

Mineralogical genetic groups of fine-psammitic and coarse-aleuritic fractions of the spreading sedimentary formation and some indicators of the submarine hydrothermal activity history (East Pacific Rise, 21° S)

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В. М. Деков, Е. Д. Мандова, В. П. Казакова — Генетические группы минералов мелкопсаммитовой и крупноалевритовой фракций осадочной формации спредингового хребта и некоторые индикаторы истории субмаринной гидротермальной деятельности (Восточно-Тихоокеанское поднятие, 21° ю. ш.). Применяя комплекс аналитических методов, детально исследован минеральный состав мелкопсаммитовой (0.10-0.50 mm) и крупноалевритовой (0.05—0.10 mm) фракций металлоносных осадков приосевой зоны Восточно-Тихоокеанского поднятия (20°30'—22°00' ю. ш.). Минеральный состав осадков данного района контролируется следующими факторами: удаленностью от континентальных массивов; глубиной океана; расположением полигона в южной аридной зоне и осевой части быстроспредингового хребта с активной гидротермальной деятельностью. Осадочная формация исследованного спредингового сегмента полигенная и в ее формировании участвуют семь генетических групп минералов: биогенная; терригенная; гидротермальная; эдафогенная; диагенетическая; гидрогенная и космогенная. Пелагический фон формируется главным биогенным карбонатом кальция и терригенными обломочными и глинистыми минералами эолового происхождения. Диагенетическое и гидрогенное минералообразование в данной обстановке имеют подчиненное значение. Тектоно-вулканические процессы в районе дают специфический "местный" материал в осадках — вулканогенно-эдафогенный, гидротермально-эдафогенный и гидротермально-осадочный.

В металлоносных осадках осадочной формации спредингового хребта накапливается ряд минералов (гидротермальной группы), которые могут быть рекомендованы в качестве поискового признака на субмаринные сульфидные руды. Наилучшими индикаторами сульфидного оруденения на исследуемом полигоне являются сульфиды Fe, Cu, Zn; барит; Fe охры; плотные, бурые Fe корочки; черные, сажистые Mn корочки; коллоидные полупрозрачные агрегаты оксигидроксидов Fe и SiO₂am, содержание которых закономерно возрастает при приближении к гидротермальным полям. Их пространственное распределение контролируется скоростью и направлением придонных течений, а также местоположением и мощностью гидротермальной системы.

Во время циклического тектоно-вулканического развития центра спрединга наблюдается закономерное изменение минерального состава исследованных фракций осадков. Перед и после гидротермальных циклов (в течение вулканических) увеличивается содержание вулканогенно-эдафогенных минералов. Во время гидротермальных циклов в осадках евозрастает концентрация гидротермально-осадочных минералов, причем на начальной и заключительной фазах образуются низкотемпературные минералы.

Abstract. The mineral composition of fine-psammitic (0.10-0.50 mm) and coarse-aleuritic (0.05-0.10 mm) fractions of metalliferous sediments from the East Pacific Rise axial zone (20°30'-22°00' S) is investigated in details by a complex of analytical methods. The mineral composition of the sedi-

ments of this region is controlled by the follow factors: remoteness from the landmasses; ocean depth; appurtenance of investigated area to the South arid zone and the axial part of the fast spreading centre with high hydrothermal activity. The sedimentary formation of the investigated spreading segment is polygenetic. Seven mineralogical genetic groups can be distinguished: biogenous, terrigenous, hydrothermal, basaltic, diagenetic, hydrogenetic and cosmogenic. The pelagic background is formed mainly by biogenous CaCO_3 and detrital and clay minerals with eolic origin. The diagenetic and hydrogenetic mineral formation have subordinate significance in that environment. The tectono-volcanic processes in the region supply a specific "local" material to the sediments — basaltic and hydrothermal.

Some of the minerals accumulating in the metalliferous sediments of the spreading sedimentary formation can be recommended as indicators for sulphide ore prospecting. The sulphides of Fe, Cu, Zn; barite; Fe umbers; compact black-brown Fe crusts; black Mn crusts; colloform semitransparent aggregates of Fe oxyhydroxydes and amorphous SiO_2 are the best indicators for sulphide mineralization in the investigated area. Their contents increase regularly towards the hydrothermal fields. The spatial distribution of the minerals related to the hydrothermal activity in the rift is controlled by the rate and direction of the seabottom currents and by the hydrothermal system locality and power.

A regular variation of the mineral composition of the investigated fractions is established during cyclic tectono-volcanic development of the spreading centre. The content of basaltic minerals increases during the volcanic cycles (before and after the hydrothermal cycles). The concentration of hydrothermal-sedimentary minerals in the sediments increases during the hydrothermal cycles. Low-temperature minerals are formed during their initial and final phases.

Introduction

More than 100 years ago sediments, differing from the rest known pelagic sediment formations due to their high amount of iron and extraordinary low concentration of aluminium, have been found near the East Pacific Rise (EPR) axis (Murrey, Renard, 1884). Only during the 60's of our century, it was proved (Скорнякова, 1964; Bonatti, Joensuu, 1966; Boström, Peterson, 1966 etc.) that these unique sediments called "metalliferous" have been widely spread, and that the anomaly of their composition is related with the additional input of a number of elements from the oceanic crust by hydrothermal fluids.

The mineral composition of the metalliferous sediments — one of the most important characteristics, which reflects the conditions and the history of their formation, has been studied from the very beginning by scientists. Hundreds of publications are dedicated to this problem, emphasizing especially on mineral composition study of sediments' ore part, using a complex of recent analytical methods.

In this work we tried to characterise the genetic mineral groups of fine-psammitic and coarse-aleuritic fractions of metalliferous sediments from the EPR axial zone ($20^{\circ}30' - 22^{\circ}00' \text{ S}$).

Geological Setting

From the very beginning of the purposeful studies on ocean metalliferous sediments, the attention of scientists have been drawn by the fast spreading south part of EPR. The ultra fast spreading ($\sim 20 \text{ cm/yr.}$) determines the extremely high hydrothermal activity in the ridge rift zone and the resulting development of the largest in the world metalliferous sediment field. Numerous Russian, American, French and German scientific expeditions have performed various scientific researches in the EPR southern part, directed towards study of definite aspects of tectonics, lithology and hydrothermal processes.

In 1987/88 the 4th cruise of R/V "Geolog Fersman" (VNII Oceangeologia, St.-Petersburg) (Fig. 1 A) was carried out in the South-East Pacific with the purpose of studying the tectono-magmatic processes in the EPR rift zone and the related massive sulphides and metalliferous sediments. Samples of metalliferous sediments along

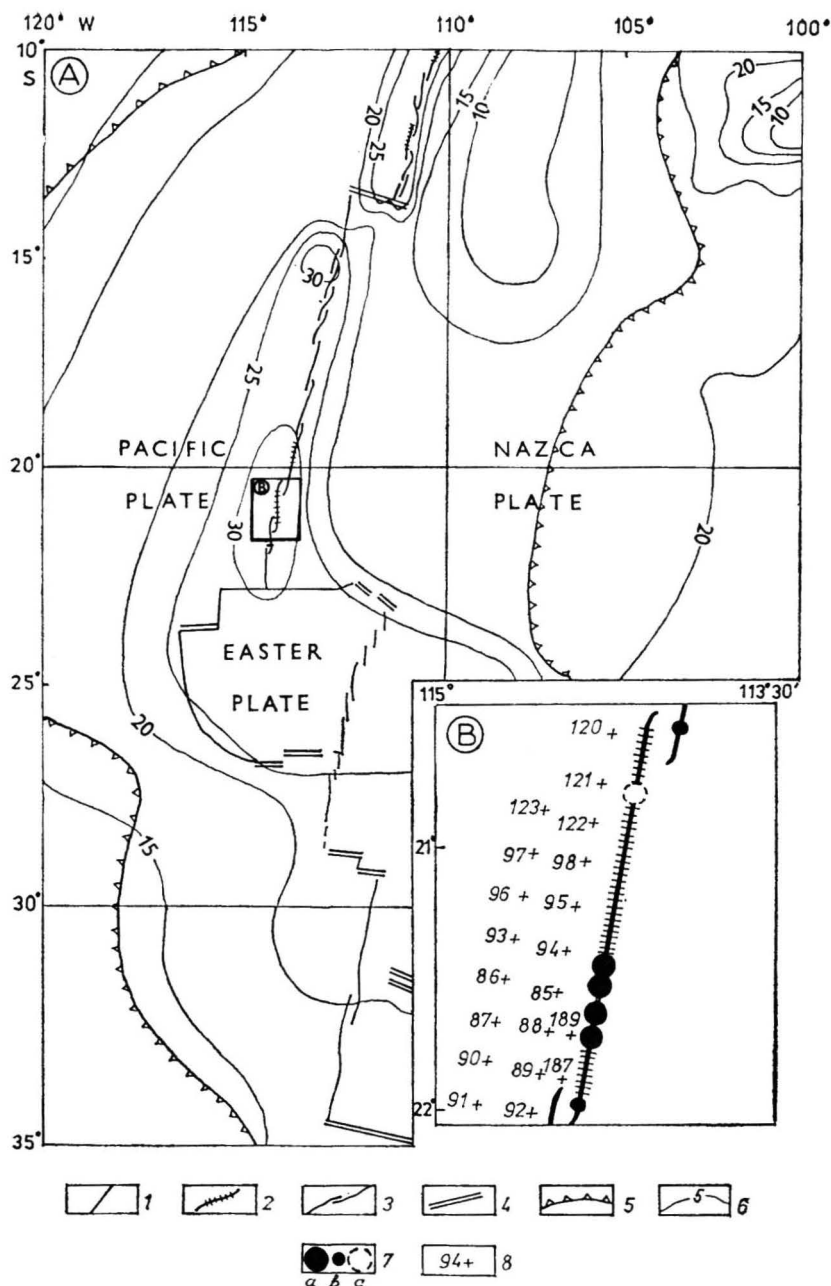


Fig. 1. Sketch map of hydrothermal ore-bearing of the EPR south part (from K p a c h o v et al., 1993) — A, and location map of the sampling stations — B

1 — EPR axial zone without graben or with poorly developed one; 2 — the same but with well developed graben; 3 — zone of overlapping; 4 — transform fault; 5 — outer boundary of EPR; 6 — contours of the sum Fe+Mn (in %, on a carbonate free basis); 7 — location of the hydrothermal vent fields in the EPR rift zone (after K p a c h o v et al., 1988; M a r c h i g et al., 1988); a — large fields, b — smaller ones, c — hypothetical ones; 8 — location of the sampling stations

three profiles: at 10, 20 and 40 km accordingly from the spreading axis with average distance between the cores of 20 km (Fig. 1 B), were taken from the 20°30'–22°00' S area located between two zones of overlapping, to the west of the ridge axis. The geological sites location was determined by the dominant transport of hydrothermal-sediment material westwards from the ridge (Marchig et al., 1986).

The area studied is situated in the EPR axial part of the south arid zone. The specific character of the ridge segment studied is determined by rather high asymmetric spreading rates — 9 cm/yr. to the east and 7 cm/yr. to the west (Herron, 1972; Rea, 1978). Sometimes rift valley is absent here and the cross-sectional rise shape is characterised by presence of relatively oblique axial bulge. The geophysical investigations performed prove the insignificant thickness of the ocean crust layers in the axial zone (Краснов et al., 1993). Detailed morphotectonic characteristics of the ridge part was done by Порошина et al. (1993).

Fields of massive sulphides and high-temperature hydrothermal activity are found in the ridge rift zone of the area studied (Краснов et al., 1988; Marchig et al., 1988). During the 4th cruise of R/V "Geolog Fersman" hydrochemical and hydrophysical studies on the sea-bottom water column have been performed (Краснов et al., 1988). The lithological composition, biostratigraphic features (Левитан et al., 1990) and the grain-size composition (Деклов, Гурвич, 1991; Деклов et al., 1993) of the sediment samples were studied; their absolute age was determined (Деклов, Купцов, 1990; 1992). Detailed climatic-stratigraphic division of the sediment cover Upper Quaternary part was done by micropalaeontological and isotope-oxygen data and palaeotemperature fluctuation reconstructions in the surface water column were carried out (Иванова, Шеклтон, 1993). The chemical elements (37 in number, including REE) behaviour in the area sediments was studied (Деклов, 1993; Деклов, Гурвич, 1993; Деклов, 1994; Деклов, 1994).

Material and Methods of Investigations

The definition sedimentary formation specifies a sediment body formed under definite tectonic and physico-geographic conditions (Богданов, 1989). The sedimentary formation of the active spreading centre builds the basal part of the ocean crust sediment cover. It lies in disconformity over the basaltic basement, while upwards it is gradually removed by sedimentary formations formed beyond the rift active part.

The metalliferous calcareous sediments of the sedimentary formation of the spreading ridge studied are represented mostly by pelitic and some aleuritic-pelitic and fine-alueritic oozes (Деклов et al., 1993). That is why, the mineralogical studies of the sediment material started with investigation of their high dispersion part (fraction $>1\mu\text{m}$). It was established to be composed of mostly X-ray amorphous and poorly crystallized oxyhydroxides of Fe and Mn (Багин et al., 1993) and Fe-montmorillonite (Деклов et al., 1993). The mineral composition investigation of aleuritic and psammitic sediment fractions was the next stage of the mineralogical studies. As the coarse-aleuritic (0.10–0.05 mm) and fine-psammitic (0.50–0.10 mm) fractions are accessible to standard optic studies from one side, and compose relatively 50% of the aleuritic and psammitic fractions respectively (Деклов et al., 1993), from the other side, we conducted more limited study only of these fractions believing the result representation was not disturbed.

One of the major ideas of this work was determination of minerals — indicators of massive sulphide fields and of hydrothermal activity history in the rift. The usage of one or other genetic mineral groups of the sedimentary formation of the spreading ridge as indicators of the hydrothermal activity development and their importance for submarine sulphide ore prospecting requires above all establishment of spatial-time links of these groups with the known ore-mineralizations. With that purpose in mind,

we studied the topmost (0-2 cm) liquid sediment layer of all sites (Fig. 1B) and samples from selected core horizons. The amount of samples taken was fixed to 100 ml natural wet sediment. The separation of the heavy and light subfractions was accomplished using standard methods (wet sifting, partition with bromophorm, specific gravity 2.9, afterwards the subfractions were examined under stereomicroscope in order to count the grains and separate minerals for further XRD-studies with DPOH-2, 57.3 mm X-ray camera Gandolfi, scanning electron microscopes JEOL T-300 and JEOL Superprobe-733 with X-ray microanalysers LINK 860-500 and System-5000 ORTEC, respectively. The coare-aleuritic fraction was examined under polarisation microscope in immersion liquids after separation of heavy and light subfractions.

Results and Discussion

The mineral composition of the sediments from the area is variegated and qualitatively varies slightly in space. This is determined by the similar conditions of sediment deposition (remoteness from the landmasses, ocean depth, bioproductivity in euphotic region). The detailed studies showed that the sedimentary formation of the given spreading centre is polygenetic. Seven mineralogical genetic groups participate in the formation: 1) biogenous; 2) terrigenous; 3) hydrothermal; 4) basaltic; 5) diagenetic; 6) hydrogenetic and 7) cosmogenic.

1) The biogenous group is represented by carbonate foraminiferal tests (psammite-aleurite) and coccolithophores (fine pelite). Carbonate detritus is also present. The other biogenous mineral — the opal, in the form of spongy spicules and skeletal remains of diatoms, radiolarites and silicoflagellates, is very scarce.

2) The pertinence of the area studied to the arid zone and its remoteness from the landmasses determine predominantly eolic nature of the terrigenous minerals in sediments and their insignificant presence. The terrigenous input in sediments is maintained by winds from South America and is determined by the petrographic composition of outcropping rocks.

The sediment quartz grains are smoothed out Plate I A, B), milky-white to dull-transparent, sometimes with dark inclusions (ore minerals, rutile, etc.). Grains partly covered with iron hydroxide coatings are also found.

The acidic plagioclases, potassium feldspars (mostly microcline), garnets, amphiboles are also well smoothed out.

The micas are represented mainly by green and brown-green biotite. Muscovite is almost constantly found, but in smaller amounts. The micaceous flakes are always extremely well smoothed out.

The acidic volcanic glass with refractive index $n=1.500-1.502$ (riolite type) is rarely met; varieties of the andesite series ($n=1.510-1.516$) are also present.

Single grains of rutile, zircon, distein and staurolite are rarely found.

3) The results from the studies helped to refer to the minerals-indicators of hydrothermal activity the Fe-oxyhydroxides, sulphides of Fe, Cu and Zn, Mn-oxyhydroxides crusts, barite, atacamite, hydrozincite and zincite (hydrothermal group), which appearance is connected with hydrothermal activity in the rift zone. Their spatial distribution is probably controlled by the rate and direction of sea-bottom currents and power of the hydrothermal system.

Fe-oxyhydroxides are most widely distributed among the minerals of this group. Their content near the hydrothermal fields constitutes tens (to 80) percents of the heavy subfractions. They are represented by the following formations:

— mostly X-ray-amorphous, powdery, nontransparent clayey-ferrous aggregates of yellow, red, brown-red, brown and dark brown colour (Plate I C). They are built up of finegrained mass of Fe- and Mn-oxyhydroxides, clay minerals and coccolithes (less) with irregularly distributed dispersions of dark-brown microglobules of Fe-hydroxides (Plate I D);

— red, brown-red and black-brown thin films (incrustations) over the surface of the foraminiferal tests. The oxyhydroxide coatings smooth the roughness between the calcite monocrystals building the tests (Plate I E) or fill their foramens (Plate IF);

— ferrous particles in the form of globules with black-brown and black colour. They are concentrated in coarse-pellitic and fine-aleuritic fractions;

— compact, nontransparent and colloform ferrous crusts with sharp uneven edges and black-brown colour (Plate I G). Separate areas of the crusts are colloform (Plate I H), built up of amorphous Fe-oxyhydroxides. Different stages of crystallization of the primary amorphous oxyhydroxide mass is well observed (Plate II A) on some parts of crust surface. The XRD data reveal presence of amorphous Fe-oxyhydroxides and goethite at different degrees of crystallization.

The crust surface is sometimes cavernous, bubbled. The general mass around the caverns is crystallized to different degree (Plate II B). Bacteriomorphous structures of the same ferrous oxyhydroxides are often met on the surface (Plate II C), which reveals possible presence of bacterial participation in Fe-fixation;

— semitransparent, yellowish-green, yellowish-orange, red silica-ferrous gels in the form of colloform lumps with microglobular structure (Plate II D). The refractive index n varies from 1.53 to 1.56. The particles colour depends on the quantitative proportions between the Fe-oxyhydroxides and $\text{SiO}_{2\text{am}}$.

According to SEM data, the gel has crystallized in local parts (Plate II E) and has flake structure, characteristic for the autogenic iron smectite from the metalliferous sediments of the Atlantis-II Deep, Red Sea, studied earlier (Б у р з о в а et al., 1979). The different distribution density and dimensions of the crystals reflect the various stages of gel crystallization process.

The XRD studies reveal that crystallized phases, represented by microcrystalline goethite and Fe-montmorillonite, are present in the XRD-amorphous gel mass. Crystallization of amorphous Fe-oxyhydroxides and $\text{SiO}_{2\text{am}}$ with formation of the above mentioned phases occurs probably during the process of transformation conversion of the sediment cover.

It was established that the distribution of oxyhydroxide iron mineral formations around the hydrothermal systems is different. Fe-umbers, compact black-brown Fe-crusts and colloform semitransparent aggregates of Fe-oxyhydroxides and $\text{SiO}_{2\text{am}}$ accumulate in the close proximity of the massive sulphide chimneys. At the same time, the powdery clayey-ferrous aggregates and the ferrous microglobules are more or less regularly spread in area sediments and are met at a distance of 40 km from the ridge axis.

The Fe, Cu and Zn sulphides in the form of fine sulphide suspension are drifted by the hydrothermal plume, precipitate and accumulate in the metalliferous sediments next to the hydrothermal vents, marking them clearly. Pyrite is the most widely spread (Plate II F), then follow the chalcopyrite and sphalerite. Marcasite is quite rare. The sulphides studied are subdivided in detrital and globular ones according to their form. The first ones are in the form of single large crystals or their fragments; the second have globular, smoothed or spheroid form.

The manganese oxyhydroxide crusts (according to XRD microanalyser data) are black, sooty, very fragile, fine-psammitic size, in the form of slightly curved lamellas. Their amount increases to the ridge axis.

Barite is established in single colourless crystals with tabular form, like microgeodes of irregularly accretion crystals or crystal accretions with globular form and white colour.

Atacamite is observed in most of the samples studied in the form of greenish, light blue, blue, powdery, nontransparent and semitransparent aggregates. No clear attachment to hydrothermal vents is observed.

Flakes and crusts of hydrozincite with convex-concave form like single findings are established in many samples. Their colour is white, slightly yellow, reddish. Zincite

is observed in white, yellowish-white "clews". Increasing of the amount of hydrozincite crusts and zincite "clews" is found towards the known ore-manifestations.

4) The formation of basaltic sedimentary material is connected with the tectonic processes, which are spatially attached to the rift tectonic zone. The basaltic group is represented by fragments of basalts, basaltic glasses and mineral grains (plagioclases, pyroxenes, olivines) from rocks disintegrated on the sea-bottom. The grain size of the basaltic clastics varies from coarse aleurite to gravel.

Basaltic fragments with psammitic-gravel size are found only in sediments from the 10 km profile sites. Their amount increases downwards the section. Most of the fragments are angular, fissured, covered with palagonite crusts.

Fragments of basic glass with dark grey, brown-black to black colour are dispersed in the area sediments. They are angular, bubbled, sometimes with fissures (Plate III A, B). Phenocrysts of olivines (Plate III C), pyroxenes, basic plagioclases are often observed in glass fragments. Besides fresh, altered glasses (palagonite formation) are met in the sediments. Dark green mossy accumulations with distinct boundaries, intercalated like "sweets", are often met on the glass fragments surface (Plate III, B, D). These are probably aggregates of clay minerals, formed as a result of halmyrolytic alteration (submarine weathering) of phenocrysts from basaltic glass.

The altered glasses are covered by yellow, orange, red palagonite coatings at local parts or on the whole surface. The basaltic fragments are sometimes completely altered, and only palagonite coatings remain (Plate III E), which conserve the morphology of the primary glasses. The coatings outside are smooth, mat (Table III, E, F), while reniform geodes of fine septal crystals (Plate III G) are observed inside. This phenomenon reflects the process of palagonite recrystallization in clayey minerals.

The palagonite, being more fragile, is strongly disintegrated than the nonaltered glasses. Insignificant admixture of palagonite crust fragments is revealed in the sediments.

The olivines, part of the pyroxenes, ilmenite (Plate III H), Ti-magnetite, basic plagioclases are referred to the basaltic minerals.

The heavy subfraction of fractions studied, consisting mostly of hydrothermal (red to brown-black clayey-ferrous aggregates, brown-black ferrous and black manganese crusts), terrigenous (amphiboles, pyroxenes) and basaltic (olivines, pyroxenes, epidotes, altered undetermined rock fragments) minerals, is in the range of 0.1-1.0%. Its amount is relatively high — up to 0.9-1% in sediments from the 10 km profile sites (st. 187, 189). Grains of pyrite and fragments of Fe- and Mn-oxyhydroxide crusts are found in almost all studied horizons. The amount of olivines usually exceeds 50% of the heavy subfraction, while the Fe-oxyhydroxide aggregates constitute almost 20% of it. The amounts of olivines and ferrous aggregates in this subfraction from 20th km profile are approximately equal — 20-40%. The olivines at the 40th km from the ridge axis are less than 10%, pyroxene findings are very rare, while the Fe-oxyhydroxide aggregates compose the main mass of the heavy subfraction (>90%). These facts are explained by the basaltic origin of the olivine. During disintegration of basalts from the extrusive axial zone this mineral falls into the sediments nearby due to its high specific gravity. The hydrothermal ferrous aggregates are transported by the plume and currents at long distances. Probably they enlarge during the transportation and after deposition.

The light subfraction usually covers more than 99% of the coarse-aleuritic fraction and is composed almost exclusively by organogenic CaCO_3 (foraminiferal tests and their detritus). Its abiogenic part was studied after treatment by 5% HCl. The general mass is represented by orange-brown oxydized fragments — >50%. Quartz, feldspars, micas, volcanic glasses, chloritized fragments, palagonite, altered undetermined grains are present. The basic varieties (basaltic) dominate among the feldspars and volcanic glasses. Negative correlation of the amounts of basic volcanic glasses and plagioclases with the distance from the spreading axis is established.

5) The diagenetic formations in area sediments are represented by iron-manganese micronodules and radial-ray phosphorite sphaerolites.

Iron-manganese micronodules are spread irregularly in the area sedimentary cover and pertain to the coarse-aleuritic and psammitic fractions. They are black-brown, black, with irregular shape and sooty, uneven, hilly surface (Plate IV A). Their surface and inner structure are microglobular (Plate IV B). The X-ray microanalyser and XRD-data reveal that the micronodules are composed of X-ray amorphous Fe- and Mn-oxyhydroxides.

Fragile radial-ray phosphorite sphaerolites (Plate IV C) with white colour and psammitic size are found in the sediments from the 10 km profile sites only. Foraminiferal tests often serve as their growth centre (Plate IV D). The sphaerolites are composed of thin ($\sim 4\mu$ m), long (up to 300μ m), needle-like crystals (Plate IV D) of phosphorite composition. We could not establish any definite regularity in their distribution in the sediment section.

The diagenetic nature of the Fe-Mn micronodules dispersed in the sediment cover of the region is beyond doubt (Б о р д а н о в et al., 1979, etc.). They are typical for the normal pelagic sediments of the given climatic zone.

The inner structure of the phosphorite sphaerolites, their growth around centres, as well as some ideas of previous researchers (Б а т у р и н, 1978) are indicative of their diagenetic origin.

6) The elements in the hydrogenic formations accumulate by slow deposition from the normal sea water (B o n a t t i et al., 1972). The mineral formations of this genetic group are extremely rare in sediments studied, and are represented by Fe-Mn crusts and micronodules. The results from the investigations proved that the latter are built up of X-ray amorphous oxyhydroxides of iron and manganese mostly.

The thin (0.1-1 mm), sooty, black iron-manganese crusts lie directly over the surface of fresh and palagonitized basaltic glasses (Plate IV E) and fragments. Their surface is hilly, microglobular.

Black, spherical, ellipsoid iron-manganese micronodules (0.1-0.5 mm) with hilly surface are found only onto the surface of fresh basaltic glasses and fragments (Plate IV F).

The hydrogenic mechanism of formation of Fe-Mn oxyhydroxides on the sediment surface and the outcropping basement of the ocean crust is well treated of in literature (К р о н е н, 1982; Б о р д а н о в et al., 1990, etc.), although some details are subjected to discussions. The direct link of the crusts and micronodules studied with the basaltic substratum and the low sedimentation rates in the region (Д е к о в, К у п - т с о в, 1990; 1992) allow to suggest a hydrogenic way of formation. The oxyhydroxide crusts and micronodules could be formed in this way, either onto basaltic glasses and fragments lying on sediment surface, or on the surface of basalts from the extrusive zone, where from they could disseminate in the sediments as a result of tectonic disintegration.

7) Cosmogenic component in the form of space dust is always present in accessory amounts in ocean sediments (Л и с и ц ы н, 1974; 1978). Spherical (Plate IV G) and drop-like particles of psammitic size and characteristic slag surface (Plate IV H) are rarely found in the investigated metalliferous sediments. They are magnetic with Fe-Ni composition mostly, while the silicate ones (Plate IV G), being less, are built up of Fe-Mg silicates with insignificant contents of Ni (X-ray microanalyser data). The shape, surface character and composition of these particles reveal their cosmic genesis.

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As evident from the discussion, many minerals (hydrothermal group), which could be recommended as criteria of submarine sulphide ore prospecting, accumulate in the fine-psammitic and coarse-aleuritic fractions of metalliferous sediments from the vi-

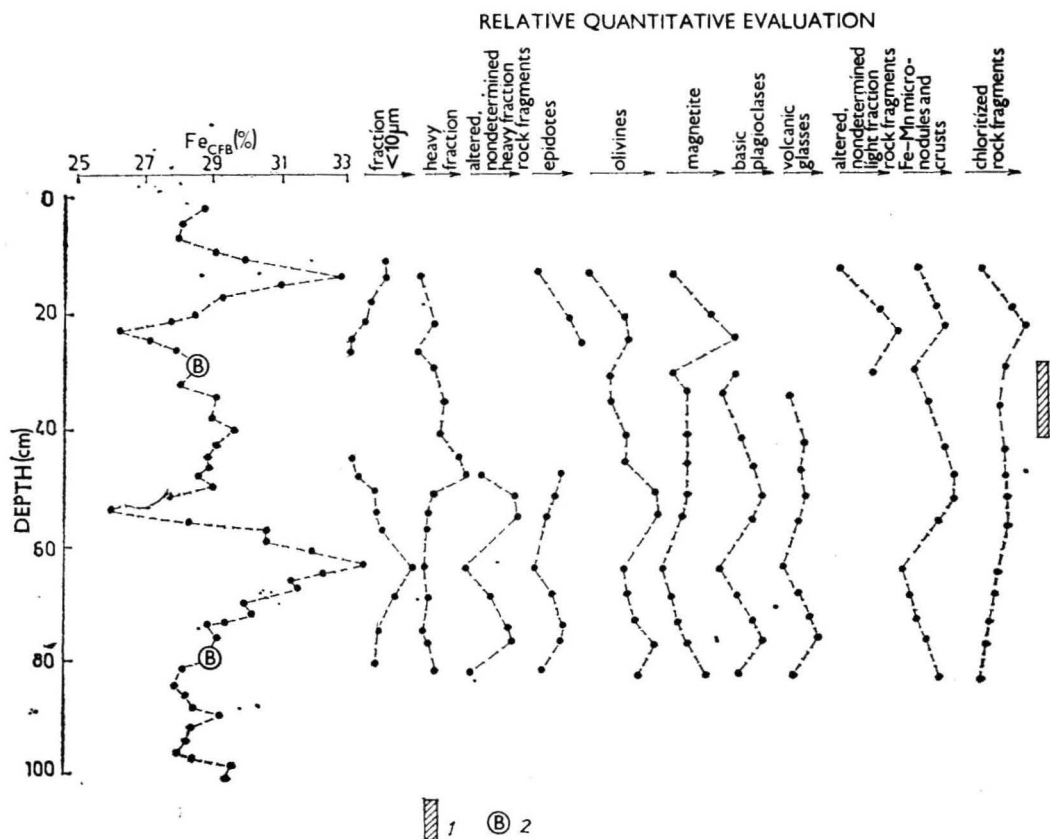


Fig. 2. Vertical distribution of Fe and some mineral components in core 121
1 — samples of high contents of eolic quartz; 2 — samples with established barite crystals

cinity of the hydrothermal systems. The best indicators of sulphide ore mineralisation at the area studied are the particles of Fe-, Cu- and Zn-sulphides; barite; Fe-umbers; compact, black-brown Fe-crusts; black, sooty Mn-crusts; colloform semitransparent aggregates of Fe-oxyhydroxides and SiO_{2am} , which amount in the sediments regularly increases towards the hydrothermal fields.

The proportions of the mineral components in the sediments vary considerably in space and time (along the core depth).

When analysing the mineral composition of sediments in order to solve problems concerning the hydrothermal activity of the spreading centre at 21°S EPR, it is important to differentiate the components, which compose the sediments — the pelagic background and those, which are related with volcanism and hydrothermal activity. Attention should also be paid to redeposition of sediment material (st. 86, 96, 123), as it could be an indicator of tectonic and volcanic activity of the given ocean floor structure.

The main sediment forming material, which forms the pelagic background, consists of biogenic CaCO_3 and terrigenous clastic and clay minerals. As mentioned above, the mineral composition of the allothigenous part of the sediments from the region is determined by the petrographic composition of the supplying area — granite-gneiss mineral complex (quartz, feldspars, micas, zircon, apatite, garnet, staurolite, disthein, rutile, sphene, etc.).

PLATE I.

SEM photomicrographs: A — well polished grain of eolic quartz; B — typical "eolic" relief of the surface (smooth, ground, with V-shaped traces) on the same enlarged grain (Plate I A); C — powdery, clayey-iron aggregate (non-transparent, yellowish-red under stereomicroscope); D — enlarged surface of the same aggregate. The basic fine-grained mass and included microglobule can be seen; E — surface of foraminiferal test. Sharp edges of calcite monocrystals and fine-grained oxyhydroxide incrustations in the unevennesses among them are seen; F — foraminiferal test surface with foramens filled by oxyhydroxide mass; G — compact, colloform iron crust with sharp edges (non-transparent, brown under stereomicroscope); H — enlarged colloform area of the same crust.

PLATE II.

SEM photomicrographs: A — part of the surface of iron crust. Different stages of crystallization of initially amorphous oxyhydroxide mass can be distinguished; B — cavernous, bubble part of the surface of iron crust; C — Fe-oxyhydroxide bacteriomorphous structures on the surface of iron crust; D — colloform lump of silica-iron gel (semi-transparent, yellowish-green under stereomicroscope); E — crystallized part of the same gel. Flake-shaped crystals are seen; F — microgeode of pyrite. Well-shaped cubic crystals are seen (with metallic lustre, greenish-yellow under stereomicroscope).

PLATE III.

SEM photomicrographs: A — angular, vesicular piece of basic glass (dark green under stereomicroscope). Conchoidal fracture and spherical cavities of open gas blebs are well seen; B — angular, vesicular piece of basic glass (black-brown under stereomicroscope). Spherical cavities of open gas blebs are seen; C — magnificent phenocryst of olivine sticking up from a piece of basic glass (Plate III A); D — mossy heaps (dark green under stereomicroscope), sticking up from a basic glass piece (right part of Plate III B); E — palagonite coating (orange red under stereomicroscope) of completely altered piece of basaltic glass. The primary morphology of the glass is well preserved; F — enlarged upper right part of the same coating. The mat outer and the crystallized inner surfaces of the coating are seen; G — enlarged reniform geodes of septal crystals of the inner surface of palagonite coating (Plate III F); H — well formed ilmenite crystals.

PLATE IV.

SEM photomicrographs: A — Fe-Mn micronodule of irregular form with sooty and hilly surface; B — enlarged fracture of the same micronodule. Microglobular inner structure is observed; C — radial-ray phosphorite sphaerolite (white under stereomicroscope); D — fragment of the inner part of phosphorite sphaerolite. Crystallization nucleus of foraminiferal test is seen; E — fresh, angular, bubbly piece of basaltic glass (the left part is seen), covered with fine, Fe-Mn crust of hilly surface (the right part of the particle); F — spherical Fe-Mn micronodule of hilly surface onto the fresh piece of basaltic glass (Table IV E); G — cosmogenic spherical particle; H — enlarged fragment of the surface of the same particle. Typical slag surface is seen.

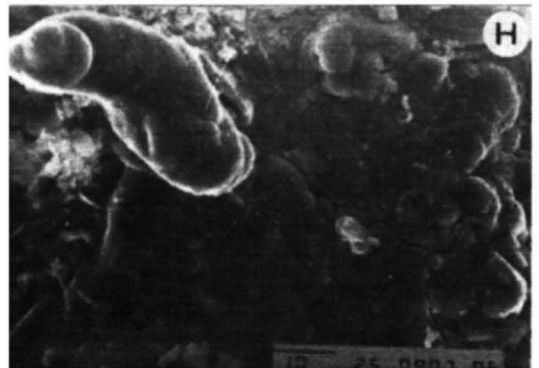
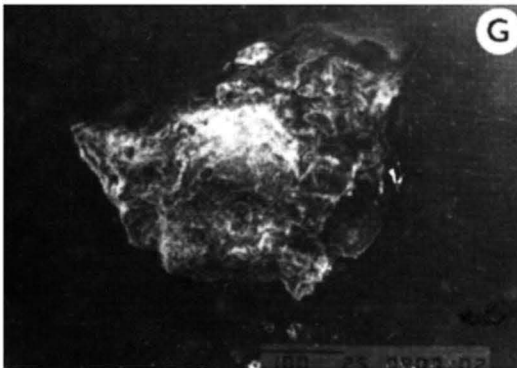
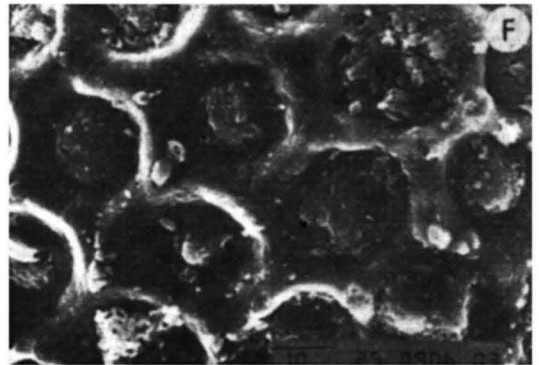
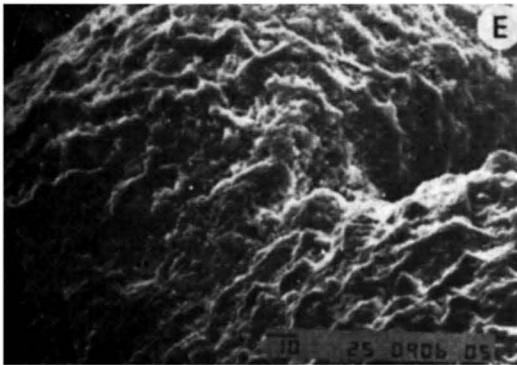
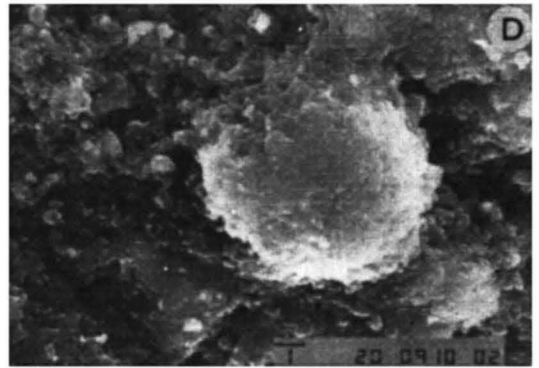
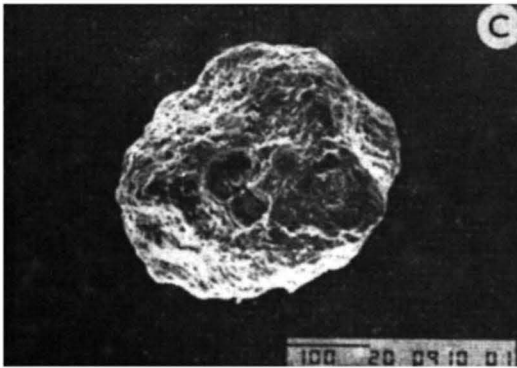
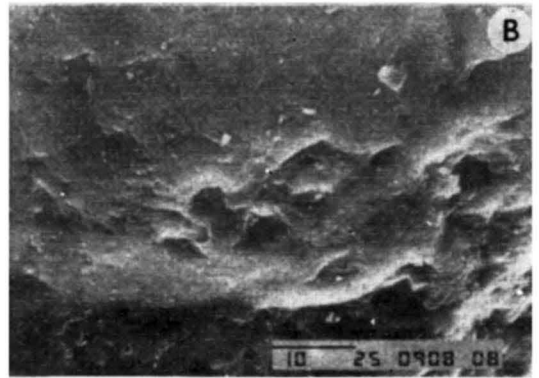
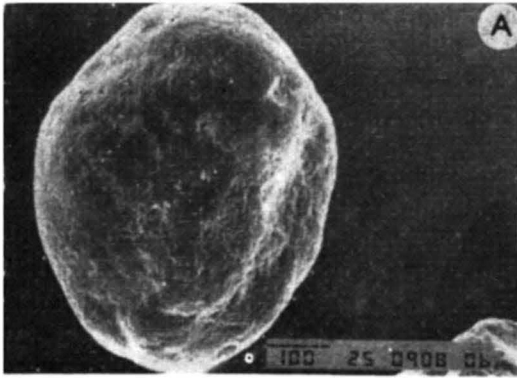
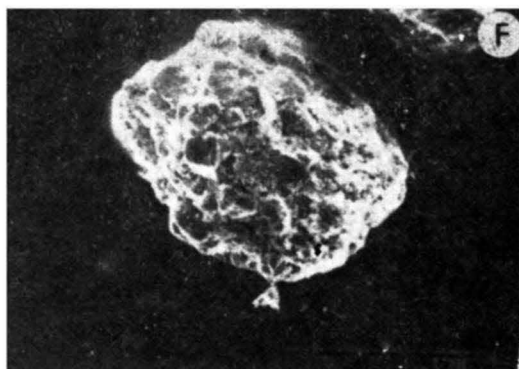
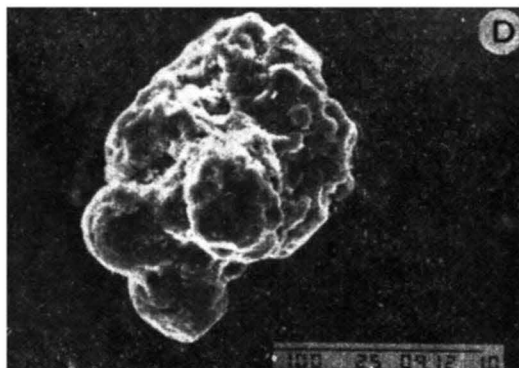
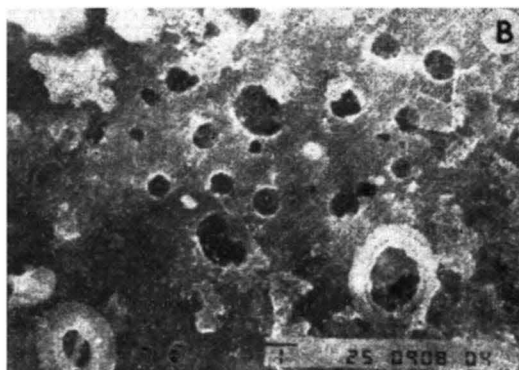
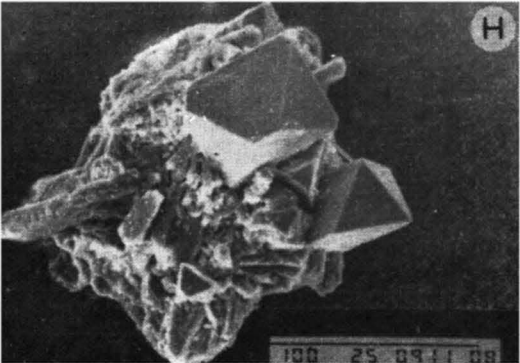
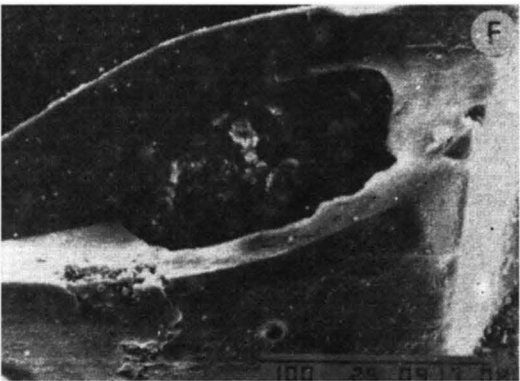
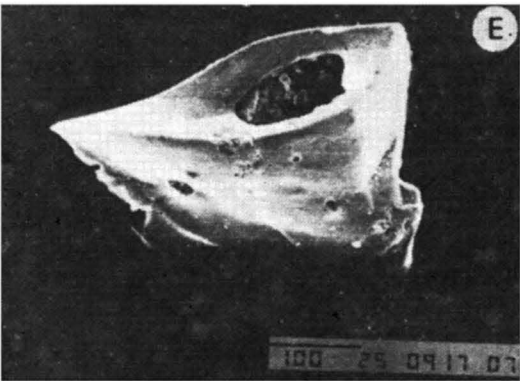
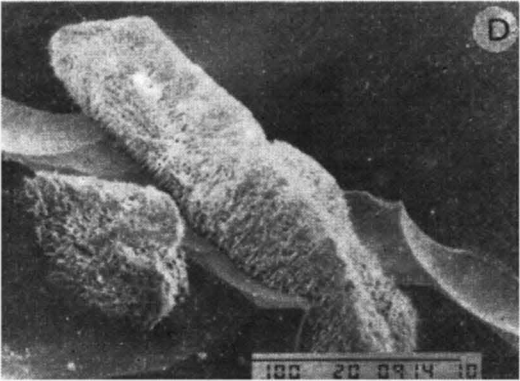
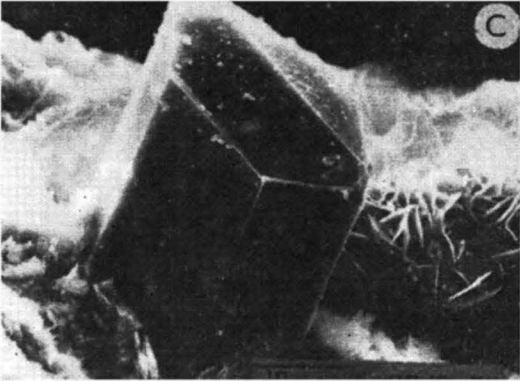
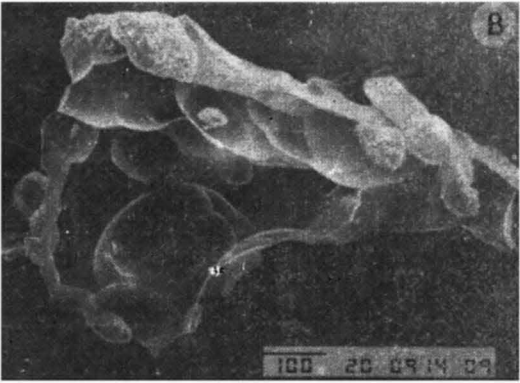
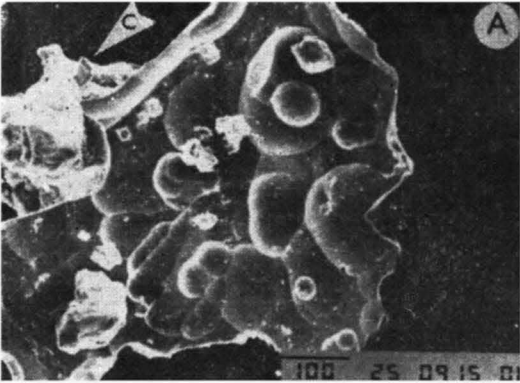
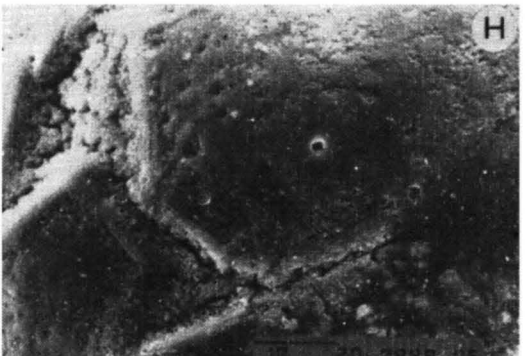
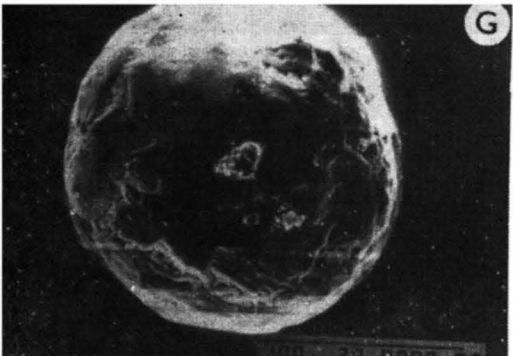
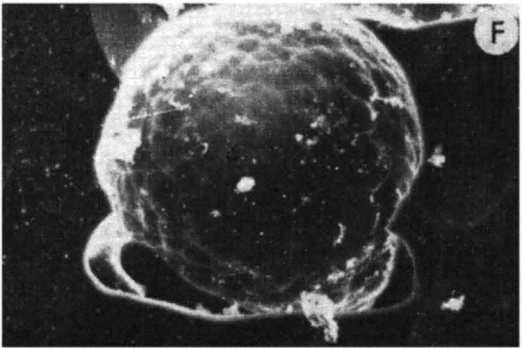
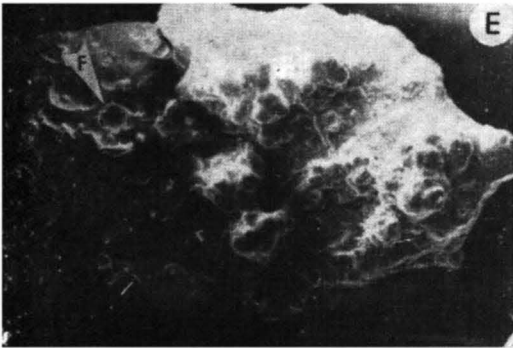
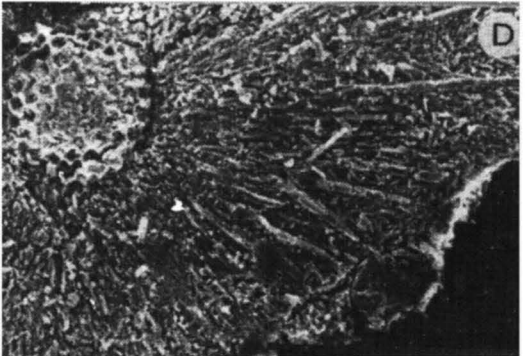
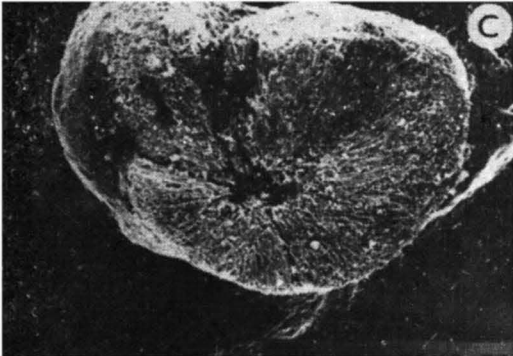
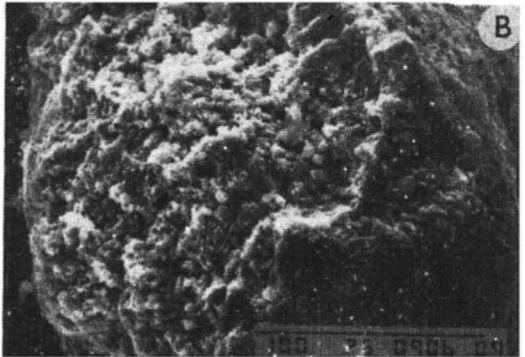
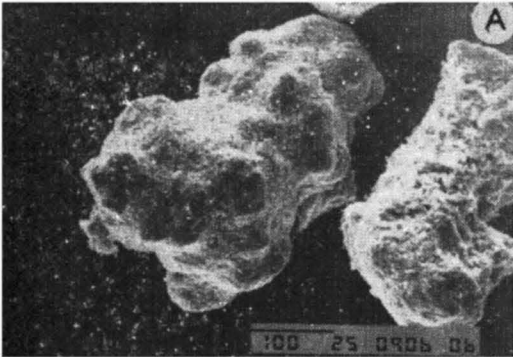


PLATE II







The volcanogenic-basaltic clastics (including the green-stone altered one), the hydrothermal-edaphic material (products from destruction of hydrothermal mounds) and solid fine particles, formed like suspension near the hydrothermal vents mouths and transported later by the sea-bottom currents, should be mentioned among the "local" material. The hydrothermal suspended particles are represented mostly by Fe- and Mn-oxyhydroxides in the sediments of the hydrothermal fields.

The dispersed basaltic material, as mentioned above, is present in the whole sediment cover of the area as a product of destruction of the fragile glassy chilling zone of basalt. The process of destruction still continues, and the findings of dispersed glass in the sediments reveal that vulcanites are outcropped on floor and the rift zone is characterised by high seismicity.

The graphics of vertical distribution of the major hydrothermal geochemical indicator — iron (on a carbonate free basis (CFB)), and of some mineralogical indicators of volcanism and hydrothermal activity (in relative units) in core 121 are represented on Fig. 2. The Fe-distribution in time reflects the intensity of hydrothermal processes. Two hydrothermal cycles are established. During these cycles, the amounts of sulphide particles, powdery clayey-ferrous aggregates, compact brown-black ferrous crusts and colloidal semitransparent lumps of Fe-oxyhydroxides and $\text{SiO}_{2\text{am}}$ in sediments increase. The amount of fractions $< 10\mu\text{m}$ increases also. A considerable part of the ejected hydrothermal material from the black smokers is probably concentrated in this part of the grain size spectrum (Dekov, Gurvich, 1991). Before and after the hydrothermal cycles, the amounts of volcanic glass, basic plagioclases, olivines and magnetite increase (up to several times). Deposition of these minerals in the beginning and the end of the hydrothermal stages probably testifies for basalt destruction growth, which is related either with the tectonic movements, or with rising of the volcanic activity.

Two other groups, absent from the background sediments, are selected among the clastic minerals. The first one includes minerals from the epidote group, chlorite and altered undetermined fragments. These minerals in the given region could be genetically bound only to the green stone altered volcanic rocks. As such relatively abyssal rocks do not outcrop the ocean floor within the rift structure studied, the mentioned minerals could be formed during the basalt alteration, caused by high temperature hydrothermal fluids, and could disperse in the water column and sediments during the volcanic stages (before and after the hydrothermal).

The second group includes fragments of Mn-crusts and barite. As these mineral formations are of low-temperature, they probably mark the initial and final low-temperature phases of hydrothermal stages (Fig. 2).

Similar phenomena are described in literature for the slow spreading Mid-Atlantic ridge — TAG hydrothermal field (Лисицын et al., 1989) and for the ridge with middle spreading rate — Juan de Fuca (Богданов, 1990). Hydrothermal processes with different intensity are observed in rifts with various spreading rate. Volcanic stages, during which the hydrothermal activity subsides, follow the hydrothermal ones in the slow- and middle-spreading ridges. Nonmetalliferous sediments are formed, while the volcanic stages are clearly marked by horizons almost completely composed of volcanoclastics. The hydrothermal activity relatively subsides during the volcanic stages and "bursts" again after them on the fast-spreading ridge studied (21°S EPR). As a result, uninterrupted (along to the section) cover of metalliferous sediments is formed. The pattern becomes more complicated by the simultaneous action of several hydrothermal fields. That is why the indicator of the volcanic stages (the volcanoclastics) is not so contrastly expressed.

Conclusion

The mineral composition of the fine-psammitic and coarse-aleuritic fractions of sediments studied is determined by the following factors: area's appurtenance to the south arid zone and axial part of the ultra fast-spreading ridge with high hydrothermal activity, remoteness from landmasses, ocean depth. The sedimentary formation of the investigated spreading segment is polygenetic. Seven genetic mineral groups participate in its formation: biogenic, terrigenous, hydrothermal, basaltic, diagenetic, hydrogenic and cosmogenic ones. The pelagic background is formed mostly by biogenic CaCO_3 and terrigenous (eolic) clastic and clay minerals. The diagenetic and hydrogenic mineral formation processes are less important in the environment. The tectono-magmatic activity in region supplies specific local material in the sediments — volcanogenic-basaltic, hydrothermal-edaphic and hydrothermal-sedimentary.

Many minerals (hydrothermal group), which could be recommended as criteria for submarine sulphide ore prospecting, accumulate in the metalliferous sediments of the spreading sediment formation. The best indicators for sulphide ore mineralisation of the area studied are: Fe-, Cu- and Zn-sulphides; barite; Fe-umbers; compact, brown-black Fe-crusts; the black, sooty Mn-crusts; colloform semitransparent aggregates of Fe-oxyhydroxides and $\text{SiO}_{2\text{am}}$. Their content in the sediments regularly increases approaching the hydrothermal fields. Their spatial distribution is controlled by the rate and direction of sea bottom currents, and by the location and powder of the hydrothermal system.

Regular variation of the mineral composition of investigated sediment fractions is observed during the cyclic tectono-magmatic development of the spreading centre. The amount of volcanogenic-basaltic minerals increases before and after the hydrothermal cycles (during the volcanic ones). The concentration of hydrothermal-sediment minerals in sediments increases during the hydrothermal cycles. Low-temperature minerals are formed during their initial and final phases.

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