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Modern Hydrothermal Activity, Formation of Complex Massive Sulfide Deposits and Associated Vent Communities in the Manus Back-Arc Basin (Bismarck Sea, Papua New Guinea)

By Werner Tufar

With 22 Figures and 2 Tables

Zusammenfassung

Anläßlich der deutschen Forschungsfahrt OLGA II mit dem Forschungsschiff „Sonne" wurden in der Spreizungszone des Manus-Back-Arc-Beckens (Bismarck-See, Papua-Neuguinea) eine Reihe von Hydrothermalfeldern entdeckt und erstmals beprobt. Die neu aufgefundenen Vorkommen zeichnen sich durch hydrothermale Mineralisationen aus. Es wurden hydrothermale Sulfid-Schornsteine, darunter sogar eine größere Anzahl aktiver Sulfid-Schornsteine („Raucher" bzw. „Schwarze Raucher") vom Ozeanboden der Tiefsee geborgen. Die komplexen Massivsulfiderz-Schornsteine sind vor allem durch ein Vorherrschen von Zink gekennzeichnet, daneben Kupfer und stellenweise etwas Blei. Gebunden an die aktiven Sulfid-Schornsteine ist eine charakteristische, reichhaltige hydrothermale Fauna mit vorherrschend Mesogastropoden, Seepocken, anomuren Crustaceen und Krabben, außerdem Pogonophoren, Polychaeten, Seeanemonen und anderen. Diese Fauna enthält eine Reihe bisher weltweit unbekannter neuer Arten. Ergänzend zu diesen Untersuchungen wurde eine detailbathymetrische Kartierung mit Strukturkartierung des Ozeanbodens über weite Profilstrecken mittels Tiefsee-Kartierungs-Fächerlotsystem (SeaBeam) durchgeführt. Es gelang eine genaue Aufnahme und damit ein exakter Nachweis der submarinen Tavui Caldera nördlich von Rabaul (Neubritannien). Außerdem wurde der Ozeanboden in Profilen zwischen der Insel Lihir und dem Emirau-Feni-Rücken kartiert sowie auf der gesamten Strecke der Überfahrten, beginnend in Suva (Fidschi) und endend in Port Moresby (Papua-Neuguinea).

Summary

During the German OLGA II Research Cruise of the Research Vessel "Sonne" several hydrothermal fields containing mineralizations were discovered on the Manus Spreading Center (Bismarck Sea, Papua New Guinea). For the first time from the ocean floor of the Bismarck Sea hydrothermal chimneys were recovered, among them a large number of active chimneys ("smokers"). These revealed the presence of

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predominantly complex massive sulfide mineralizations rich in zinc, besides some copper and in places some lead. Connected and associated with the active sulfide chimneys (smokers) is an abundant and diverse fauna consisting of mesogastropods, barnacles and other crustaceans, pogonophorans, polychaetes, sea anemones etc. including new species previously unknown throughout the world. In addition, bathymetric multibeam-sonar surveys (SeaBeam) were performed near Rabaul (New Britain) documenting the newly discovered submarine Tavui Caldera, and also between Lihir Island and the Emirau-Feni Ridge, as well as along the route of travel to the primary region investigated, starting in Suva (Fiji) and ending in Port Moresby (Papua New Guinea).

Contents

1. Introduction

For hardly longer than one decade divergent plate margins have been known as seafloor spreading centers characterized in places by zones of intense modern hydrothermal activity and mineralizations. Well-known examples are the East Pacific Rise and the Galápagos Rift and their respective complex massive sulfide deposits (e. g. Both et al., 1986, Corliss et al., 1979, Edmond et al., 1982, Francheteau et al., 1978, 1979, Hekinian et al., 1978, 1980, Malahoff et al., 1983, Spiess et al., 1980, Tufar, 1987, 1989, Tufar et al., 1984, 1985, 1986, Zierenberg et al., 1984).

Consequently, in the last few years the detection and investigation of modern hydrothermal activity and sulfide formation in back-arc basins has become especially interesting. Of particular interest in this context is the Manus Back-Arc Basin and its fast spreading center (Fig. 1) showing a spreading rate of greater than 100 mm per year. Concerning the tectonic position the Manus Basin shows a typical back-arc location with respect to the New Britain Arc-Trench System.

The evidence for hydrothermal mineralization on the seafloor at a water depth of around 2500 meters over a horizontal distance of approximately 150 m was reported by Both et al. (1986) from the northwestern Manus Basin, based on seafloor camera photos. These photos also show fauna (gastropod shell debris, crabs, horny corals) associated with inactive hydrothermal chimneys. Sampling by dredging from near the chimneys yielded neither biological material nor specimens from hydrothermal

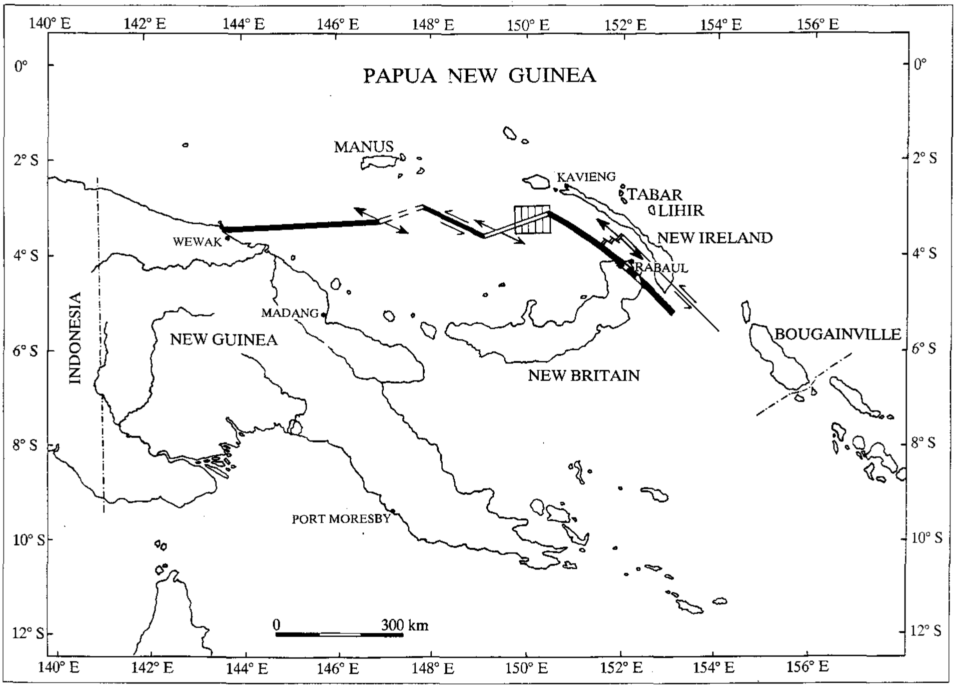

Fig. 1. Location map of Papua New Guinea showing the area investigated (hatched region) in the Manus Back-Arc Basin. Spreading centers and transform faults indicate the active plate boundary.

chimneys. Thus, the nature and mineralogical as well as chemical composition of these chimneys remained to be clarified.

In the past few years the investigation and clarification of the Manus Spreading Center and its hydrothermal activity and mineralization have assumed a high scientific priority internationally and therefore become a focal point of research cruises on the part of the Soviet Union, Japan and Germany.

The German Research Cruise OLGA II (**O**zeanische **L**agerstätten: **G**eologisch-Mineralogische **A**nalyse = Oceanic Deposits: Geological-Mineralogical Analysis) of the University of Marburg, under the direction of the author, was carried out with the German Research Vessel ''Sonne'' in the Manus Basin during May and June 1990. This expedition was the first to conduct a comprehensive economic-geological mapping of coherent deposits of modern hydrothermal mineralizations (smokers) in a back-arc basin with detailed statistical sampling.

2. Investigations along the route of travel from Fiji to the Manus Basin

At the beginning and the end of the research cruise a considerable number of geophysical traverses could be established along the route of travel. Starting in Suva

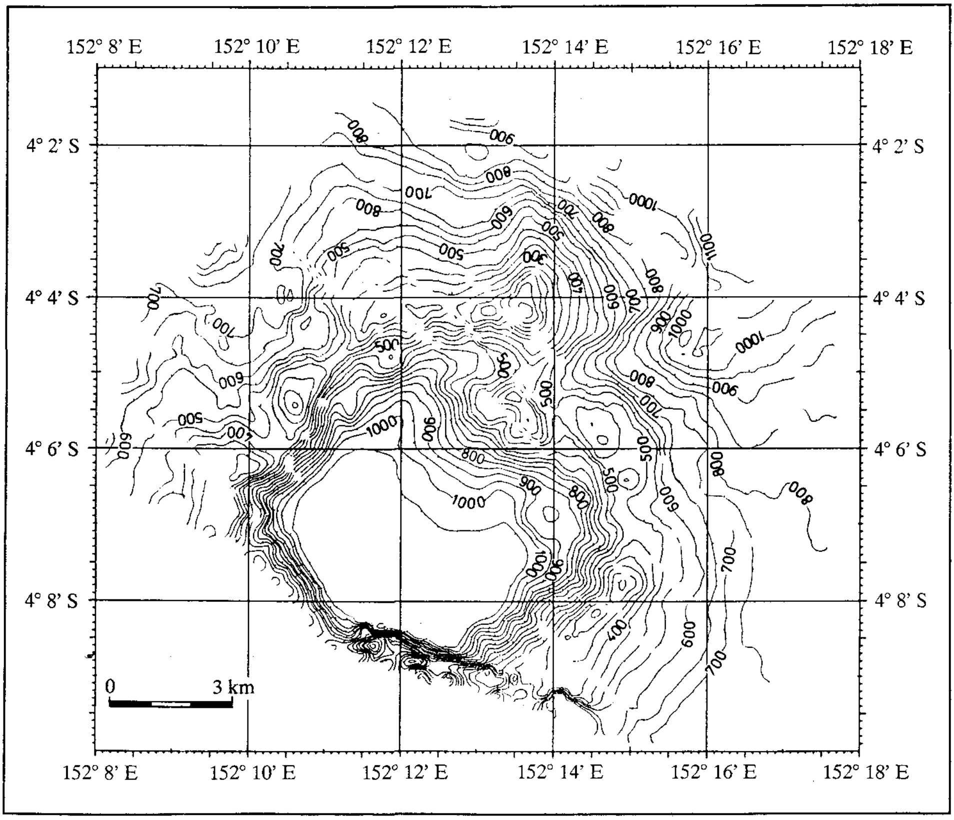

Fig. 2. Detailed bathymetric map of the submarine Tavui Caldera north of Rabaul (New Britain) (depths are in meters, with 50 m contour intervals).

(Fiji) the ocean floor was continuously mapped by bathymetric multibeam-sonar surveys (SeaBeam) across the North Fiji Basin, along the northern Vanuatu Arc and the San Cristobal Trench off the Solomon Islands, finally traversing the Solomon-New Britain Trench to Rabaul (New Britain, Papua New Guinea). Apart from bathymetric profiles, a major aim was to clarify the true nature of two suspected volcanic seamounts, the Kana Keoki and the Coleman southwest of Rendova, central Solomon Islands. At least for the Kana Keoki seamount there is good evidence for a central crater (caldera), indicating its volcanic origin, while the exact topography of the Coleman seamount remains unclear.

In accordance with the high priority for study by the Papua New Guinea Government the newly found submarine Tavui Caldera just north of Rabaul was mapped at their request in detail by SeaBeam surveys (Fig. 2). This mapping took place in close cooperation with SOPAC (South Pacific Applied Geoscience Commission) and the Department of Minerals and Energy, Geological Survey of Papua New Guinea. Besides the exact morphology of the Tavui Caldera, the presence of numerous previously unknown satellite cones could be shown. Samples recovered by dredging exemplify the dominance of various types of pumice with some pyroclastic material and samples of rhyodacite on the caldera floor.

3. Investigation of the Manus Spreading Center

The main aim of the OLGA II Research Cruise was an economic-geological investigation of the northeastern Manus Spreading Center, which was mapped in detail from 3° 42' S, 149° 37' E through 3° 0' S, 150° 34' E (Figs. 3-4) by SeaBeam profiling and OFOS (Ocean Floor Observation System) surveys, as well as by TV Grab studies, revealing a number of active hydrothermal areas associated with modern hydrothermal mineralizations. The presence of these modern active hydrothermal areas and mineralizations could be substantiated and localized within the central graben of the Manus Spreading Center from the northeastern to the southwestern end of the area investigated.

Essential to all subsequent work is the detailed bathymetric mapping, which clearly demonstrates the presence of a linear spreading ridge. Readily detected is the variable morphology of the ridge along strike. While northeast of 150° 12' E a distinct central graben (water depth around 2400 to 2500 m) is discernible, it gradually disappears southwest of this point to eventually result in an axial high lacking the typical graben morphology (water depth around 2200 m). In the southwest a seamount was discovered, centered at 3° 31.9' S, 149° 52.4' E (Fig. 3).

Changes in morphology are invariably linked to changes in the lava types and in the chemistry of the volcanics and the spreading rate: while fast spreading and variable chemistry typify the southwestern part, more homogeneous volcanics and slow spreading are characteristic of the northeastern part. There, frequently occurring mid-ocean ridge basalt (MORB) is seen, in places also back-arc basin basalt (BABB). Typical of the northeastern part is the extremely widespread presence of homogeneous, dense, massive, mostly glassy pillow lavas and striated pillows in the central graben (Figs. 5-7). Minor lobate, sheet, pahoehoe, and aa lava flows occur and may mostly be attributed to a less moderate morphology. In the southwestern part sheet flows, lava flows of (ropy) pahoehoe (Fig. 17), lava tubes, mostly collapsed (Fig. 18), etc. commonly occur.

Typical tectonic structures, such as cracks, crevices, fractures, fissures (''gjars'') up to even a few meters across, chasms, faults, fault scarps etc. in the newly formed crust of the Manus Spreading Center, document an intense ongoing tectonization (Fig. 19).

3.1 Modern hydrothermal activity, sulfide deposits and associated vent communities

Distinct indications of hydrothermal activity (e. g. temperature anomalies, occurrence of hydrothermal precipitates, characteristic vent communities) were recorded at many places along the part of the ridge investigated. Furthermore, water samples often showed methane anomalies.

Of particular importance are four major hydrothermal fields (Hydrothermal Field 1 through Hydrothermal Field 4, Figs. 3-18, 20-22) discovered and localized along the part of the Manus Spreading Center investigated.

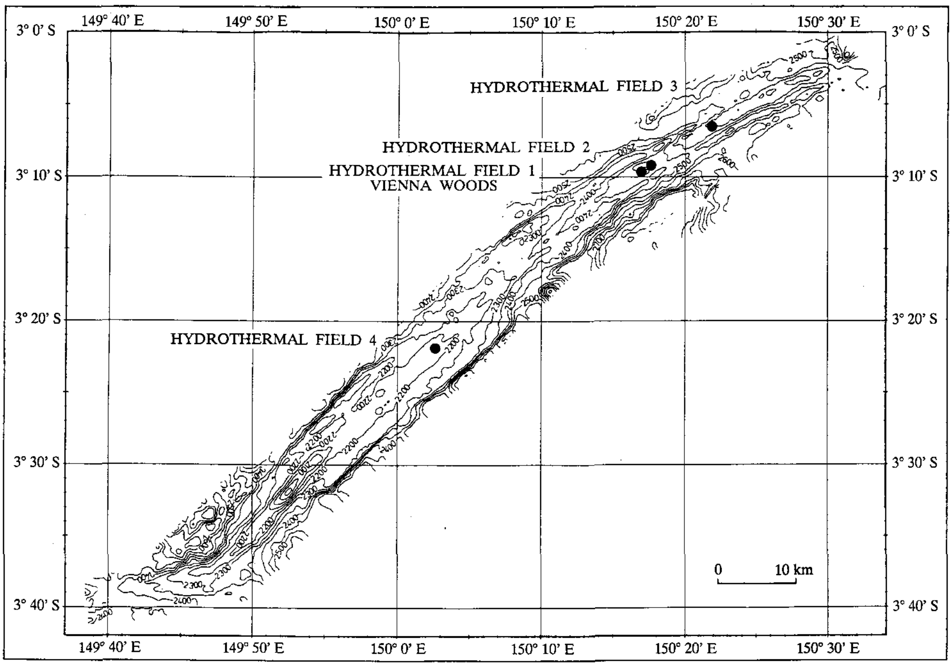

Fig. 3. Bathymetric map of the Manus Spreading Center from 3° 42' S, 149° 37' E to 3° 0' S, 150° 34' E showing the location of the four major hydrothermal fields (depths are in meters, with 50 m contour intervals).

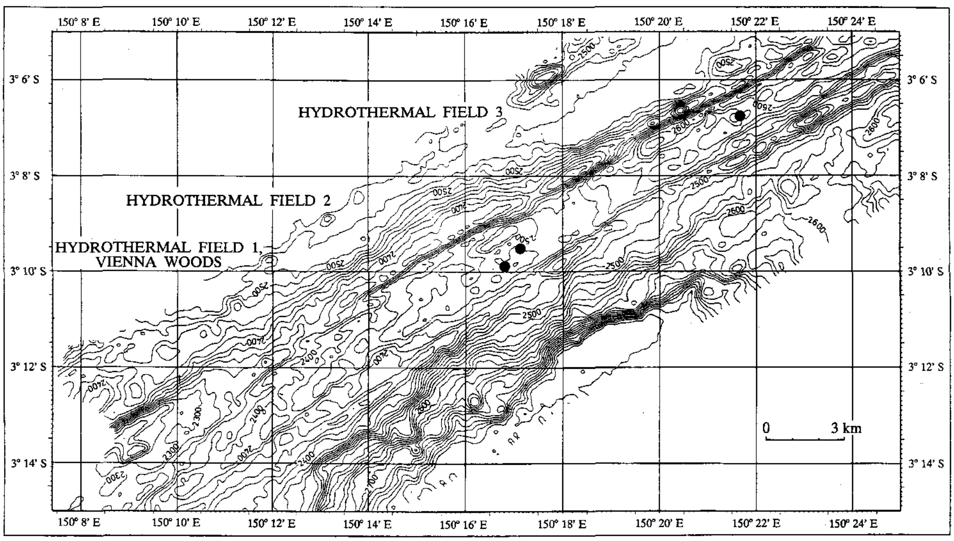

Fig. 4. Detailed bathymetric map of the Manus Spreading Center from 3° 15' S, 150° 8' E to 3° 5' S, 150° 25' E showing the location of Hydrothermal Field 1, Vienna Woods, Hydrothermal Field 2 and Hydrothermal Field 3 (depths are in meters, with 20 m contour intervals).

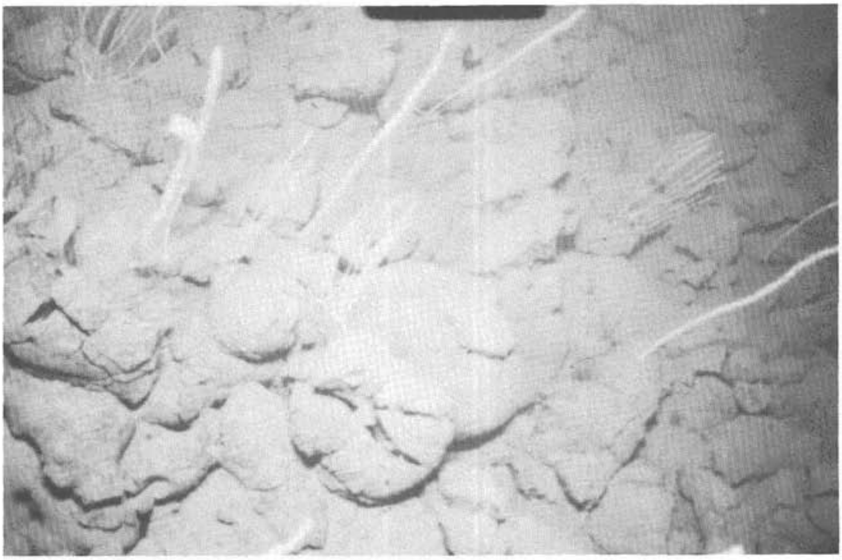

Fig. 5. Hydrothermal Field 3, 3° 6.69' S, 150° 21.65' E, water depth 2562 m. Abundance of antler-like soft corals and horny corals (Gorgonaria spec.?) living on pillow lavas and revealing rich nutrient supply.

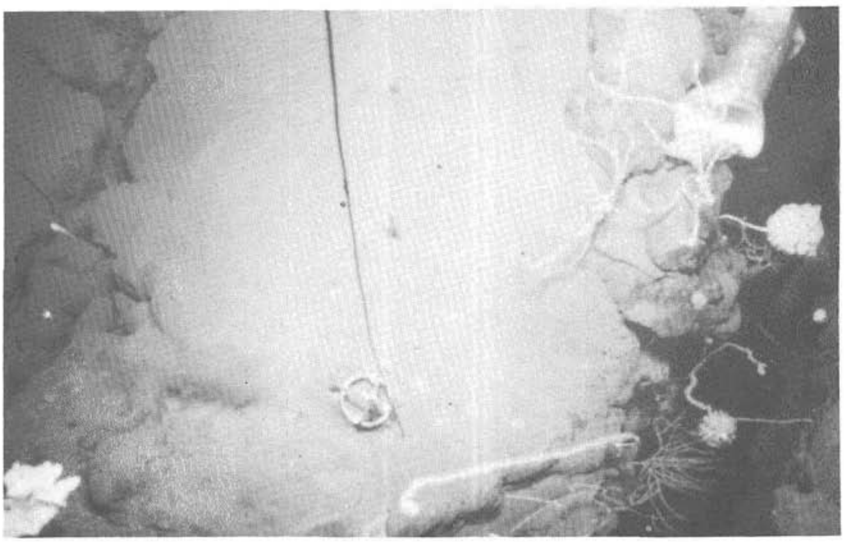

Fig. 6. Hydrothermal Field 1, Vienna Woods, 3° 9.85' S, 150° 16.82' E, water depth 2494 m.
Abundance of fauna such as dandelion-like siphonophores, antler-like soft corals and horny corals (Gorgonaria spec.?) together with a giant sponge living on pillow lavas in and near fractures (fissures, ''gjars''), indicating rich nutrient supply. The 26 cm diameter instrument basket at the end of the cable serves in addition as a scale (also valid for Figures 8-9, 19-20).

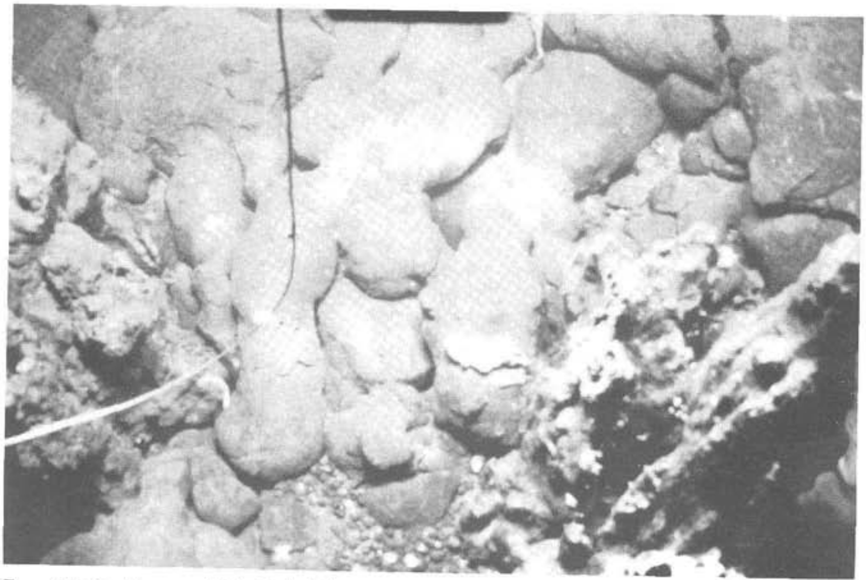

Fig. 7. Hydrothermal Field 1, Vienna Woods, 3° 9.79' S, 150° 16.79' E, water depth 2492 m.
Hydrothermal sulfide chimneys grown on pillow lavas. In places, gastropod shell debris (center of lower margin of photo), some galatheid crabs and locally a fish (right of center of upper margin of photo) can be seen.

Fig. 8: Hydrothermal Field 1, Vienna Woods, 3° 9.87' S, 150° 16.84' E, water depth 2486 m.
Galatheid crabs marching over sulfide chimneys, collapsed sulfide chimneys and gastropod shell debris, often partly dissolved.

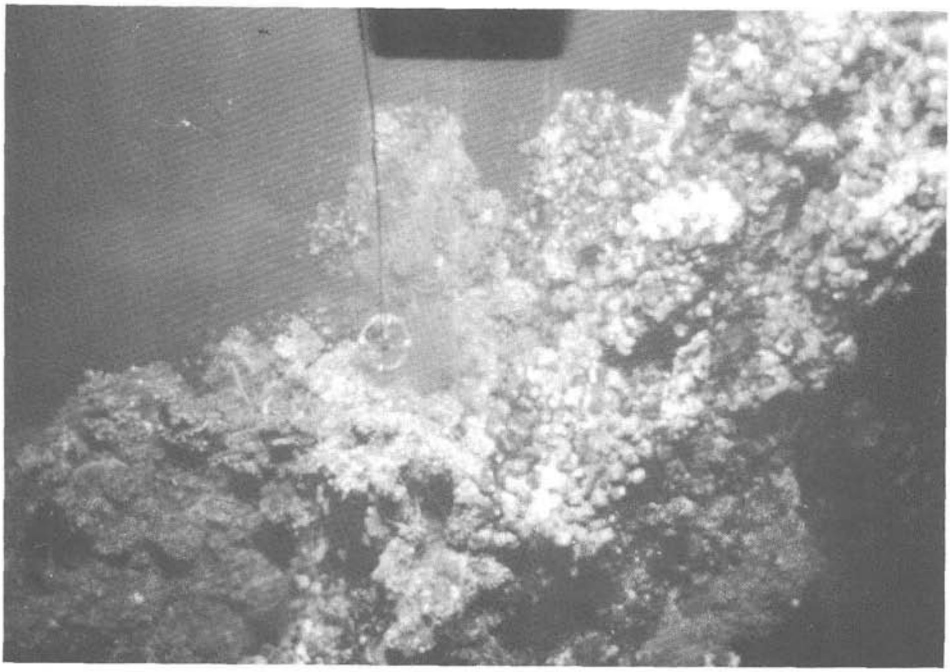

Fig. 9a

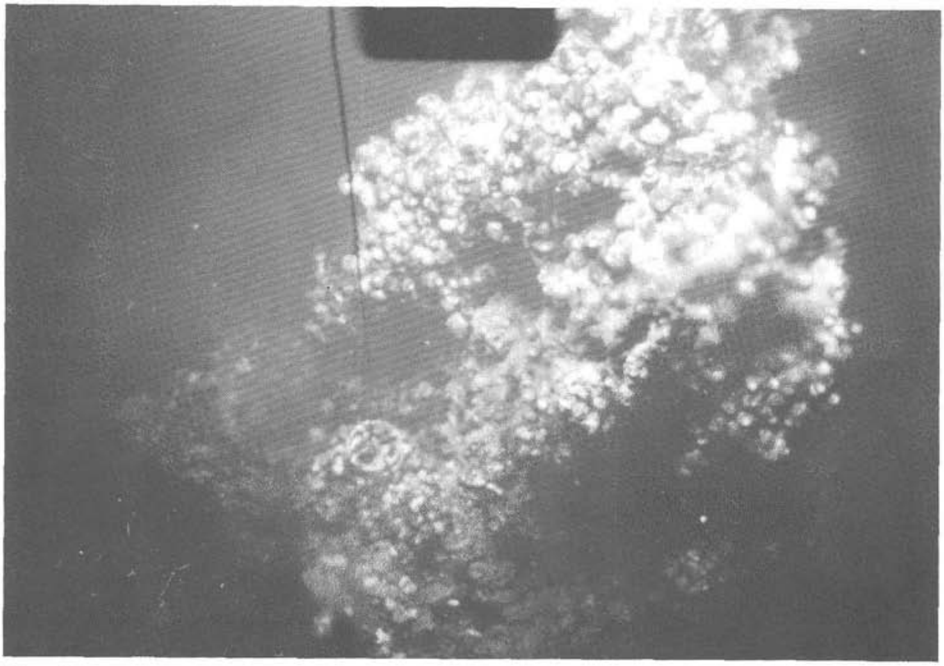

Fig. 9b

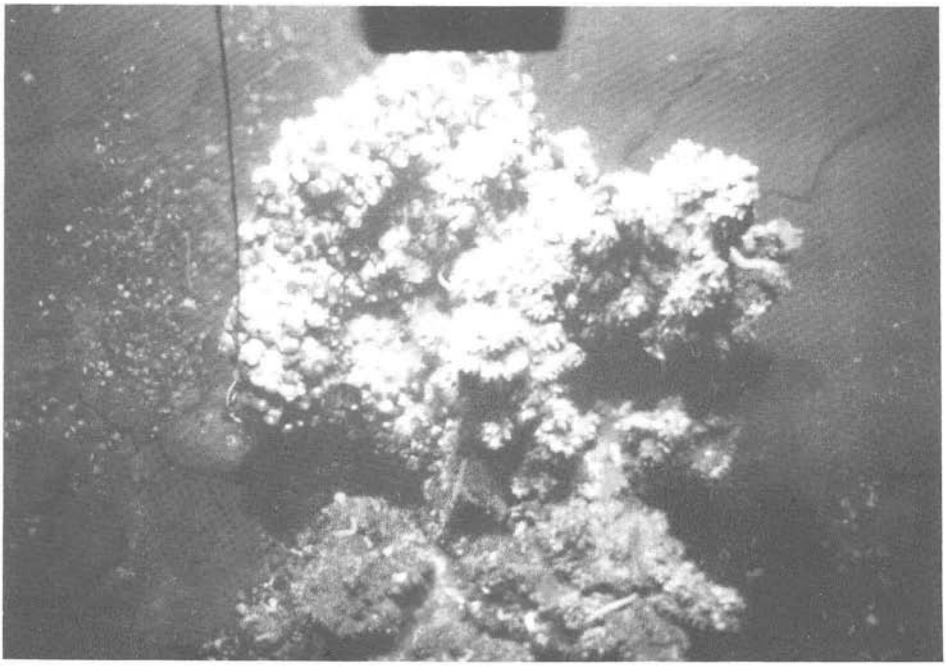

Fig. 9c

Fig. 9. Hydrothermal Field 1, Vienna Woods, 3° 9.79' S, 150° 16.79' E, water depth 2494 m (Figure 9a); 3° 9.40' S, 150° 16.92' E, water depth 2495 m (Figure 9b); 3° 9.88' S, 150° 16.78' E, water depth 2490 m (Figure 9c).
Active sulfide chimneys (smokers) densely coated by living gastropods, mostly black snails (new genus, new species), along with *Alviniconcha* cf. *hessleri,* as well as by barnacles (one or more new species; Figure 9c) and some pogonophorans (Figures 9a, 9c). In places some crabs are marching over the chimneys. More or less colorless hydrothermal solutions are seen to emanate from the sulfide chimneys running through these dense coatings of living gastropods etc. and causing "defocussing" effects because of the shimmering hydrothermal solutions (formation of schlieren).

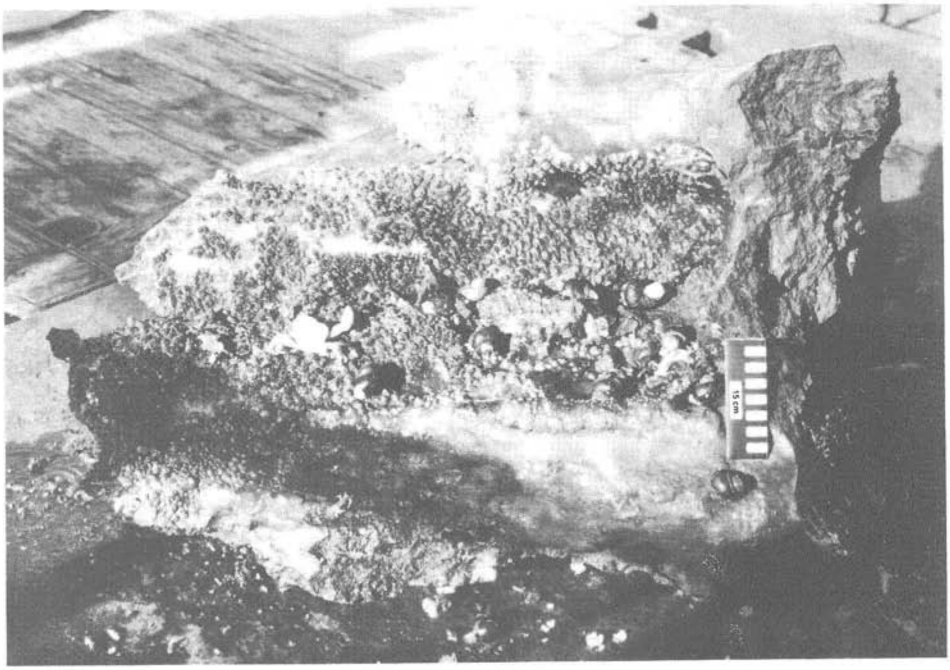

Fig. 10. Hydrothermal Field 1, Vienna Woods, Sample SO 68 - OLGA II - 17 GTVA, 3° 9.86' S, 150° 16.78' E, water depth 2500 m.
Large portion of an active, Zn-rich sulfide chimney densely coated by living barnacles (one or more new species), black gastropods (new genus, new species) and crabs. Photo taken immediately after recovering of the chimney from the ocean floor on board the German Research Vessel ''Sonne''.

Fig. 11a

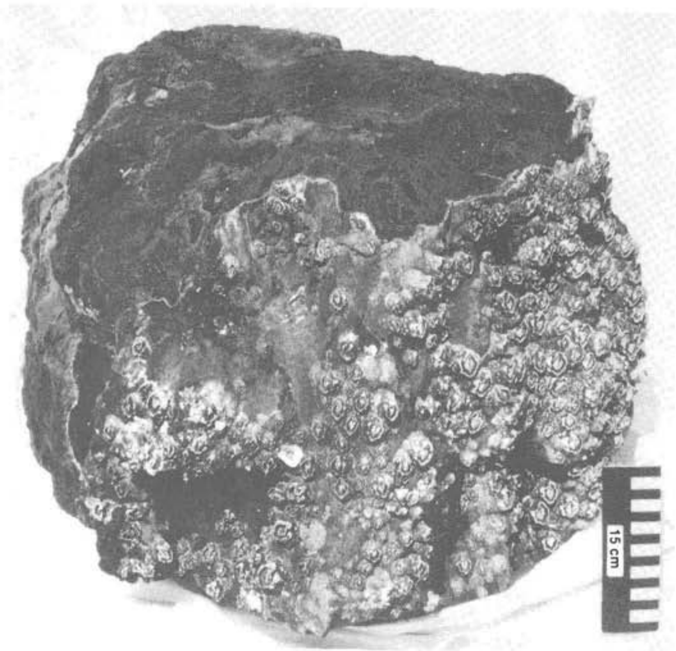

Fig. 11b

Fig. 11. Hydrothermal Field 1, Vienna Woods, Sample SO 68 - OLGA II - 26 GTVA, 3° 9.88' S, 150° 16.78' E, water depth 2491 m.
Portions of an active, Zn-rich sulfide chimney, densely coated by living barnacles (*Chionelasmus*?, one or more new species).

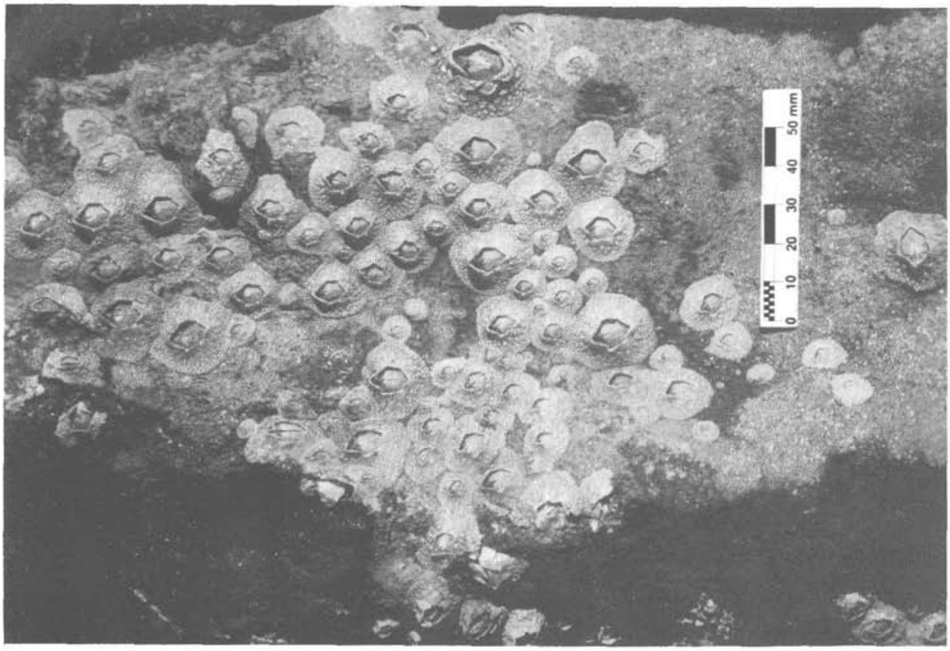

Fig. 12a

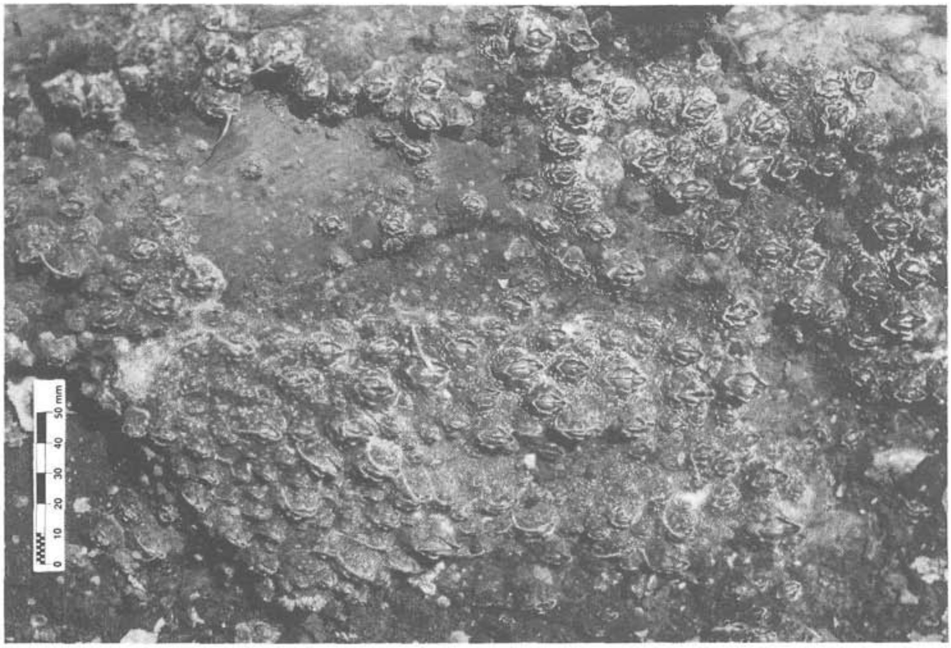

Fig. 12b

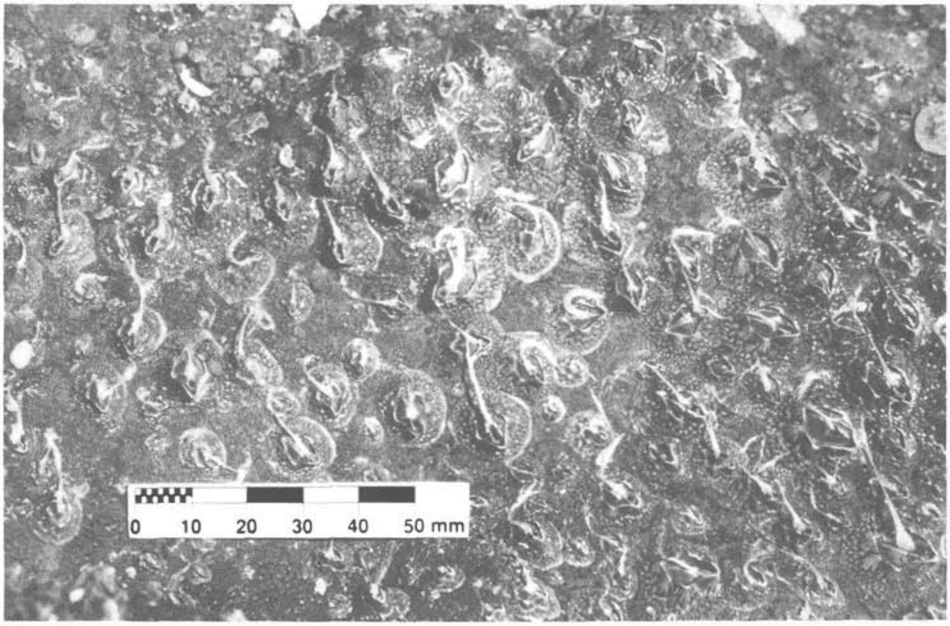

Fig. 12c

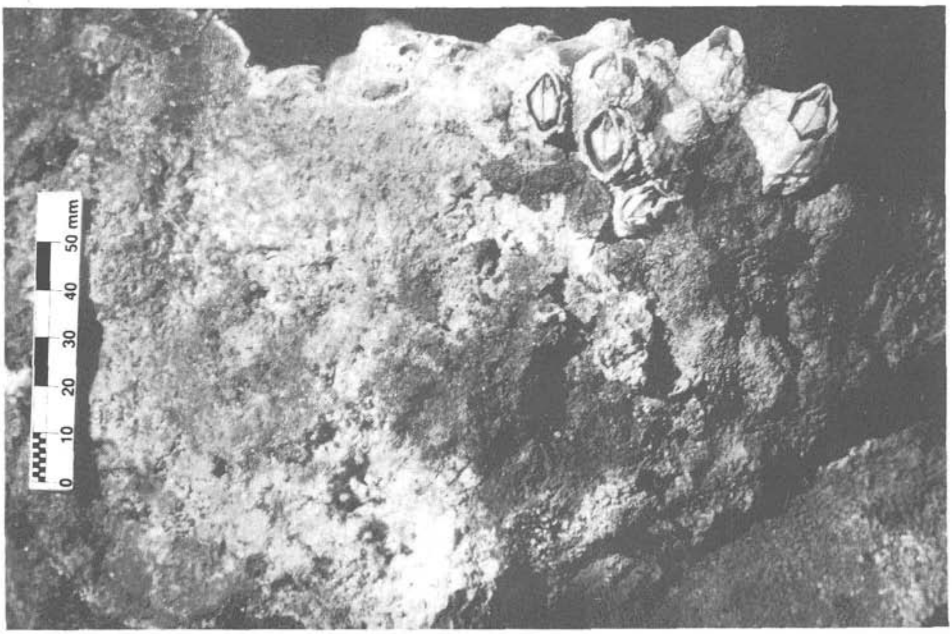

Fig. 12d

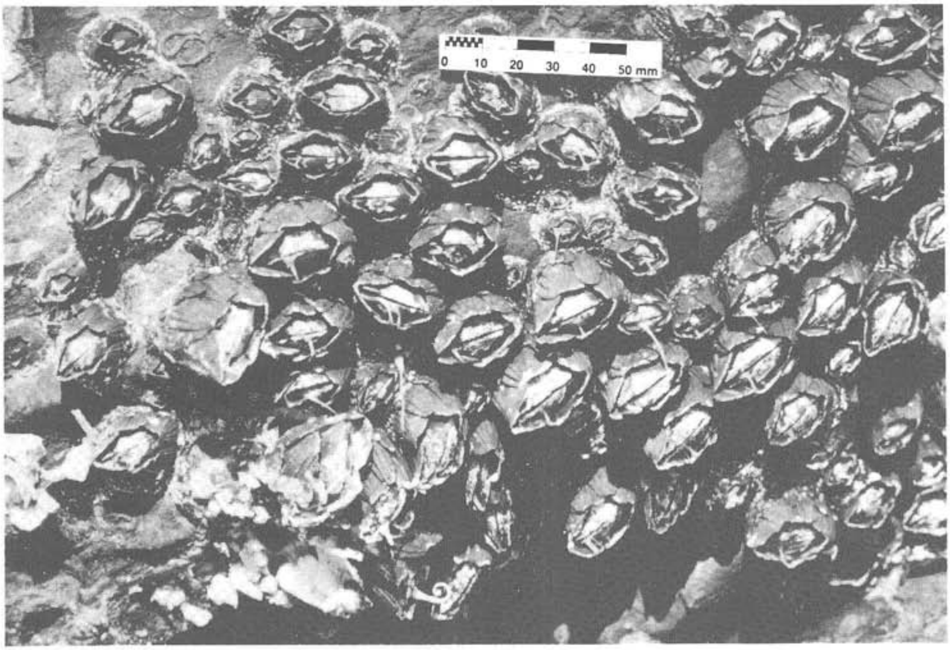

Fig. 12e

Fig. 12. Hydrothermal Field 1, Vienna Woods, Sample SO 68 - OLGA II - 15 GTVA, 3° 9.88' S, 150° 16.79' E, water depth 2491 m (Figure 12a); Sample SO 68 - OLGA II - 17 GTVA, 3° 9.86' S, 150° 16.78' E, water depth 2500 m (Figures 12b-12c); Sample SO 68 - OLGA II - 25 GTVA, 3° 9.86' S, 150° 16.79' E, water depth 2489 m (Figure 12d); Sample SO 68 - OLGA II - 35 GTVA, 3° 9.85' S, 150°16.80' E, water depth 2493 m (Figure 12e).

Details from active, Zn-rich sulfide chimneys exhibiting typical dense coatings of living barnacles (*Chionelasmus*?, one or more new species). In Figure 12d coatings of native sulfur (left upper portion of photo) occur together with barnacles. Photos taken immediately after recovering of the respective chimneys from the ocean floor on board the German Research Vessel ''Sonne''.

Fig. 13. Hydrothermal Field 1, Vienna Woods.
Living black snails (new genus, new species of mesogastropods) collected from the dense coatings of active sulfide chimneys on board the German Research Vessel ''Sonne'' after recovering of the respective chimneys occurring at water depths around 2500 m from the ocean floor. Typically, each black snail shell shows a partly dissolved apex. In places small limpets (new species) can be seen on top of shells of the black snail.

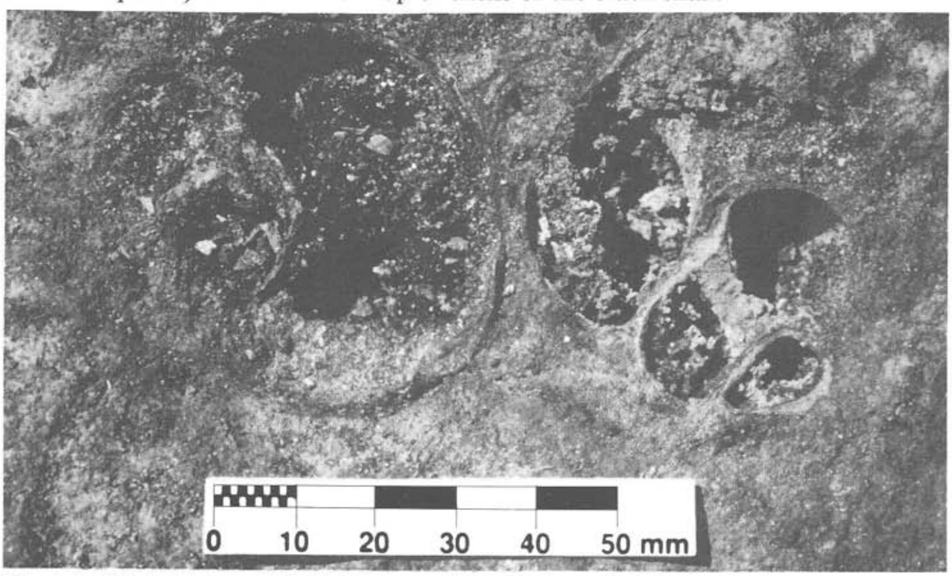

Fig. 14. Hydrothermal Field 1, Vienna Woods, Sample SO 68 - OLGA II - 16 GTVA, 3° 9.86' S, 150° 16.80' E, water depth 2494 m.
Detail of a Zn-rich sulfide chimney exhibiting modern fossilization of the black snail shells.

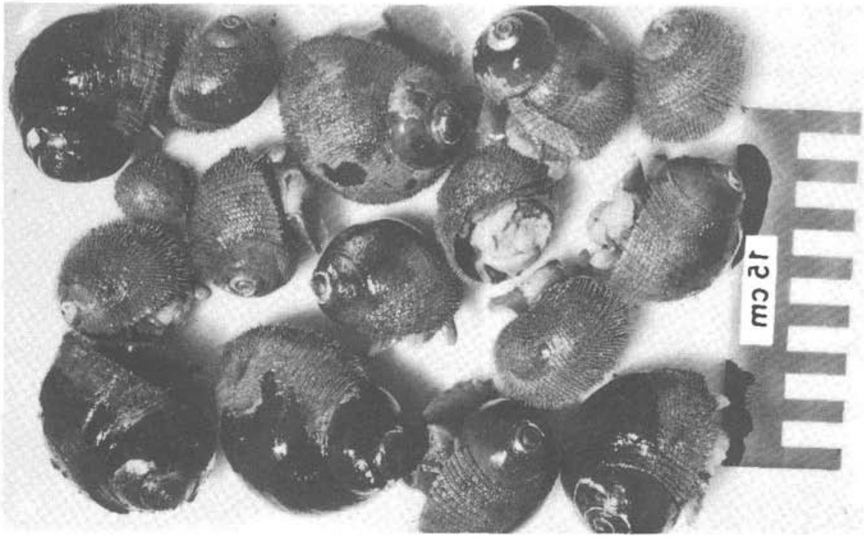

Fig. 15. Hydrothermal Field 1, Vienna Woods.
Living gastropods (*Alviniconcha* cf. *hessleri*) collected from the dense coatings of active sulfide chimneys on board the German Research Vessel ''Sonne'' after recovering of the respective chimneys from the ocean floor occurring at water depths around 2500 m. Typically, each gastropod shell shows a partly dissolved apex.

Fig. 16. Hydrothermal Field 1, Vienna Woods.
Living bythograeid crabs collected from the dense coatings of active sulfide chimneys on board the German Research Vessel ''Sonne'' after recovering of the respective chimneys occurring at water depths around 2500 m from the ocean floor.

Most strikingly, hydrothermal activity is documented in Hydrothermal Field 1, ''Wienerwald'' (''Vienna Woods'') (Figs. 3-4, 6-16), centered at 3° 9.86' S, 150° 16.78' E and extending for about 1000 meters along strike, by inactive - and even active - complex massive sulfide chimneys. The active chimneys (smokers) are seen to emanate colorless and milky smoke and in places to spew black smoke (black smokers). Commonly, outlets of the hot springs and vents are seen to branch off from central feeder channels, thereby causing lateral buildup of the chimneys. In places, repetition of this process has resulted in huge sulfide chimneys and columns which can reach to more than 20 meters in height. Several of these complex massive sulfide chimneys are encountered about the center of each hydrothermal vent, while the height and volume of the smokers are substantially reduced in places towards the periphery and show transition to crusts and/or low sulfide mounds. Very characteristic for the active chimneys is a dense coating consisting of gastropods, barnacles, pogonophorans, galatheid and bythograeid crustaceans etc. (Figs. 9-16). Besides sulfide chimneys and smokers, white smokers were also found, consisting of anhydrite and opaline silica, in places along with some barite.

Smaller in size and more or less inactive, but otherwise comparable with Hydrothermal Field 1, Vienna Woods, was Hydrothermal Field 2, centered at 3° 9.47' S, 150° 17.04' E and extending over a striking length of about 500 m.

Hydrothermal Field 3, discovered in the northeastern part of the ridge investigated (Figs. 3-4), centered at 3° 6.67' S, 150° 21.75' E, extends over a longer distance striking NE-SW along the ridge. It is characterized in places by smaller sulfide chimneys, but mostly by mounds consisting of hydrothermal precipitates (nontronite, iron and manganese hydroxides etc.) and in places by typical vent communities (gastropods etc.) directly comparable to those of Hydrothermal Field 1, Vienna Woods, thus also revealing a hydrothermal active stage for Hydrothermal Field 3.

Especially in the northeastern part of the ridge (Hydrothermal Field 1, Vienna Woods, through Hydrothermal Field 3) coating with hydrothermal precipitates, such as nontronite and manganese hydroxides, is frequently encountered around lava cavities. In proximity to hydrothermal vents, volcanics often display a thick cover of hydrothermal sediment (e. g. nontronite, manganese hydroxides) and in places considerable hydrothermal alteration. There, particularly in Hydrothermal Field 1, Vienna Woods, gradual transitions from altered and mineralized country rocks to sulfide precipitates are observed, together with stockwork mineralizations in the fissured and brecciated volcanics. Stockwork mineralizations pass directly over into sulfide chimneys. Moreover, peripheral grading of sulfide precipitates into oxides and hydroxides is apparent.

Peripherally, Hydrothermal Field 1, Vienna Woods, Hydrothermal Field 2 and Hydrothermal Field 3 can exihibit in places a significant growth of antler-like corals, horny corals and dandelion-like siphonophores, sometimes associated with some giant sea anemones and/or sponges (Figs. 5-6). The abundance of fauna occurring reflects a rich nutrient supply in the respective areas.

Hydrothermal activity, in places connected with formation of sulfide chimneys, was also recorded in the southwestern part of the Manus Spreading Center investigated, for example on the axial high of the spreading ridge far to the southeast at 3° 22.18' S,

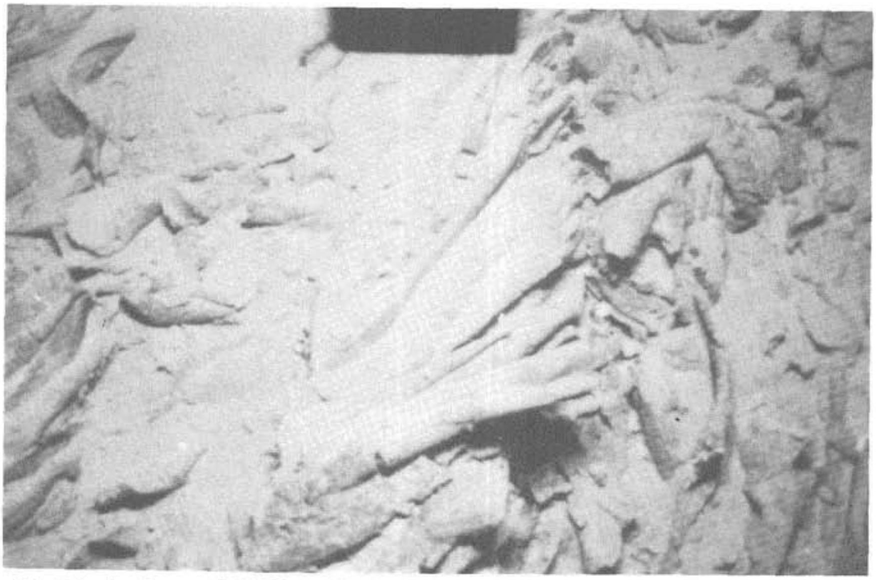

Fig. 17. Hydrothermal Field 4, 3° 22.28' S, 150° 2.37' E, water depth 2183 m. Typical ropy pahoehoe lava containing hydrothermal sediment (nontronite) in interstices.

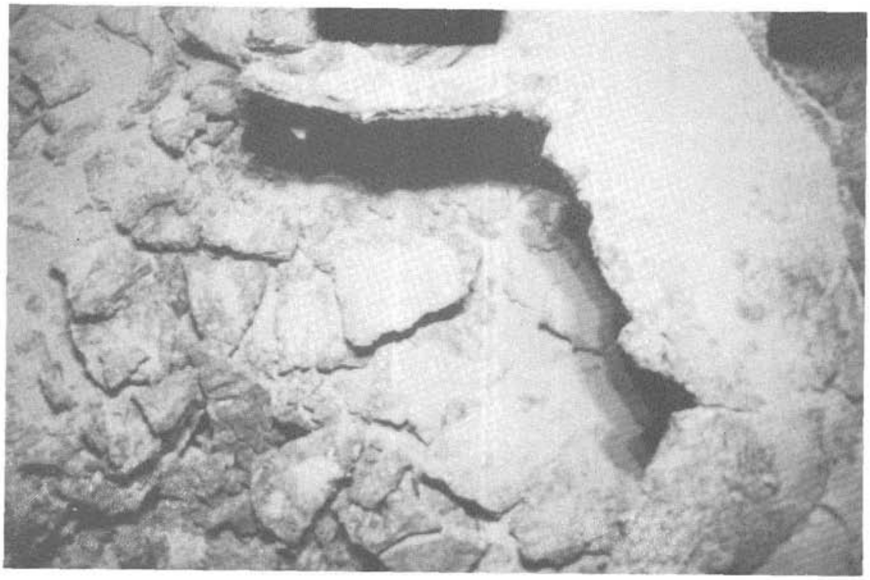

Fig. 18. Hydrothermal Field 4, 3° 22.50' S, 150° 1.91' E, water depth 2186 m. Collapsed lava tube coated with sediment, partly of hydrothermal origin.

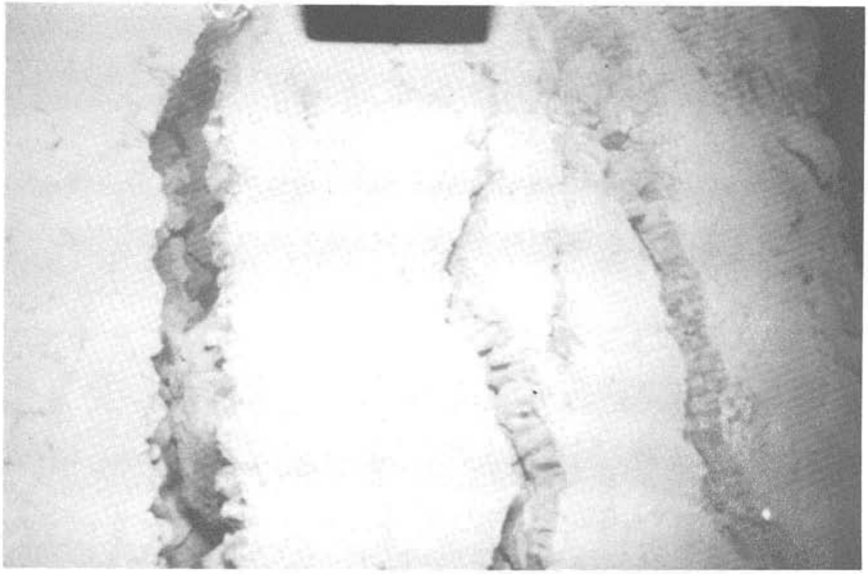

Fig. 19. Hydrothermal Field 4, 3° 22.50' S, 150° 1.91' E, water depth 2182 m. Set of subparallel fractures (fissures, ''gjars'') transsecting the axial high of the ridge.

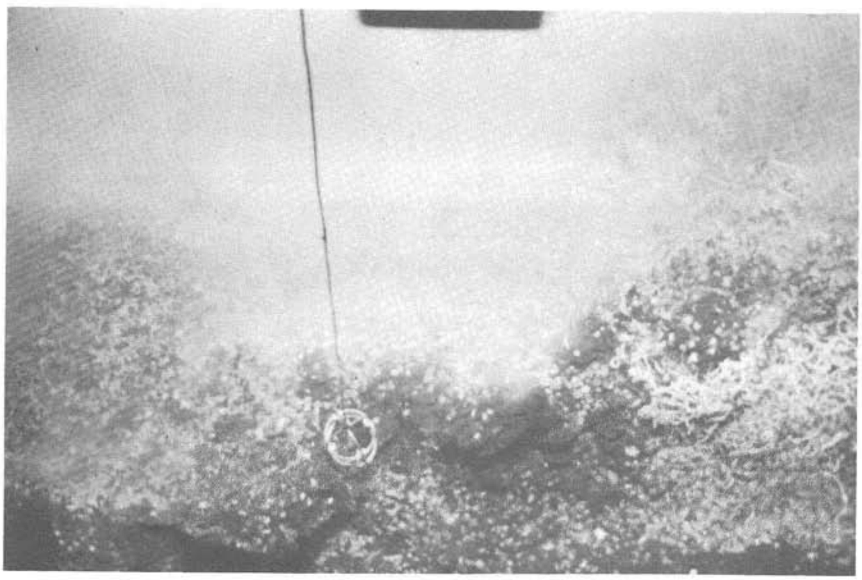

Fig. 20. Hydrothermal Field 4, 3° 22.26' S, 150° 2.20' E, water depth 2186 m. Hydrothermal vents emanating milky smoke associated with vent communities consisting of frequent thickets of tube worms (*Ridgeia* spec.), as well as galatheid crabs and bythograeid crabs.

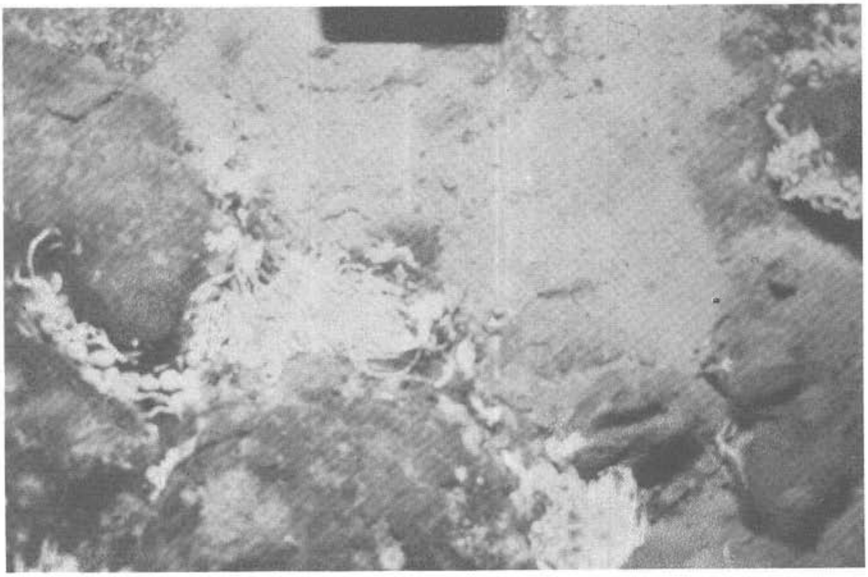

Fig. 21. Hydrothermal Field 4, 3° 22.27' S, 150° 2.16' E, water depth 2189 m. Pillow lavas hosting interstitial colonies (''bouquets'') of tube worms (*Ridgeia* spec.) together with pink sea anemones (new species). Distribution of fauna denotes the sites of hydrothermal venting.

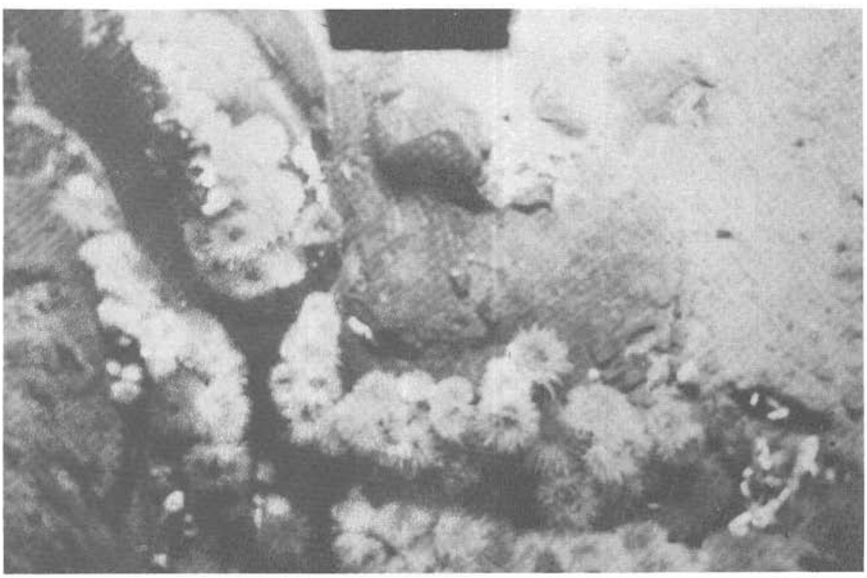

Fig. 22. Hydrothermal Field 4, 3° 22.27' S, 150° 2.16' E, water depth 2183 m. Colonies consisting mostly of pink sea anemones (new species) and some tube worms (*Ridgeia* spec.) bordering fractures in pillow lavas and indicating hydrothermal venting.

150° 2.24' E. Just as in the other areas, temperature anomalies are also obvious in Hydrothermal Field 4. Furthermore, emanating hydrothermal solutions causing milky smoke, even over some distance, are observed together with hydrothermal mineralizations and associated hydrothermal fauna (e. g. vestimentiferan tube worms such as *Ridgeia* spec., pink sea anemones, Figs. 20-22).

The complex massive sulfide mineralizations along the part of the Manus Spreading Center investigated are invariably restricted to the central graben. They occur in different spatial associations. Clusters of chimneys are commonly juxtaposed to or surrounded by partly fresh pillows. They display circular to elliptical outlines and a strong hydrothermal sediment coating of the intervening ocean floor. The linear distribution of hydrotherms may be attributed to fissures paralleling the spreading axis.

Table 1. Chemical composition of selected hydrothermal complex massive sulfide samples from Hydrothermal Field 1, Vienna Woods, and Hydrothermal Field 2 (in wt. %).

Sample	Fe	Zn	Cu	Pb	SiO_2
19	27.9	9.9	0.40	2.17	38.0
24	13.8	12.0	2.32	0.82	22.3
33	18.2	32.5	2.10	0.29	34.0
35	12.0	8.6	0.30	2.59	45.0
44	14.9	38.2	1.30	1.40	25.9
46	16.4	37.0	1.40	0.59	33.2
47	23.5	25.4	0.50	0.59	16.3
49	21.4	29.9	1.05	0.22	27.6
55	12.1	31.6	1.90	0.20	22.1
66	17.1	29.1	1.06	1.00	16.3
67	10.3	34.2	1.51	0.33	12.9
68	13.1	22.7	1.43	1.03	26.7
69	11.1	35.1	1.25	0.33	13.0
73	16.2	26.9	1.37	0.86	35.2
75	10.3	33.1	8.60	0.66	28.1
80	16.1	37.4	2.44	0.27	24.4
92	25.8	25.3	1.66	0.20	27.1
97	11.3	33.4	3.75	0.04	6.1
100	8.9	34.3	0.91	0.19	29.5
101	16.1	35.1	1.31	0.19	34.3
106	16.8	34.5	0.81	0.15	34.3
108	13.1	32.3	1.67	0.44	10.0
111	21.0	31.9	12.30	0.15	21.1
114	15.6	33.9	1.10	0.13	35.5
117	8.5	39.3	1.96	0.06	2.5

Particularly apparent is the content of base metals in the sulfide chimneys recovered from the Manus Back-Arc Spreading Center (Table 1). All samples exhibit a predominance of zinc sulfides, often amounting to an average of 30%–40%. Iron sulfides contribute 20%-30%, while copper sulfides are frequently present in considerable amounts (up to 5%, average of 2% or less). Locally, significant lead contents were determined (up to 2.5%). Major ore minerals are sphalerite, wurtzite, schalenblende, pyrite, marcasite, melnikovite-pyrite and in places chalcopyrite. Galena can be observed in places as an accessory ore mineral and sometimes as a minor or locally even as a major mineral constituent. In places the zinc sulfides contain relatively high concentrations of silver (up to several hundred grams per ton). This complex massive sulfide paragenesis is supplemented by variable amounts of gangue material (e. g. opaline silica, anhydrite, barite or native sulfur). The recovered portions of active sulfide chimneys often demonstrated the odor of hydrogen sulfide, even after being brought on board the research vessel.

Table 2. Preliminary list of selected fauna from the vent communities of Hydrothermal Field 1, Vienna Woods.

Mollusca
1. Gastropoda, Prosobranchia, Archaeogastropoda, limpets (three new species)
2. Gastropoda, Prosobranchia, Mesogastropoda, *Alviniconcha* cf. *hessleri*
3. Gastropoda, Prosobranchia, Mesogastropoda, black snail (new genus, new species)

Arthropoda
1. Crustacea, Cirripedia, Balanomorpha, *Chionelasmus*? (one or more new species)
2. Crustacea, Decapoda, Natantia, Bresiliidae, cf. *Rimicaris*
3. Crustacea, Decapoda, Reptantia, Anomura, Galatheidae
4. Crustacea, Decapoda, Reptantia, Brachyura, Bythograeidae

Annelida
1. Polychaeta, Sabellida, Serpulidae?
2. Polychaeta, Phyllodocida, Polynoidae
3. Polychaeta, Alvinellidae
4. Polychaeta, Syllidae?

Pogonophora

Tentaculata
1. Bryozoa

Cnidaria
1. Scyphozoa, Coronata, Nausithoidae, cf. *Stephanoscyphus*
2. Anthozoa, Hexacorallia, Actiniaria
3. Anthozoa, Octocorallia, Gorgonaria?
4. Hydrozoa, Hydroidea
5. Hydrozoa, Siphonophora

Porifera

A further characteristic of the modern hydrothermal activity is an abundant and astonishingly diverse hydrothermal fauna connected and associated with the modern metallogenesis. These vent communities, newly discovered by the OLGA II Research Cruise, consist of gastropods, barnacles, galatheid and bythograeid crustaceans, pogonophorans, polychaetes, sea anemones, octopods, fish etc., including new species previously unknown throughout the world (Figs. 8-16, Table 2). Very typical is the dense coating of the active chimneys, mostly by gastropods and barnacles, and also by pogonophorans, galatheid and bythograeid crustaceans etc., as exemplified in Hydrothermal Field 1, Vienna Woods (Figs. 9-13, 15-16).

These gastropods can even be found fossilized and pseudomorphosed in sulfide chimneys, representing an impressive document of modern fossilization (Fig. 14).

Mostly colorless hydrothermal solutions, exhibiting lower temperatures, are seen to emanate from the chimneys running through these dense coatings of organisms, partly dissolving the gastropod shells, especially their apex (Figs. 9, 13, 15). In places, high temperature black smoke is also observed jetting out of sulfide chimneys.

It is worthy of mention that the gastropods and crabs associated with active sulfide chimneys (smokers) and recovered with portions of these from the ocean floor, i. e. from water depths around 2500 m (pressure around 250 bar!) were still living on board the research vessel (atmospheric pressure only one bar!) over a period of up to two weeks.

In contrast to the vent communities of the active hydrothermal fields in the north-eastern part of the region investigated, the southwestern part of the Manus Spreading Center region investigated exhibits a hydrothermal fauna characterized by vestimentiferan tube worms (e. g. *Ridgeia* spec.) and pink sea anemones (new species) (Figs. 20-22). Due to the presence of vestimentiferan tube worms, these vent communities can be compared to some extent with those of the East Pacific Rise and the Juan de Fuca Ridge.

Chemoautotrophic, extremely thermophilic bacteria (archaebacteria), in the meantime observed in the laboratory in OLGA II active smoker samples, represent the nutritional basis for the fantastically abundant fauna associated with the hydrotherms and smokers.

Consequently, the nutrient supply and hence the type and diversity of the ecosystem is determined and restricted by the degree of hydrothermal activity. Active smokers (black smokers, as well as smokers emanating milky or colorless smoke) are typified by a dense biological coating of gastropods, barnacles, pogonophorans, galatheid and bythograeid crustaceans etc. Declining activity is characterized by a rapid decrease in these associated organisms, finally showing only a few barnacles. An even further decrease in hydrothermal discharge is documented by a gradual appearance of dandelion-like siphonophores, antler-like soft corals and horny corals, mostly along fissures associated in places with giant sea anemones. The subsequent extinction of all fauna and commencing oxidation (e. g. halmyrolysis) of the complex massive sulfide chimneys indicate the lack of reducing conditions and hence the cessation of hydrothermal activity.

4. Investigations near Lihir Island and along the route of travel to Port Moresby

At the end of the OLGA II Research Cruise, investigations were carried out near Lihir Island. This island is particularly distinguished by a modern hydrothermal gold mineralization, i. e. a gold deposit in statu nascendi. A bathymetric map was produced of the formerly unknown area between Lihir Island and the Emirau-Feni Ridge. A distinct upwarp of the ridge was recorded. Dredging yielded Tertiary limestone. OFOS and TV Grab studies near Luise Harbour (Lihir Island) revealed a uniformly dipping ocean floor of sediment which was morphologically featureless apart from occasional massive scattered blocks of limestone. Very slight temperature anomalies were also recorded. One small inactive chimney was observed. Sampling yielded calcareous sediment, while hard rock was not present.

Finally, during transit, a section paralleling New Ireland, across the Solomon Plate and through the western Woodlark Basin on the way from the Manus Basin past Lihir Island to Port Moresby was mapped by SeaBeam surveys.

5. Conclusions and outlook

The northeastern Manus Spreading Center examined during the German OLGA II Research Cruise exhibits differences in structures and morphology. Differences are also evident in the form and chemical composition of the volcanics (basalts). While the spreading center in the northeastern part shows a central graben bounded laterally on both sides by walls, this is not true for the southwestern part. There, the ridge occurs only as an axial high lacking a typical central graben structure.

In many places, indications of hydrothermal activity were discovered and localized, including four extended hydrothermal fields, characterized by mineralizations. Three of them are still active and furthermore typified by vent communities.

Of particular importance is Hydrothermal Field 1, Vienna Woods, exhibiting various kinds of active smokers, mostly rich in zinc sulfides and in places densely coated by organisms. These coatings of vent communities consist mostly of gastropods and barnacles, besides polychaetes, pogonophorans, crabs, shrimps etc. These vent communities contain new species previously unknown throughout the world, e. g. a black mesogastropod.

To a certain extent the present vent communities are comparable to those reported from the Mariana vents (e. g. HESSLER et al., 1988, OKUTANI and OHTA, 1988) within the Mariana Trough (Mariana Back-Arc Basin), particularly with respect to the occurrence of gastropods (*Alviniconcha hessleri*) in this new type of hydrothermal fauna.

In contrast to this hydrothermal fauna, the southeastern part of the Manus Spreading Center investigated, i. e. Hydrothermal Field 4, exhibits vent communities characterized by pink sea anemones (new species) and vestimentiferan tube worms (e. g. *Ridgeia* spec.), the latter comparable to vent communities typical of the East Pacific Rise and Juan de Fuca Ridge.

The main aim of the OLGA II Research Cruise, namely a detailed economic-geological investigation and mapping of coherent deposits of modern hydrothermal mineralizations in the Manus Back-Arc Basin with detailed statistical sampling, was realized very successfully.

The materials recovered provide good evidence for recent hydrothermal activity and extensive ore deposition at depths of between 2000 and 2500 meters below sea level with high concentrations of base metals (notably zinc and copper), significant amounts of silver and traces of gold.

Even a large number of active sulfide chimneys (smokers) could be recovered from the deep-sea ocean floor, together with associated hydrothermal fauna, providing in addition an excellent overview of these - in part - totally unknown new vent communities.

Most importantly, even though the goals of the OLGA II Research Cruise were decidedly economic-geological, the biological finds made were in fact equally as significant as the economic-geological results.

Of importance are also the SeaBeam mappings on the travel routes from Suva (Fiji) to the Manus Back-Arc Basin and from there via Lihir Island to Port Moresby. Of special interest in this connection is the detailed SeaBeam survey of the submarine Tavui Caldera north of Rabaul.

Furthermore, it is worth mentioning that the OLGA II Research Cruise serves as an excellent example of support to other research cruises and thus of international cooperation. At the midpoint of the OLGA II Research Cruise, i. e. at the end of May and beginning of June, 1990, the USSR Academy of Sciences ''Akademik Mstislav Keldysh'' 21st Research Cruise, under the direction of Prof. Dr. Lisitzin, came to the Manus Spreading Center to conduct investigations. The author provided detailed SeaBeam bathymetric maps and results of OFOS (Ocean Floor Observation System) and TV Grab studies, including the exact coordinates of the hydrothermal mineralized areas and active smoker fields and its associated - in part completely unknown throughout the world - fauna, together with samples to the ''Akademik Mstislav Keldysh'' 21st Research Cruise, as a fundamental basis for the diving program conducted with their two submersibles. This data significantly enhanced the effectiveness of the Russian submersible dives. The results and materials obtained by the OLGA II Cruise were impressively confirmed by the ''Akademik Mstislav Keldysh'' 21st Cruise.

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