$) with Total Sensation-Seeking scores and with each other. For example, cavers who are very active in group social activities also tend to be active in sport caving and carousing activities, as well as being high in Sensation Seeking. However, those high in Carousing or Sport or Group caving were not identical. While all three groups' scores correlated significantly ($p < .05$) with the Sensation-Seeking subscales of Experience Seeking and Disinhibition, only those high in Sport caving tended to have high scores on the subscale for Thrill and Adventure Seeking.

Locus of Control scores only correlated significantly with carousing, with high external Locus of Control being significantly correlated ($p < .05$) with amount of carousing.

As an interesting adjunct, all variables were compared for males vs. females. None of the caving related variables showed any significant difference. In fact, only two of all the variables were significantly different: gross income and Thrill and Adventure Seeking subscores. Zuckerman (1978a) had already reported the later in several studies. An unpublished survey by Carol Vesely and Dave Bunnell, conducted at the 1979 NSS Convention, did find significant differences in caving activity between males and females. It is hypothesized that this discrepancy is the result of sampling technique. At a convention, female dependents who are not primarily cavers in their own right are more apt to respond to a survey. On the other hand, non-caving dependents would be unlikely to take the time to respond to a mail survey.

In summary, spelunkers, as reflected by the NSS sample, seem to be a heterogeneous group in personality, with scores on Sensation-Seeking and I-E Locus of Control scales varying as in the general population. High Sensation-Seeking, however, does seem to differentiate between very active and less active cavers. In addition, the Sensation-Seeking subscales differentiate among different types of cavers, with all active groups showing high scores in Experience Seeking and Disinhibition, but only active Sport cavers showing high scores on Thrill and Adventure Seeking.

Locus of Control does not seem to differentiate the active versus less active cavers, except in the area of carousing, where belief in external control was correlated with carousing activity. Thus, those cavers who are more likely to drink, take drugs, be sexually promiscuous and party frequently are more likely to believe in external locus of control.

Such data adds further construct validity to the concepts of Sensation-Seeking and Locus of Control, in that these personality dimensions seem to have some expected behavioral correlates. Although the original prediction that spelunkers as a total group would be generally higher in Sensation Seeking was not supported, it can be seen that the amount and intensity of caving activity definitely correlates with Sensation Seeking. Although caving activity, in general, did not correlate with external locus of control, intensity of carousing activity did. Thus, while spelunkers do not seem to be a homogeneous group, clearly distinguishable from the general population, the amount and type of caving activity, however, does seem to have various personality correlates.

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Analysis of the Propagation of Error in Cave Surveys

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Abstract

Recent years have seen significant progress in cave surveying and mapping techniques. Along with the increased reliance on computer techniques for cave mapping and the analysis of survey data, the subject of cumulative error arises increasingly often.

This analysis uses probability equations to show that the zone of uncertainty generated by the statistical errors in a survey shot is in the shape of an ellipsoid. The process for the statistical addition of these ellipsoids for a series of survey shots is discussed.

Zusammenfassung

In modernen Jahren haben Höhlenforscher in Bezug auf Höhlenvermessungstechnik und Höhlenkartographie bedeutsame Fortschritte gemacht. Weil das Vertrauen auf Computers fur Höhlenkartographie und Analysis der Höhlenvermessungen immer mehr steigt, kommt die Frage der kumulativen Fehlern immer mehr oft hervor.

Diese Analysis nutzt Wahrscheinlichkeitsgleichungen um zu zeigen, dass der Unsicherheitsbereich durch statistischen Messungsfehler erzeugt die Gestalt eines Ellipsoids hat. Die statistische Addition von diesen Ellipsoiden wird für eine Reihe von Vermessungspunkten beschrieben.

Diese Analysis kann man fur die Abschätzung von Kreisverschlussfehler nutzen. Sie gibt auch relative Bedeutungen zu den Berechnungen die man für die Anpassung eines Vermessungsverschluss durch die Methode der Mindestquadraten nutzen kann.

Important aspects of cave surveys and maps are the determination of the interrelationships of cave and the relationships of cave passages to topographic and geologic surface features. The determination of these distance relationships involves both the calculated survey distance between the two points in question and the value for the potential amount of error based on the level of accuracy of the measurements.

Survey error analysis is also sueful in cave survey computer programs. These programs are used to close all the surveyed loops in the cave so there will not be any discrepancies between the first and last stations in each loop. Mathematically, the most sophisticated type of closure program is a simultaneous closure program[1] which uses the method of least squares[2] and weighting based on error propagation calculations. Appropriate weighting in the simultaneous equations results in the least amount of distortion during the closure adjustment process.

The accuracy of a cave map depends on the accuracy and precision of surveying instrument use. There are several error causing problems involved in the process of surveying which cause inaccuracy and map distortions. These problems can be classified into three kinds: statistical error, systematic error, and blunders. Statistical errors include small measurement errors resulting from the intrinsic lack of precision in the typical cave surveying instruments; measurement errors caused by the fact that humans are using the instruments; and the error in positioning the instruments at the survey stations. Statistical errors are characterized by: the occurrence of error in some random amount in every measurement; the regular cancellation of error as well as the addition of error because of the opposite error directions that are possible; and the regular mathematical propagation of the cumulative error. Systematic errors include: inaccurate compass readings caused by a compass magnetically or mechanically out of alignment; incorrect tape readings caused by a stretched tape; et cetera. Systematic errors are characterized by: the occurrence of the error in a defined amount in the same direction in every measurement; lack of cancellation by errors in opposite directions; and a regular propagation of error that is faster than the propagation of statistical error. Blunders include: reading the compass backwards within a 10-degree interval, i.e., 117° instead of 123°; a spurious reading of the wrong scale on the clinometer; incorrect transcription of data such as 110 feet versus 11.0 feet; et cetera. Although blunders occur randomly and can sometimes cancel each other, they do not occur in a random amount in every measurement and they do not follow a regular propagation pattern.

The intrinsic amount of precision in the cave survey instruments, and the precision inherent in the use of the instruments by cave surveyors define the amount of statistical error that propagates along a surveyed passage. It is relatively difficult to lessen the level of statistical error. Conversely, blunders and systematic errors result from mistakes and poor instrument use, and the detection of these kinds of error provides for an opportunity to correct poor survey closures.

Because blunders disturb the normal propagation of statistical error, and systematic errors propagate at a much faster rate, the presence of these kinds of errors can be detected by comparing a calculated expected amount of statistical error with the observed survey error.

The statistical error of cave surveys is based on the standard deviations of error in the surveying instruments, which are the compass, tape, and clinometer. These three sources of error cause three mutually perpendicular linear spacial errors, generating a three-dimensional error space or zone of uncertainty. These three generating axes are: A, the axis perpendicular to the survey shot in the 'horizontal plane' generated by compass errors of too far to the right or left; B, the axis parallel to the survey shot generated by tape errors of too far or too near; and C, the axis perpendicular to the A and B axes, generated by clinometer errors of too much above or below the true position of the sighted station.

The standard deviations of the error on the axes A, B, and C of a survey shot can be calculated using Gauss' law of propagation of errors[3]: if F is a function of several random variables, $F = f(A,B,C,D....)$, and the standard deviations of the variables (e.g., σ_A, σ_B, etc.) are known, the square of the standard deviation of F is: $\sigma_F^2 = \left(\frac{\partial S}{\partial A}\right)^2 \sigma_A^2 + \left(\frac{\partial S}{\partial B}\right)^2 \sigma_B^2 + \left(\frac{\partial S}{\partial C}\right)^2 \sigma_C^2 + \ldots.$, with the partial derivatives evaluated at their average values. For the application of Gauss' law and further analysis, each survey shot will have its own three-dimensional coordinate system in which the survey shot will be defined as being on the y axis with zero inclination of the y axis. The length of the survey shot in this coordinate system will then be, allowing for the existence of errors in the measurement of D (distance), θ (bearing), and ϕ (inclination), $Ly = D \cos\theta \cos\phi$. As defined, the average values of θ and ϕ in the survey shot's coordinate system are zero (cancellation of errors) and the average value of Ly would be $\overline{Ly} = D$. Applying the Gauss equation, the variance of the error along the y axis is $\sigma_{Ly}^2 = \sigma_D^2 (\cos\theta \cos\phi)^2$. Evaluated at the average values $\theta = 0$ and $\phi = 0$; $\sigma_{Ly}^2 = \sigma_D^2$. Similarly, the length of a survey shot in the horizontal perpendicular direction, allowing for errors in D, θ, and ϕ, is $L_x = D \sin\theta \cos\phi$. The average value of L_x is, of course, zero. However, the application of Gauss' equation gives the variance of error in the x axis as $\sigma_{Lx}^2 = D^2 \sigma_\theta^2 (\cos\theta \cos\phi)^2$, which, when evaluated at average values of D, θ, and ϕ, gives $\sigma_{Lx} = D^2 \sigma_\theta^2$. The variance of error in the vertical distance, $L_z = D \sin\phi$, is $\sigma_{Lx}^2 = D^2 \sigma_\phi^2 \cos\phi = D^2 \sigma_\phi^2$. σ_θ and σ_ϕ must be in radians.

The equation of the normal probability curve, or probability distribution function (p.d.f.), if: $f(x) = \left(\frac{1}{\sqrt{2\pi\sigma_x^2}}\right) e^{-(x_i-\overline{x})/2\sigma_x^2}$ [4], where x_i is the observed value of the random variable, f(x) is the graphic vertical distance above the x_i position on the horizontal scale, $\overline{x}$ is the average value of the variable, and σ_x is the standard deviation of the variable x (σ_x^2 is the variance of x). In the case of three dimensional survey error, we have a trivariate distribution: $f(x,y,z) = [f(x)][f(y)][f(z)] = \left(\frac{1}{\sqrt{2\pi}}\right)^3 \left(\frac{1}{\sqrt{\Sigma\sigma_{xi}^2\sigma_{yi}^2\sigma_{zi}^2}}\right) \exp\left\{-\frac{1}{2}\left[\frac{(x_i-\overline{x})^2}{\sigma_{xi}^2} + \frac{(y_i-\overline{y})^2}{\sigma_{yi}} + \frac{(z_i-\overline{z})^2}{\sigma_{zi}}\right]\right\}$.[5] The graph of the p.d.f. of the trivariate distribution is a four-dimensional surface with each combination of errors $x_i-\bar{x}$, $y_i-\bar{y}$, and $z_i-\bar{z}$ being associated with a certain probability P.

An important statistic is chi square, defined as: $\chi_n^2 = \sum_{i=1}^{n} \left(\frac{x_i-\bar{x}}{\sigma_{xi}}\right)^2$.[6] The chi square appears in the trivariate p.d.f.: $f(x,y,z) = \left(\frac{1}{\sqrt{2\pi}}\right)^3 \left(\frac{1}{\sqrt{\Sigma\sigma_{xi}{}^2\sigma_{yi}{}^2\sigma_{zi}{}^2}}\right) \exp\left\{-\frac{1}{2}\chi_3^2\right\}$. The value of n is equal to the number of geometrically independent variables and is called the degree of freedom of the chi square. In the case of a trivariate distribution, n=3.

When χ^2 is set equal to a constant (such as 1), the resulting equation, $1 = \left(\frac{x_i-\bar{x}}{\sigma_x}\right)^2 + \left(\frac{y_i-\bar{y}}{\sigma_y}\right)^2 + \left(\frac{z_i-\bar{z}}{\sigma_z}\right)^2$, is the three-dimensional equation of an ellipsoid. This ellipsoid is called a contour of equal probability.[7] This means that all points $x_i-\bar{x}$, $y_i-\bar{y}$, $z_i-\bar{z}$ on the sllipsoid's surface are associated with the same probability. The probability that a point will occur within an ellipsoid can be obtained from a table of chi square areas for different constant values of χ^2. Each survey shot has associated with it an independent three-dimensional error. The next problem is to derive an equation for the p.d.f. of the error resulting from a series of survey shots. For a survey string of several survey shots, the string's error space is the result of all the individual survey shot error spaces combined. A statistical variable which is a sum of other statistical variables has a p.d.f. which is the convolution of the p.d.f.s of the summed statistical errors.

According to the reproductive property of a chi-square distribution[8], if S_i chi-square variables, each with n_i degrees of freedom, are added statistically, the resulting quantity (the convolution) is also a chi-square distributed variable which has $n = \sum_{i=1}^{s} n_i$ degrees of freedom. In the present trivariate case, all the n_i=3, so the chi-square for a string has 3S degrees of freedom, where S is the number of shots in the string. The chi-square variable for a survey string of S shots is: $\chi_{3S}^2 = \frac{[\Sigma x_i-\Sigma\overline{x_i}]^2}{\sum_{i=1}^{s}\sigma_{xi}{}^2} + \frac{[\Sigma y_i-\Sigma\overline{y_i}]^2}{\Sigma\sigma_{yi}{}^2} + \frac{[\Sigma z_i-\Sigma\overline{z_i}]^2}{\Sigma\sigma_{zi}{}^2}$. As explained earlier, the averages of error variables which can be in opposite directions are zero. The values of x_i, z_i, $\sum_{i=1}^{s} x_i$, etc., are therefore all zero. The chi-square part of the trivariate distribution p.d.f. can now be written as: $\chi_{3S}^2 = \frac{(\Sigma x_i)^2}{\sum_{i=1}^{s}\sigma_{xi}{}^2} + \frac{(\Sigma y_i)^2}{\Sigma\sigma_{yi}{}^2} + \frac{(\Sigma z_i)^2}{\Sigma\sigma_{zi}{}^2}$.

This equation is in as many x, y, and z variables as there are survey shots, since each survey shot is in its own coordinate system.

The calculation of χ^2 for the three-dimensional error of a survey string requires that all the individual survey shot coordinate systems be related to the same coordinate system. Therefore, we need to develop transformation equations to transform an ellipsoid equation to another coordinate system. We can define a prime coordinate system where the y' axis is at 0° North, the x' axis is at 90° East, and the z' axis is at 90° up. Each survey shot coordinate system is defined so that the bearing (direction) of that shot is on the y axis in that shot's coordinate system and the inclination is 0° in that system. The actual instrumentally measured azimuth and clinometer readings for each survey shot are then θ_i and ϕ_i respectively, the transforming angles between the coordinate system of the shot and the prime coordinate system.

The transformation equations are: $x_i = x'\,\mathrm{Cos}\,\theta_i - y'\,\mathrm{Sin}\,\theta_i$, $y_i = x'\,\mathrm{Sin}\,\theta_i\,\mathrm{Cos}\,\phi_i + y'\,\mathrm{Cos}\,\theta_i\,\mathrm{Cos}\,\phi_i + z'\,\mathrm{Sin}\,\phi_i$, $z_i = -x'\,\mathrm{Sin}\,\theta_i\,\mathrm{Sin}\,\phi_i - y'\,\mathrm{Cos}\,\theta_i\,\mathrm{Sin}\,\phi_i + z'\,\mathrm{Cos}\,\phi_i$. The substitution of these transforming equations into the trivariate chi-square equation results in an ellipsoid in only three spatial variables (x', y', and z'), rather than 3S spatial variables. The number of degrees of freedom is now reduced to 3 by the constraining transformation equations: $\frac{x'^2}{\Sigma\sigma_x{}^2} + \frac{y'^2}{\Sigma\sigma_y{}^2} + \frac{z'^2}{\Sigma\sigma_z{}^2} = \chi_3^2$.

The statistical addition of ellipsoids in the same coordinate system and on congruent axes is in the form: $\frac{x^2}{\Sigma a_i{}^2} + \frac{y^2}{\Sigma b_i{}^2} + \frac{z^2}{\Sigma c_i{}^2} = \chi_3^2$. In order that ellipsoids from various other coordinate systems be added, we use the coordinate system transformation equations. It is necessary, however, that to avoid a summation equation which causes ellipsoids to become smaller instead of larger, we convert each ellipsoid to a complementary form: $a_i{}^2x^2 + b_i{}^2y^2 + c_i{}^2z^2 = \chi_3^2$ before substituting the transformation equations.

Substitution of the transforming equations into the complementary ellipsoid equation produces the general rotation and summation form: $(\Sigma A_i')x'^2 + (\Sigma B_i')y'^2 + (\Sigma C_i')z'^2 + (\Sigma D_i')x'y' + (\Sigma E_i')y'z' + (\Sigma F_i)x'z'$, where $A_i' = a_i{}^2\,\mathrm{Cos}^2\,\theta_i + (b_i{}^2\,\mathrm{Cos}^2\,\phi_i + c_i{}^2\,\mathrm{Sin}^2\,\phi_i)\,\mathrm{Sin}^2\,\theta_i$, $B_i' = a_i{}^2\,\mathrm{Sin}^2\,\theta_i + (b_i{}^2\,\mathrm{Cos}^2\,\phi_i + c_i{}^2\,\mathrm{Sin}^2\,\phi_i)\,\mathrm{Cos}^2\,\theta_i$, $C_i' = b_i{}^2\,\mathrm{Sin}^2\,\phi_i + c_i{}^2\,\mathrm{Cos}^2\,\phi_i$, $D_i' = 2(b_i{}^2\,\mathrm{Cos}^2\,\phi_i + c_i{}^2\,\mathrm{Sin}^2\,\phi_i - A_i')\,\mathrm{Sin}\,\theta_i\,\mathrm{Cos}\,\theta_i$, $E_i' = 2(b_i{}^2 - c_i{}^2)\,\mathrm{Cos}\,\theta_i\,\mathrm{Sin}\,\phi_i\,\mathrm{Cos}\,\phi_i$, and $F_i' = 2(b_i{}^2 - c_i{}^2)\,\mathrm{Sin}\,\theta_i\,\mathrm{Sin}\,\phi_i\,\mathrm{Cos}\,\phi_i$, and where $a_i{}^2 = D_i{}^2\,\sigma_\theta{}^2 = D_i{}^2\,\sigma_{compass}{}^2$, $b_i{}^2 = \sigma_D{}^2 = \sigma_{tape}{}^2$, and $c_i{}^2 = D_i{}^2\,\sigma_\phi{}^2 = D_i{}^2\,\sigma_{clinometer}{}^2$.

After summation in this form, the system of equations can be solved for a_Σ, b_Σ, c_Σ, θ_Σ, and ϕ_Σ by using the equations $\Sigma A_i' = a_\Sigma{}^2\,\mathrm{Cos}^2\,\theta_\Sigma + (b_\Sigma{}^2\,\mathrm{Cos}^2\,\phi_\Sigma + c_\Sigma{}^2\,\mathrm{Sin}^2\,\phi_\Sigma)\,\mathrm{Sin}^2\,\theta_\Sigma$, etc. The equation of the ellipsoid of summation is: $\frac{x'^2}{a_\Sigma{}^2} + \frac{y'^2}{b_\Sigma{}^2} + \frac{z'^2}{c_\Sigma{}^2} = \chi_3^2$. The semi-axes are the standard deviations: $a_\Sigma = \sigma_{x_\Sigma}$, $b_\Sigma = \sigma_{y_\Sigma}$, and $c_\Sigma = \sigma_{z_\Sigma}$, as with the ellipsoids of a single survey shots.

We now have the size of the error ellipsoid of a string of survey shots in terms of its semi-axes, and we have the orientation of the ellipsoid in three-dimensional space in terms of θ_Σ and ϕ_Σ. For most applications, the desired result is a radial equation. Such an equation will give the magnitude of error at any given bearing and inclination (θ_V, ϕ_V) in the prime coordinate system. The substitution of cartesian to spherical coordinate system transformations into $\chi_3^2 = \frac{x'^2}{a_\Sigma{}^2} + \frac{y'^2}{b_\Sigma{}^2} + \frac{z'^2}{c_\Sigma{}^2}$ results in the radial equation:

$$r^2 = \chi_3^2 \Big/ \left[\frac{\mathrm{Sin}^2\,\theta_I\,\mathrm{Cos}^2\,\phi_I}{a_\Sigma{}^2} + \frac{\mathrm{Cos}^2\,\theta_I\,\mathrm{Cos}^2\,\phi_I}{b_\Sigma{}^2} + \frac{\mathrm{Sin}^2\,\phi_I}{c_\Sigma{}^2}\right].$$

If the summer ellipsoid is at orientation θ_Σ, ϕ_Σ with respect to the prime system, the radial equation in terms of variable bearing θ_V and variable inclination ϕ_V in the prime coordinate system is:

$$r^2 = \chi_3^2 \Big/ \left[\frac{\mathrm{Sin}^2(\theta_V-\theta_\Sigma)\,\mathrm{Cos}^2(\phi_V-\phi_\Sigma)}{a_\Sigma{}^2} + \frac{\mathrm{Cos}^2(\theta_V-\theta_\Sigma)\,\mathrm{Cos}^2(\phi_V-\phi_\Sigma)}{b_\Sigma{}^2} + \frac{\mathrm{Sin}^2(\phi_V-\phi_\Sigma)}{c_\Sigma}\right],$$

since $\theta_I = \theta_V - \theta_\Sigma$ and $\phi_I = \phi_V - \phi_\Sigma$.

The value of χ_3^2 is obtained from a table of three degrees of freedom chi-square areas for any choice of confidence level. Specific examples are: $\chi_3^2 = 6.25$[9] for a 90% confidence value (90 percent of all no-blunder surveys without systematic errors will be within the calculated r value) and $\chi_3^2 = 2.37$ for a 50% confidence level.

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Motiv Höhle und Motivation Zur Höhlenforschung

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Zusammenfassung

WELCHES SIND DIE SPEZIFISCHEN MOTIVE ZUR HÖHLENFORSCHUNG? - Diese Frage wind zwar da und dort ansatzweise diskutiert. Im vorliegenden Referat soll sie in einem größeren Rahmen aufgeworfen werden[1].

WORUM ES NICHT GEHT: Sportliche und Wissenschaftliche Interessen allgemeiner Art. Thema sind ausschließlich Motive, die für die Höhlenforschung im Unterschied zu anderen Berufen und Hobbys SPEZIFISCH sind.

Insbesondere ZEHN MOTIV-GRUPPEN kommen zur Sprache:

1. NEUGIER Dunkel - Geheimnis. Erstbegehung - Entdeckung von Neuem. Pioniergeist. Analogie: WISSENSCHAFTLICHE Entdeckungen und neue Erkenntnisse
2. EINDRINGEN: Man bleibt nicht an der Oberfläche, sondern dringt ins Erdinnere ein. Analogie: Eindringen in PHILOSOPHISCHE Gedankengänge, die "unter die Oberfläche der Dinge" führen.
3. VERBORGENEZUSAMMENHÄNGE: Zusammenschluß von Höhlen oder Höhlenteilen schafft neue Orientierungsmöglichkeiten. Analogie: Zusammenhangsnachweis zwischen WISSENSCHAFTLICHEN SYSTEMEN schafft neue Theorien.
4. ÄSTHETISCHE WAHRNEHMUNG: Gänge, Hallen, Schächte sind Hohlformen. Hohlraum-Plastik. Lebendiges Spiel von Licht und Schatten. Vergleich mit abstrakter KUNST (auch Musik)
5. KONTRASTERLEBNISSE: Absteigen - Wiederaufsteigen. Geborgenheit - Gefahr
6. RAUM- und ZEITERFAHRUNG: In Höhlen wird die Zeit als gestrafft (36 Stunden wie 24-30), der Raum umgekehrt als gedehnt erlebt (Überschätzung der Entfernungen in Höhlen)
7. HÖHLE ALS VAGINA UND UTERUS: Assoziationen zur PSYCHOLOGIE
8. FLUCHT VOR ZIVILISATION. Höhle als letztes Residuum der Natur
9. FLUCHT IN DIE VERGANGENHEIT: Höhlen als prähistorische und archäologische Stätten. Versteinerungen repräsentieren frühere Erdzeitalter
10. WIEDERGEBURT: Wechsel zwischen Sonne (Leben) und Dunkelheit (lebensfeindliches Klima. Vergleich der Rückkehr zur Erdoberfläche mit Erwachen zu neuem Leben.

Bei der Erörterung dieser Motive wird auf Mythen, Märchen, Iraumsymbole hingewiesen. Es wird nicht unterstellt, die genannten Motive müßten dem Höhlenforscher bewußt sein. Sie sollen auch nur zur Diskussion gestellt werden.

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[1]) Der Ref. ist Höhlenforscher im Hobby und Philosophie-Assistent im Beruf; er vertritt die Ansicht, daß er in beiden Fällen dasselbe tut - nur auf unterschiedliche Weise.

Abstract

WHAT ARE SPECIFIC REASONS FOR EXPLORING IN THE FIELD OF SPELEOLOGY? As this subject has been sometimes arisen among several groups of cavers, it is this paper's intention to discuss its main points.[1] What's not focused are general (sporting and scientific) ambitions, focused are exclusively merely speleologic motivations.

Especially ten motivations should be mentioned:

1. CURIOSITY: darkness, mystery. first exploration, discovery of new passages. pioneer spirit. Analogy: scientific discoveries and addition of new elements to knowledge.
2. PENETRATION: Walking on the surface forbids itself as speleologists indulge in the earth. Analogy: Indulging in philosophic ways of thinking, which should lead to cores of problems.
3. HIDDEN CONNECTIONS: Discovering that certain caves belong together may give new hints concerning orientation about the respective region. Analogy: Proving connections among scientific systems creates new theories.
4. ESTHETIC RECOGNITION: Galleries, halls, pits are hollow bodies. Hollow sculpture, liveley play of light and shadow, comparable with modern art (as well as music).
5. EXPERIENCE OF CONTRASTS: Descending and ascending. Homelikeness and danger.
6. EXPERIENCE OF SPACE AND TIME: Inside caves, time is seen to be shorter (e.g. 36 hours as 24-30), meanwhile space seems to be larger (overestimating of distances in caves).
7. CAVE AS VAGINA AND UTERUS. Associations towards psychology.
8. FLEEING FROM CIVILISATION: Caves as last residences of nature.
9. TURNING TOWARDS THE PAST: Caves as prehistoric and archaeologic places. Petrifactions represent former earth ages.
10. REBIRTH: Change between sun (life) and darkness (climate hostile to life). Comparison of returning to earth's surface with awaking to new life.

Analyzing these motivations is done with regard to myths, fairy-tales, symboles and dreams. It is not supposed that the above mentioned motivations are to be conscious to speleologists. They should merely be brought into discussion.

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[1] Writer of this, a speleologist by hobby and assistant-professor of philosophy by profession, supposes that in both cases he is doing one and the same thing, but in different manners.

Ist die Speleologie eine Wissenschaft oder ein Sport? Sicherlich beides. Nun spricht aber auch vieles dafür, daß sich die Motivation zur Speleologie nicht auf die Erkenntnis der geologischen Verhältnisse und hydrologischen Zussammenhänge in einer Karstgegend und auch nicht auf bloßes sportliches Training beschränkt. Denn gemessen an diesen Zielen sind der Aufwand, der zumindest in einigen der westlichen Industrieländer mit der Höhlenforschung getrieben wird, und ihre Verbreitung doch wohl überdimensioniert. Als motivationaler Antrieb zur Höhlenforschung müssen offensichtlich auch andere als rein sportliche und rein wissenschaftliche Motive im Spiel sein, Motive, durch deren Betrachtung vielleicht verständlich wird, warum die Höhlenforschung für viele, die sie betreiben, ein Selbstzweck ist. - Was sind das für Motive?

In diesem Beitrag soll dieser Frage in lockerer, assoziativer (nicht wissenschaftlicher) Weise nachgegangen werden. Dabei ist es nibht das Ziel, motivationale. Aspekte aufzuweisen, die die Höhlenforschung mit anderen Tätigkeiten teilt. So ist beispielsweise die Kamteradschaft, obwohl sie bei Höhlenbefahrungen eine große. Rolle spielt, für die Motivation zu gerade diesem Sport sicher nicht typisch. Ähnliches gilt für die Faszination, die vom Element des Wassers ausgeht: auch sie dürfte für manchen Höhlenliebhaber einen eigenen Anreiz darstellen, aber wäre sie wirklich das Entscheidende, so könnte man ebensogut Wildwasserkajak fahren oder segeln. - Es sollen hier statt dessen einzig und allein Motive zur Sprache kommen, von denen man annehmen kann, daß sie für die Höhlenforschung im Unterschied zu anderen Beschäftigungen SPEZIFISCH sind. Ein Teil dieser Motive ließe sich sicherlich aus psychologischer Warte fruchtbar erhellen. Auch Bezüge zu philosophischen und wissenschaftlichen Themen sind wahrscheinlich. Auf all das soll hier ausdrücklich hingewiesen werden. Aber auch die Bedeutung des Motivs der HÖHLE in Märchen, Mythen und in der Traumsymbolik sollte man nicht übersehen. Vielleicht verraten diese Zusammenhänge sogar etwas über unsere Motivation zu diesem - wie doch wohl jedermann zugibt - extravaganten Wissenschafts-Sport.

Es sind insgesamt ZEHN teilweise miteinander zusammenhängende Motive oder Motivgruppen, die erörtert

- oder genauer: angedeutet - werden sollen (denn zu einer wirklichen Erörterung ist die zur Verfügung stehende Zeit zu knapp).

Neugier

Schwarze Öffnungen im Felsen erregen unsere Neugier. Im Bergesinnern werden Geheimnisse vermutet. Zur Motivation des Speleologen gehört aber, daß er sich nicht mit dem Geheimnis begnügt: Er will es lüften, er will etwas Neues entdecken. In der Tat: Welcher Speleologe möchte nicht wenigstens einmal an einer Erstbegehung dabeigewesen sein? Häufig wird mit einer Höhle so etwas wie der Inbegriff des Unbekannten oder Unerforschten assoziiert. Wer in eine Höhle steigt, wagt sich ins "Reich des Ungewissen" vor. Tiefe Höhlen bieten den besonderen Reiz, daß auch für diejenigen, die das Geheimnis gelüftet haben, noch ein Teil des Geheimnisses zurückbelibt. Kurze und ganz erforschte Höhlen sind für manchen weniger faszinierend als lange und teilweise noch unerforschte.

Dieser Motivkomplex legt einen Vergleich mit der GEWINNUNG VON NEUEN ERKENNTNISSEN und mit ENTDECKUNGEN in der WISSENSCHAFT nahe: Höhlen wirken in der Landschaft ähnlich wie Lücken oder Löcher in unserem Wissen: Man kann nur den Eingang lokalisieren, kennt aber nicht den Weg, der von da aus weiterführt. Im Bereich solcher Lükken und Löcher behält, was wir AHNUNGEN nennen, seinen Spielraum. - Gleich wie der Wissenschaftler, konstruiert oder erschafft sich der Höhlenforscher nicht selbst den Weg, den er im Unbekannten entdeckt und einschlägt. Diese Verwandtschaft rückt den Speleologen dem Wissenschaft-Treibenden näher als dem Künstler oder Bastler. Sowohl der Höhlenforscher als auch der Wissenschaftler müssen zwar normalerweise kreative Leistungen erbringen, damit sie etwas Neues entdecken. Aber das Entscheidende ist, daß in beiden Spartan das Neue nicht erschaffen, sondern gefunden und entdeckt wird.

Eindringen

Der Höhlenforscher bleibt bekanntlich nicht an der Oberfläche. Er dringt in die Erde, in die Dunkelheit ein, er stößt gleichsam in die Materie vor und erschließt neue Systeme.

Auch zu diesem Aspekt existiert eine Analogie; sie führt aber nun nicht in die Wissenschaft, sondern in die Philosophie: Von den Philosophen sagt man gleichfalls, sie drängen unter die Oberfläche der Dinge, sie versuchten, den Geheimnissen, die uns umgeben, auf den Grund zu gehen und zu erkennen, "was die Welt im innersten zusammenhält" (Goethe, Faust I). Ein Philosoph muß es sich genauso wie ein Speleologe gefallen lassen, daß man von ihm sagt, er bewege sich im Dunkeln. Auch Philosophen schließen sich oft in komplizierte Systeme ein. Der Unterschied ist nur, daß sich der Höhlenforscher in FELSENGÄNGEN, der Philosoph dagegen in GEDANKENGÄNGEN verliert. Philosophen und Speleologen haben es gemeinsam, daß sie die Tiefe suchen und sich in einer umso wohltuenderen Spannung befinden, je tiefer sie vorstoßen. Zwei Gefahren gehören in Beiden Disziplinen zum Charakter des spezifischen Abenteuer: die Gefahr, in der Tiefe und im Dunkeln allein zu sein (wenn nämlich für Andere die Schwierigkeit, zu folgen, übergroß wird), und die Gefahr, aus der Tiefe und aus dem Labyrinth nicht wieder zurückzufinden.

Verborgene Zusammenhänge

Ein Zusammenschluß von verschiedenen Höhlensystemen wird in der Höhlenforschung in der Regel als besonderes Eriegnis gefeiert, ähnlich wie die Entdeckung von Neuland - wie wenn mit einer Verbindung zwischen zwei Höhlen etwas Neues entdeckt würde. Tatsächlich führt jeder Zusammenschluß zu etwas Neuem: Neu ist jeweils der Gesamtzusammenhang, in dem die Elemente, die zuvor voneinander unabhängige Systeme gebildet haben, nun vereinigt sind. Mit einem Zusammenschluß erweitern sich die Orientierungsmöglichkeiten, verändert sich das Gesamtbild eines Systems. - Auch dieser Aspekt hat im Bereich der Erkenntnis eine Parallele: Der Zusammenschluß von zwei verschiedenen Theorien zu einer umfassenden Theorie schafft einen neuen Orientierungsrahmen, neue Erklärungsmöglichkeiten. Sie können ebenso bedeutend oder noch bedeutender sein als Erweiterungen von begrenzten Theoriebereichen. Beispielsweise hat Newton die Theorie von Galilei über die Fallbewegungen auf der Erde und die Theorie von Kepler über die Gesetze der Himmelsmechanik zusammengeschlossen. Durch die neue Theorie der Gravitation, die Newton so geschaffen hat, ist geradezu ein neues Weltbild entstanden.

Ästhetische Erfahrung

a) Der Höhlenforscher hat es mit einer besonderen Art von Körpern und Formen zu tun: mit Hohlkörpern und Hohlformen. Während im Alltag unsere Aufmerksamkeit vor allem den materiellen Gegenständen gilt und der Zwischenraum zwischerihnen eine sekundäre Bedeutung hat, liegen in der Höhlenforschung die Dinge umgekehrt: Hier ist der Hohlkörper das Entscheidende, und seine materiellen Umgrenzungen sind von zweitrangiger Bedeutung.

b) Die Formen, die man in der Höhle antrifft, sind von größter Vielfalt - jedenfalls von wesentlich größerer Vielfalt als die immer gleichen Formen in einem künstlichen Tunnel. Der für Höhlen charakteristische Formenschatz übertrifft - und das ist wohl das Wesentliche - denjenigen industrieller Fertigprodukte bei weitem: und bekanntlich sind die meisten Gegenstände unseres täglichen Umgangs industriell vorgefertigt. Daher kann als wahrscheinlich angenommen werden, daß unser ästhetisches Empfinden von Höhlen in einer Weise angesprochen wird, die unsere ästhetischen Alltagserfahrungen korrigiert oder kompensiert. - Innerhalb der ästhetischen Hervorbringungen unserer Kultur sind die Hohlformen in Grotten wohl am ehesten vergleichbar mit Katakomben, Kathedralen und Kristallpalästen, und die oft kargen, oft bizarren Korrosionsgebilde und Sinterkonkretionen mit künstlerischen Plastiken und Skulpturen.

c) Die in der Höhlenforschung übliche Azetylenbeleuchtung mit offener Flamme auf dem Helm führt bei jeder Höhlenbegehung zu einem lebendigen Spiel von Licht und Schatten, das sich kaum jemals in genau gleicher Weise wiederholt und das mit seinem bewegten Wechsel von Licht- und Schattenfiguren die Phantasie anregt. - Hier liegt der Vergleich zur abstrakten Kunst nahe: zur optischen Kunst, d.h. zur ungegenständlichen Malerei (die aber statisch ist) und zu Kunstformen, die mit Dynamik und zeitlichem Wechsel der Figuren operieren, also etwa zu verschiedenen Formen der Musik (die aber keinen optischen Eindruck vermittelt).

Kontrasterfahrung

Die Befahrung einer Höhle ist ein Erlebnis, das durch Kontraste entscheidend geprägt wird: Kontraste bilden der Wechsel von Licht (Außenwelt) und Dunkel (Untergrund), von Wärme (Außenwelt) und Kälte (Höhle; in kalten Ländern sind die Kontrastpole in Winter vertauscht), von Schwitzen und Frieren, von Leben und Lebensfeindlichkeit, von Lärm (bei starken Wassergeräuschen) und Stille (bis hin zu völliger Geräuschlosigkeit, wie sie der normale Alltag nicht kennt). Eine zusätzliche und für die psychologische Seite der Höhlenforschung sicher besonders wichtige Art von Kontrasterlebnis liegt im Gegensatz zwischen Gefahr und Geborgenheit, den eine Höhle in sich birgt: Grotten gelten mit ihrer Dunkelheit und ihren Abgründen als gefährlich, aber sie bieten Schutz vor Frost und Hitze; darüber hinaus stellen sie ein wesentlich stabileres und zeitbeständigeres Obdach dar als alle Kunstbauten.

Raum- und Zeiterfahrung

Die Erfahrung von Raum und Zeit in Höhlen weicht von der im Freien mehr oder weniger deutlich ab. Eine Höhle entwickelt und verändert sich im allgemeinen in sehr langen Zeiträumen. Fast könnte man den Zeitfaktor vernachlässigen und sagen, eine Höhle sei ein zeitloser Ort. Und analog dazu ließe sich eine Höhle als raumlosen Ort bezeichnen - da nämlich durch die Dunkelheit die perspektivische (dreidimensionale) Raumwahrnehmung sehr weitgehend behindert wird (nur im visuellen Nahbereich bleibt die Perspektivik ungestört).

Im Unterschied zur Außenwelt fehlt unter der Erdoberfläche zudem der rhythmische Wechsel von Tag und Nacht, was die Einschätzung des Zeitablaufs erschwert, und es fehlen räumliche Erkennungsmarken, was die Distanzenschätzung behindert. Zur Einschätzung von Raum und Zeit ist man daher weitgehend auf die Rhythmen der eigenen Aktivität angewiesen. Die Fortbewegung in Höhlen ist nun aber normalerweise mühsamer als in der Außenwelt: man legt bei gleichem Aufwand an physischer und psychischer Energie kürzere Strecken zurück als draußen. Dies hat einen doppelten Effekt: a) auf die Zeit: Die "innere Uhr" läuft langsamer. Eine Höhlen-Stunde dauert länger als eine draußen verbrachte Stunde; eine gegebene Zeitdauer wirkt in der Höhle entsprechend kürzer (z.B. werden 36 Stunden wie 24-30 Stunden erlebt; in gewissen Märchen sind die Relationen gewaltig übertrieben. Beispiel: 7 Tage im Reich der Zwerge = 7 Jahre in der menschlichen Zivilisation). - b) auf den Raum: Das bei der Distanzenschätzung in Höhlen intuitive angelegt Metermaß ist gestaucht. Die Streckeneinheit in der Höhle wird kürzer gewählt als in der Außenwelt; eine gegebene Raumstrekke wirkt in der Höhle daher entsprechend länger (das Ausmaß der Überschätzung von unterirdischen Distanzen kann bekanntlich außerordentlich hoch sein).

Zu diesem Aspekt läßt sich eine eigentümliche

Analogie anführen: die Raum- und Zeit-Dilatation in der RELATIVITÄTSTHEORIE: Wenn sich zwei Bezugssysteme A und B in großer (im Vergleich zur Lichtgeschwindigkeit nicht vernachläßigbarer) Geschwindigkeit relativ zueinander bewegen, dann sind sowohl die Zeitspannen als auch die räumlichen Strecken im System B für einen Beobachter in A in der Bewegungsrichtung gestrafft (gestaucht); dasselbe gilt für Zeitverhältnisse und Raumstrecken auf A für einen Beobachter auf B. - Dieser Vergleich zeigt zwei ähnliche Weisen einer Infragestellung unseres alltäglichen Raum- und Zeitempfindens. Aber die Analogie ist in doppelter Weise unvollständig. Erstens: Während nach der Relativitätstheorie in jedem System andere räumliche und zeitliche Maßstäbe gelten, werden in Höhlen dieselben Maßstäbe und Uhren benützt wie in der Außenwelt; die im Erdinnern intuitiv unterstellten abweichenden Maßeinheiten sind subjektiv und erweisen sich im Vergleich mit den objektiven Maßeinheiten als Produkte von Wahrnehmungs- oder Empfindungstäuschungen. Zweitens: Raum- und Zeitdilatation laufen in der relativistischen Physik in gleicher Richtung (der Stauchung in der Zeitdimension entspricht eine Stauchung in der Raumstrecke); in der Höhle dagegen in umgekehrter Richtung (der Stauchung von Zeitspannen steht die Ausdehnung der geschätzten Raumstrecken gegenüber).

Höhle als Vagina, Uterus und Muttersymbol

Es gibt eine große Zahl von Mythen und Sagen, in denen das Motiv HÖHLE vorkommt. Seine Bedeutung weist einerseits in Richtung auf Glück (v.a. in chinesischen Märchen), andrerseits auf den Zusammenhang von Zeugung und Fruchtbarkeit. Der etymologische Zusammenhang von "Mutter" (lat: "mater") und "Materie" (lat. "materies", eig. "Mutterstoff") ist nachgewiesen. Die mythologische Gleichsetzung von Mutter und Erde, die auch in den Fruchtbarkeitsriten urzeitlicher Völker eine Rolle spielt, legt bei der Vorstellung vom Eindringen in bzw. Austreten aus dem Erdinnern entsprechende Associationen nahe. In manchen Mythen sind daher mit dem Gang in die Unterwelt Zeugung und Geburt, aber auch Tod und Wiedergeburt, motivlich miteinander verknüpft. Das Höhlensymbol bildet demnach eine Nahtstelle in den mythologischen Bildern des Kreislaufs von Leben und Tod.

Stark vereinfacht und verkürzt kehrt die Höhlensymbolik in der PSYCHOLOGIE von S. Freud (als Sexualmotiv) und C.G. Jung (Höhle als Mutter und Gebärmutter) wieder. Zwar ist diesen psychologischen Assoziationen ihre Berechtigung wohl kaum abzusprechen; aber offensichtlich greifen sie in dem Maße zu kurz, als sie den weiteren Zusammenhang, aus dem sie herausgelöst sind, außer acht lassen.

Flucht Vor der Zivilisation

Außer dem Urwald und den höchsten Gebirgen dieser Erde bleiben nur noch der Meeresgrund und das Erdinnere als von der Zivilisation unberührte Zonen übrig. Der Abstieg in die Höhle wirkt dabei besonders extrem, denn Höhlen sind - abgesehen von ihrer Eingangsregion - nicht nur keine Zivilisationsstätten, sondern auch keine Lebensräume. Tiefe Höhlen gehören weitgehend (d.h. wenn man von ihrer relativ dünnen Besiedlung durch Mikroorganismen absieht) zum Bereich der anorganischen Natur. Damit bilden sie zur Alltagsumgebung einen besonders krassen Gegensatz (vgl. 5).

Abstieg in Die Vergangenheit

Daß in Höhlen die Zeit stillsteht (vgl. 6.), erweckt die Assoziation an Urzeitliches, die ja bekanntlich viele Menschen mit der Höhle verbinden. Höhlen sind tatsächlich Stätten archäologischer und paläontologischer Funde. In die Kalkschichten, durch die sich Höhlen ziehen, sind Versteinerungen eingelagert, die frühere Erdzeitalter repräsentieren. - Der Vergleich von Erde und Mutter (7.) legt den Vergleich des Abstiegs durch die Schichten mit dem Bild des Abstiegs zu früheren Generationen (zum Reich der Mütter nach Goethes Faust II) nahe. Mit dem Schritt ins Anorganische wird gleichsam ein Rückblick in die tiefste erdgeschichtliche Vergangenheit vollzogen (vgl. 8.).

Wiedergeburt

Dieses Motiv, das mit dem Wechsel von Höhle (Dunkelheit, Leblosigkeit) und Erdoberfläche (Licht, Wärme, Leben) zusammenhängt, schließt sich an die Motive 5., 7. und 9. an. Die Rückkehr aus dem Erdinnern an die Sonne erleben manche Speleologen als Höhepunkt einer Höhlenfahrt.

Mit der Aufreihung von diesen zehn Motiven wird weder ein Anspruch auf Vollständigkeit erhoben noch unterstellt, daß jeder Höhlenforscher in all diesen Punkten sich selbst wiedererkennen müsse. In bezug auf jedes einzelne Motiv müßte durch Umfrage mit statistischer Auswertung ermittelt werden, ob und wieweit es einen signifikanten Aspekt in der Motivation zu Höhlenbegehungen darstellt (mit einer solchen Umfrage könnten allerdings nur die bewußten Motive festgestellt werden).

Die hier angestellten Überlegungen haben in der vorliegenden Form einzig und allein die Funktion einer Anregung zu eigenen Gedanken und zur Diskussion. - Der Verf. will zum Schluß bekennen, daß er Höhlenforscher im Hobby und Philosophie-Assistent im Beruf ist und daß er die Ansicht vertritt, in Beruf und Hobby ein und dasselbe zu betreiben - allerdings auf verschiedene Weise.

Karst and Caves in the Turks and Caicos Islands, B.W.I.

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Abstract

Karst and caves in the Turks and Caicos Islands, B.W.I., are formed in eolian calcarenite, the episodic deposition of which is interpreted to have developed as a result of Pleistocene eustasy. The Conch Bar Caves in the Middle Caicos represent the largest, and de facto the only known cave system in the island group. The caves are developed in at least three horizontal levels, the genesis of which is evidently connected with fluctation of sea level and variable intensity of precipitation in the Pleistocene. Two main phases of extensive breakdown occurred in the caves; the earlies one during groundwater activity in the main level, and a later phase that opened cave domes and connected them with shallow surface karst depressions. Speleothems of the Conch Bar Caves belong to several generations. Bulkly stalagmites and stalagnates, later corroded and weathered, probably form the oldest generation. The youngest generation is represented by white, recently active stalactites. Archaeological survey (Kotas 1980) resulted in discovery of discontinuous Arawak settlement in the caves.

Zusammenfassung

Karst und Hoehlen auf den Turks und Caicos Inselen (B.W.I.) werden im aeolischen Kalksandstein gebildet. Die episodische Ablagerung des Kalksandsteins wurde so ausgelegt, dass sie sich als ein Ergebnis von Pleistozaen-Eustase entwickelt hat. Die Conch Bar Hoehlen auf den Middle Caicos stellen das groesste und de facto einzige bekannt Hoehlensystem auf der Inselgruppe dar. Die Hoehlen sind in mindestens drei ausgepraegten horizontalen Hoehlenniveaus ausgebildet, deren Entstehung augenscheinlich mit der Meeresspiegelschwankung und variabler Intensitaet von Niederschlag aufgrund der Pleistozaen-Klimaaenderungen verbunden ist. Swei Hauptphasen von ausgepraegtem Durchbruch fanden in den Hoehlen statt: die frueheste waehrend Suesswasseraktivitaeten im Hauptniveau und eine spaetere Phase, die Hoehlendome oeffnete und sie mit seichten Oberflaechenkarstdolinen verband. Die Tropfstaine der Conch Bar Hoehlen gehoeren zu mehreren Generationen. Dicke Stalagmiten und Stalagnate, die spaeter korrodierten und verwitterten formen wahrscheindlich die aelteste Generation. Die juengeste Generation ist vertreten durch weisse, juengst aktive Stalaktiten. Die Archaeologische Erkundung (Kotas 1980) resultierten in der Entdeckung von Anzeichen der Arawak Ansiedlung in der Hoehlen.

Geologic and Geomorphic Setting

The basic geologic and geomorphic features of the Turks and Caicos Islands are presented elsewhere (Gregor 1980) as generally similar to them of Bahama Islands and, in some aspects, to them of Bermuda (Forney 1976). Relatively extensive areas of flat land, generally a few meters in elevation, are the dominant geogorphic features of the major islands, especially of the Caicos group. To the south of the group, the low-lying carbonates give way to vast areas of dry and wet tidal flats up to 13 km of width (East Caicos). In many islands, there are one or more parallely set ranges of hills, often over 22 m in elevation (the highest point 49.8 m), bordering the north, north east and east coast of the islands. The hills are formed of eolian calcarenite (place named colitic limestone), the episodic deposition of which is interpreted to have developed as a result of Pleistocene eustasy (Bermuda: Bretz 1960, Land et al. 1967, in Harmon et al. 1978). Littoral marine carbonates and platform margin patch reefs were formed as a result of platform submergence during warm periods of high sea level. These in turn provided a source for shoreline dune calcarenites. During periods of platform emergence and exposure (cold periods of low sea level) rainwater diagenesis of the carbonate occurred.

The Conch Bar Caves represent the most outstanding karst phenomenon in the Turks and Caicos Islands. Developed within an older formation of the calcarenite, they extend for a few kilometers within a coastal dune elevation (Conch Bar Hill) striking WNW-ESE, which is situated at the northern coast of the Middle Caicos. According to observations in the caves, the calcarenite is cross bedded, generally with dips to the west and east. The more moderate bedding dips are characteristic of the eastern windward side of the elevation (30o/15° SE, 70°/24° SE), the sheerer dips of the western slip face (180°/35° W, 160°/35°SW). It is very probable that the strike of eolian crossbedding controls the direction of passage development in the caves.

Cave Passages and Levels

The length of the Conch Bar Caves exceeds 2.5 km, but only a few tens of meters have been mapped (Fig. 1). Therefore, the following contemplations are only preliminary. Developed as a result of groundwater solution during earlier periods of platform emergence, the caves consist of passages and domes. The passages form four horizontal (subhorizontal) cave levels:

(A) the upper level, the rock bottom of which is situated 12-16 m above present sea level;

(b) the main level, permanently free of seawater, the rock bottom of which is situated 2-6 m above present sea level;

(C) the lower level, always partially flooded with seawater, the rock bottom of which is situated up to 2 m above sea level and down up to 2 m below sea level;

(c) (?) the lowest level, now permanently below sea level.

The upper level (A) is known in discontinuous fragmetns; they are relic of cave passages, the course of which was discontinued by the development of cave domes. In comparison with the main level, cross profiles of the upper level show substantially smaller dimensions.

The main level (B) represents the most extensive part of the Conch Bar Caves. It is noted by spacious tunnel passages (with many typical solutional forms - blind pockets, deeps, etc.), the rock bottom of which is often articulated by vertical crevices and connected with the lower level.

Sea level in the lower cave level (C) varies with local tides; the tidal range is about 0.8 m. Owing to numerous freshwater trickles belongint to the zone of vertical circulation, the water is brackish. The largest part of the level, permanently flooded with seawater, was found in the eastern part of the cave system. Local names as the East Seawater Chambers, the Ocean Passage, North Lake, South Lake, the Ocean Channel, etc. are characteristic of this part. The depth of water amounts to 1.6 m at low tide and up to 2.4 m at rising tide in the Chambers. The lower cave level extends for at least 300 m to the south of the known part of the Conch Bar Caves. At this distance, a large karst depression was found south of the Entrance No. 1 The sinkhole was formed by solution and collapse - remainders of the original low cave arch are preserved at its south east margin. Low passages almost completely filled with sediments and seawater were discovered between the caves and the sinkhole.

There is probably another level in the cave system, the lowest one (D), at present permanently below sea level, the existence of which is presumed but has not been proved as yet.

Cave Domes

The passage system of the Conch Bar Caves is articulated by more or less spacious cave domes. They originated by solution and collapse. The bottom of the domes (corresponding with the main level) is covered by bulky calcarenite blocks in some places. The blocks are intensively karstified as well as the ceiling above them; that testifies that the breakdown occurred during groundwater activity in the main level (the older phase of breakdown). In some cases, bulky stalagmites and stalagnates are based on the blocks. There are numerous rock pillars in the domes, some separated from the ceiling and formed as "rock flowers". The ceiling is often performed by vertical, round-shaped solutional chimneys. Some domes (Fig. 1) are open to the surface by large circular or eliptic holes which arised from solution (large sinkholes above the domes and subsequent perforation of the rock partition by vertical chimneys) and collapse (the younger phase of breakdown).

Speleothem Deposits

Six basic morphogenetic type of speleothems, mostly secondary calcite formations, were found in the Conch Bar Caves: stalagmite, stalactites, stalagnates, flowstones and mineral coatings, helicitites, and plastic sinter (soft sinter, Mondmilch). Bulky stalagmites and stalagnates (up to 4 m high and 1.5 m in diameter) are the most conspicuous speleothems of the caves. They are often irregularly formed, sometimes doubled, corroded and weathered. These speleothems represent the oldest generation (with up to 35 cm thick bottom sinter); they were formed under intensively sintering water trickles of the zone of verticle circulation whereas the present trickles (as far as they exist) seem only to be dripping the tops of the stalagmites.

Quite different conditions were found in the East Seawater Chambers. Conic and spherical stalactites, straw stalactites, stouted straw stalactites with eccentric outgrowths, plural stalactites, small curtains and draperies are characteristic of the local dripstone decoration. They are milk-white, drenched by vertical trickles. Local stalagmite formations are represented by thic sinter crusts with sinter basins, low and flat sinter heaps, and high and slim stick stalagmites. A trickle dripping from a stalactite and forming a white heap within the tidal zone is a vivid example of recent sinter formation. We often can find broken speleothems cemented to the bottom sinter.

Three types of stalagmite sites are present in the caves: sites permanently above sea level, sites periodically flooded by seawater, and sites permanently below sea level. At all these types of sites we may find marine incrustations of aragonite and Mg-calcite on top of speleothems as a result of temporary flooding of the caves with seawater. Such occurences are common in presently submerged and periodically flooded parts of the caves, and in the parts free of seawater within a few meters of present sea level.

Cave Development

This is the firstworking hypothesis on relative chronology of main development phases of the Conch Bar Caves:

(1) Genesis of the upper level (A) at a 10-12 m elevation of sea level. (2) Genesis of the main level (B) at a 0-2 m elevation of sea level. (3) Extensive breakdown of the cave ceiling during the development of the main level; beginning of the development of cave domes. (4) Genesis of the lower level (C) at a -2 to -4 m elevation of sea level. (5) (?) Genesis of the lowest level (?). (6) Formation of the oldest speleothem generation. (7) Late phases of sea level fluctuation, temporary flooding of the caves with seawater, sinter corrosion and formation of younger speleothem generations in air filled part of the caves. (8) Stabilization of sea level approximately at present level, collapse of the rock partition between cave domes and surface sinkholes, origin of large circular cave entrances, continuing formation of speleothems in caves free of seawater, sinter corrosion. (9) Settlement in the caves (probably 5th - 16th century A.D.). (10) Recent karst processes; formation of the youngest spelethem generation, recent breakdown, etc.

The caves were probably formed during the Middle Pleistocene (in sense of Woldstedt 1954). At least, a distinct regression (depression of sea level) occurred between the genesis of the upper and main cave level. Considering the course of Pleistocene climate, the Yarmouthian (Mindel-Riss) may have been favourable of the genesis of the upper level, and the Illinoian (Riss) of the genesis of the main and lower cave level. However, this schedule is only hypothetical. According to Woldstedt's (1958) classification of the Pleistocene, the genesis of the upper level occurred at the end of the Middle Pleistocene, and the genesis of the other cave levels at the beginning of the Late Pleistocene. The calcarenite deposition and primary phase of the karst and cave development can be ascribed to earlier phases of the Pleistocene.

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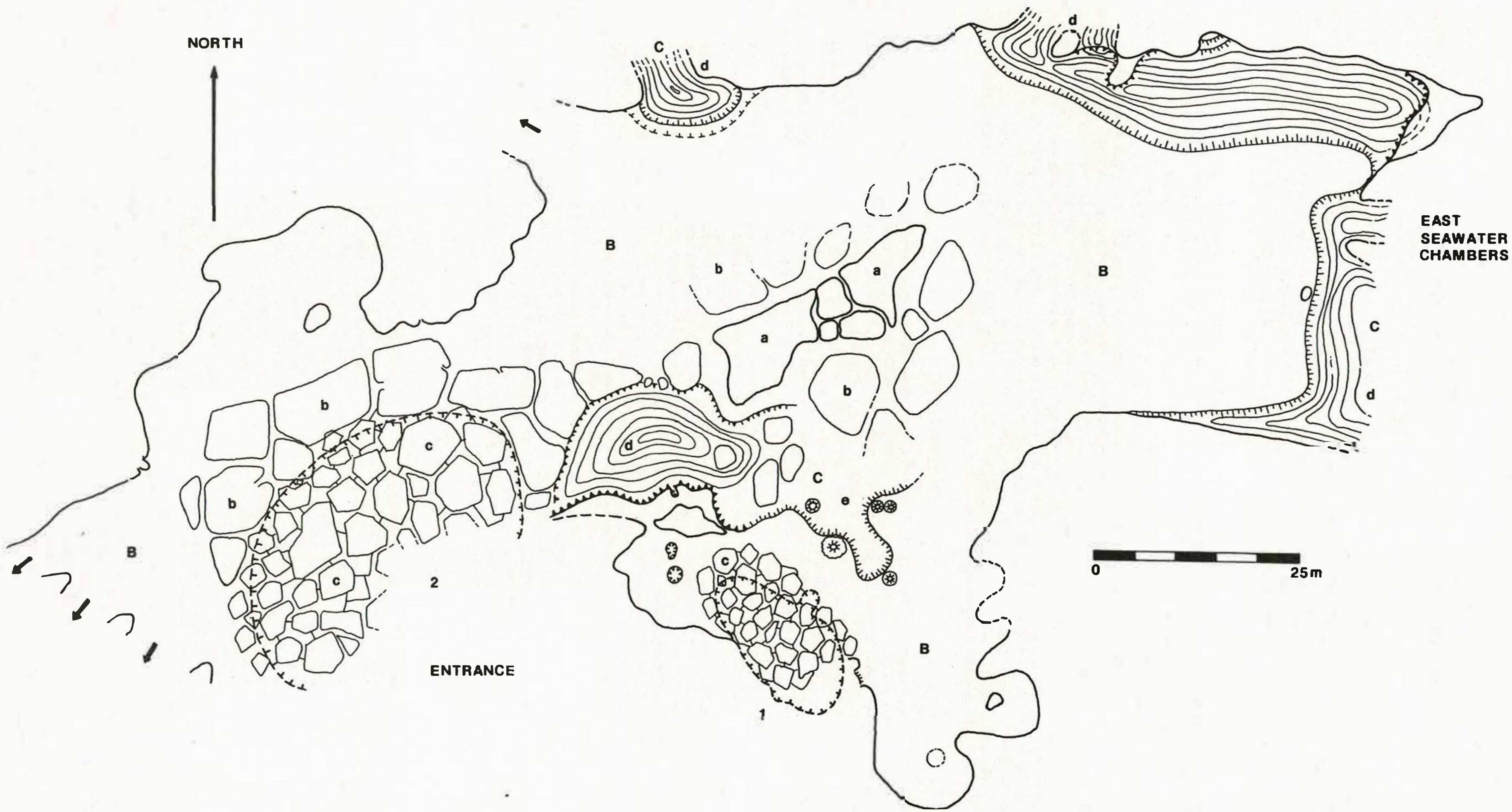

Explanation to Figure 1

B - the main cave leve (B)

C - the lower cave level (C)

a - rock pillars

b - coarse blocks - the 1st phase of breakdown

c - blocks and minute scree of the 2nd phase of breakdown

d - cave parts always flooded with seawater

e - cave parts periodically flooded with seawater

Geological Development and Age of the Caves in the Moravian Karst (Czechoslovakia)

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Abstract

Two different interpretations of hte number and geological age of the cave levels in the Moravian Karst were presented in the last decades. Geomorphologists (Panos 1963, Stelcl 1963) developed a hypothesis indicating three levels (though Panos, 1963, admitted a higher number of introduction of the therm of "posthumous levels"), geologists (Burkhardt 1949, Pelisek 1950) found up to fifteen cave storeys. The principal definition of the terms "cave level" and "cave storey" was published by Stelcl (1963) and completed by Gregor (1977). Our (Gregor et al., 1969-1977) investigation of the northern part of the Moravian Karst resulted in disclosure of 9-11 cave levels (in sense of Stelcl-Gregor's definition) differing in age, the genesis of which is related to changes of the local erosion level, and can be correlated with the development of the valley network.

According to Panos (1963) and Stelcl (1963) the valley and cave network of the Moravian Karst was established in the Paleogene. In the Lower Miocene, the valley network was deepened and the origin of two or more distinct cave levels occurred. The development of the valley and cave network was discontinued by Lower Tortonian transgression. Later, after regression of the Lower Tortonian sea, the surface (valley) drainage was restored and impervious Lower Tortonian marls were removed. The origin of several (?) posthumous levels between the Paleogene one and the Lower Miocene levels was related to this process. The intensity of exhumation of the valley network reached the maximum in the Upper Pliocene. A ware of retrogressive erosion employed the low-lying Lower Miocene levels, swiftly slipped from the karst points of issue to the ponors and evoked deep articulation of the karst pediment in the marginal areas.

In the author's opinion, the valley and cave network of the Moravian Karst (except the Lazanky Valley - Kettner 1970) was established in the Pliocene and developed duringthe Pleistocene. Three main karst-erosion sybcycles can be distinguished in the cave development. The first subcycle was commenced in the Pliocene and brought to an end by an expressive sedimentation phase (Pribyl 1973), probably before the Riss (in the Mindle or M/R). The second subcycle was commenced after this sedimentation phase, and brought to an end in the Interglacial R/W, or, more probably, in Wl. The third and last karst-erosion subcycle proceeded in the Uppermost Pleistocene and Holocene; it is still lasting.

Zusammenfassung

Zwei verschiedene Interpretationen der Anzahl und des geologischen Alters der Hoehlenniveaus im Maehrischen sind im Verlauf der letzten einige Jahrzehnte praesentiert worden. Die Geomorphologen (Panos 1963, Stelcl 1963) haben die Hypothese aufestellt in der drei Niveaus angedeutet sind (obwohl Panos, 1963, eine grossere Anzahl moeglich hielt, durch die Einfuehrung des Ausdruckes "posthume" Hoehlenniveaus). Die Geologen (Burkhardt 1949, Pelisek 1950) fanden bis zu 15 Hoehlenetagen. Die prizipielele Definition der Ausdruecke "Hoehlenniveau" und "Hoehlenetage" wurde durch Stelcl (1963) veroeffentlich und durch Gregor (1977) vollendet, Unsere (Gregor u.a., 1969-1977) Untersuchungen des noerdlichen Teils des Maehrischen Karstes resultierte in der Entdeckung yon 9 bis 11 Hoehlenniveaus (im Sinne der Stelcl-Gregor Definition), unterschiedlich in Alter, deren Entstehung auf die Aenderungen des oertlichen Erosionsniveaus zurueckgefuehrt wurde, und die der Entwicklung des Talnetzes entsprechen.

Laut Panos (1963) und Stelcl (1963) wurde das Talund Hoehlennetzwerk des Maehrischen Karstes waehrend der Palaeogen gebildet. Waehrend der unteren Miozaen vertiefte sich das TAlnetz, und dies war der Ursprung der zwei mehr auspepraegten Hoehlenniveaus. Die Entwicklung des Tal- und Hoehlennetzwerkes war bei der Ueberflutung der unteren Torton beendet. Spaeter, nach dem Ruecktritt des unteren tortonischen Meeres, wurde die Oberflaechen (Tal) -drainierung wiederhergestellt, und undurchlaessige untere tortonische Margel wurden entfernt. Die Entstehung der (?) mehreren posthume Niveaus zwischen dem palaeogene Niveau und den unteren miozaenen Niveaus war mit diesem Prozese verbunden. Die Intensitaet der Exhumation des Talnetzwerkes kam zu ihrem Hoehepunkt im Verlauf der oberen Pliozaen. Eine Welle der retrogressiver Erosion benuetzte die niederliegenden Miozaenniveaus, glitt schnell von den Karstausgangspunkten zu den Ponors, und verursachte tiefe Auspraegung des Karstpediments in den Randgeieten des Karstes.

Es ist die Ansicht des Verfassers, dass das Tal- und Hoehlennetzgebilde des Maehrischen Karstes (mit Ausnahme des Lazanecky Trockentales - Kettner 1970) im Verlauf des Pliozaens gebildet wurde, und im Verlauf des Pleistozaens entwickelt war. Drei Hauptsubzyklen der Karsterosion koennen in der Hoehlenentwicklung unterschieden werden. Der erste Subzyklus begann im Pliozaen undbrachte eine ausdruckvoll Sedimentationsphase zu Ende (Pribyl 1973), wahrsheinlich bevor dem Riss-Glazial (im Mindel-Glazial oder Interglazial Mindel - Riss). Der zweite Subzyklus begann nach dieser Desimentationsphase und endete im Interglazial R/W, oder, mehr wahrscheinlich, in W 1. Der dritte und letzte Subzyklus begann waehrend des oberen Pleistozaens; dieser Subzyklus dauert noch an.

* * *

Two different therms have been used to describe horizontally (subhorizontally) set caves and cave passages in the Moravian Karst: "cave storety" and "cave level". Absolon (1905-1911) introduced an idea based on the existence of three cave storeys, in his opinion genetically connected with "three interglacial periods." On the basis of cave entrances, and cave sediments, Zapletal (1931) found six cave storeys in the northern part of the Moravian Karst and three storeys in the southern part, and Pelisek (1950) fifteen cave storeys (four of them of Pliocene age) in the central part of the Moravian Karst. According to Rysavy (1955-1956) the caves of the northern part of the Moravian Karst are developed in three distinct cave levels, the lowest of which is subdivided into three interfering partial levels.

The principal definition of the therms "cave storey" and "cave level" was published by Stelcl (1963) and completed by Gregor (1977). According to this definition, cave storeys are horizontal (subhorizontal) caves (cave passages), situated one above another at different heights. Cave storeys are usually limited in extent, and their origin is not depended upon the erosion base; the main role is played by local structural and tectonic conditions. Cave storeys cannot be compared with valley terraces, and individual phases of the cutting down of karst streams.

Cave levels are formed by continuous systems of horizontal (subhorizontal) caves and cave passages whose origin is connected with the level of the erosion base, i.e. depends upon the level of underground karst streams. Cave levels may be followed along long distances. They can be compared with terraces and individual phases of the cutting down of karst streams. Vertically, they take up a differently wide belt formed by 2nd and 3rd Cvijic's hydrographical zone.

In Stelcl's (1963) opinion, the surface stream of the Moravian Karst cut down in three sucessive phases divided by orogenic movements. The movements took place towards the end of the Oligocene, and between the Helvetian and Lower Tortonian. The youngest erosion phase was influenced by climatic changes in Early Holocene. Stelcl and Panos (1963) developeda hypothesis indicating three cave levels in the Moravian Karst: (A) the highest one, genetically connected with the 1st phase of the valley cut down, of Oligocene age, (b) the lowest one, genetically connected with the level of the valley rock bottom, of Lower Miocene age, and (C) a higher cave level situated above the lowest one, genetically connected with the surface of Pleistocene valley sediments, of Holocene age. The presented number is at variance with Panos's (1963a) opinion on the origin of two Loer Miocene (Burdigal and Upper Helvetian) cave levels and several "posthumous" cave levels in the northern part of the Moravian Karst.

In 1969-1977, the author performed geologic and geomorphological research in the northern part of the Moravian Karst, especially in the Sloup and Macocha region (the Sloupske udoli Valley, the Sloupsko-sosuvske jeskyne Caves, the Pusty zleb Valley, the Macocha Abyss, the Punkevni jeskyne Caves, etc.). At least, nine cave levels were found in the Sloup-Macocha region, at different heights related to the level of the Punkva River in the Velky vytok (karst outlet). These are the relative heights of the relevant cave issue points in the region: cca 80 m, 72 m, 56 m, 45 m, 24 m, 18 m, 10 m, 0 m, and -22 m. However, there are two more problematic cave levels in the region, situated cca 110 m and 4 m above the level of the Punkva River. The mentioned cave levels (except the 110 m one) are filled with allochthonous fluvial sediments. They resulted from erosional and solutional water activity of underground streams of the Sloupsky potok Brook and the Punkva River, and are genetically connected with changes of level of the local erosion base. It is possible to correlate them with terraces and valley forms. Their origin was conditioned by Pleistocene climatic changes and by the role of Quaternary tectonics (neotectonics - Gregor 1978).

According to the study of cave sediments (Pribyl 1973), and cave and valley geomorphology, the cave levels of the northern part of the Moravian Karst were formed during three main karst-erosion subcycles, each of them was brought to an end by an expressive sedimentation phase. However, a certain equal number of cave levels cannot be ascribed to each of the subcycles. Up to 7 or 9 (11) cave levels known in the region originated during the first (the longest and most intensive) subcycle. It was commenced in the Pliocene (the 1st stage of the valley cut down) and broutht to an end by a powerful sedimentation phase, for certain before the Interglacial R/W, and very probably before the Riss (at the end of the Mindel, or in the Interglacial M/R). The second subcycle was commenced after this sedimentation phase, under favourable climatic conditions of the Middle (sensu Woldstedt 1954) or Late (sensu Woldstedt 1958) Pleistocene, and brought to an end by a less powerful sediementation phase at the end of the Interglacial R/W, or more probably, at the beginning of W 1 . The third and last karst-erosion subcycle proceeded in the Uppermost Pleistocene and Holocene; it is still lasting.

It is evident that each individual subcycle, owing to climatic changes, consisted of a number of partial karst-erosion and accumulation phases, during which periods of cave senility, reactivation and rejuvenation occurred. It is very difficult to parallel these phases with the course of Pleistocene climate. According to Geze (1965), karst erosion took place after culmination of cold periods, according to Kettner (1970) during warm periods. Pelisek (1950) ascribed intensive speleogenesis to warm periods, and very slow speleogenesis to cold periods. In the course of Quaternary climate not only cold and warm periods but also dry and humid periods occur. Though various combinations may be found, the principle of connection of humid with warm, and dry with cold periods is generally accepted. However, the climatic changes form a continous succession which is divided into many single phases and secondary minute oscillations.

Neogene sediments in situ (?) were found only in a few caves situated high up above the Pleistocene valley network (the 110 m cave level). Test wells drilled in valleys of the Moravian Karst found only Quaternary sediments - except the Lazanecky zleb Valley and the low part of the Punkva Valley (up to 120 m thick Lower Badenian sediments in the Lazanecky zleb Valley) but this part of the valley network occupies a quite different position in the geomorphological development and paleohydrography of the Moravian Karst (Kettner 1970, Gregor 1977).

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Sur L'Equipement Adeno-Sensoriel du Pedipalpe de L'Opilion Troglophile Sabacon Paradoxum Simon (Palpatores, Sabaconidae)

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Résumé

Chez l'Opilion troglophile Sabacon paradoxum les auteurs décrivent l'ultrastructure des poils tomenteux glandulaires et sensoriels des pédipalpes. Chaque unité adénosensorielle est composée de 5 à 6 neurones dont les dendrites sont entourés d'une gaine cuticulaire; la partie basale de l'axonème présente 9 doublets présentant chacun un tubule clair et un tubule dense aux électrons. Les neurones sont enveloppés par une première, puis une seconde cellule enveloppe laquelle est entourée par 3 cellules glandulaires aplaties, dont la sécrétion emplit la lumière du poil.

La partie externe du sensille est faite de 2 parties: une basale, lisse et une distale présentant de nombreux pores par lesquels la sécrétion est émise et de nombreux spinules entre lesquels elle s'accumule.

Abstract

In the troglobitic Harvestmen Sabacon paradoxum the authors describe the ultrastructure of the "villous hairs" of the pedipalps. Each adeno-sensorial unit consists of 5 or 6 bipolar neurons, the dendrites of which are ensheated by a cuticular sheat; beyond the centriole the axonema is made of 9 doublets with one light and one electron dense tubule. The neurones are wrapped by a first, then a second sheat cell, surrounded by three flat cells, glandular in nature, the secretion of which fills the lumen of the hair.

The external region of the sensillum is made of 2 parts: the basal part is smooth, while the distal has many pores through which the secretion is emitted and many spinules between which it accumulates.

Sabacon paradoxum est un Opilion troglophile dont l'aire de répartition s'étend sur le Sud de la France et le Nord de l'Espagne (Dresco, 1952, 1955, Lopez et coll. 1979, 1980). Dans les Pyrénées françaises et espagnoles et dans le massif de Montseny en Catalogne, il est connu de quelques stations situées entre 950 m et 2000 m d'altitude; il y vit sous les pierres, parmi les feuilles mortes et les mousses dans des biotopes humides et ombragés. Dans le sud du Massif Central (Aveyron, Lozère, Gard et Hérault), il n'est connu que des grottes ou de galeries de mines; il y est rencontré en hiver avec les autres composants de la faune pariétale, sur les parois très humides ou sous les pierres dans la zone de pénombre des entrées. Il peut se reproduire dans les grottes ainsi que le montre la découverte de pontes fixées en goutte pendante aux voûtes ou aux surplombs rocheux dans trois cavités (Lopez et coll. 1980).

L'originalité principale des Sabaconidae réside dans la forme du tarse de leur pédipalpe et la présence de poils particuliers que portent le tarse et le tibia de ces appendices. Le tarse est en effet, en forme de haricot et il est replié sur le tibia. Tibia et tarse sont recouverts de poils glandulaires dont la partie apicale a une forme propre aux Sabacon d'où le nom de poils tomenteux qui leur a été donné.

L'existence de poils glandulaires sur le pédipalpe n'est pas propre au Sabacon; elle se retrouve également chez certains Ischyropsalidae et chez les Nemastomatidae. Ils ont été décrits pour la première fois dans cette dernière famille, chez Nemastoma lugubre (Rimsky-Korsakov, 1924) sous le terme de "Kugelhaare". Ils ont fait ensuite l'objet d'une étude ultrastructurale (Wachman, 1970) chez trois autres espèces. Leur morphologie externe est très différente de celle des poils de Sabacon ainsi qu'il a été montré (Lopez et coll. 1980) à l'aide du microscope à balayage. Ces poils retiennent à leur extrémité une certaine quantité de sécrétion visqueuse à laquelle on a attribué un rôle dans la capture des proies.

Il nous a donc paru intéressant de reprendre en ultrastructure l'étude de ces formations sécrétrices et sensorielles afin d'en déterminer la constitution et la nature.

Materiel et Methodes.

Les animaux étudiés sont des adultes des 2 sexes récoltés dans la grotte de la Baccoulette (Hérault). Les pédipalpes et les thorax ont été fixés selon les méthodes déjà décrites (Juberthie et coll. 1980).

1. Morphologie externe (fig. 1 et 2).

Chaque poil mesure 160 μm de long; relié au tégument par un bourrelet circulaire, il se compose d'une partie proximale lisse et d'une partie distale qui porte des spinules sur sa face antérieure. Du fait que la partie proximale est inclinée vers l'extrémité de l'article et la partie distale spinulée redressée, la sécrétion est toujours orientée vers l'extrémité de l'article.

1 - 2. Bourrelet d'insertion. Il est constitué de 2 couronnes jointives l'une externe très dense aux électrons, l'autre interne claire. Sa face inférieure s'attache sur des élevures de l'épicuticule lamellée du tégument. Sans constituer une véritable embase, ce bourrelet semble donner au poil une certaine souplesse verticale au niveau de son insertion et un léger jeu latéral.

1 - 3. Portion proximale. Elle est subcylindrique, lisse et présente une gouttière axiale postérieure, large et peu profonde. Elle est caractérissée par la présence d'une centaine de canaux intrapariétaux, sub-rectilignes disposés selon des génératrices et parfois anastomosés. Ces canaux communiquent avec la cavité interne du poil par des ouvertures évasées; chacune renferme un bouquet de digitations flexueuses paraissant attachées à la paroi et semblables aux filaments épicuticulaires du tégument. La cuticule est très opaque au niveau de la gouttière, grise ailleurs. La cavité du poil est remplie d'une substance sécrétée par les cellules glandulaires.

1 - 4. Partie distale spinulée. La face antérieure porte des spinules raides et pleins. La paroi est homogène, sans canaux, moyennement dense sauf au niveau de la gouttière, profonde et en T, où elle est formée d'un abondant matériel dense. A ce niveau la cavité du poil possède sur toute sa longueur une différenciation chitineuse originale, agencée comme un long ressort à boudin, localement attaché à la paroi. Les spires, de section circulaire, ont un diamètre d'enroulement égal aux 2/3 de celui du poil. Il pourrait donner une certaine élasticité à la partie distale. La cavité interne contient une substance, émise à l'extérieur, entre les spinules, par des pores en forme de boutonnières effilées, alignés longitudinalement de façon irrégulière; la sécrétion forme une masse retenue par les spinules.

1 - 2. Partie sensorielle (fig. 3).

2 - 1. De 6 à 8 neurones sensoriels bipolaires groupés la composent. Leur segment proximal, long, élargi à son extrémité, renferme un centriole sans racine ciliaire, portant 9 expansions lamellaires. Chaque centriole est relié par du matériel dense à la partie de la membrane plasmique qui jouxte la cavité. Il donne 9 doublets à symétrie rayonnée; le tubule B est clair tandis que le tubule A est plein et dense et porte deux bras. Plus haut les tubules deviennent indépendants et épars. Au-delà des controles, les dendrites sont entourés d'une gaine cuticulaire depuis la base jusqu'à l'extrémité du poil.

2 - 2. Cellule gliale. Une cellule de ce type est accolée aux périkaryons sensoriels; elle envoie une lame gliale qui entoure les corps cellulaires sans pénétrer entre eux et sans envelopper les segments proximaux. 1 - 2 - 3. Cellule enveloppe n°1. Son corps cellulaire s'étend sous l'hypoderme et au contact des neurones sensoriels; son cytoplasme longe les segments proximaux et se transforme en une lame qui entoure leur extrémité en se refermant sur elle-même par un méso; autour de la zone centriolaire elle délimite une large cavité lymphatique interne remplie d'un liquide dense aux électrons, et se termine au contact de la gaine cuticulaire. Elle présente une longue et étroite cavité extracellulaire collabée par de longues microvillosités. Elle élabore des grains de sécrétion de forme irrégulière, les uns gris, les autres denses; de nombreuses petites vésicules hérissées ou non sont visibles près des microvillosités ainsi que des figures de pinocytose au bord de la cavité. Elle sécrète la substance qui remplit la cavity lymphatique interne.

2 - 4. Cellule enveloppe n° 2. Allongée, elle s'étend le long des segments proximaux, du côte opposé à la précédente, à mi-hauteur; elle se referme sur elle-même par un méso, entoure la lère cellule et la base de la gaine cuticulaire; elle se prolonge le long de la gaine presque jusqu'à l'extrémité du poil par une languette cytoplasme émettant localement des digitations. Du côté externe, elle présente à son extrémité un bouquet de microvillosités et participe à la formation de la cavité lymphatique externe.

1 - 3. Cellules glandulaires (Adénocytes).

Constituants les plus volumineux, elles sont au nombre de trois, une centrale, et deux périphériques. Elles entourent les axones du nerf pédipalpaire, les neurones, les cellules enveloppe 1 et 2 et se présentent donc comme des cellules enveloppe de troisième ordre.

Chaque adénocyte est aplati en lame trapézoïdale flexueuse, plus ou moins perpendiculaire à la surface de l'article et s'incurvant dans le sens transversal en segment de cylindre ou en dièdre. De ce fait, les adénocytes d'une même unité s'imbriquent les uns dans les autres en adoptant une disposition plus ou moins concentrique. Leur extrémité inférieure émet des prolongements pédiculisés délimitant un espace de filtration labyrinthique au-dessus de la membrane basale. L'extrémité supérieure de l'adénocyte périphérique s'applique sur le pourtour de la base du poil, entre une cellule hypodermique étirée en languette tandis que celle de l'adénocyte central s'applique contre la cellule enveloppe 2. La cohésion des adénocytes ne paraît assurée qu'au niveau des bords et de la base par des desmosomes et des jonctions septées. Les faces libres ménagent entre elles de longues cryptes flexueuses en rapport avec la cavité lymphatique externe du poil; ces faces sont extrêmement hérissées de microvillosités. Dans chaque adénocyte, l'élément essentiel est constitué par des grains de sécrétion arrondis et de faible densité; ils peuvent occuper sans ordre apparent toute la hauteur de la cellule ou s'aligner à la base des microvillosités soit sur une rangée, soit en double file alternante. Cette sécrétion emplit les cryptes intercellulaires et la cavité lymphatique externe du poil.

Discussion et Conclusion

La structure des poils tomenteux des pédipalpes permet de leur assigner une double fonction sensorielle et glandulaire. La nature de leur fonction sensorielle n'est pas clairement établie; la présence d'une gaine cuticulaire enfermant plusieurs dendrites sans corps tubulaire plaiderait pour une fonction gustative mais l'existence d'un pore terminal n'est pas prouvée; l'existence d'une structure en forme de ressort hélicoïdal est l'indice d'une déformation de la partie distale du poil et de la gaine; cette formation, de même que la structure particulière de la partie basale de l'axonème caractérisée par un doublet plein plaideraient pour un mécanorécepteur d'un type tout à fait particulier.
Ces poils ont aussi une fonction glandulaire, probablement liée à la capture des proies, et sont ainsi similaires aux soies des Nemastomatidae (Wachsman, 1970); leur sécrétion est retenue par une palette spinulée et non par une collerette comme chez ces derniers.

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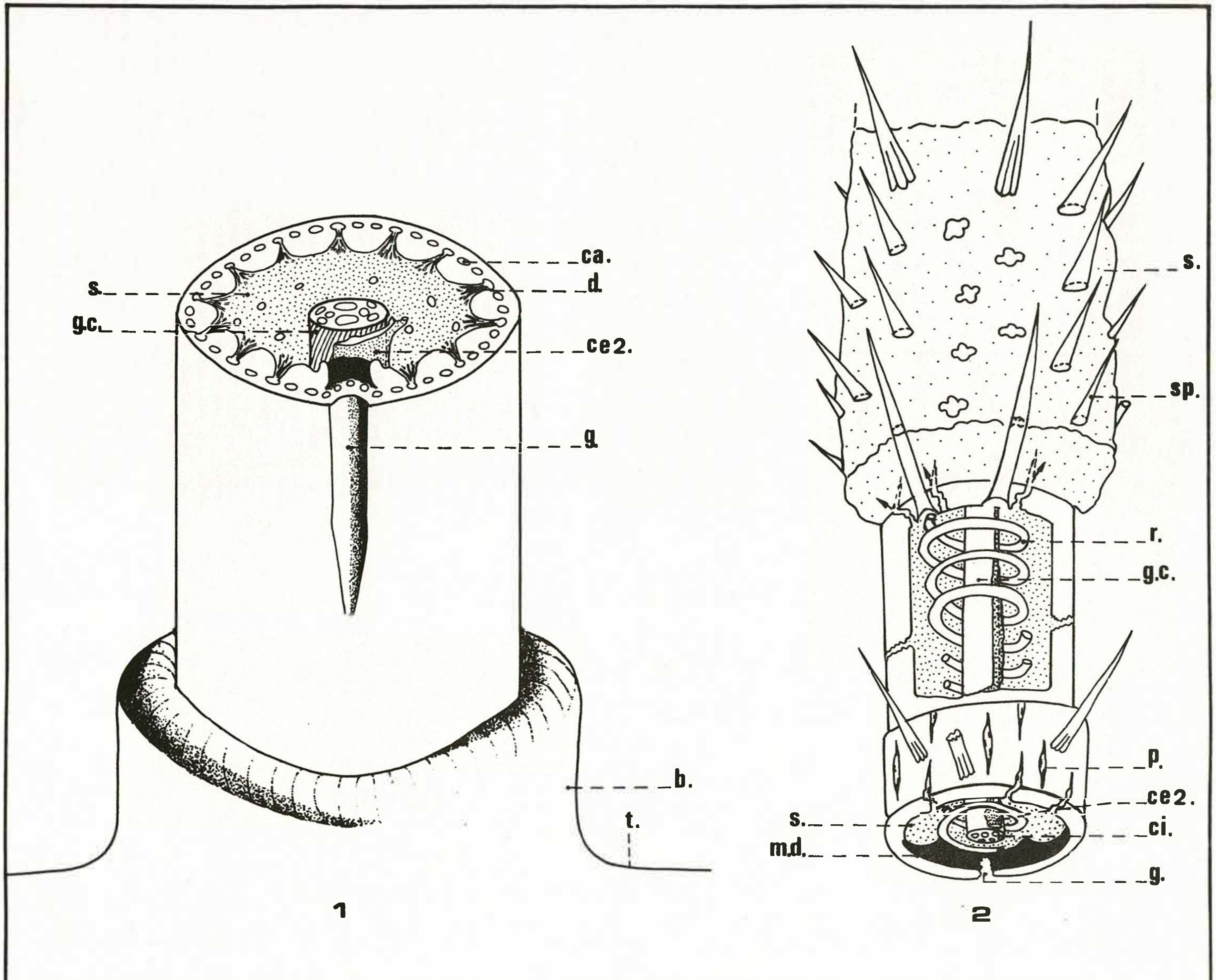

Figure 1. Base d'un poil tomenteux du pédipalpe.

Figure 2. Portion de la partie distale spinulée du même poil; b. bourrelet d'insertion; c. a. canal intrapariétal; Cl_2, cellule enveloppe n° 2; ci, cil; d. digitations; g. gouttière; g. c. gaine cuticulaire m. d., matériel dense; P., pore; r, différentiation chitineuse en forme de ressort; s, sécrétion; sp, spinules; t, tégument.

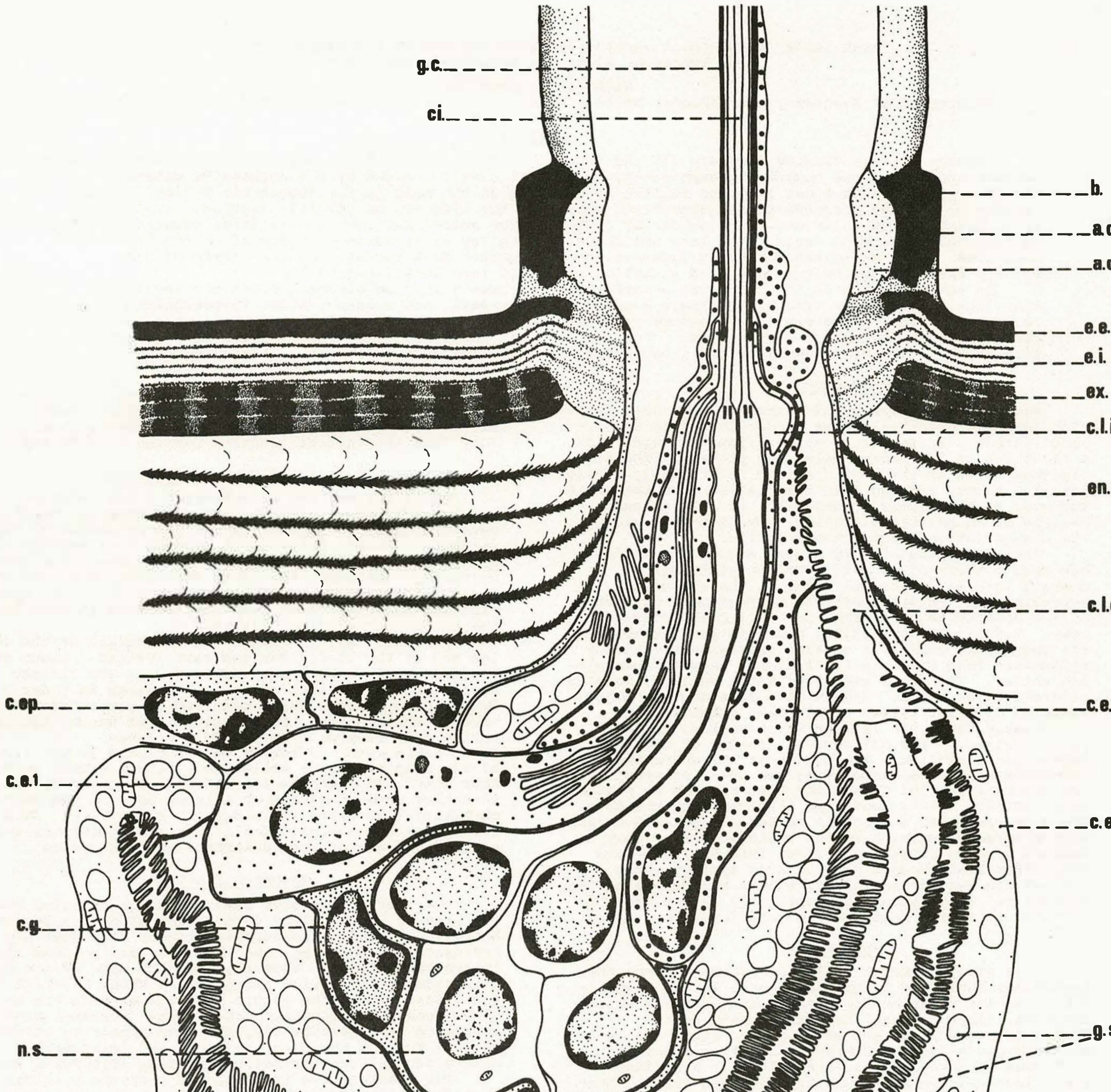

Figure 3. Schéma d'unité adéno-sensorielle d'un poil tomenteux du pédipalpe. Mêmes abréviations que fig. 1 et, ac, couronne claire; ad, couronne sombre; $Cl_{1,2,3}$ cellules enveloppes 1, 2, 3; C ep, cellule épidermique cg, cellule gliale; cle, cavité lymphatique externe; cl i, cavité lymphatique interne; d, desmosome et desmosome septé; ee, epicuticule externe; e i, épicuticule interne; en, endocuticule; ex, exocuticule g s, grain de sécrétion; mb, membrane basale; n, axones; ns, neurone sensoriel.

Karst Valley Development and the Headward Advance of the Sequatchie Valley of Tennessee Along the Sequatchie Anticline

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Abstract

Caprock streams flowing down dip off the Sequatchie Anticline of Tennessee often breach the silicious caprock and invade the underlying carbonates. A conduit cave is formed by the aggressive waters of an invading stream as it flows from its swallet to a rising at the head of the Sequatchie Valley. Slope retreat by sapping proceeds in all directions away from the site of the initial invasion, resulting in large karst valleys completely surrounded by caprock. The anticlinal mountain is first reduced to karst valleys which are then assimilated into the Sequatchie Valley as it advances headward up the Sequatchie Anticline. Thus subterranean stream invasion, conduit cavern development, and the growth of karst valleys play a major role in changing anticlinal mountain into anticlinal valley.

An investigation of the processes associated with karst valley development along the Sequatchie Anticline involved dye tracing, geologic mapping, cave surveys, and a quantitative investigation of subsurface erosional processes. Two conduit cave systems were monitored for fifteen months by continuous recording instrumentation and frequent water sampling and analysis. They were treated as open systems, with input occurring at swallets and from diffuse sources, the output occurring at risings.

Introduction

The Sequatchie Valley of Tennessee is a deep incision into the relatively flat sandstone-capped Cumberland Plateau. It is six to eight kilometers wide with a floor 400 to 500 meters below the plateau. The precipitous walls of the canyon extend in virtually straight, parallel lines, cutting into the plateau from the south for over 90 kilometers (Figure 1). It is a classic example of an anticlinal valley, having formed along the thrust-faulted Sequatchie Anticline.

The geomorphic history of the Sequatchie Valley has been a story of an anticlinal mountain being changed into an anticlinal valley. The anticlinal mountain still exists along the northernmost portion of the Sequatchie Anticline, north of Crab Orchard Cove. Between the anticlinal mountain and the head of the Sequatchie Valley is an area approximately twenty kilometers long which is transitional between mountain and valley. This is a region of karst valleys, locally referred to as coves. Within this area are six major examples of karst valley development (Figure 1).

Grassy Cove, the largest karst valley, or anticlinal polje, is the hollowed-out center of the Sequatchie Anticline. The flanks of the anticline remain as mountains surrounding the cove, protruding 300 meters above the Cumberland Plateau, and in places well over 400 meters above the flat floor of the cove. The cove resembles a volcanic caldera, a great mountain with a large depression in the center. Grassy Cove is drained by Cove Creek which flows into Mill Cave and then under Brady Mountain to a large spring at the head of the Sequatchie Valley, eleven kilometers to the southwest. This spring, appropriately called Head of Sequatchie, is the headwaters of the Sequatchie River.

Hypothesis

This study of karst valley development along the Sequatchie Anticline is part of a much larger investigation of the relationship between subterranean stream invasion, slope retreat, topography, subsurface hydrology, conduit cavern development, structure, and stratigraphy along the Cumberland Plateau Escarpment of Tennessee (Crawford, 1979 and 1980). A surface-subsurface erosion model was hypothesized stating that conduit caves form by subterranean invasion by surface streams along retreating caprock escarpments. The model includes the following:

1) Invasion occurs near the contact between the impermeable, clastic caprock and the underlying carbonates as caprock streams, highly aggressive to calcium carbonate, dissolve the most efficient flow routes through the carbonates to resurgences near the escarpment base.
2) Suspended and bed loads contribute to the enlargement of the conduits by abrasion.
3) Most conduit caves are enlarged almost exclusively by the corrosion and corrasion of swallet streams, particularly during floods.
4) Other cinduit caves result from vertical shaft input which is also aggressive to calcium carbonate since its source is the perched caprock aquifer.
5) Percolation input becomes supersaturated on losing carbon dioxide upon entering the cave atmosphere and consequently is not important in cavern development.
6) Subsurface streams take a "stair step" route down the escarpment due to intermittent impermeable strata.
7) A sinkhole plain resulting from weathering of carbonates containing less soluble material follows the retreating escarpment.
8) A structural high may result in a stream cutting through the caprock and invading underlying carbonates behind the escarpment. Slope retreat by sapping proceeds away from the initial invasion forming a karst valley.

Testing of Hypothesized Model

Field testing the hypothesized model involved dye tracing subsurface streams, geologic mapping, mapping cave systems, and a quantitative investigation of subsurface erosional processes. Conduit cave systems at the head of the Sequatchie Valley were monitored for fifteen months by continuous recording instrumentation and frequent water sampling. They were treated as open systems, with input occurring at swallets and from diffuse sources, the output occurring at risings.

Recording stream gauges were installed at the swallet and at the rising for two cave systems. About three hundred water samples were taken during the fifteen months at the swallets and at the risings in order to investigate changes which occurred as water travelled through the systems. Percolation input was monitored by taking drip samples from within the caves. Some of the less stable water variables were analyzed in the field at the time of sample collection, others within twenty-four hours, in a mobile laboratory. The more stable variables were analyzed at a later date in the geochemistry laboratory at Vanderbilt University. Data collection and analysis dealt with the solutional and suspended loads of the subsurface erosion system.

Research Findings

Dye tracing and cave investigations revealed that in the area of karst valley development along the Sequatchie Anticline, invading subsurface streams flow down dip influenced by jointing, and that they are perched upon impermeable strata. However, near the base of the anticline they turn to flow along joints which parallel the anticlinal axis. The joints near the base of the anticline appear to have been produced by increased bending, indicated by a steeper dip, and they appear to extend through some of the more resistant and impermeable strata such as the Hartselle Formation (Figures 2 and 3).

The quantitative input-output analysis provided considerable evidence in support of the hypothesized model. During the research period:

1) Caprock streams were always aggressive to calcium carbonate.
2) Water resurging at risings was virtually always aggressive swallet input. Mixing corrosion was also partly responsible for the aggressivity at the rising. (This is indicated in the 37.10% difference between measured and calculated output at Bristow Spring, Table 1).
3) Percolation input was always supersaturated with calcium carbonate on joining the cave system.
4) An inverse correlation existed between total hardness and discharge for the swallet input and rising output, indicative of the importance of floods in conduit cavern development (Figures 4 and 5).
5) Percolation total hardness and aggressivity was not correlated with drip rate but instead with drip water temperature, which reflects soil temperature and biogenic CO_2 content of the soil atmosphere (Figures 6 and 7).
6) All suspended sediment samples were negative for calcite and dolomite, but due to impoundment problems associated with the caves investigated, the negative abrasion results are considered inconclusive.

Conclusions

Caprock streams flowing down dip off the Sequatchie

Anticline, on breaching the sandstone caprock, are diverted underground into the underlying carbonates. The aggressive water of invading caprock streams forms conduit caves as it flows from swallets to risings at the head of the Sequatchie Valley. Slope retreat by sapping proceeds in all directions away from the site of the initial invasion. Large karst velleys result from this subterranean invasion, and it appears that karst valley development plays a major role in changing anticlinal mountain into anticlinal valley, thereby greatly affecting the headward advance of the Sequatchie Valley along the Sequatchie Anticline.

By assimilation of karst valleys the Sequatchie Valley has advanced headward up the Sequatchie Anticline from the southwest toward the northeast. The anticlinal mountain is first reduced to karst valleys as surface-flowing streams are diverted underground, and finally the karst valleys are assimilated into the Sequatchie Valley itself as it advances headward. A very important factor which has contributed to the formation of karst valleys in a sequential fashion from southwest to northeast in advance of the Sequatchie Valley, has been the increased thickness of the Pennsylvanian caprock from southwest to northeast. It has progressively required more time for streams flowing down the dip of the anticline to cut through the Pennsylvanian caprock in a southwest to northeast direction. Karst valley development therefore appears to have marched right up the anticline from the southwest being followed by the headward advance of the Sequatchie Valley (Figure 8).

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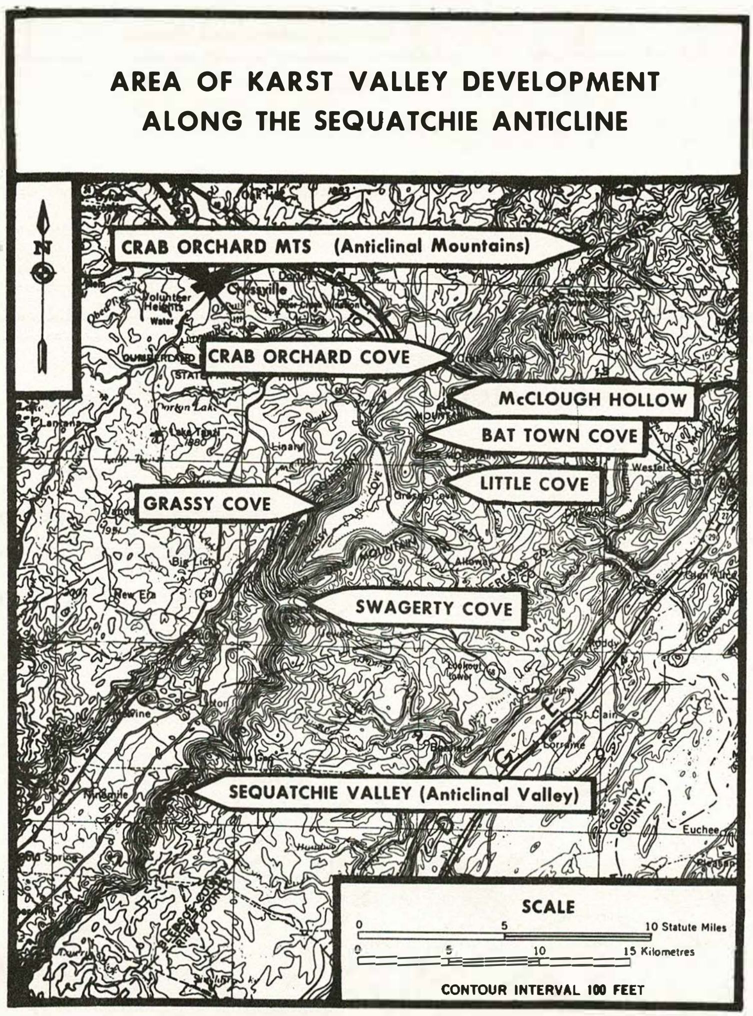

FIGURE 1.

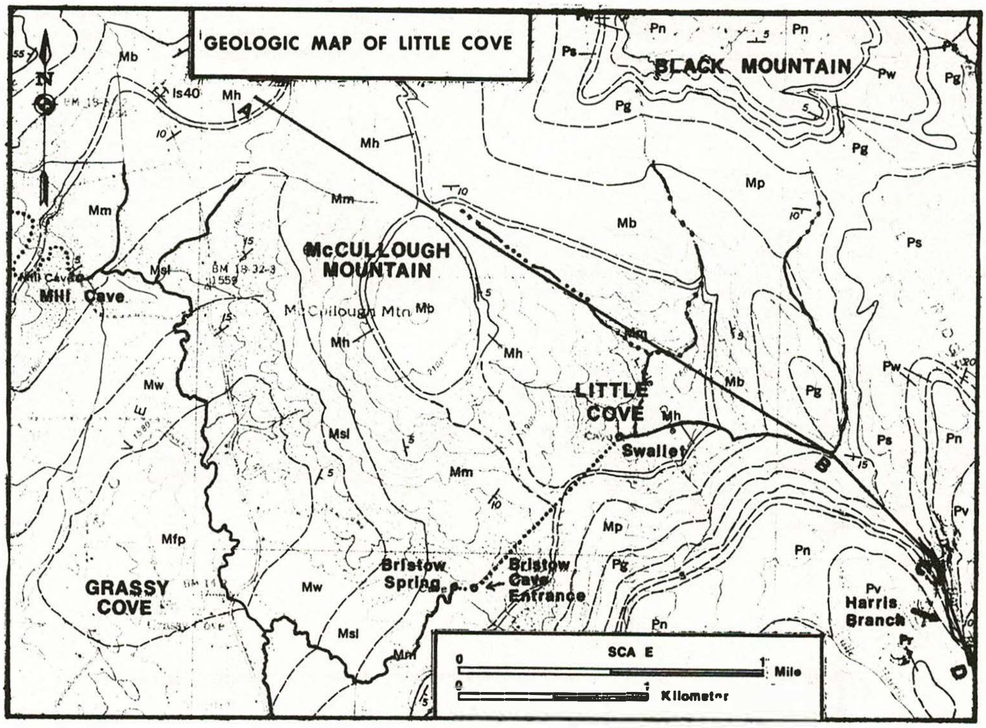

FIGURE 2.

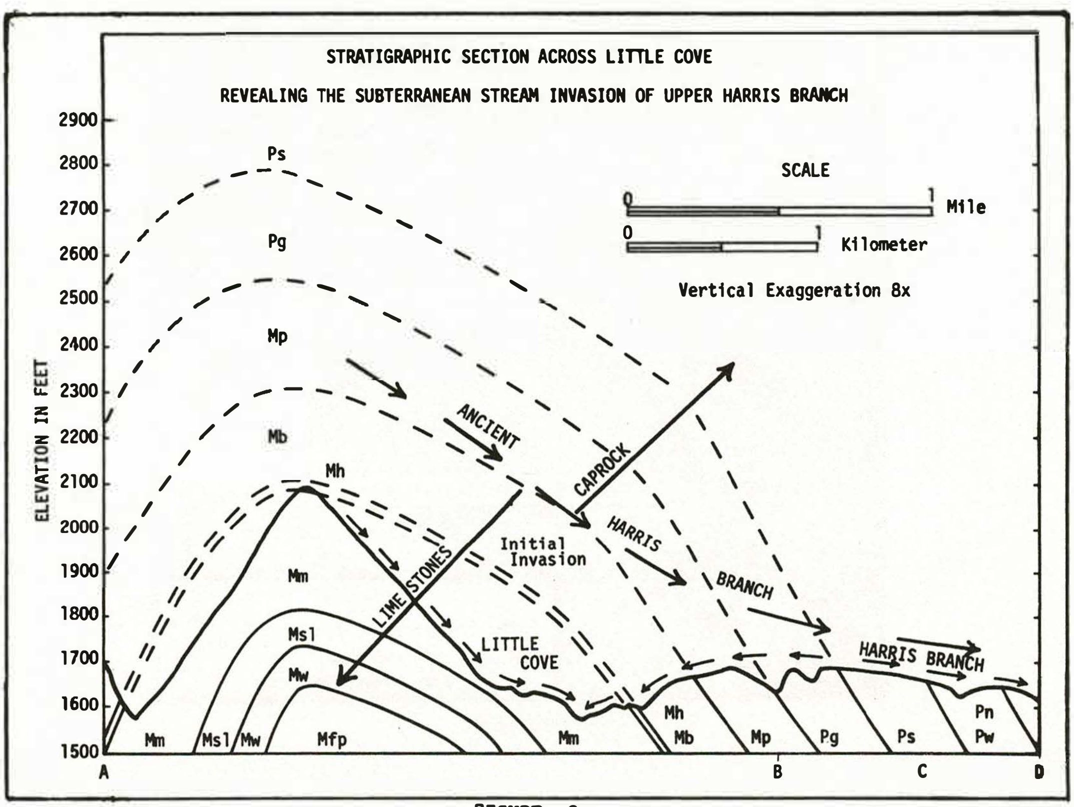

FIGURE 3.

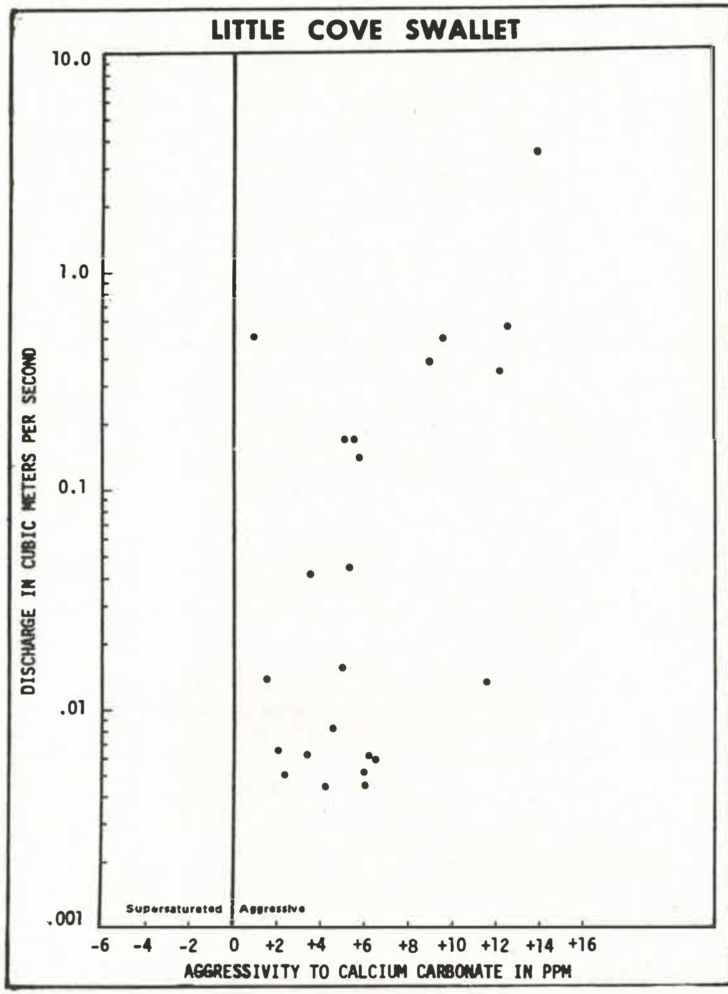

FIGURE 4.

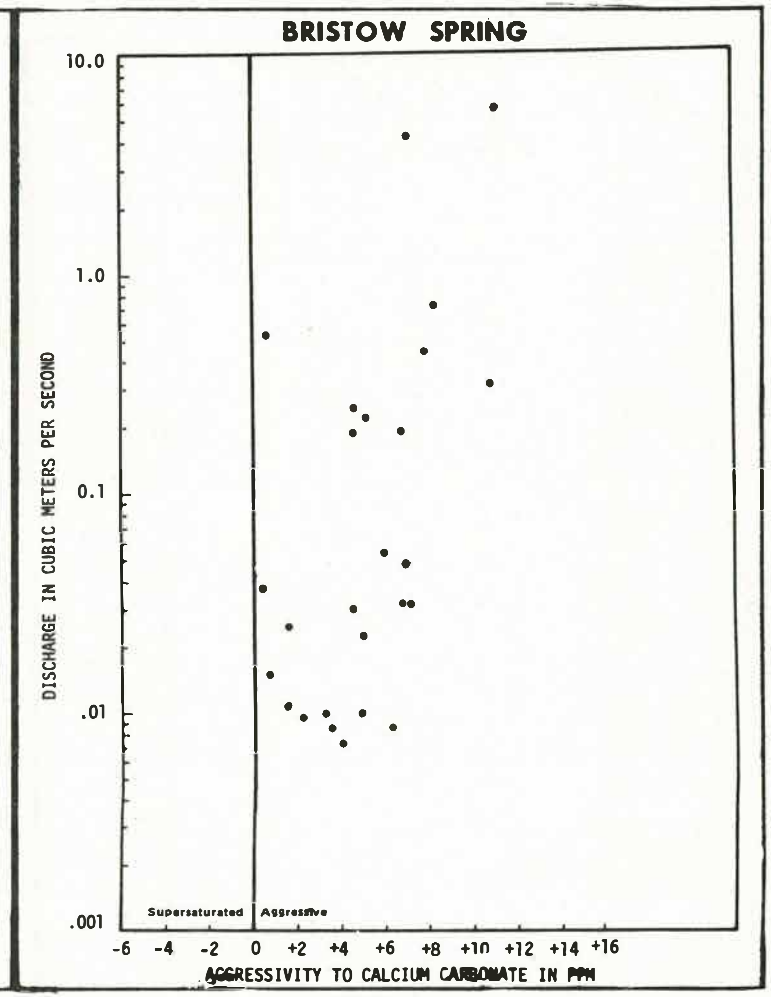

FIGURE 5.

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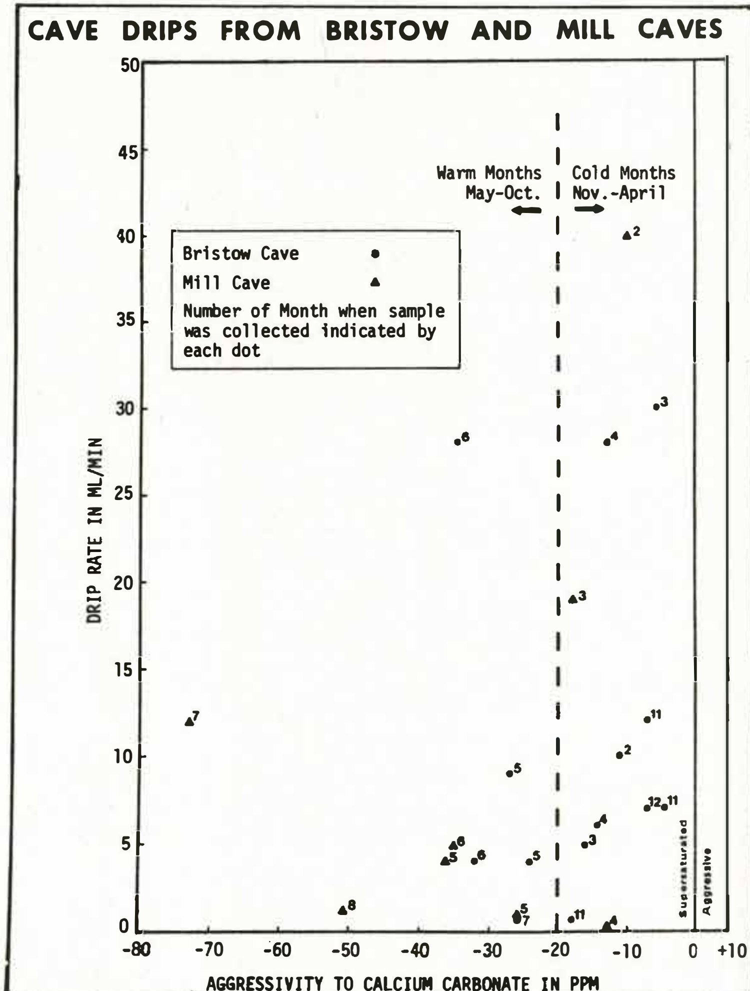

FIGURE 6.

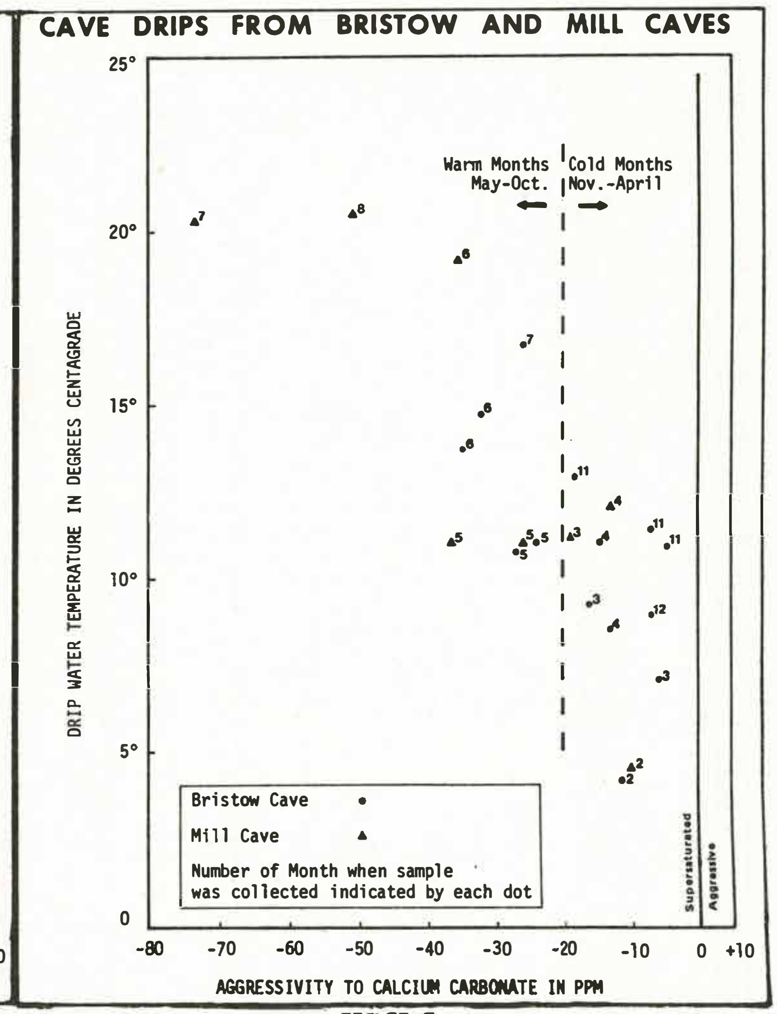

FIGURE 7.

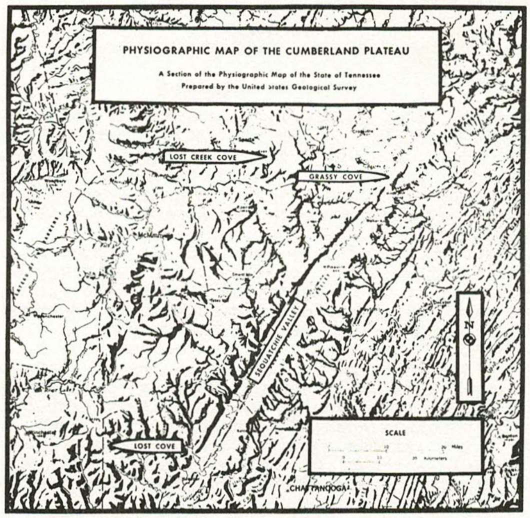

FIGURE 8.

MEAN INPUT - OUTPUT MEASUREMENTS FOR THE LITTLE COVE - BRISTOW SPRING SYSTEM FOR THOSE OCCASIONS WHEN SWALLET INPUT, DIFFUSE INPUT, AND RISING OUTPUT WERE EACH SAMPLED ON THE SAME DAY

	SWALLET INPUT Little Cove Swallet			DIFFUSE INPUT Bristow Cove Drips			RISING OUTPUT Bristow Spring			
	MEAN INPUT	PERCENT OF OUTPUT	+	MEAN INPUT	PERCENT OF OUTPUT	=	MEAN MEASURED OUTPUT	MEAN CALCULATED OUTPUT	DIFFERENCE BETWEEN MEASURED AND CALCULATED OUTPUT	PERCENT DIFFERENCE BETWEEN MEASURED AND CALCULATED OUTPUT
DISCHARGE	.54105 CMS	88.17		.07257 CMS	11.83		.61362 CMS			
TOTAL HARDNESS	77.56 PPM	88.17	+	197.11 PPM	11.83	=	89.44 PPM	91.70 PPM	2.26 PPM	2.53
AGGRESSIVITY	+6.673 PPM	88.17		-16.16 PPM	11.83		+6.345 PPM	+3.972 PPM	+2.373 PPM	37.40

TABLE 1.

Ground Water Geothermal Energy from Subsurface Streams in Karst Regions

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Abstract

The objective of this research is to ascertain if ground water heat pumps utilizing cave streams or large springs are an economically feasible and environmentally sound alternative to conventional heating/cooling systems in karst areas. Instrumentation for continuously monitoring water temperature, stream discharge and water quality has been installed at two locations along the Lost River as it flows under the city of Bowling Green, Kentucky. A ground water heat pump system is being built in order to investigate potential heat pump problems and the environmental effects of possibly altering the water temperature of subsurface streams.

Preliminary findings indicate that there are economic advantages in using subsurface streams, such as, not needing a discharge well. Large units for commercial buildings or "community systems", with one well serving several residences, appear to be economically feasible alternatives to conventional heating/cooling systems. Only natural gas heat/electric air conditioning is competitive, but this is expected to change rapidly with government decontrol of natural gas prices.

Potential findings also indicate that termal alteration, even by large scale use of cave streams may not be a serious problem. This is due to the ability of the karst aquifer to act as a natural heat exchanger, thus rapidly restoring heat pump discharge (which is only changed by 2.8°C (5°F) in passing through the water-to-refrigerant heat exchanger of most heat pumps) to its original temperature.

If ground water heat pump technology applied to subsurface streams is found to be economically attractive and environmentally sound, cities such as Bowling Green, Kentucky, located over large subsurface streams, may benefit greatly through the utilization of a less expensive, environmentally clean, locally abundant and renewable energy resource for space conditioning of residences and commercial buildings.