12. LOWER CRETACEOUS AMMONITES FROM THE SOUTH ATLANTIC LEG 40 (DSDP), THEIR STRATIGRAPHIC VALUE AND SEDIMENTOLOGIC PROPERTIES

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ABSTRACT

Eleven ammonites have been cored during Leg 40. They were found concentrated in the lower parts of the drilled section at Sites 363 (Walvis Ridge) and 364 (Angola Basin), and permit recognition of upper Albian, middle Albian, and upper Aptian. So far, no lower Albian could be recognized. A high ammonite density can be assumed for the South Atlantic Mid-Cretaceous.

In contrast to data available so far, the Walvis Ridge associations consisting of phylloceratids and desmoceratids show more open-basin relationships than those of the Angola Basin, which are composed of mortoniceratids, desmoceratids, and heteromorphs.

Paleobiogeographically, the South Atlantic fauna can be related to the well-known onshore faunas of Angola, South Africa, and Madagascar as well as to the European Mid-Cretaceous. This means that the opening of the South Atlantic and its connection with the North Atlantic occurred earlier as was generally presumed, i.e., in the middle Albian. Records of lower Aptian ammonite faunas from Gabon and Brazil remain doubtful.

High rates of sedimentation prevailed especially in the Aptian and Albian, in connection with the early deepening of the South Atlantic basins.

The mode of preservation of the ammonites suggests that they were deposited on the outer shelf or on the upper continental slope and were predominantly buried under sediments of slightly reducing conditions.

In spite of a certain variability of the depositional environment, the ammonites show a uniform and particular mode of preservation. Its most conspicuous feature is prevalent fracturing and collapsing of the ammonite shell, a phenomenon rarely found in other carbonate rocks. Later on, all shells were pyritized, dissolved, and the steinkerns compressed. The mineralization consists of (probably disordered) glauconite, framboidal pyrite, and elongated calcite. The mass of framboidal pyrite was formed only after the overburden produced shell fracture, compactional striation, and joint planes, indicating a certain depth of formation below the depositional interface.

Remains of the siphuncle are found on two ammonites. Connecting rings and annular calcareous deposits can be identified. The connecting rings show additional lamellae on the inside and outside and are made up of granular calcium phosphate (apatite). The primary or secondary origin of the phosphate is discussed.

INTRODUCTION

The eleven ammonite specimens discussed here were submitted to us by H. Bolli, Co-Chief Scientist of Leg 40. The specimens are from the lower cored sections of Sites 363 (Walvis Ridge) and 364 (Angola Basin). Location of these sites is shown in Figure 1. Despite their poor preservation, most of the specimens could be determined specifically and assigned to *Phylloceras (Hyphophylloceras)*, *Hamites*, *Puzosia*, *Beudanticeras Cainoceras*, and *Neokentroceras*. One specimen could only be identified as belonging to the family Mortoniceratidae. For detailed zonation the "trachyostraceous" (highly ornamented) species (species of *Cainoceras* and *Neokentroceras*) are most useful. Dating of the lower cored sections of Sites 363 and 364 were especially important, since the data available on Aptian and Albian foraminifers and nannoflora are to some extend contradictory. In addition, it is important for the interpretation of the early history of the South Atlantic, a subject to which many authors have contributed during the last several years (Maack, 1969; Reyment and Tait, 1972; Beurlen, 1974; Kennedy and Cooper, 1975). At the same time, questions arose concerning the biogeographic relationships of the South Atlantic Mid-Cretaceous, the sedimentary environments, depth of deposition, and, perhaps, a differing subsidence of the actual Walvis

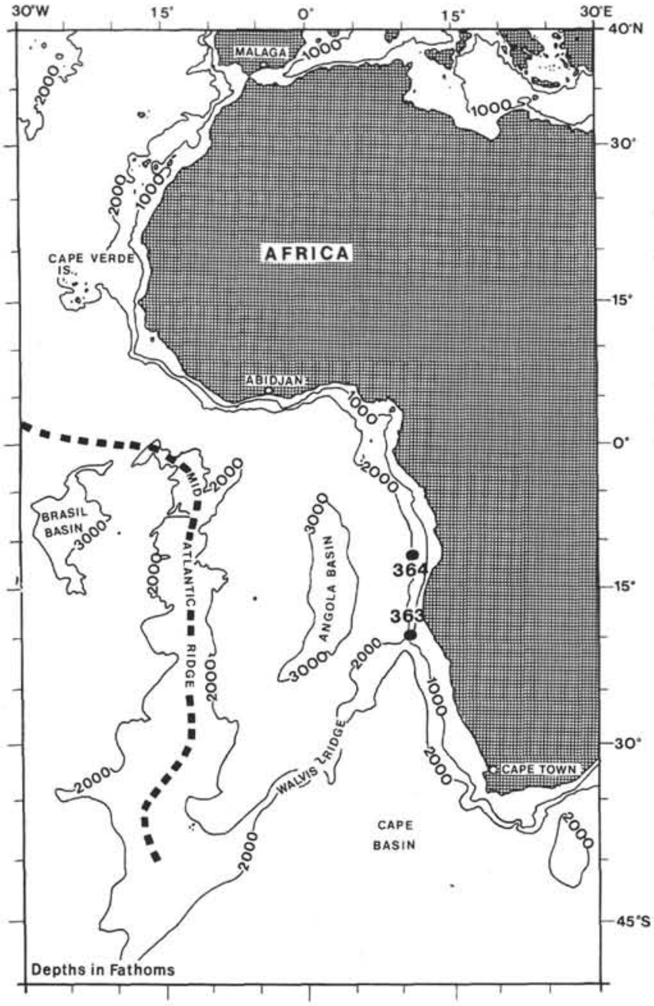

Figure 1. *Locality map of Sites 363 and 364 (Leg 40) where ammonites have been cored.*

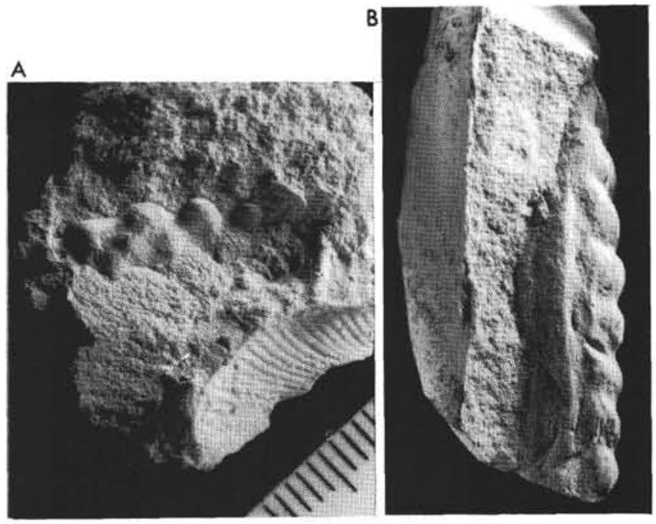

Figure 2. *Albian ammonites from Site 364 (Angola Basin): (A)* Neokentroceras *sp. (cf.* crassinodosum *Haas). NMB coll. J. 28118 A. Lateral view of fragment. Sample 37-2 (bottom); middle/upper Albian. 2/1. (B)* Cainoceras *n. sp. ex aff.* liberum *van Hoepen. NMB coll. J. 28184. Ventral view (See also Plate 2, Figure 5). Sample 32-2, 60-64 cm. Lower upper Albian. 2/1.*

Ridge and the Angola Basin from the very beginning of the South Atlantic.

Therefore, not only systematic and stratigraphic correlation were investigated, but also the mode of ammonoid preservation. From this point of view it has to be mentioned that most specimens are crushed, and generally only one side of the specimens can be observed or prepared. In most cases, this is due to glauconitic and pyritic mineralization. Whether or why in most cases this mineralization affected only one side of the specimens we were unable to discern (in the core samples, bottom/top orientation was not indicated). Only in one case (Figure 2[B]), a ventral side could be prepared on which the mineralized layer disappears rapidly and irregularly.

Despite the fact that no clear suture lines were observed, in most cases phragmocone and body chamber could be distinguished by different modes of preservation. While the body chambers are filled with sediment and preserved as steinkerns (Plate 1, Figures 1, 3, 5; Plate 2, Figures 1, 2, 5), the compressed phragmocones generally show a poor and fine-grained pyritization (Plate 2, Figures 2, 3) and remained unfilled. Therefore, it is of special interest that in two cases (Plate 2, Figures 1, 4) the siphuncle has been preserved. It needs no further comment that this mode of preservation renders specific determination difficult. In two cases attachment of serpulids (Plate 1, Figure 5) and *Placunopsis* (Plate 2, Figure 4) was observed.

The matrix in which the specimens under discussion are preserved is a marly chalk and chalky limestone.

SYSTEMATIC DESCRIPTIONS

The studied ammonites belong to three of the four suborders of Cretaceous ammonites, Phylloceratina, Ancyloceratina, and Ammonitina. Lytoceratina have not yet been recognized.

Suborder PHYLLOCERATINA Arkell, 1950

Superfamily Phyllocerataceae Zittel, 1884

Family PHYLLOCERATIDAE Zittel, 1884

Genus PHYLLOCERAS Suess, 1865

Subgenus Hypophylloceras Salfeld, 1924

Wiedmann (1964) demonstrated some years ago that most of the true Cretaceous phylloceratids, that is, those without any pronounced constrictions, flares, or even ribbing, can easily be referred to *Phylloceras* (*Hypophylloceras*). This is also true for two phylloceratids from Site 363 which have the typical fine and dense ribbing of *Hypophylloceras*. They may indicate that the lower part of the cored section is upper Aptian or Albian.

Phylloceras (Hypophylloceras) velledae (Michelin)
(Plate 1, Figure 1)

1834 *Amm. Velledae* Michelin, pl. 35.
1964 *Ph. (H.) velledae* (Michelin). — Wiedmann, p. 201, pl. 11, fig. 1; pl. 13, fig. 4; pl. 21, fig. 4; text-fig. 49 (and further bibliography).
1968 *Ph. (H.) velledae velledae* (Mich.). — Wiedmann and Dieni, p. 25, pl. 1, fig. 5.

This species, and especially the typical subspecies, have been discussed at some length by Wiedmann and Dieni (1968). D'Orbigny's (1842, pl. 82, fig. 1, 2). The figured specimen was proposed as neotype since Michelin's (1834) type specimen has been lost. From the original diagnosis and the neotype it is obvious that most of the subsequently figured specimens cannot be attributed to *Ph. velledae*. This is especially true for the specimen O. Haas (1942) described from the Albian of Angola, which has been regarded as *Ph. (H.) seresitense tanit* (Perv.). The true *Ph. (H.) velledae*, however, was found to have an oval to subtriangular whorl section, very fine and dense ribbing on the exterior lateral side, a diphyllitic saddle E/L, but a triphyllitic saddle L/U_2. The umbilicus is completely closed.

The whorl section, as far as could be deduced from the flattened specimen, and the type of ribbing, identify one of the Leg 40 specimens, illustrated in Plate 1, Figure 1, as *Ph. (H.) velledae*, and most probably *Ph. (H.) velledae velledae*. Unfortunately, even though the small specimen seems to be part of the phragmocone, the suture line could not be observed. This would agree with the observation that *Ph. velledae* is a large species.

The present species, as redefined in 1964, is known from only the Albian of France, Mallorca, and Sardinia; in Madagascar it persists into the Cenomanian. Maximum occurrence of the species is in the middle Albian, to which Core 32, Section 3, of Site 363 (Walvis Ridge) has been assigned.

Ph. (Hypophylloceras) cf. morelianum (D'Orbigny)
(Plate 1, Figure 2)

cf. 1841 *Amm. Morelianus* D'Orbigny, p. 176, pl. 54, fig. 1, 2 (only).
see 1964 *Ph. (H.) velledae morelianum* (D'Orb.). Wiedmann, p. 199, pl. 13, fig. 1 (?), 2; text-fig. 48 (and further citations).

This other Leg 40 phylloceratid (Plate 1, Figure 2) is much more poorly preserved than the above specimen and can therefore be only doubtfully referred to *Ph. morelianum*. It has the ribbing of the forms belonging to the group of *Ph. velledae*, in which *Ph. morelianum* has been included as subspecies (Wiedmann, 1964). Both forms show strong similarities, especially in the suture lines. The fragmentary specimen from Core 37, Section 2, of Site 363 (Walvis Ridge) seems to represent the phragmocone; it differs slightly from true *Ph. morelianum* by its stronger and more widely spaced ribbing. Therefore, open nomenclature seems to be called for.

Ph. (H.) morelianum is predominantly an upper Aptian form.

Suborder ANCYLOCERATINA Wiedmann, 1966

Superfamily ANCYLOCERATACEAE Meek, 1876

Family BACULITIDAE Meek, 1876

Subfamily PTYCHOCERATINAE Meek, 1876

Genus HAMITES Parkinson, 1811

One specimen of a heteromorphic ammonite was recovered from the basal part of Site 364. It is referred to the genus *Hamites* as previously defined (Wiedmann, 1962; Wiedmann and Dieni, 1968). It ranges from the upper Aptian to the Turonian.

Hamites tenuis Sowerby
(Plate 1, Figure 3)

1814 *Hamites tenuis* Sowerby, p. 136, pl. 61, fig. 1.
1941 *Hamites tenuis* Sowerby. Spath, p. 628, pl. 68, fig. 14; pl. 70, fig. 2, 16, 17; pl. 71, fig. 2; text-fig. 228 (and further citations).
1942 *Hamites tenuis* Sowerby. Haas, p. 177, pl. 43, fig. 5-7; text-fig. 26c-e.

A body chamber fragment of a small-size hamitid specimen was found in the lowermost cored section of Site 364. It is characterized by very fine and dense oblique ribbing on the lateral sides (Plate 1, Figure 3). A section of the whorl in length to the corresponding whorl height contains 6-8 ribs. The beginning of the terminal hook is preserved, but is crushed. Thus, the mode of coiling is very similar to that of the specimen Spath (1941, pl. 71, fig. 1) described as being transitional to *H. maximus rectus* Brown. If *H. tenuis* is truly separable from *H. maximus* and allied forms by virtue of its smaller size, our specimen must be referred to it.

H. tenuis has been described from the middle Albian (Euhoplitan-Dipoloceratan). It is known from England, France, Angola, and Mozambique (?).

Since we found *H. tenuis* together with *Neokentroceras* (Figure 2a), which is known only from the lower upper Albian, we regard Core 37, Section 2, of Site 364 (Angola Basin) to be close to the middle/upper Albian boundary.

Suborder AMMONITINA Hyatt, 1889

Superfamily HOPLITACEAE H. Douvillé, 1890

Family DESMOCERATIDAE Zittel, 1895

Subfamily PUZOSIINAE Spath, 1922

Genus PUZOSIA Bayle, 1878

Several specimens of both sites belong to this genus which has been found (Wiedmann and Dieni, 1968, p. 110) to range from Albian to Coniacian.

Puzosia mayoriana (D'Orbigny)
(Plate 1, Figures 4, 5)

1841 *Amm. Mayorianus* D'Orbigny, p. 267, pl. 79, fig. 1-3.
1923 *Puzosia mayoriana* (D'Orb.). Spath, p. 42, tex-fig. 10; non pl. 1, fig. 9, 10 (sed *P. spathi*).
1963 *Puzosia* aff. *mayori* D'Orb. Collignon, pl. 263, fig. 1145.
Puzosia mayori var. *recteradiata* Collignon, pl. 264, fig. 1152.

Several authors have pointed out that the type species of *Puzosia* is a rather restricted form that calls for careful revision. We cannot undertake this here; a first step towards a better understanding of the Albian puzosiids has already been taken by Wiedmann and Dieni (1968, p. 110).

We attribute two specimens (Plate 1, Figures 4, 5) found in Core 31, Section 3, of Site 363 (Walvis Ridge) to this species as defined by D'Orbigny (1841). It is characterized by strong and sigmoidal constrictions that decrease in number with age, and an open umbilicus. This perfectly agrees with the cored specimens, as well as the typical ribbing of the external lateral sides. Whether these fragments belong to the phragmocone or to the body chamber is not clear, however. On the basis of their pyritization, they seem to be phragmocones.

Puzosia mayoriana has been recorded from various places in Europe and Africa. It seems to be dominant in the upper Albian, but occurs also in the middle Albian and Cenomanian. Core 31 of Site 363 is here dated as upper Albian.

Puzosia quenstedti (Parona and Bonarelli)
(Plate 2, Figure 1)

1897 *Desmoceras quenstedti* Parona and Bonarelli, p. 81, pl. 11, fig. 3.
1968 *Puzosia quenstedti* (Parona and Bonarelli). Wiedmann and Dieni, p. 114, pl. 10, fig. 11; pl. 12, fig. 3; text-fig. 72, 73 (and further citations).

The "group of *P. quenstedti*" as defined by Wiedmann and Dieni (1968), differs from *P. mayoriana* by straighter constrictions which are much less pronounced but more numerous (6-7), and by a closer umbilicus. These features are seen in the well-preserved specimen from Core 29, Section 2, of Site 364 (Angola Basin), shown on Plate 2, Figure 1. The body chamber is preserved and filled with sediment. The specimen is small, measuring 28 mm in diameter, with a phragmocone diameter of 22 mm. It is the only specimen for which approximate measurements can be given. Another feature is the preservation of the siphuncle (see section on Preservation of Ammonites).

P. quenstedti has been recorded from the middle and upper Albian of France, Sardinia, Madagascar, and Angola. The present specimen is placed in the upper Albian.

Subfamily BEUDANTICERATINAE Breistroffer, 1953

Genus BEUDANTICERAS Hitzel, 1902

Beudanticeras cf. newtoni Casey
(Plate 2, Figure 2)

cf. 1961 *Beudanticeras newtoni* Casey. Casey, p. 147, pl. 26, fig. 12; pl. 27, fig. 2-5; pl. 28, fig. 7, 8; pl. 29, fig. 2; text-fig. 47a-c, e, f.

A crushed specimen from Site 363 (Walvis Ridge), Core 33, Section 4, may be referred to the genus *Beudanticeras*. It is nearly smooth, and small, with part of the body chamber preserved. The smooth shell and the extremely closed umbilicus suggest *B. newtoni* Casey.

Beudanticeras is an Albian genus of nearly worldwide distribution. It is abundant in the Albian of Madagascar (Collignon, 1963). *B. newtoni* has been described from the upper lower Albian of southern England. We regard our specimen to be middle Albian.

Superfamily ACANTHOCERATACEAE Hyatt, 1900

Family Mortoniceratidae Spath, 1925

Four of our specimens can be attributed to this group of strongly sculptured index fossils of the upper Albian. Only three of them could be determined generically, however. These were assigned to *Cainoceras* van Hoepen and *Neokentroceras* Spath.

Genus CAINOCERAS van Hoepen, 1942

It is difficult to distinguish this genus from the contemporaneous *Prohysteroceras* Spath, and we cannot offer a solution on the basis of the two specimens from Site 364 which belong to this group and are more or less well preserved.

It is of extreme interest that Stevens (1974) described an "indet. ammonite cf. *Prohysteroceras (Goodhallites) richardsi* Whitehouse" from Site 263 of Leg 27, Cuvier Abyssal Plain, off western Australia. This form has much in common with the present specimens and has been, likewise, dated as upper Albian.

The most impressive feature of *Cainoceras* is its similarity, in lateral view, with *Deshayesites* and *Dufrenoyia* of the Aptian. This might be another source of misdating in the South Atlantic faunal realm. As Reyment and Tait (1972) have pointed out, records of the lower Aptian *Deshayesites* in younger sediments from Gabon (De Klasz and Gageonnet, 1965, p. 285) and Sergipe, Brazil (Schaller, 1969, p. 71) remain dubious. These specimens may not only be referred to *Neodeshayesites* (Reyment and Tait, 1972, p. 83), but also to *Cainoceras*.

Cainoceras cf. angustidorsatum van Hoepen
(Plate 2, Figure 3)

cf. 1942 *Cainoceras angustidorsatum* van Hoepen, p. 136, fig. 141, 142.

C. angustidorsatum is a relatively high-whorled involute species with crowded ribs (16 per half whorl). These ribs originate in pairs from small umbilical tubercles, are sinuous, and become increasingly thick up to the clavate marginal tubercles. They rapidly disappear on the narrow and flattened ventral side which is subdivided by a tender median keel. Secondary ribs occur only occasionally.

The specimen from Site 364 (Angola Basin) is rather poorly preserved but may, nevertheless, doubtfully be referred to van Hoepen's species. It is preserved in a black pyritic matrix and may, therefore, represent the phragmocone.

C. angustidorsatum is an endemic species of the lower upper Albian of Zululand (van Hoepen, 1942).

Cainoceras n. sp. aff. liberum van Hoepen
(Plate 2, Figure 5; Text-Figure 2[B])

cf. 1942 *Cainoceras liberum* van Hoepen, p. 128, fig. 126-128.

C. liberum, type species of the genus, is an open-whorled form with a hexagonal cross-section, and strong, sinuous ribs which originate in pairs from small umbilical tubercles. They become more and more flattened on the outer sides, bearing distinct clavi on the marginal shoulder. On the flattened venter, the ribs strongly project and rapidly disappear before reaching the small and feeble siphonal keel.

At first glance, the specimen (Plate 2, Figure 5) from Site 364 (Angola Basin) has much in common with the lower Aptian *Deshayesites*. The type of ribbing is nearly identical and this may be the reason, as mentioned above, for the doubtful citations of this lower Aptian genus from the South Atlantic realm. We were thus happy that the ventral side of the specimen could be prepared (Figure 2[B]). This shows a small and tender siphonal keel. This is the typical feature of cainoceratids but is missing in the deshayesitids. Similarly, the projection of the ventral ribs, which is typical for mortoniceratids and, especially, cainoceratids, could easily be recognized. The problem of incomplete shell mineralization and preservation has been mentioned previously.

Differences with *C. liberum*, however, are found in details of the ribbing. While in *C. liberum*, like in most cainoceratids, the ribs bifurcate mainly at the umbilical tubercles, this bifurcation is observed only occasionally in the South Atlantic specimen. Additional bifurcation is, however, observed in the middle of the lateral side as well as on its outer portion. Single ribs are irregularly intercalated. General type and course of ribbing as well as a relatively open umbilicus point, however, to *Cainoceras*. This permits the specimen under discussion to be placed in this South African genus. It most likely represents a new species characterized by a special type of rib bifurcation.

As all other species of *Cainoceras*, *C.* sp. aff. *liberum* is regarded to be lower upper Albian.

Genus NEOKENTROCERAS Spath, 1921

Only one very small fragment of this characteristic genus has been found.

Neokentroceras sp. cf. N. crassinodosum Haas
(Text-figure 2[A])

cf. 1942 *Neokentroceras choffati* var. *crassinodosa* Haas, p. 50, pl. 7, fig. 19.

Characteristic features of *Neokentroceras* are its small size, the extremely pronounced umbilical, weak or absent lateral, and strong and clavate marginal tubercles. Costation is reduced; the keel is low. All these features are found on a small fragmentary specimen that occurs with *Hamites tenuis* and Mortoniceratidae gen. et sp. indet. in Core 37, Section 2, of Site 364 (Angola Basin). Because *Neokentroceras* can hardly be confused with any other ammonite genus, even a small fragment can be identified. As can be seen from Figure 2a, it is a trituberculate form with conical umbilical and lateral tubercles and clavate marginal tubercles. No trace of ribs can be observed. This permits its doubtful assignment to the trituberculate *N. crassinodosum* Haas.

Neokentroceras is known from the lowermost upper Albian of Angola, Tunisia, Madagascar, India, and Brazil and is thus a form typical of the Southern Hemisphere. Together with the middle Albian *Hamites tenuis* from the same level, it suggests a level at the middle/upper Albian boundary.

Mortoniceratidae gen. et sp. indet.
(Plate 2, Figure 4)

A large, poorly preserved ammonite was recovered from Site 364 (Angola Basin). The poor preservation seems to be due to subsolution of the steinkern, which has been colonized by small *Placunopsis*, suggesting a near-shore depositional environment. Specific or generic identification of this specimen is impossible. It may belong to the Mortoniceratidae, which have a range of upper middle Albian to lower Cenomanian. The occurrence of *Neokentroceras* sp. and *Hamites tenuis*, however, indicates placement near the middle/upper Albian boundary.

STRATIGRAPHIC AND PALEOGEOGRAPHIC INFERENCES

Site 363

Three-hundred meters of Aptian and Albian sediments were penetrated at Site 363 on the Walvis Ridge (Figure 3). Ammonites were found at five levels. Despite the absence of trachyostraceous ammonites, we can assume that the interval from 436 to 590 meters belongs to the middle and upper Albian (Table 1). The presence of lower Albian cannot be substantiated, and the interval from 590 to 715 meters (total depth) belongs in the upper Aptian. Paleoenvironmental interpretation of the exclusively "leiostraceous" (smooth) ammonites of Site 363 poses difficulties. They suggest a bathyal rather than a submarine ridge or shelf environment, but because we are dealing with only 11 specimens, we regard this as a rather tenuous conclusion. Foraminifers suggest a depth of deposition in excess of 1000 meters.

All the ammonites from Site 363 show obvious affinities with the European-North Atlantic faunal province, but they are also found in Madagascar.

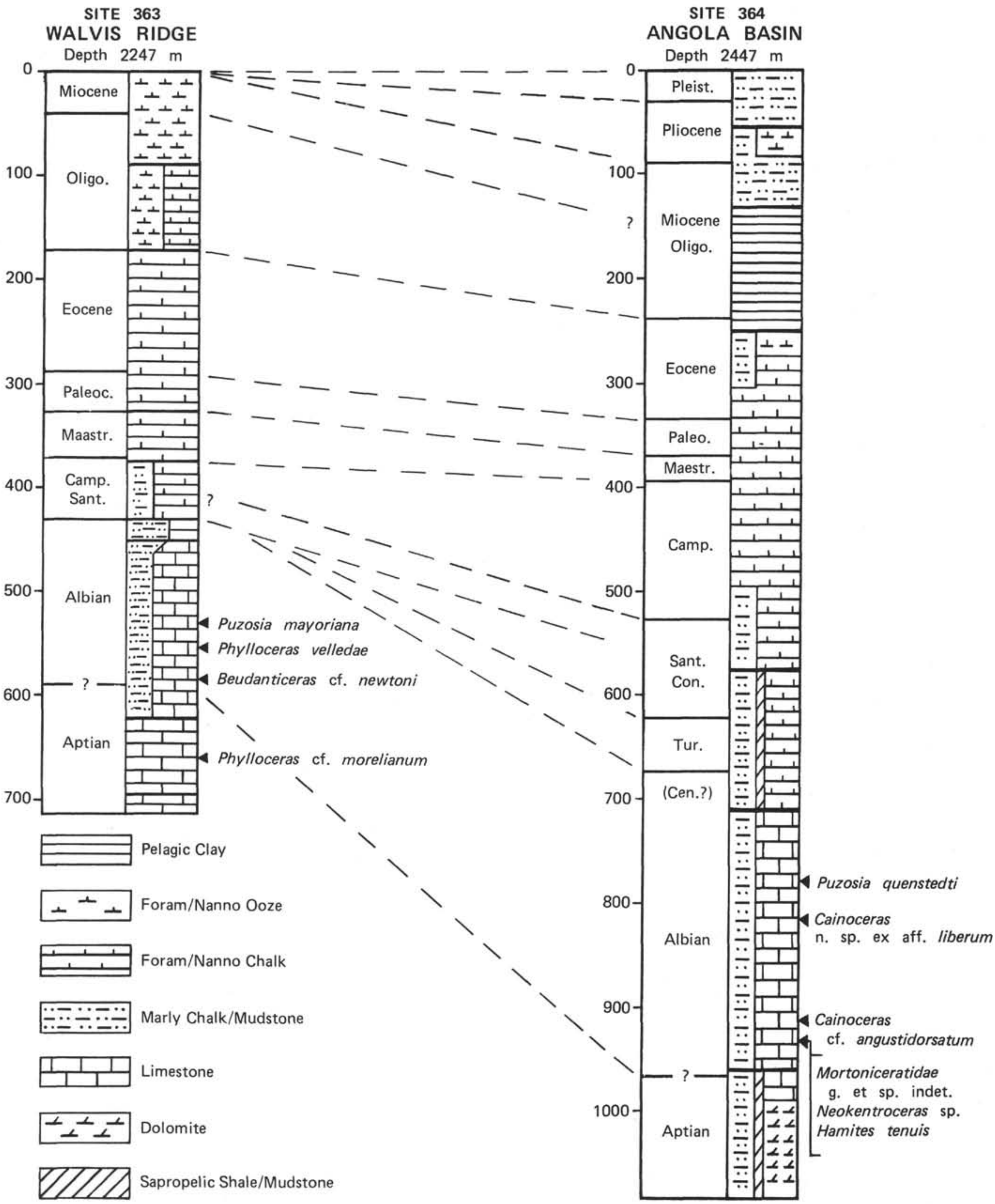

Figure 3. *Stratigraphic columns of Sites 363 and 364 (Leg 40), kindly provided by H. Bolli. Position of cored ammonites is indicated.*

TABLE 1
List and Position of Cored Ammonites

Site 364 (Angola Basin)	
Sample 29-2, 26-29 cm:	*Puzosia quenstedti* - upper Albian
Sample 32-3, 60-64 cm:	*Cainoceras* n. sp. ex aff. *liberum* - upper Albian
Section 37-1, (top):	*Cainoceras* cf. *angustidorsatum* - middle/upper Albian
Section 37-2 (bottom):	*Hamites tenuis*
	Neokentroceras sp. (cf. *crassinodosum*)
	Mortoniceratidae gen. et sp. indet. - middle/upper Albian
Site 363 (Walvis Ridge)	
Sample 31-3, 19-22 cm:	*Puzosia mayoriana* - upper Albian
Sample 31-3, 37-39 cm:	*Puzosia mayoriana* - upper Albian
Sample 32-3, 29-32 cm:	*Ph. (Hypophylloceras) velledae* - middle Albian
Sample 33-4, 149-151 cm:	*Beudanticeras* cf. *newtoni* - middle Albian
Sample 37-2, 129-131 cm:	*Ph. (Hypophylloceras)* cf. *morelianum* - upper Aptian (?)

Contrary to the majority of recent reconstructions of the mid-Cretaceous South Atlantic (K. Beurlen, 1961, 1974, fig. 2; Maack, 1969, fig. 12a; Reyment and Tait, 1972, fig. 6, 7), the connection between the North and South Atlantic occurred much earlier than generally thought, perhaps as early as the late Aptian. A similar conclusion is suggested by the Aptian/Albian nannofloras; *Nannoconus*, of the *truitti* group, for example, show obvious Tethyan relationships.

Site 364

The lower part of the section drilled at Site 364 (Angola Basin) can be dated as Albian and upper Aptian(?). Ammonites were found at four levels here (Table 1). It is noteworthy that all four ammonite-bearing levels belong to the upper Albian and only one species can be referred to the middle Albian. As at Site 363, no lower Albian beds have been recognized so far on the basis of ammonites. The Aptian/Albian boundary might be drawn at the base of Core 39 at a depth of 975 meters, where inoceramids of the *anglicus* group occur with obvious Cenomanian(!) affinities (E. Kauffman, personal communication). They are described by T. Matsumoto (this volume). Moreover, these dates conflict with dates based on foraminifers and nannofossils. Core 35 (between the levels containing cainoceratid species) has been dated with *Hedbergella trochoidea/H. gorbachikae* as upper Aptian, and Cores 38 and 39 with *Globigerinelloides algerianus* as upper Aptian. Nannofossils indicate that Cores 34-42 are equivalent to the *Praediscosphaera cretacea* and *Parhabdolithus angustus* zones, which are lower and middle Albian. No explanation for these discrepancies can be offered.

The ammonite fauna of Site 364 consists of several trachyostraceous and one heteromorphic species, which can be related to inner shelf or epicontinental rather than to a bathyal environment. This is supported by sedimentological observations (see section on ammonite preservation) and by the settlement of *Placunopsis* on at least one of the ammonites (Plate 2, Figure 4).

CORRELATION WITH ON-SHORE SECTIONS

Problems arise in relating the drill-hole data to the outcropping Cretaceous of Angola. Recent investigations of the Benguela district (Howarth, 1965; Cooper, 1974) confirm that at least in this region the Albian is complete and characterized by a lower interval with *Douvilleiceras*, a middle interval with *Oxytropidoceras* and *Manuaniceras*, and, finally, a rich upper Albian interval with *Dipoloceras*, *Mortoniceras*, *Elobiceras*, *Prohysteroceras*, *Neokentroceras*, *Stoliczkaia*, and *Anisoceras*. The lower Albian with *Douvilleiceras* has been regarded as the "earliest undoubted marine beds" (Cooper, 1974, p. 84) of Angola, despite the fact that Hoppener (1958, p. 75) described two marine Aptian transgressions. Cenomanian and Turonian sequences of Angola have recently been described in detail by Howarth (1968) and Cooper (1973). This means that, with the exception of the uncertain Aptian, the mid-Cretaceous is more complete on the mainland than off shore. We do not hesitate to relate the off-shore unconformities of Albian age (like those of the Upper Cretaceous) to bottom currents and the formation of a new circulation pattern within the South Atlantic as a result of its connection with the North Atlantic.

PALEOGEOGRAPHY

There is no doubt at present that the break-up of Gondwana and the opening of the South Atlantic started earlier than has been previously believed, that is, in the Upper Jurassic (Dingle and Klinger, 1971, 1972). This first marine transgression from the south made little progress during the Neocomian. We know from the pioneer studies of Krömmelbein (1966) and Krömmelbein and Wenger (1966) that there was a Neocomian continental connection, with contiguous non-marine sequences further north, in eastern Brazil as well as in Gabon. At both sides of the South Atlantic, that is, in the Sergipe Basin of Brazil as well as in Gabon and Angola, the lower Aptian is characterized by extensive evaporite deposits, which indicate that there was still little progress of the transgression from the south. However, it has not yet been determined whether these evaporites were deposited in a single basin or in coastal basins or lagoons separated by a marine central South Atlantic (Belmonte et al., 1965). The first uniform marine transgression in the northern part of the South Atlantic can now be dated (at least for the Brazilian basins, Gabon and Angola) as late Aptian. Continuing into the early, middle, and especially the late Albian, initial subsidence of the South Atlantic can be assumed on grounds of relatively high sedimentation rates, at least off Angola and Namibia. The combination of subsidence and the remarkable intra-Albian unconformity seen at Sites 363 and 364 we explain by the activity of bottom currents. These currents were presumably the result of a new circulation system within the South Atlantic due to its connection with the North Atlantic. On this basis, and the invasion of North Atlantic and European faunas into the South Atlantic, as is documented by ammonites, inoceramids, and nannoflora, the postulated land barrier joining northeastern Brazil with Nigeria (Beurlen, 1961, 1974; Maack, 1969; Reyment and Tait, 1972) becomes unnecessary. These results are largely in agreement with those of Kennedy and Cooper (1975) who on biogeographic grounds, postulated a submergence of this Albian to Turonian(!) barrier as early as the early late Albian. Similarly, the Cenomanian and Turonian South Atlantic faunas do not support the previous idea of an independent South Atlantic faunal realm. From the present documentation it can be assumed that the common history of the North and South Atlantic started earlier, that is, during the middle Albian (Figure 4).

PRESERVATION OF AMMONITES

Introduction

The mode of preservation of ammonites is quite varied: they exhibit many types of internal sedimentation, compaction, mineralization, wall preservation, etc., which can be combined in various ways; very often even body chamber and phragmocone underwent different fossilization.

In contrast to this general variation, ammonites are preserved uniformly in a certain bed because of a special depositional and diagenetic environment. For this reason, recent studies regard ammonites as a tool for analyzing the environment, and try to make out the factors responsible for the different modes of preservation (Seilacher, 1976a, b; Neumann and Schumann, 1974; Schlager, 1974).

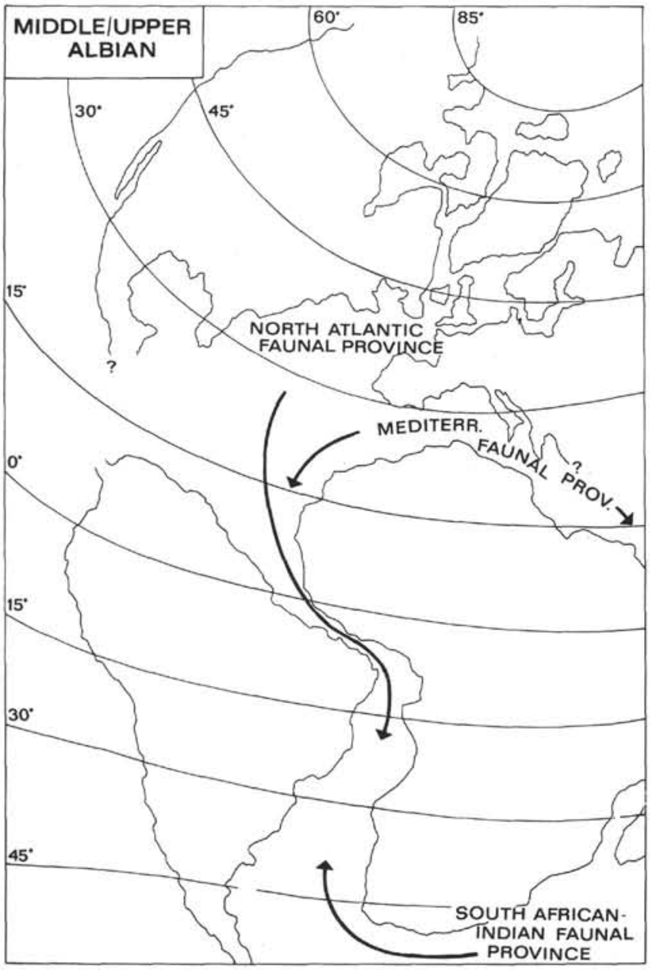

Figure 4. *Opening of the South Atlantic towards the North, based on faunal evidence (paleogeographic reconstruction after Phillips and Forsyth, 1972).*

In this context the ammonites from Sites 363 and 364 are worth considering. Their mode of preservation can be analyzed in two ways. First, we can look for features indicating a certain depositional or diagenetic environment, and vice versa we can study the influence of a factor known in this special case: the influence of slight and late induration (the time of induration of the surrounding sediment is an important factor in ammonite fossilization).

Assuming that some day ammonite preservation will be useful for the interpretation of depositional and diagenetic environments, we first describe these ammonites in great detail and then try to explain what their preservational features mean.

Description

General features: Plates 1 and 2 show internal molds (steinkerns and flattened impressions) of the ammonites of Sites 363 and 364; the external molds are not figured (except for Plate 1, Figure 4 and Plate 2, Figure 1), since they are mirror-symmetrically identical. Notice that the morphological details such as ribs and constrictions produced blurred impressions. Shell material itself is not preserved, but a thin film of minerals marks the former position of the shell and separates internal and external mold. Disregarding the often very thin mineral film, the sediment-filled parts of the ammonites are "sculpture-steinkerns," though features of the external or internal shell surface (growth lines and suture lines) are not impressed on the external mold and the steinkern, respectively.

Burial of aragonitic shells: With regard to the oceanic locality and its present depth, it is conceivable that the aragonite of the shell was dissolved before burial. The mode of preservation (e.g., the diagenetic shell fracture) indicates, however, that all ammonites were embedded without dissolution.

Internal sedimentation: When cephalopod shells rest on the sea floor, their body chambers are usually filled with sediment; not so their phragmocones, in which the extent of sedimentation depends on the environment.

On the ammonites from Sites 363 and 364 the body chambers were filled as one would expect, but considerable differences in the filling of the phragmocone were noted: some are filled completely or at least for the most part (Plate 2, Figure 1 and probably Plate 2, Figure 3), others are largely free of sediment (Plate 2, Figure 2; Plate 1, Figure 4, and ?Plate 2, Figure 4). After burial of the empty septal chambers, they were filled only a little bit by diagenetic minerals.

Shell fracture: The ammonite shells from both sites are diagenetically fractured into irregular fragments: in the majority of the body chambers and phragmocones, the fracture lines are clearly visible (Plate 1, Figures 1-5; Plate 2, Figure 1), and on three specimens they can be made out indistinctly (Plate 2, Figures 2, 4, and 5); one shell is too poorly preserved to judge whether fracturing occurred or not (Plate 2, Figure 3).

As could be expected from earlier work, the fracture lines preferentially run in concentric and radial directions (cf. Müller, 1957, p. 92). As a rule, the fragments are displaced against each other not more than a fraction of a millimeter, but at a few fracture lines displacement reaches some millimeters (Plate 6,

Figure 5, arrowed). Further, a few fragments are set angularly against each other. These peculiarities characterize the firmness of the sediment and of the shell at the time of fracturing.

Diagenetic shell solution: The aragonite of the outer shell wall was dissolved after fracturing had taken place. Remains of the shell carbonate cannot be detected, so probably no shell aragonite was transformed into (preservable) calcite before shell solution.

Mineralization: During diagenesis, three minerals were concentrated in and on the ammonites: listed according to their arrangement and their sequence of formation, these are glauconite, pyrite, and calcite.

On all specimens from Site 364 and on two from Site 363 (Plate 1, Figure 4; Plate 2, Figure 2), glauconite is found in the form of an extremely thin incrustation, at the most some hundredths of a millimeter thick. Pyrite occurs in variable amounts on all ammonites, but preferentially in the incomplete filled phragmocones. Moreover, some calcite was formed new in cavities of the irregularly thick pyrite cover of the phragmocone (Plate 2, Figures 2 and 3; Plate 1, Figures 2 and 4). Altogether, the three minerals form only a very thin layer, 1 to 2 mm thick at the most.

The mineral determined as glauconite appears as an olive-green film exhibiting no crystal shape even in scanning electron micrographs (Plate 3, Figures 1 and 2). Thin pieces of it also look olive-green under the polarizing microscope, but do not show any pleochroism. In some spots tiny crystals are seen, arranged radially, or subparallel, and their optical properties resemble those of mica.

An energy-dispersive X-ray analysis (Plate 3, Figures 3 and 4) of the mineral under discussion proved the presence of Mg, Al, Si, K, Fe, and perhaps Ca, though most of the Ca seems to be present in adherent particles of calcite (cf. Plate 3). Of these elements, K and Fe are important, because the potassium content rules out chlorite (or a smectite-chlorite mixed layer) and the relatively high iron content (Fe>>Mg) is compatible with Al-illite. The X-ray diffraction pattern of a small quantity of powder contaminated by rock admixtures showed no peaks other than calcite and quartz. When we tried to get further material and to free it from calcite by diluted acetic acid, the mineral disintegrated into a gel.

From these facts, together with the marine environment and the non-volcanic matrix, it may be concluded that the mineral is a glauconite in a broad sense. It is certainly not an ordered glauconite (Burst, 1958), but an extremely disordered type, probably a glauconite-montmorillonite mixed layer. The glauconite can be considered as authigene, because redeposition of glauconized ammonites seems unlikely in fine-grained sediments.

The glauconite is confined to the outer wall and is not found in the septal chamber. As far as the shells are filled with sediment, the glauconite is in direct contact with the filling. In this context, one specimen overgrown by *Placunopsis* (Plate 2, Figure 4) is of special interest, because the overgrowth marks the former outer boundary of the wall. Here we can see the succession: steinkern-glauconite-pyrite-bivalve-pyrite.

The pyrite looks like a brownish black powder. It marks the position of the outer wall of the ammonites and in particular is concentrated in phragmocones not completely filled by sediment. However, in none of the specimens are septa found replaced by pyrite. Altogether, the amount of pyrite deposited is small: the pyritic film occupying the space between the steinkern and the surrounding rock is very thin, and even in the phragmocones it reaches not more than 1 to 2 mm in thickness.

Under the microscope, the surface of the pyritic film is on all ammonites more or less bulged in the form of hemispheres and spheres. These either touch each other or are scattered across the surface (Plate 4, Figure 4).

Scanning electron micrographs reveal that the pyritic spheres as well as the pyritic mass in between consist of small free idiomorphic crystals. Their dominant crystal form is the octahedron; hexahedrons are sometimes added (Plate 5, Figure 4). The composition of the crystals of Fe and S (Fe<<S) was verified by energy-dispersive X-ray analysis.

The diameter of the (hemi-)spheres is variable; generally it is between 7 and 15 μm (Plate 4, Figure 2), but in some areas between 15 and 40 μm (Plate 4, Figure 3). Inside the individual spheres, as well as in the intermediate mass, the crystal size varies considerably; the edges of the octahedrons measure 0.2 to 1.2 μm (Plate 5, Figure 6). On the average, the crystals of the doubled-sized spheres are slightly larger (0.2 to 1.5 μm; cf. Plate 5, Figures 5 and 6).

The pyrite crystals are more densely packed at the surfaces of the spheres than inside them or in the intermediate mass (cf. Plate 4, Figures 6 and 7). Relative to their genesis it may be of interest that sometimes a substance is intercalated between the pyrite crystals, giving them a glued or fringed appearance (Plate 5, Figures 1-3). Some data indicate that all or part of the pyrite formed after shell fracturing had taken place:

1) The thickness of the pyrite film of one specimen abruptly changes from fragment to fragment (Plate 6, Figure 5).

2) On several ammonites there are cracks filled by pyrite, which exhibits the same features as the ordinary mass of pyrite (crystal form, variation in size, arrangement, sometimes framboidal spheres).

3) Some of the largest fractures look like joint planes (e.g., Plate 6, Figure 5, arrowed). Pyritized compactional striations similar to slickensides also prove a relatively late formation of the pyrite; glauconite, in turn, was passively scratched by the sliding.

Apart from the two size classes of spheres, there are also size classes of crystals: Plate 6, Figures 1 and 2 show a field of larger sized pyrite (the crystal edges measure 2.5 to 3.0 μm) directly adjacent to the ordinary-sized mass of pyrite. Three different size classes of pyrite are present side by side in the filling of a siphuncle (Plate 6, Figures 3 and 4: 0.4 to 0.5 μm/1.0 to 1.5 μm/2.5 to 3.0 μm).

Calcite: The calcite occurs as rosettes composed of elongated crystals (Plate 7, Figures 1 and 3). Lengthwise grooves and corresponding ridges (Plate 7,

Figure 2) suggest twins of aragonite, but detached crystals neither reacted to Feigl solution nor produced a strontium (or magnesium) peak during energy-dispersive X-ray analysis. Between themselves the intergrown crystals leave peculiarly formed clefts (Plate 7, Figures 4 and 5).

Compaction: As far as can be determined, the sediment in body chambers and in other filled parts of the shells is compressed to less than half its original thickness; thus, the filling was compacted to almost the same degree as the surrounding sediment. This does not rule out a (certain) compaction, when the shell was still preserved: the striations on the glauconite mentioned above, arranged parallel to inclined surfaces of ribs and tubercles (Plate 2, Figure 5), indicate resistance to compaction by the ammonite as a whole body.

Unfilled phragmocones or parts of phragmocones collapsed, forming a thin layer of minerals. It is worth noting that the casts of their peripheral fragments are still domed (Plate 2, Figure 4).

Relicts of the siphuncle: In two of the ten ammonites, siphonal remains have been laid bare by the fracturing.

In the first specimen, the plane of fracture meets the siphuncle in the two outer whorls: first near the body chamber and then in the next inner whorl (cf. Plate 8, Figure 5); here the siphuncle can be traced for half a whorl in an unbroken line (Plate 8, Figure 6). In both places the siphuncle is displaced from its originally outside (ventral) position close to the inside of the whorl, where the possibly inclined lying shell had its lowest level.

Under the binocular microscope one can recognize a delicately walled tube composed of white compact material. The tube measures about 0.2 mm in diameter. In parts it is filled with sediment, as in the fragment near the body chamber and at the innermost end of the visible siphonal line. However, most of the visible section is free of sediment and is flattened and fractured. In this unfilled portion, the position of the septa has been marked: the white tube is interrupted at regular intervals (arrowed in Plate 8, Figure 6), and the parts of the tube adjacent to the interruptions contain some pyrite.

Scanning electron micrographs (Plate 8, Figures 1-4) show that the wall of the tube consists of several layers. The principal component is a relatively thick central layer, and a thinner lamella, separated by a small (artificial?) interstice, occurs on the outside. A closer inspection of Plate 8, Figure 1 reveals two outer lamellae; the first lamella (at the bottom of the figure) wedges out and is overlapped by a second one (edge in a broken line), which takes the center of the figure. An inner lamella becomes apparent on Plate 6, Figure 3 (arrowed at the inner side of the central layer).

The total thickness of the wall ranges from 10 to 15 μm. Its ultrastructure is granular with a grain size of about 0.1 to 0.2 μm (Plate 8, Figure 2). Only Ca and P are detectable by energy-dispersive X-ray analysis, both in large amounts. From this it may be concluded that the granules consist of calcium phosphate (apatite).

The second specimen shows the siphuncle in its primary position (Plate 2, Figure 4, arrowed). The substance of the siphuncle is as white as in the first specimen, but considerably more massive: a siphonal tube barely 1 mm in diameter has produced a compact phosphatic layer 0.2-0.3 mm thick. Using the scanning electron microscope, one can see that the phosphatic material consists of granules of exactly the same properties as described above (cf. Plate 8, Figure 2). It is of special interest that some phosphatic substance is spread beyond the boundaries of the siphuncle.

Discussion

Indications of the Depositional Environment

Ocean depth: Today, the ammonite-bearing beds occur at about 2800 to 2900 m (Site 363) and 3200 to 3400 m (Site 364) below sea level. The preservation of the ammonites suggests an ocean depth at the time of deposition somewhat less than today.

This is first suggested by the bodily incorporation of the ammonite shells into the sediment. The aragonite of the shell was not dissolved before burial, so the deposition site was above the aragonite compensation depth. With that the depth of deposition is not fixed, but a lower limit is set. The deepest embedding of aragonite in recent oceans was observed at the Rio Grande Rise, where pteropods and heteropods are dissolved in a depth of 3200 to 3400 meters (Melguen and Thiede, 1975)[1]. As a rule, the (open-ocean) aragonite compensation depth is, however, between 1000 and 3000 meters (Chen, 1968; Pilkey and Blackwelder, 1968; Bosellini and Winterer, 1975).

The authigenic formation of glauconite provides us with a further indication: there is general agreement that glauconite (in a broad sense) is formed mainly within a depth range of 20 to 700 meters (Cloud, 1955; White, 1974; according to Porrenga, 1967; 30 to 2000 m). Deeper occurrences of glauconite are known, but for the most part this glauconite seems to be detritic, except at the Scotia Ridge southeast of the Falkland Islands, where clay-mineralogic data indicate an authigenic origin at a depth of 880 to 3260 meters (Bell and Godell, 1967). However, the normal depth zone, where glauconite is formed, is on the outer shelf and the upper continental slope. In our case, such a "most probable" depth of formation agrees well with that based on evaluation of the ratio of benthic to planktonic foraminifers (see Bolli, this volume).

Hence, in spite of their deep present-day occurrence, these ammonites are no "deep-sea" ammonites.

Slightly reducing conditions: The occurrence of authigenic glauconite on the ammonites not only confines the depth range of deposition, but also—as is well known—indicates further details of the depositional environment, as for instance, slightly reducing conditions (see White, 1974: Eh 0-100 meV). Here we presuppose that the glauconite is of ordinary origin, that is, formed by halmyrolysis, corresponding to the observation that the glauconite is formed first in the succession of minerals.

(Slightly) reducing conditions in the uppermost bottom layers are also indicated by the fact that a part of the phragmocones was not filled by sediment. As far

[1]In marginal seas like the Mediterranean (Tyrrhenian Sea, Messina Cone) pteropods are preserved even up to the greatest depths of 3500 meters and almost -4000 meters, respectively.

as we know from other examples, phragmocones free of sediment seem to have been caused by a retarded oxidation of the organic components of the siphonal funnel or, in other words, by (slightly) reducing conditions.[2] This is compatible with the observation that deeper in the sediment our ammonites were slightly pyritized; in other examples of unfilled phragmocones, too, pyritized ammonites or other indications of reducing conditions were found in the sediment.

Remarkable Features of the Preservation

Shell fracture: It is remarkable that only in a few carbonate rocks ammonite shells are collapsed: usually the carbonate sediment hardened before sufficient stress and overburden was reached, or else the shells dissolved previously.

At Sites 363 and 364, most or perhaps all ammonites are fractured and collapsed; body chambers and filled and unfilled phragmocones are equally affected. Such a mode of preservation is more often found in clays or clay-rich sediments, where it results from late or poor induration, as at Sites 363 and 364.

Shell collapse requires a certain stress, if it is not caused or facilitated by dissolution. Our material does not show signs of dissolution at the time of collapse: fragments from the external side of the shell are still curved, indicating that the shell wall was hard at the time of collapse. Moreover, fragments are usually displaced against each other only a little: Hence the sediment was not soupy, but more or less stiff, perhaps comparable to plastic clays. Consequently, we have to assume a certain overburden at the time of collapse.

Shell solution: It is noteworthy that after the relatively late collapse the aragonite of the shell wall was finally dissolved and not transformed to calcite. Perhaps this is a consequence of the special sediments of these sites, which are rich in coccoliths and planktonic foraminifers (all calcite), so that the aragonite of the ammonite shell was one of the most soluble components.

Mineralization

Pyrite: Usually the pyrite of pyritized ammonites should be formed very close to the depositional interface at the expense of much sulfate, which has to be supplied by the seawater. In our case the mass of the pyrite formed deeper in the sediment, because it was formed after the stage of fracturing and, furthermore, fills joints, both indications of a certain overburden. It cannot be excluded that the formation of the pyrite began somewhat earlier, but only a relatively late formation can be proved.

Formation of pyrite below a certain overburden does not seem to be rare in chalk and sediments similar to chalk. In several serial analyses of pore fluids of deep-sea chalks, there is a break in the curve of sulfate at a depth of roughly 100 meters below the surface: up to this depth the decrease in the sulfate content is conspicuous (cf. Neugebauer, 1974, p. 159 and Fig. 4 and 5). This indicates a formation of (bacterial) pyrites as far as 100 meters below the depositional interface. The relatively "deep" formation of pyrite is of interest in connection with another peculiarity of the pyrite: it has the same characteristics as framboidal pyrite and its accompanying pyritic mass (cf. Schneiderhöhn, 1923; Neuhaus, 1940; Fabricius, 1961; and many others). The size, form, and distribution of the crystals are the same, and so is the diameter of the framboids; even the two size classes of framboids are found. If the crystals of pyrite in Plate 5, Figure 1, were to be dissolved, the remainder, the intercalated substance, probably would be similar to the "residue of soft microfossils" described by Love (1958).

Framboidal pyrite is often described as a filling of foraminifers, radiolarians, and ostracodes (for instance, Fabricius, 1961; Beall and Fischer, 1968). Its deposition on "pyritized" ammonites was not noticed hitherto, apart from Bayer, 1975, p. 20, who mentioned framboid-like pyrite on a liassic ammonite from northern Germany. The black powdery film of pyrite described here does not bear much resemblance to the ordinary pyrite of pyritized ammonites. Hence it has to be assumed either that the fine-grained framboidal pyrite usually recrystallized later (as we suspect) or that pyritization of ammonites by framboidal pyrite is an exceptional case.

It is peculiar that the pyrite marks only the outer wall of the shell, but not the septa. This could indicate that the septa are dissolved before the (late) formation of pyrite and before the solution of the shell; in one case a very early solution of the septa can be proven (see below).

Calcite: One can argue that the calcite is an artifact produced by evaporation, just like halite, which was often found. As soon as seawater has access, however, aragonite would be expected; the calcites of Plate 7 are therefore considered to be of diagenetic origin. If we follow Folk (1974), the elongated habit of the calcite results from a relatively high magnesium content in the pore fluid. The strange grooves, ridges, and clefts of these calcites cannot be explained at the present stage.

Relicts of the Siphuncle

Structure: According to Mutvei and Reyment (1973), the wall of the siphuncle consists of an inner fleshy siphonal cord, a thin outer primary conchiolin membrane, and a chain of rings in between: from septal wall to septal wall reaches a connecting ring, followed by an annular calcareous deposit; the annular deposit inserted at each septal wall and all connecting rings together form a continuous tube.

When comparing the relicts of the siphuncle to this structure, the thick central layer of the phosphatic sections of the tube (Plate 8, Figures 1-4) corresponds to the connecting rings, and the empty spaces between the phosphatic sections (Plate 8, Figure 6, arrowed) correspond to the annular deposits; the carbonate of the annular deposits has been dissolved like all carbonate of the ammonite shell. The interpretation of the outer lamellae, however, is not clear; Plate 8, Figure 1 may show the end of the attachment of a

[2]A filling indicates that the sediment had access to the septal chambers, normally through the siphonal openings, after the siphonal funnels were destroyed (Seilacher, 1976a).

"siphuncular" membrane[3] on the siphonal tube. Unfortunately, no further reconstruction is possible from this detached fragment of the siphonal tube. The interpretation of the inner lamella is completely open.

Composition: The siphonal funnels found in two ammonites are preserved in calcium phosphate (most probably in apatite). At present there is a question whether the calcium phosphate is a primary or a secondary constituent: siphonal funnels preserved in calcium phosphate have been well known since Grandjean (1911), but the most prominent authors, such as Schindewolf (1967), Erben and Reid (1971), and Mutvei and Reyment (1973), considered conchiolin solely the primary constituent, calcium phosphate being supplied by diagenetic alteration. By contrast, Andalib (1972), Bayer (1975), and Dauphin (1975) regard the calcium phosphate as a primary constituent.

The question cannot be settled without further investigations. An argument in favor of primary calcium phosphate is that when there are remains of ammonite siphuncles and they are tested with chemical or X-ray methods, they always contain calcium phosphate, regardless of facies and quality of preservation. Moreover, siphuncles of Nautilus are preserved in calcite even when they are found in the same bed as the siphuncles of ammonites (Grandjean, 1911; Andalib, 1972). But another fact reminds us to be careful: By analogy to the diagenesis of the phosphate of bones, the carbonate-fluor apatite of the ammonite siphuncles (Andalib, 1972) should be a diagenetic product derived from hydroxyapatite; therefore, diagenetic reactions and alterations are likely, at least at an ultrastructural scale.

In the light of this discussion it remains an open question whether the fine-grained structure of the siphonal wall of Plates 8 and 6 is original or not. However, the granules of calcium phosphate are nearly equal in size, and look very similar to a granular structure observed on the wall of the well-preserved ammonites from Lukow, Poland (the best material of Andalib, 1972). On the other hand, the granules of siphonal apatite, figured by Bayer (1975, Fig. 3) are twice as large as those in our figures.

Displacement of the siphuncle: The siphuncle of Plate 8, Figure 6 has been shifted without disruption from its originally external position very close to the inside of the whorl. This mode of preservation was hitherto unknown in phragmocones filled with sediment. The siphuncle moved as a whole and not in segments of the length of a chamber, which means: (1) The septa were dissolved previous to the displacement (but not the annular calcareous deposits) and (2) The chambers were still free of sediment or filled with a soupy sediment. The displaced siphuncle therefore proves a synsedimentary or very early diagenetic solution of the septa of this ammonite. This is in contrast to the diagenetic fate of the outer wall of the shell, which was dissolved at a somewhat later stage, according to the character of fracturing. Solution of the septa before solution of the outer wall also occurs in other beds (Seilacher, 1976b).

Comparison: Not taking into account a certain variability, which depends on the depositional environment (internal sedimentation, glauconite formation), the ammonites show a uniform and particular mode of preservation (fractured and collapsed shells, relatively late solution of the shell, non-fossilized septa, only slight mineralization, and framboidal pyrite). The question arises where in other beds these features occur together in a similar way.

Some ammonites from the lithographic limestone of Solnhofen (Tithonian, southern Germany) show a certain similarity, combining unfilled phragmocones, shell fracture, and shell solution (Seilacher, 1976b). However, fracturing (if occurring at all) is restricted to body chambers, and the phragmocones collapsed without fracturing (Seilacher, 1976b). It is noteworthy, that the Solnhofen limestone is also rich in coccoliths (Flügel and Franz, 1967).

The most similar mode of ammonite preservation we found comes from a very fine grained glauconite-bearing Santonian carbonate sandstone of Braunschweig, northern Germany[4]. The inner whorls of this ammonite are free of sediment and have collapsed; the outermost chambers are filled with sediment (similar to Plate 2, Figure 2). The ammonite is slightly pyritized by black (apparently framboidal) pyrite, and the shell is fragmented and was later dissolved away. The only essential difference seems to be pyritization of the septa before their solution. It has to be emphasized that this sandstone is still as friable as chalky limestone.

RESULTS

The ammonites of Sites 363 and 364 show many specific features of fossilization, because of their "bad" mode of preservation. These characteristics result from differences in the structural, mechanical, and chemical properties of the outer shell, the septa, and the siphuncle, which affected the course of fossilization, when the ammonites were exposed to a particular set of depositional and diagenetic conditions.

Studied in detail, the mode of preservation gives clues to the depositional environment. The ammonites, though presently found in great depth, were not deposited in a deep-sea environment; their most probable depth of deposition was within the range of the outer shelf down to the upper continental slope, indicated by the burial of the shell aragonite and the formation of glauconite on it. In addition, the glauconite, and in an even higher degree the incompletely filled phragmocones, indicate slightly reducing conditions in the uppermost layers of the ocean floor.

The diagenetic fate of the ammonites is above all governed by the poor and late induration of the surrounding sediment. Consequently, the shells are more or less fractured and collapsed, a phenomenon

[3] = Kammerlamelle Schindewolf's (1967). One siphuncular membrane "seems to be subdivided into two sheets, which are fused together dorsally from the siphuncular tube" (Erben and Reid, 1971).

[4] *Hauericeras pseudogardeni*, Ziegelei Weinsberg. Museum Geol.-Paläont. Institut Tübingen.

rarely found in other carbonate rocks. Later on, the shells were dissolved instead of being transformed to calcite.

A further peculiarity is the framboidal pyrite. It was formed here under a certain overburden; hitherto it was thought that the formation of framboidal pyrite is restricted to a very early stage of diagenesis (Füchtbauer and Müller, 1969, p. 260).

Relicts of the siphuncle are exposed in two of the ammonites. The bodily preserved parts, which in the main correspond to the connecting rings, are preserved in calcium phosphate (apatite), and consist of very fine granules. The question whether the calcium phosphate and the granular structure are of primary or secondary origin needs final clarification. The connecting rings additionally show inner and outer lamellae.

In a sediment-filled phragmocone, the siphuncle was shifted for the length of half a whorl from the external to the internal side. This indicates that the septa were dissolved during deposition or in very early diagenesis, and therefore earlier than the outer shell of the ammonite.

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PLATE 1

Figures 1, 3, and 6 are whitened.

The beginning body chamber is marked by a triangle; since no suture lines can be observed, the boundary can be defined by different preservation of phragmocone and body chamber.

Figure 1 — *Phylloceras (Hypophylloceras) velledae* (Michelin), Hypotype, Naturhist. Museum Basel (NMB) J 28116.
Sample 363-32-3, 29-32 cm; depth ca. 560 meters. Middle Albian. 2/1.

Figure 2 — *Phylloceras (Hypophylloceras)* cf. *morelianum* (D'Orbigny). NMB J 28117.
Sample 363-37-2, 129-131 cm; depth ca. 655 meters. Upper Aptian (?). 2/1.

Figure 3 — *Hamites tenuis* Sowerby. Hypotype, NMB J 28118.
Sample 364-37-2 (bottom); depth ca. 935 meters. Middle/upper Albian. 3/1.

Figure 4 — *Puzosia mayoriana* (D'Orbigny). Hypotype, NMB J 28119.
Sample 363-31-3, 37-39 cm; depth ca. 540 meters. Upper Albian. 2/1.

Figure 5 — *Puzosia mayoriana* (D'Orbigny). Hypotype, NMB J 28120.
Sample 363-31-3, 19-22 cm; depth ca. 540 meters. Upper Albian. 2/1.

PLATE 2

Figures 1, 4, and 5 are whitened.

Figure 1a, b — *Puzosia quenstedti* (Parona and Bonarelli). Hypotype, NMB J 28121.
Sample 364-29-2, 26-29 cm; depth ca. 775 meters. Upper Albian. 2/1

Figure 2 — *Beudanticeras* cf. *newtoni* Casey. NMB J 28122.
Sample 363-33-4, 149-151 cm; depth ca. 575 meters. Middle Albian. 2/1.

Figure 3 — *Cainoceras* cf. *angustidorsatum* van Hoepen. NMB J 28123. Arrows point to keel with siphuncle.
Sample 364-37-1 (top); depth ca. 935 meters. Middle/upper Albian. 2/1.

Figure 4 — Mortoniceratidae gen. et sp. indet. NMB J 28125. Overgrown by *Placunopsis*.
Sample 364-32-2 (bottom); depth ca. 935 meters. Middle/upper Albian. 1/1.

Figure 5 — *Cainoceras* n. sp. ex aff. *liberum* van Hoepen. NMB J 28124.
Sample 364-32-3, 60-64 cm; depth ca. 830 meters. Upper Albian. 2/1.

(see p. 724)

PLATE 1

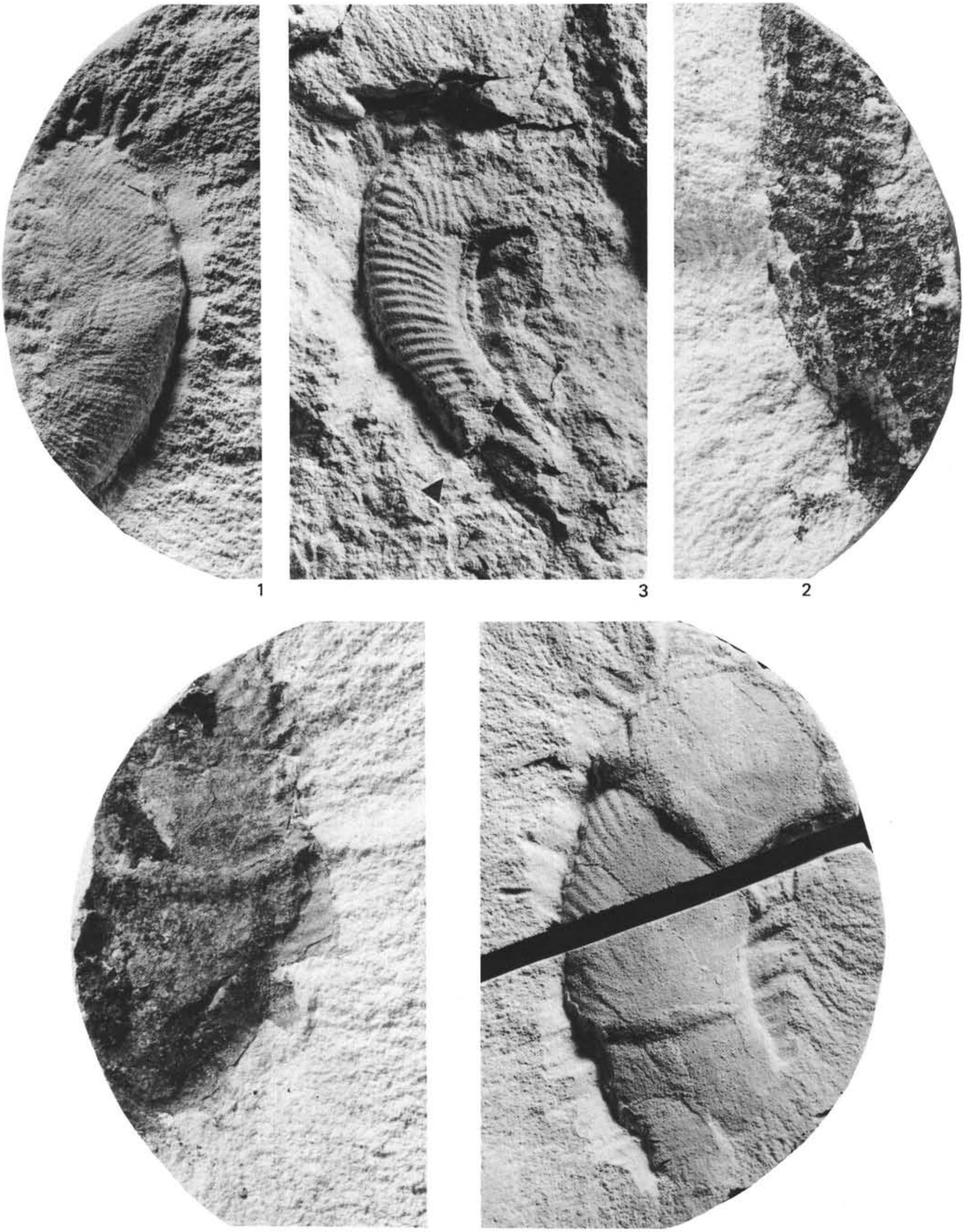

PLATE 2

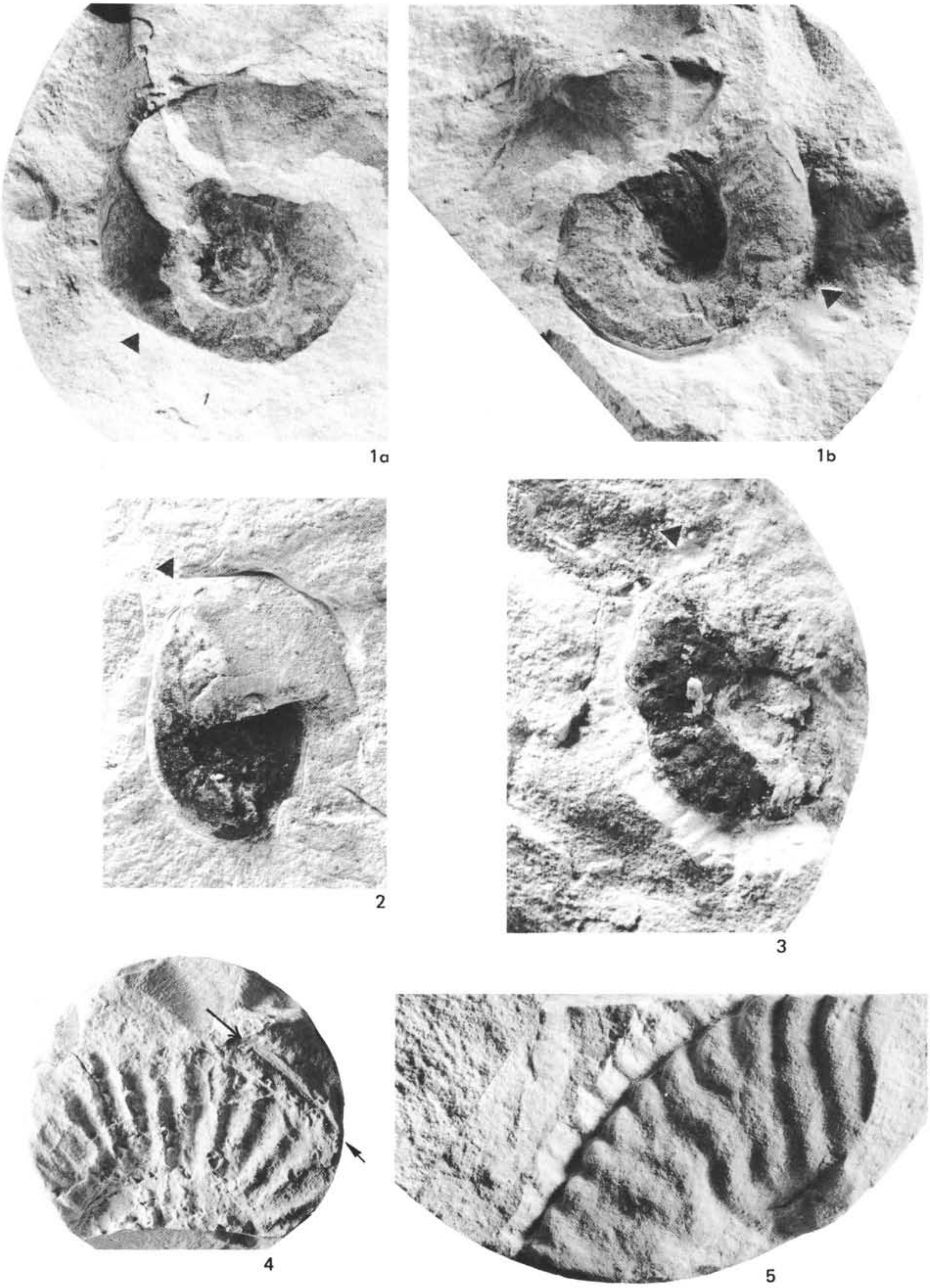

PLATE 3

Glauconite on the ammonites. All SEM samples of Plates 3-8 have been prepared solely by fracturing and C or Au/Pd coating.

Figure 1 Glauconite on *Puzosia mayoriana*.
Sample 363-31-3, 37-39 cm; SEM No. Tüb. 51138-3205-2b.

Figure 2 Glauconite on *Cainoceras*. No recognizable crystals.
Sample 364-32-3, 60-64 cm; SEM No. Tüb. 52058-3204-2a.

Figure 3 Energy-dispersive X-ray analysis of the glauconite of Figure 4, showing Mg, Al, Si, K, Fe of glauconite, Ca of calcite (adherent carbonate particles), and Na, Cl of halite (from water of imbibition). The Fe peak is of the same order of magnitude as the K peak and larger than the Mg peak. Vertical scale: 50,000 counts. Data of analysis: 20 KV, 2600 c/sec.×350 sec., carbon coated, No. Tüb. M 886.

Figure 4 The central area of this figure was analyzed for Figure 3. Glauconite on *Cainoceras*.
Sample 364-32-3, 60-64 cm; SEM No. Tüb. 52817-3204-2e.

(see p. 726)

PLATE 3

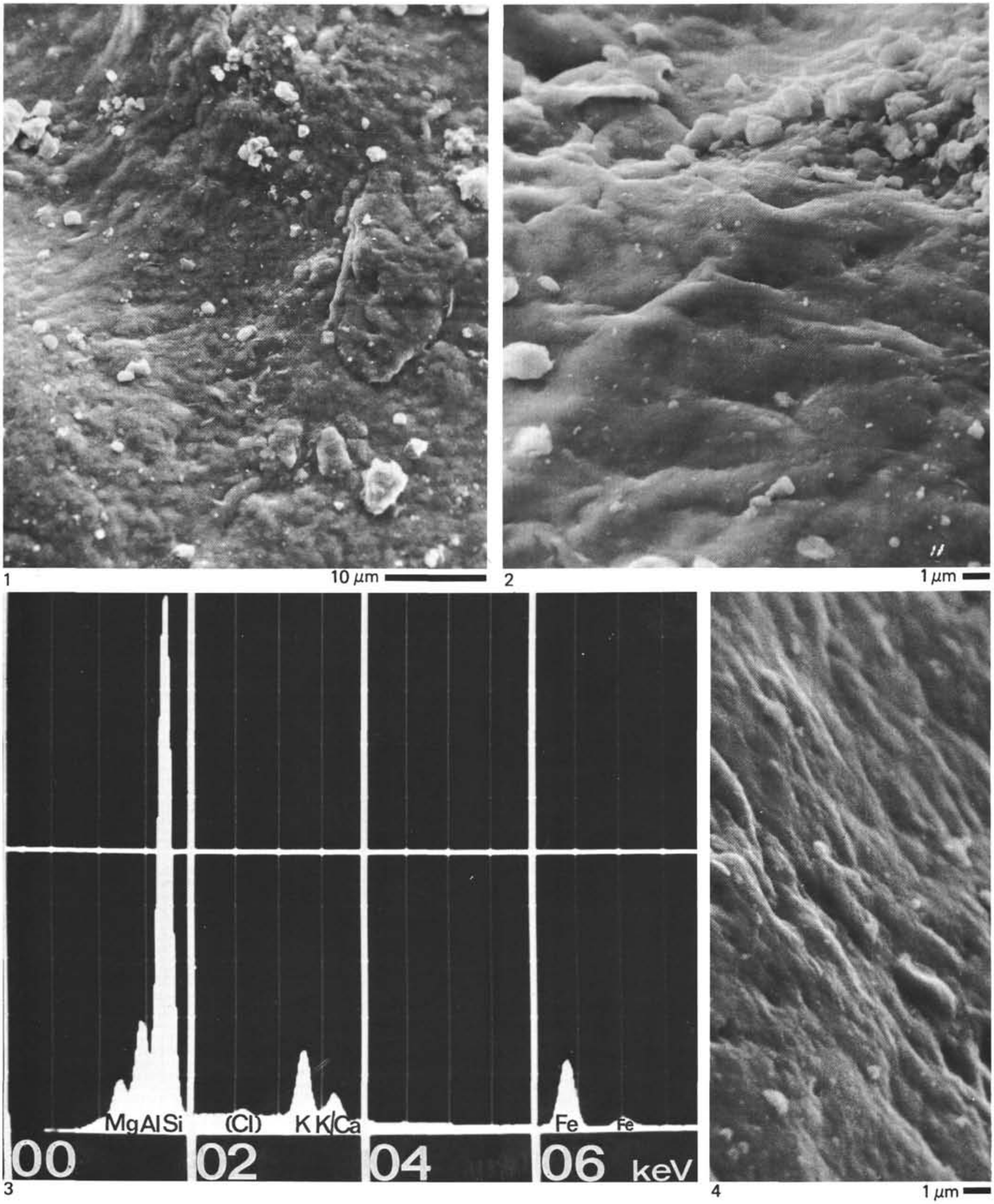

PLATE 4

Framboidal pyrite on the ammonites. Figures 1-3, 6-7: *Puzosia mayoriana,* Sample 363-31-3, 19-22 cm; Figures 4-5: *Puzosia mayoriana,* Sample 363-31-3, 37-39 cm.

Figure 1	Spheres of pyrite protruding out of a mass of pyrite. Surface of the pyrite film. SEM No. Tüb. 51746-3228-1a.
Figure 2, 3	Two size classes of pyrite spheres found on adjacent areas of the outer shell. Same scale in both figures. SEM Nos. Tüb. 51756-3228-2aa, 51743-3228-1a.
Figure 4	Free spheres of pyrite from the matrix rock. Note the different crystal habit; the distance of the sphere from the shell is 10-15 μm. SEM No. Tüb. 51116-3205-15b.
Figure 5	Detail of Figure 4. Octahedrons and hexahedrons are of equal importance. SEM No. Tüb. 51165-3205-15b.
Figures 6, 7	Comparison of the pyrite of the spheres (Figure 6) and of the mass surrounding them (Figure 7) using the same scale: the crystals are more densely packed at the surface of the spheres; the pyritic mass shows areas of bigger and smaller crystals; the octahedron is the dominant crystal form. SEM Nos. Tüb. 51754-3228-2aa, 51747-3228-1b.

(see p. 728)

PLATE 4

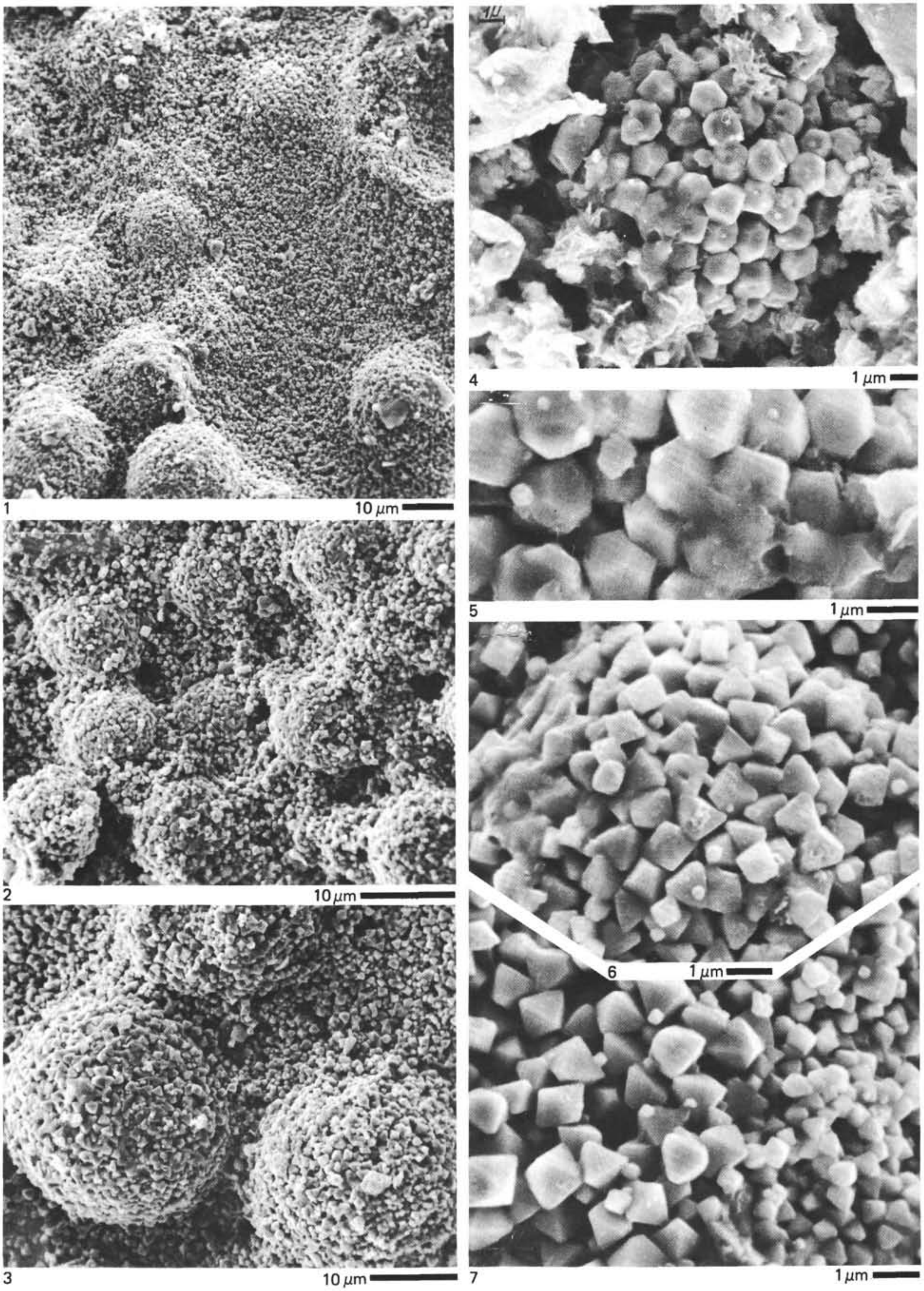

PLATE 5

Frambiodal pyrite on the ammonites (continued). Figures 1-4: *Puzosia mayoriana,* Sample 363-31-3, 37-39 cm; Figures 5, 6: *Puzosia mayoriana,* Sample 363-31-3, 19-22 cm.

Figure 1	An unidentified substance covers the framboidal pyrite (cf. the microfossils of Love, 1958). SEM No. Tüb. 51089-3205-1a.
Figure 2	The same substance is intercalated between the crystals of the spheres and of the pyritic mass. Big arrow: a sphere of pyrite in the process of disintegration into pyritic mass. SEM No. Tüb. 51124-3205-1c.
Figure 3	The substance connects the crystals of pyrite in form of fringes (arrowed: crystals?); see also Figure 2. SEM No. Tüb. 51090-3205-1a.
Figure 4	Crystal forms of the pyritic mass; the octahedron dominates, at times hexahedrons are added (arrowed). SEM No. Tüb. 51135-3205-2b.
Figures 5, 6	Crystal size of the bigger (Figure 5) and smaller (Figure 6) class of spheres; same scale. SEM Nos. Tüb. 51734-3228-1a, 51753-3228-2aa.

(see p. 730)

PLATE 6

Figures 1, 2: *Puzosia mayoriana,* Sample 363-31-3, 37-39 cm; Figures 3, 4: *Puzosia quenstedti,* Sample 364-29-2, 26-29 cm; Figure 5: *Puzosia mayoriana,* Sample 363-31;3, 19-22 cm.

Figure 1	Cluster of large crystals of pyrite (a disintegrated sphere ?) resting on a film of ordinary sized pyrite. SEM No. Tüb. 51163-3205-15a.
Figure 2	Enlargement of Figure 1; l = large-sized crystals of pyrite; m = middle or ordinary sized crystals of pyrite; see also Figure 4. SEM No. Tüb. 51161-3205-15a.
Figure 3	Broken-up siphuncle with infilling of pyrite; ws = wall of the siphuncle. Arrowed: inner lamella of the siphonal tube. SEM No. Tüb. 52564-3209-2.
Figure 4	Enlargement of Figure 3 with three size classes of crystals of pyrite; s = small, m = middle (ordinary), l = large. SEM No. Tüb. 52563-3209-2.
Figure 5	Pyritized fragments; pyritization varying in thickness; l = less heavily pyritized fragments. Arrowed: a relatively strong displacement, the plane of fracture covered by framboidal pyrite.

(see p. 731)

PLATE 5

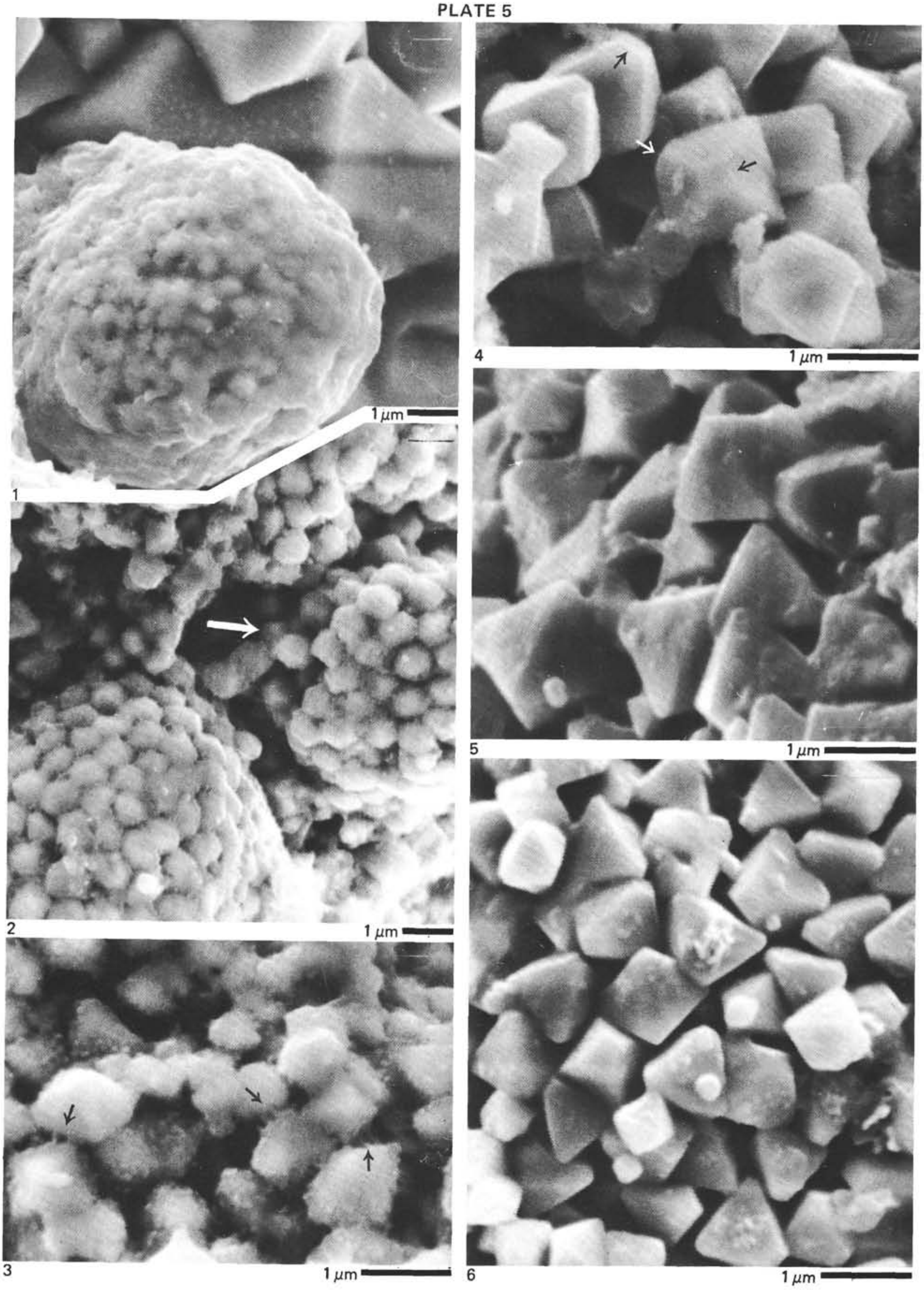

PLATE 6

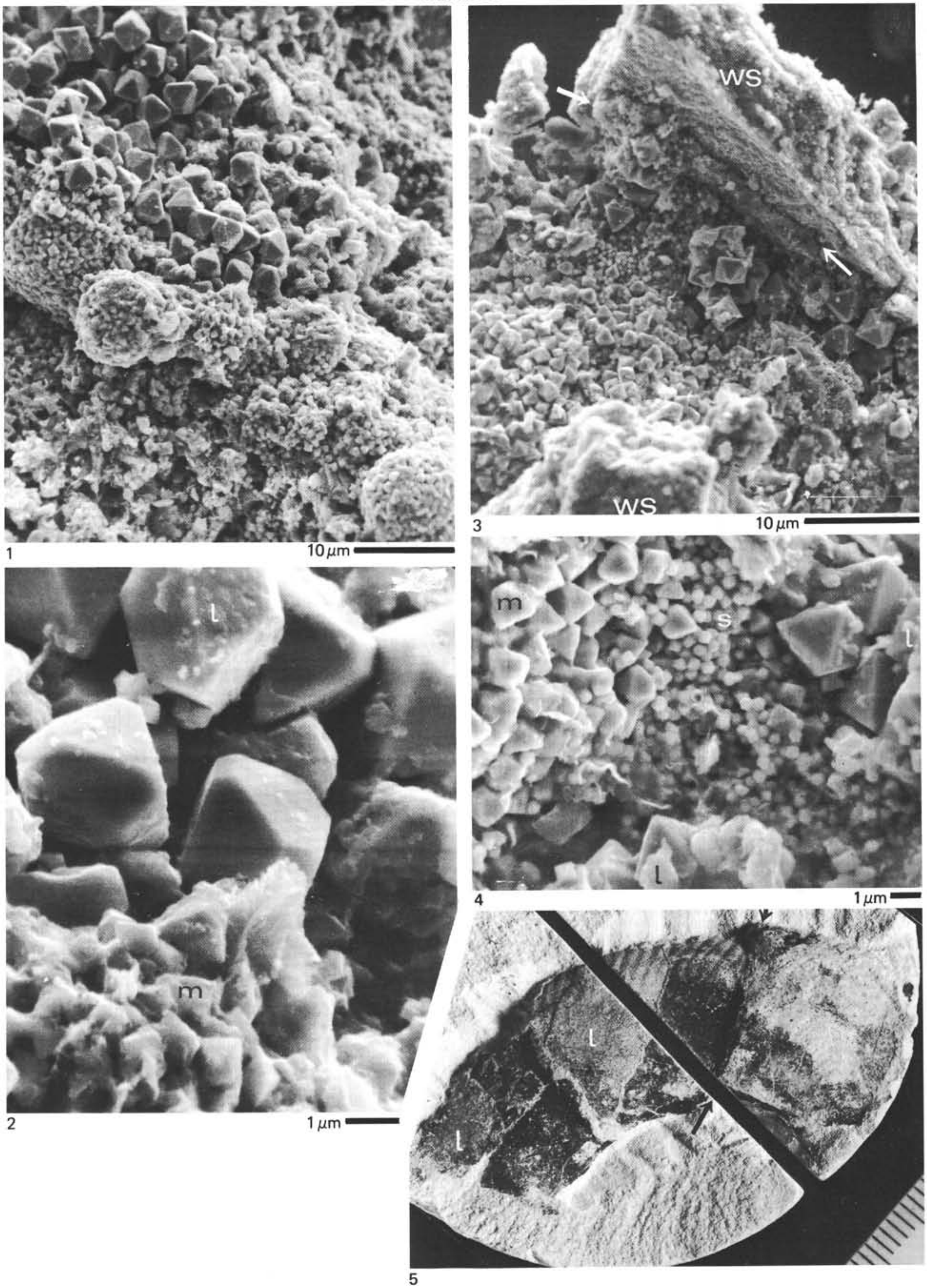

PLATE 7

Neogenic calcite on the ammonites. Figures 1, 2: *Puzosia mayoriana,* Sample 363-31-3, 37-39 cm; Figures 3, 5: *Cainoceras* cf. *angustidorsatum,* Sample 364-37-1 (top).

Figures 1, 3	Rosettes of calcite. SEM Nos. Tüb. 51118-3205-1a, 51784-3227-2a.
Figure 2	Peculiar grooves and ridges (arrowed). SEM Nos. Tüb. 51121-3205-1b.
Figure 4	Peculiar clefts and intergrowths. SEM No. Tüb. 51774-3227-1a.
Figure 5	Enlargement of Figure 4. SEM No. Tüb. 51773-3227-1a.

PLATE 8

Phosphatic relicts of the siphuncle. *Puzosia quenstedti,* Sample 364-39-2, 26-29 cm.

Figure 1	Fragment of a siphonal tube (connecting ring), outside view. The dashed line marks the edge of an outer lamella wedging out. SEM No. Tüb. 52556-4309-5.
Figure 2	Enlargement of Figure 1; granular calcium phosphate (apatite). SEM No. Tüb. 52553-3209-5.
Figure 3	Same fragment as in Figure 1, interior view. Dashed line: the edge of the outer lamella comes through to the inside. Crosses in Figures 1 and 2: identical points. SEM No. Tüb. 52571-3209-5.
Figure 4	Enlargement of Figure 3; interstice between the outer lamella and the thick main layer. SEM No. Tüb. 52570-3209-5.
Figure 5	Position of the exposed relicts of the siphuncle (black arcs). Area within frame see Figure 6. Triangle: boundary between body chamber and phragmocone.
Figure 6	Detail of Figure 5 with a continuous line of the displaced siphuncle. The arrows mark the position of the annular calcareous deposits. Dashed line: position of the whorls; dotted lines: siphuncle not preserved.

(see p. 734)

PLATE 7

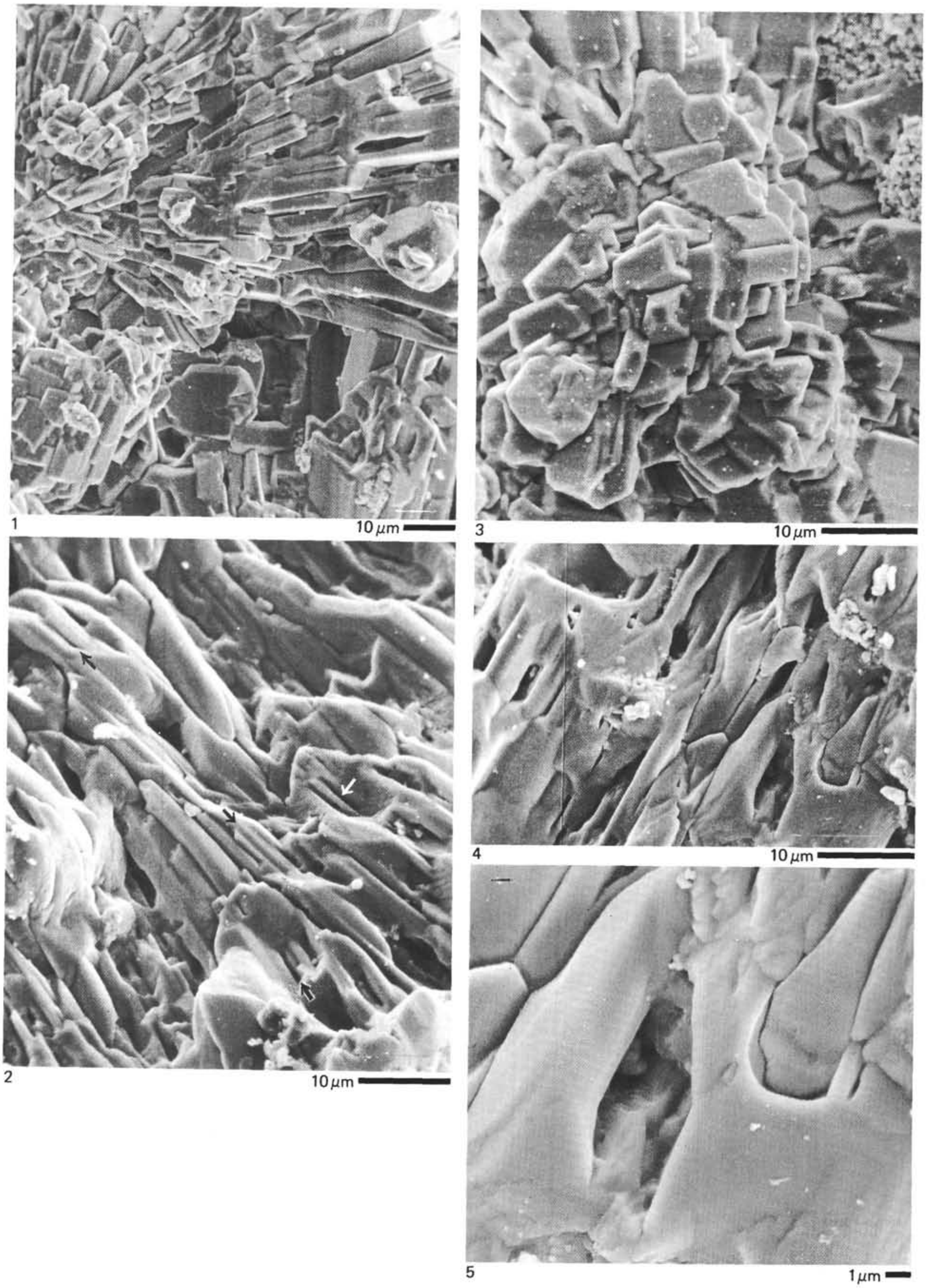

PLATE 8