ISSN 1028-334X, Doklady Earth Sciences, 2012, Vol. 442, Part 2, pp. 163–167. © Pleiades Publishing, Ltd., 2012.
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GEOLOGY

Peculiarities of Present-Day Sulfide Mineralization at 19°15’—20°08’ N, Mid-Atlantic Ridge

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Presented by Academician M.A. Fedonkin

Received June 24, 2011

Abstract—Based on studies conducted on the 33rd cruise of the R/V *Professor Logachev* in 2010, a new type of sulfide mineralization of the mid-oceanic ridges has been established. It was formed in the present-day organogenic sediments due to diffuse penetration of hydrothermal fluids that emanated along the fractures in basalts on the slopes of the Mid-Atlantic Ridge.

DOI: 10.1134/S1028334X1202002X

Massive sulfide ores from the ocean are chimney-like ore mounds (black smokers) formed under highly forced hydrothermal fluids, which are vented on the seafloor in various geological settings, mainly, in spreading zones of the mid-oceanic ridges. The bedded sulfide ores hosted in the present-day sediments in near-continental zones (Guaymas Basin, Gulf of California; Middle Valley, Pacific Ocean) have been studied less. At the same time, massive sulfide deposits—ancient analogues of the contemporary oceanic massive sulfide ores—are thick stratiform bodies embedded, as a rule, in sedimentary and volcanosedimentary rocks [1]. This is also similar to other type of deposits (cuprous sandstones and shales) formed under underground waters that emanated to submarine bottom sediments [2, 3]. Both types are characterized by high concentrations of copper, lead, zinc, and rare elements and are the main sources for them. Enrichment in metals is explained by protracted circulation of ore-bearing fluids in sediments that serve as barrier for metals [4], whereas venting of hydrothermal ore-bearing fluids in seawater results in their dispersion. Less than 5% in the initial stage and up to 50% in further periods is precipitated in sulfide mounds which are formed on a seafloor near the hydrothermal vents [5, 6]. The destruction of unstable massive sulfide ores under seawater began just after their formation [7, 8].

Based on our study during the 33rd cruise of the R/V *Professor Logachev*, we identified a new type of sulfide edifices for the mid-oceanic ridge which are formed in sediments under diffuse hydrothermal fluids emanating along the fractures in basalts on the slopes of the Mid-Atlantic Ridge.

The thirty-third cruise was conducted by the Federal State Unitary Enterprise “Polar Marine Geosurvey Expedition” in 2010 at 19°15′–20°08′ N of the Mid-Atlantic Ridge. The objects of study were Zenith-Victory (20°08′ N) and Peterburgskoe (19°52′ N) hydrothermal fields discovered in the 31st and 33rd cruises of the R/V *Professor Logachev*, respectively. Both fields are located beyond the rift valley on its slopes (Fig. 1).

During the cruise, we studied the structure and mineral composition of hydrothermal sulfide edifices and host sediments sampled with a TV-grab and box-corer, the physical–chemical properties of sediments using an Expert-001 potentiometer, and the hydrophysical properties of the bottom waters.

The Zenith-Victory hydrothermal field is situated on the slope of the ~~western~~ wall of the rift valley at a depth of ~~2370~~–2750 m in a marginal deep fault zone (Fig. 1) [9, 10]. The field extends for 2550 m from west to east on a slope widening from 100–150 up to 800–1000 m from south to north and is spatially associated with basalts. The field consists of three orebodies, mineralized basalts, and ore-bearing and carbonate foraminifera–coccolith and coccolith–foraminifera bottom sediments, locally, with interlayers of pteropod sediments. The orebodies include separated groups of hydrothermal sulfide edifices and hydroxide–ferrous (with Mn) ~~bodies~~ in sediments. The largest orebody I (600 ~~±~~ 1300 m) occupies the northern part of the ore field. The Th/U age of 12 sulfide samples varies from 59.5 ± 7.5 up to less than 2.0 ka [9]. Bottom sediments 10 to 60 cm (near orebodies) and up to 100–140 cm thick (at the flanks of the ore field) are unevenly distributed and occupy ~40% of ore field.

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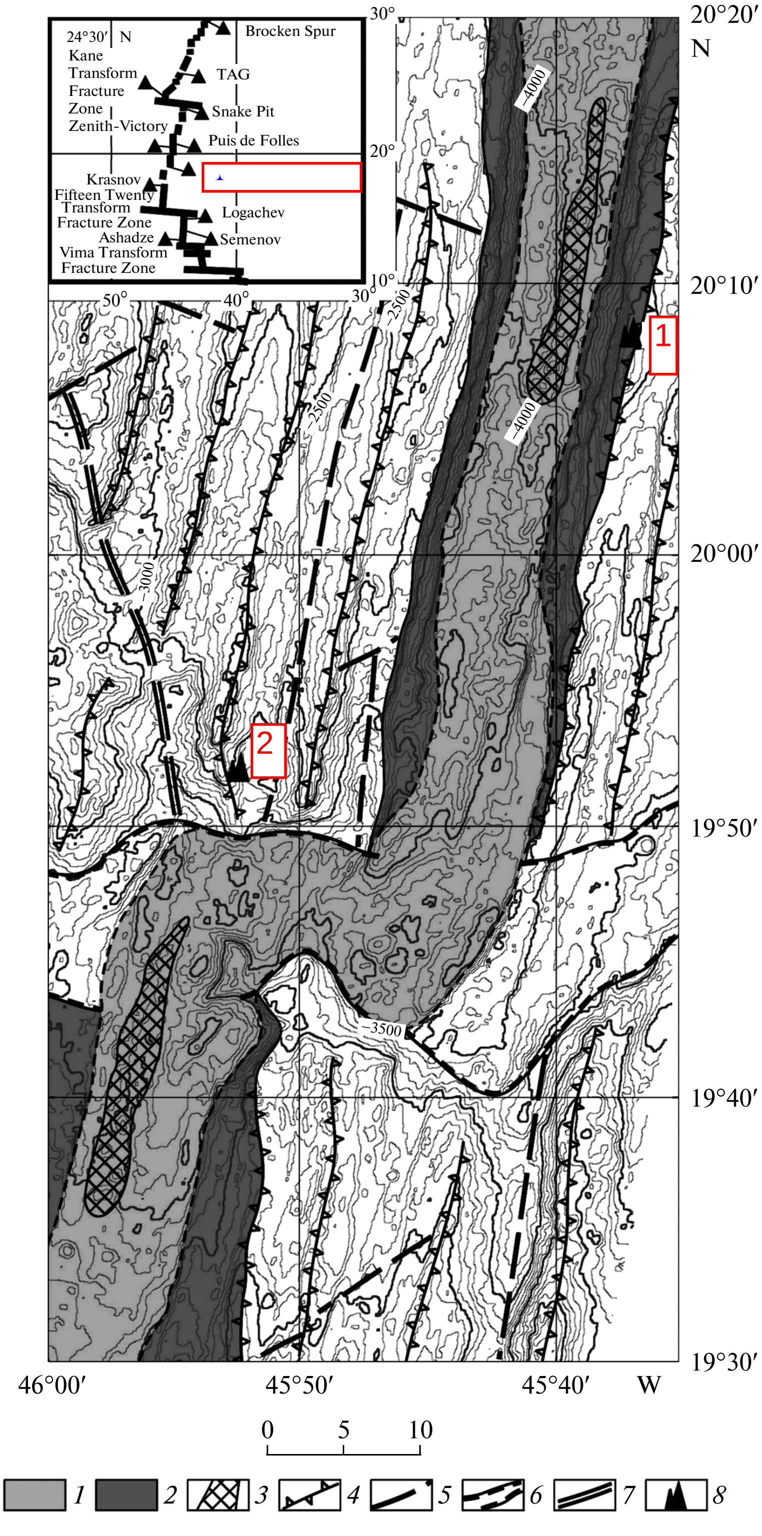

Fig. 1. Location of hydrothermal fields at 19°30′–20°20′ N, Mid-Atlantic Ridge [10]. (*1*) Bottom of the rift valley; (*2*) slopes of the rift valley; (*3*) axial neovolcanic uplifts; (*4*) axes of the top surfaces of rift ridges on the flanks of the Mid-Atlantic Ridge; (*5*) major faults; (*6*) the 19°47’ N Fracture Zone; (*7*) large graben; (*8*) location of hydrothermal fields: Zenith-Victory (1), Peterburgskoe (2).

The field is poorly active. The hydrophysical anomalies of temperature, salinity, and density and higher contents of dissolved Mn related to the diffuse activity were established at the northeastern flank of the field.

The Peterburgskoe hydrothermal field is located at a depth of 2800–3100 m on a flatten area at the southern closing of the terrace of the second rift ridge of the western valley wall, on the boundary with the large nontransform fracture fault zone at 19°47′ N (Fig. 1). The field extends for 1400 m along the slope, is 800 m wide, and consists of six small (from 50 ± 100 m up to 100 ± 280 m) orebodies. Orebody V (st. 159) is composed of rich copper ores, whereas orebodies I–IV are composed of Fe–Mn rocks and metalliferrous sediments. Orebody VI was found by an electrical survey. The orebodies are surrounded by carbonate sediments up to 150 cm thick composed of pteropod, foraminifera, coccolith–foraminifera, and foraminifera–coccolith silts and sands, occasionally, with edafogene material in the basement. The carbonate sediments are locally lithified. The metalliferrous sediments include oxidized brown sediments up to 50 cm thick with poorly preserved microfauna and edafogene material in the basement of the section. The physical–chemical parameters (Eh and pH) of ore-bearing sediments near sulfide edifices and carbonate background sediments are sharply distinct. The background sediments studied in 36 columns beyond the hydrothermal fields are characterized by stable pH (7.4 to 7.8) and always positive Eh (+235 mV to +267 mV) typical of the whole thickness of sediments (up to 1.5 m). In the near sulfide edifices of orebody V, these parameters abruptly changed up to –130 Mv (Eh) and 6.8 (pH).

Based on plankton foraminifera, the age of sediments is 0–128 ka (Holocene–Late Pleistocene) [10]. Basalts underlying sediments in the area of orebodies are usually intensely altered, locally, up to friable quartz–chlorite rocks.

Pyrite–marcasite, pyrite–marcasite–chalcopyrite, pyrite–marcasite–sphalerite–chalcopyrite, pyrite–marcasite–chalcopyrite, and dominant chalcopyrite–pyrite–marcasite ore types with copper sulfides and bornite have been identified. Iron and, less, manganese hydroxides, jarosite, and atacamite group minerals occur in all ore types. Nonopaque minerals include widespread opal, native sulfur, barite, chlorite, and sporadic aragonite. Sphalerite was found only in orebody I from the Zenith-Victory hydrothermal field.

The ore types from the Zenith-Victory ore field are zonally distributed. Pyrite–marcasite–sphalerite–chalcopyrite ores are developed in the eastern part of the orebody where they occupy a N–S trending ridgetop area extending along the slope and coinciding with hydrophysical anomalies. The remaining territory is occupied by chalcopyrite–pyrite–marcasite ores (locally with an admixture of copper sulfides) divided by carbonate sediments with hydroxide-ferrous bodies with Mn. The zoning of the Petersburgkoe field is expressed in a body of rich copper sulfide ores in the southwestern part of the field (orebody V) encompassed with hydroxide-ferrous rocks and ore-bearing and carbonate sediments.

Most sulfide samples from both fields include several types of individual hydrothermal edifices with characteristic sizes and forms. Small (10–12 cm, occasionally, lesser) and large (30 to 60 and up to 70 cm) edifices can be found. The clasts of edifices are sporadic and usually include fragments of strongly leached and oxidized sulfides significantly (20–80%) replaced by iron hydroxides. The crosscutting and stratiform morphological types of edifices were identified. The crosscutting edifices have a streamline pear-shaped or mushroomlike form, and stratiform edifices are characterized by platelike, lens-shaped or loaflike morphology (Figs. 2a–2d). Both types contain no through hollow channels but have a lot of channel traces like round or gaplike craters concealed on edifice surfaces. The surfaces of undestroyed edifices are covered with iron hydroxides and, in many cases, opal film.

The interior structure of edifices is uniform, made up of multichannel massive–porous ores with crystalline texture in the lower (narrowed) and central parts of edifices and aphanitic texture with shell cleavage in the top and along the side walls usually composed of massive silver marcasite. The central channels are obliterated and may be imagined as subvertical closed lens-shaped hollows (Fig. 2d) incrusted with pyrite, chalcopyrite, and other hydrothermal minerals. The central zone gives rise to numerous variously oriented side channels with peripheral varieties concentrically rimming the edifice core. These peripheral channels are lens-shaped hollows parallel to walls and alternating with zones of massive marcasite.

The mineral zoning is generally related to the porosity. The framework of the edifice consists of marcasite and marcasite–pyrite ores with chalcopyrite and secondary copper sulfides in most porous areas (channel relics). Sphalerite is a major ore-forming mineral of Cu–Zn–Fe ores; it occurs both in the thin- to fine-crystalline framework of sulfide edifices along with marcasite and in hollow infillings.

Sulfide ores, especially in stratiform edifices, frequently inherit the layered structure of host sediments (Fig. 2c) and, locally, the psammitic texture of foraminifera sands (Fig. 2e).

The distinctive peculiarity of the studied sulfide edifices is their close association with sediments. The following interrelations have been revealed during the study of sulfide edifices and sediments: (i) the height of sulfide edifices corresponds to the thickness of sediments near the edifices and is less than 60 m (in random cases, up to 65–70 cm); (ii) sulfide edifices contain relics of sedimentary structures and textures (Figs. 2c, 2e); (iii) sulfide ores are characterized by inclusions of foraminiferas and/or pteropods replaced by sulfides or other hydrothermal minerals depending

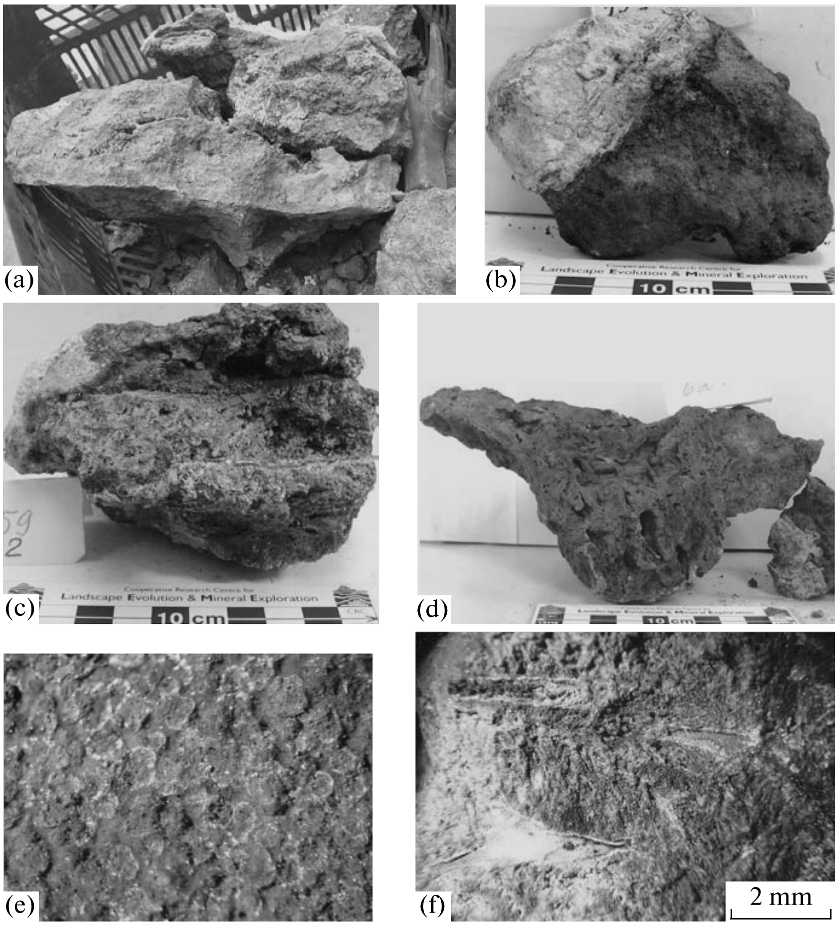

Fig. 2.

on the composition of the microfauna of host organogenic sediments (Figs. 2e, 2f); (iv) a 1- to 2-cm thick crust of lithified sediments, as a rule, covers the surface (usually the top) of edifices (Figs. 2a–2c); and (v) ore-bearing sediments are hydrothermally altered.

All the information stated above indicates the formation of sulfide ores at the expense of metasomatic replacement of carbonate sediments with sulfides. Most of the sulfide edifices include individual edifices formed by diffuse hydrothermal fluids penetrating through the fractures in basalts. The formation of sulfide ores was accompanied by considerable hydrothermal reworking of host sediments resulting in their compaction, lithification (locally up to sandstones (Fig. 2e)), dissolution of organogenic carbonates and its replacement with iron hydroxides, opal, and sulfides in sulfide edifices, and formation of sediment crusts in the edifice top. These data and the structures and textures frequently inherited from host sediments are the primary evidence of formation of sulfide ores due to penetration of hydrotherms into the sediment. The hydrophysical study has revealed indications of the present-day hydrothermal activity resulting in wall-rock alteration and fluctuations of physical–chemical parameters of sediments near the sulfide edifices. The sharp decrease in Eh (up to negative values) and increase in pH with depth bring out clearly the influence of acid reductive ascending hydrothermal fluids on sediments.

Thus, for the first time in the mid-oceanic ridges, a new type of mineralization which was formed under weakly forcing hydrothermal fluids ascended along the fractures in basalts into carbonate organogenic bottom sediments on the slopes of the Mid-Atlantic Ridge.

ACKNOWLEDGMENTS

The thirty-third cruise was supported by the Federal Agency on Mineral Resources of the Ministry of Natural Resources and Ecology of Russian Federation and, in part, by the Russian Foundation for Basic Research (project no. 08-05-00799).

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