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Criteria for the Detection of Hydrothermal Ecosystem Faunas in Ores of Massive Sulfide Deposits in the Urals

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Abstract—The ore-formational, ore-facies, lithological, and mineralogical-geochemical criteria are defined for the detection of hydrothermal ecosystem fauna in ores of the volcanic-hosted massive sulfide deposits in the Urals. Abundant mineralized microfauna is found mainly in massive sulfide mounds formed in the jasperous basalt (Buribai, Priorsk, Yubileinoe, Sultanov), rhyolite–basalt (Yaman-Kasy, Blyava, Komosomol'sk, Sibai, Molodezhnoe, Valentorsk), and the less common serpentinite (Dergamysh) formations of the Urals ($O-D_2$). In the ore-formational series of the massive sulfide deposits, probability of the detection of mineralized fauna correlates inversely with the relative abundance of felsic volcanic rocks underlying the ores. This series is also marked by a gradual disappearance of colloform pyrite, marcasite, isocubanite, pyrrhotite, and pyrite pseudomorphoses after pyrrhotite; increase of the amount of bornite, fahlores, and barite; decrease of contents of Se, Te, Co, and Sn in chalcopyrite and sphalerite; and decrease of Tl, As, Sb, and Pb in the colloform pyrite. Probability of the detection of mineralized fauna in the morphogenetic series of massive sulfide deposits decreases from the weakly degraded sulfide mounds to the clastic stratiform deposits. The degradation degree of sulfide mounds and fauna preservation correlates with the attenuation of volcanic intensity, which is reflected in the abundance of sedimentary and volcanosedimentary rocks and the depletion of effusive rocks in the geological sections.

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INTRODUCTION

Fauna is scarce in ores of the volcanic-hosted massive sulfide (hereafter, VHMS) deposits. Mineralized "corals" or tubeworms along with pelecypods were found for the first time in ores of the Sibai deposit (South Urals) as early as in 1947. (Ivanov, 1947, Ivanov et al., 1960). Fossil tubeworms were detected later in ores of several VHMS deposits in the Urals, Oman, Pontides, Cyprus, Ireland, New Caledonia, Philippines, and California (Avdonin, 1996; Kuznetsov et al., 1988; Lein et al., 2004; Little et al., 1997, 1999a, 1999b; Malakhov and Denisova, 1974; Maslennikov, 1999, 2006; Moskalev, 2002; Oudin and Constantinou, 1984; Prokin et al., 1985; Pshenichnii, 1984; Tunnicliffe, 1991). Despite long-term search history, mineralized fauna were found, however, not in all VHMS deposits (Herrington et al., 2002). This statement is also valid for the recent hydrothermal massive sulfide ecosystems: some of them are marked by the abundance of organism colonies, whereas microfauna are missing or chaotically and scarcely distributed in other ecosystems. Causes for the colonization of some massive sulfide-forming systems by organisms and their absence in other systems remain enigmatic so far. Bioproductivity is allegedly governed by the spreading rate and distance between ecosystems, duration of cycles, age and depth of oceans, concentrations of hydrogen sulfide, and contents of toxic elements such as As and Pb (Desbruyeres et al., 1994; Galkin, 2002; Van Dover, 2000). It is believed that habitation of the benthic fauna is most favored by focused jet or diffuse influx of reduced gases together with hydrothermal solutions. This is accompanied by their neutralization and mixing of reduced gases (H_2S, CH_4, H_2) with seawater oxygen, which are essential for the vital activity of organisms (Tunnicliffe, 1991).

In recent years, the authors of the present paper have expanded significantly the list of fauna-bearing

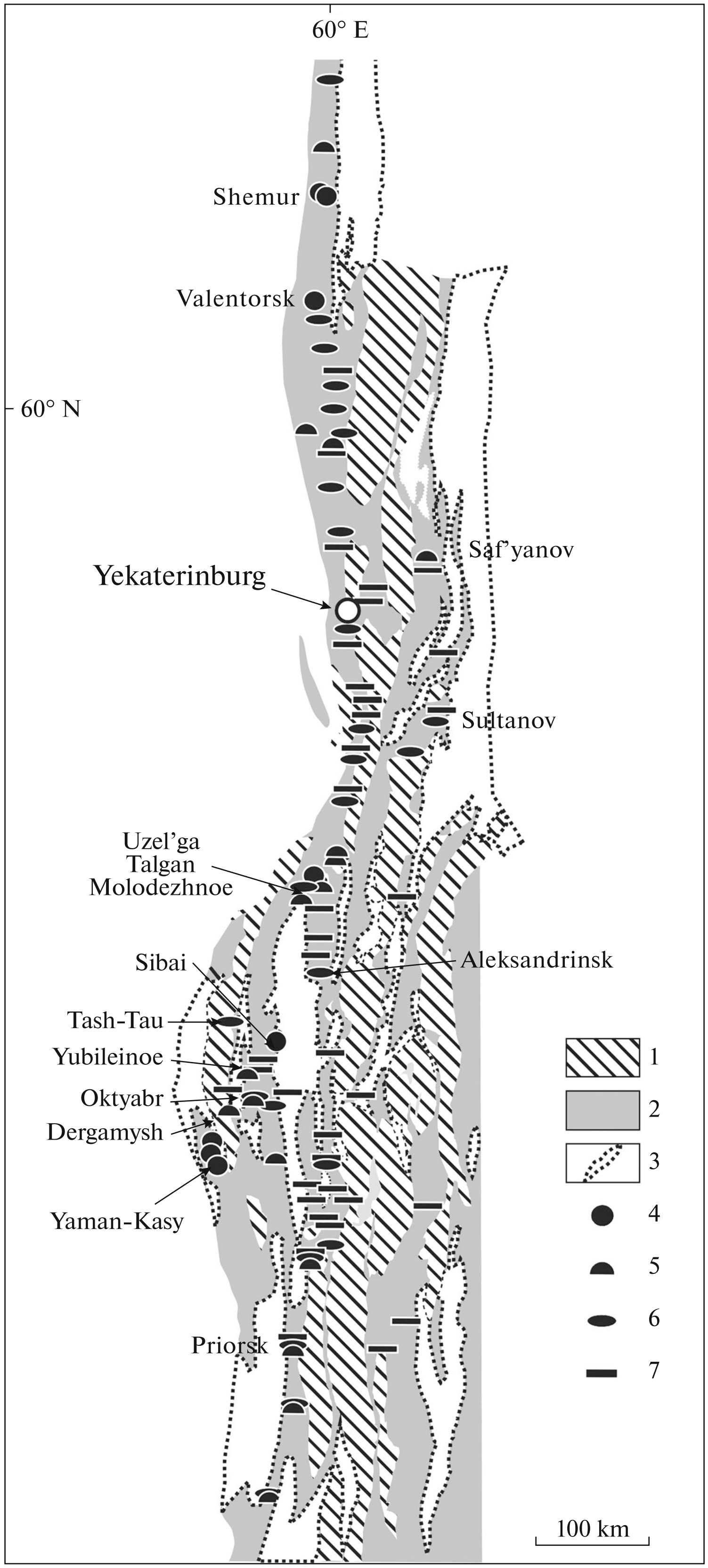

Fig. 1. Schematic location of VHMS deposits in the Urals. Based on (Kontar and Libarova, 1997; Maslennikov et al., 2013). (1) Early Paleozoic basement; (2) Middle Paleozoic volcanic belts; (3) Upper Paleozoic volcanosedimentary complexes; (4–7) massive sulfide bodies: (4) weakly disintegrated seamounts, (5) intensely disintegrated seamounts, (6) ore clastic lenses with relics of sulfide mounds, (7) stratiform lenses of layered ore clastites.

VHMS deposits in the Urals and Pontides. In addition to the known finds of black smokers (Herrington et al., 1998; Oudin and Constantinou, 1984), we have detected numerous fragments of paleosmoker vent chimneys, indicators of the influx of hydrothermal solutions, in ores of many VHMS deposits in the Urals, Pontides, Rudnyi Altai, and Hokuroko that belong to various types of ore–host rock complexes (hereafter, ore-formational) and ore-facies (Maslennikov, 1999, 2006; Maslennikov et al., 2010; Maslennikova and Maslennikov, 2007). Our materials provided insight into relationship of the bioproductivity of VHMS deposits with the composition of ore-hosting formations (rock associations), ore-facies specifics of ore bodies, mineral composition of hydrothermal vents, and chemical composition of sulfides as indicators of the physicochemical constraints of fauna habitat near the hydrothermal solution discharge sources.

METHODS

Our studies are based on the ore-formational (Eremin et al., 2000; Prokin and Buslaev, 1999; Seravkin, 2010; Zaikov et al., 2001) and ore-facies (Maslennikov and Zaikov, 2006; Zhabin et al., 1977) analysis of VHMS deposits. Minerals were identified in a JEOL-763 microprobe equipped with wave-length dispersive spectrometers and a modernized REMM-202M electron microscope equipped with LZ-5 energy-dispersive device at the Institute of Mineralogy, Ural Branch, Russian Academy of Sciences (Miass). Trace-elements in sulfides were determined by the well-known LA-ICP-MS method (beam diameter 35 μm) at the International Centre for Ore Deposit Researches (CODES) of the University of Tasmania (Hobart, Australia) and the Institute of Mineralogy, Ural Branch, Russian Academy of Sciences (Danyushevsky et al., 2011).

ORE-FORMATIONAL CRITERIA

Diverse fauna relicts were found at paleohydrotherm discharge sites in the massive sulfide-bearing ultramafic, basalt, rhyolite–basalt, and basalt–andesite–dacite–rhyolite formations (rock associations) of the Urals. The finding sites are shown in the scheme of morphogenetic types of VHMS deposits (Fig. 1). Positions of these deposits in geological sections are shown in Fig. 2.

Ultramafic formation. We detected numerous inclusions of mineralized tubeworms only in the cobalt–copper massive sulfide ores in the weakly disintegrated sulfide mound of the Dergamysh deposit confined to ultramafic rocks of the Sakmara subzone (Figs. 2, 3, 4a). The ore-hosting rocks show properties typical of both mid-oceanic ridges and island-arc basins. Therefore, this deposit is assigned to either the Atlantic or the ultramafic-rich Cyprus (Ivanov subtype in the Urals) ore-formational type (Melekestseva et al., 2013; Nimis et al., 2004; Seravkin, 2010; Zaikov, 2006; Zaikov et al., 2001).

Basalt formation. The VHMS copper deposits confined to basalts are scarce in the massive sulfide-bearing West Magnitogorsk and Dombarov–Mugodzhar zones that are reconstructed as ensimatic island arc and back-arc basin, respectively (Seravkin, 2010; Zaikov, 1991, 2006). We detected fragments of paleosmoker vent chimneys and rare pyrite–quartz pseudomorphoses after tubeworms in porous and clastic ores of the Buribai VHMS copper deposit confined to the Lower Devonian boninite–tholeiite basement of the West Magnitogorsk arc. Jaspers intercalating with sulfide turbidites include quartzose shell imprints (Maslennikov, 1999). Mineralized fauna are lacking in VHMS copper deposits of the Dombarov–Mugodzhar zone assigned to either the Cyprus (Zharly-Asha in the Urals) or Besshi (Dombarov in the Urals–Letnee, Zimnee, and Levoberezhnoe deposits) ore-formational types (Prokin and Buslaev, 1999).

Rhyolite–basalt formation. Depending on position in the geological section, composition of ore-hosting rocks, and Cu/Zn values in ores, the Ural-type VHMS deposits are divided into at least three subtypes: U-I, U-II, and U-III (Prokin et al., 2011; Seravkin, 2010). As is evident from Fig. 2, VHMS copper deposits of subtype U-I are confined to island-arc basalts closely associated with felsic volcanics, for example, in rocks overlying the ores (Yubileinoe) or underlying them (Priorsk, Sultanov). This subtype can be considered a transitional member between the Cyprus and Ural types (Maslennikov et al., 2014). We detected small tubeworms in all studied deposits of this subtype (Figs. 4b–4d).

Sulfide mounds in the VHMS copper–zinc deposits of subtype U-II are commonly separated from the mafic basement by small felsic volcanic rock edifices. Ore metasomatites are developed after basalts in some ore deposits (Novyi Sibai, Yaman-Kasy) (Figs. 2, 3). The mineralized fauna associated with paleosmoker chimneys and diffusores are most diverse in sulfide mounds of the Yaman-Kasy VHMS copper–zinc deposit (Figs. 5a–5d): Vestimentifera, Polychaeta, Serpulida, inarticulate Brachiopoda, Bivalvia, Gastropoda, and Monoplacophora (Kuznetsov et al., 1993; Little et al., 1997, 1999b; Maslennikov, 1999; Shpanskaya et al., 1999; Zaikov, 2006; Zaikov et al., 1995). Ore bodies of the Novyi Sibai deposit include Bivalvia, Vestimentifera, and Polychaeta (Figs. 5e, 5f) (Avdonin, 1996; Ivanov, 1947; Ivanov et al., 1960; Kuznetsov et al., 1988; Little et al., 1997, 1999b; Maslennikov, 1991; Prokin et al., 1985; Shcheglova and Borodina, 1956). Rare remains of tubeworms occur in ores of the Komosomol'sk deposit (Pshenichnii, 1984) and in ore dumps of the Blyava deposit (Fig. 4e).

Andesibasalt–andesite–dacite–rhyolite formation. Small tubeworms replaced by pyrite, sphalerite, and barite occur only sporadically in ores of the VHMS

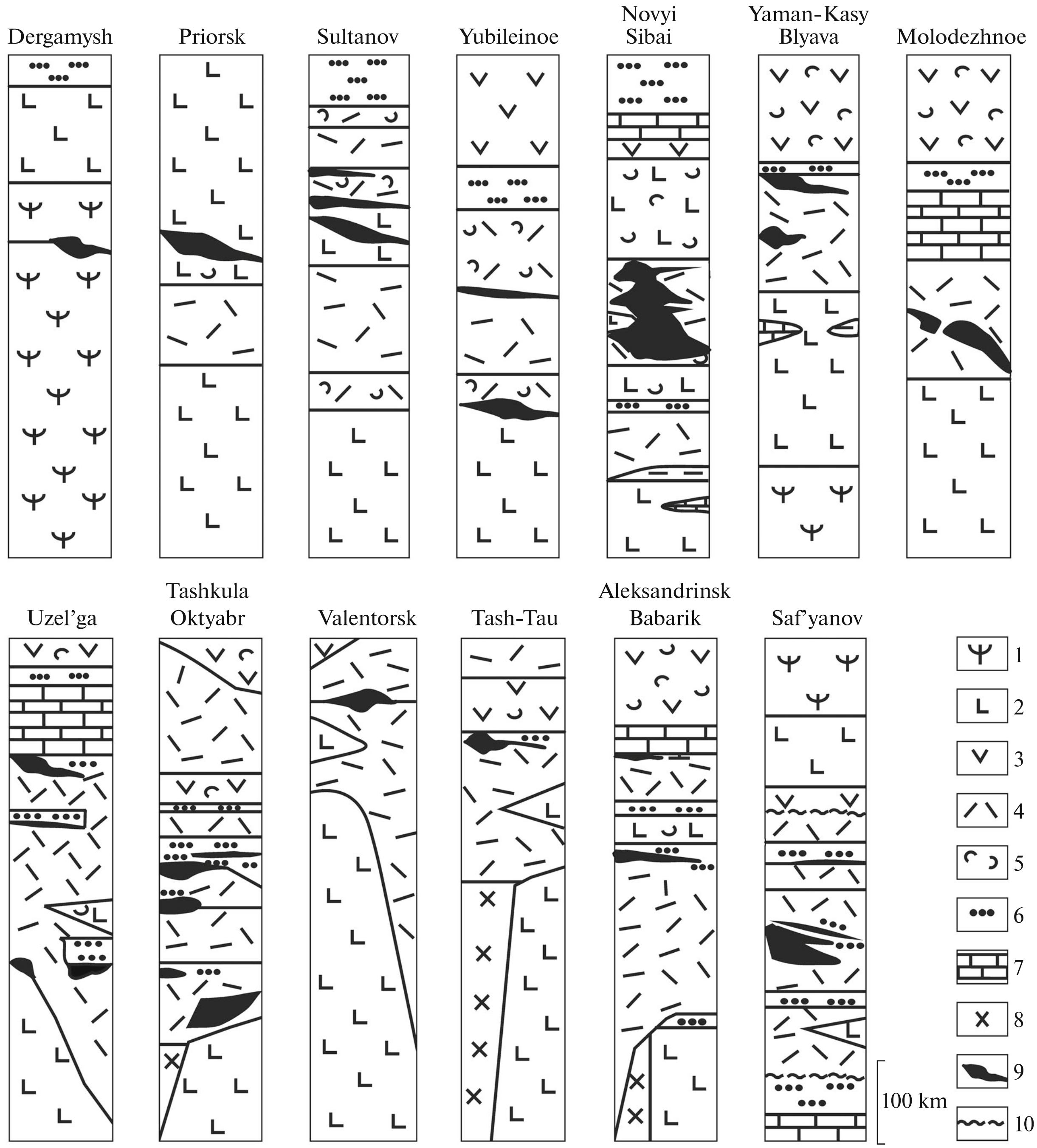

Fig. 2. Lithological composition and structure of the ore-hosting complexes in VHMS deposits of the Urals. (1) Ultramafics and serpentinites; (2) basalts, andesibasalts, and boninites (underlying the ores or coeval with them); (3) andesites and andesibasalts (overlying the ores); (4) andesidacites, dacites, and rhyolites; (5) volcanoclastites of the respective (2–4) composition; (6) layered volcanosedimentary rocks (undifferentiated); (7) limestones; (8) comagmatic plagiogranites; (9) massive sulfide bodies; (10) position of the inferred cleavage plane.

copper–zinc deposits (subtype U-III) confined to the Lower Devonian island-arc in the East Magnitogorsk zone (Molodezhnoe, Uzel'ga-4) (Fig. 4f). In the Karpinsk–Pavdinsk island-arc zone, we detected quartz pseudomorphoses in ores of the Vantorsk deposit assigned to the Baimak type in (Kontar, 2013; Kontar and Libarova, 1987) (Fig. 4g). The pseudomorphoses are likely developed after colonies of small tubeworms (Polychaeta) associated with numerous paleosmoker vent chimneys. Ore body of the Valentorsk deposit is only separated from the andesibasalt basement by a thin andesidacite and dacite sequence

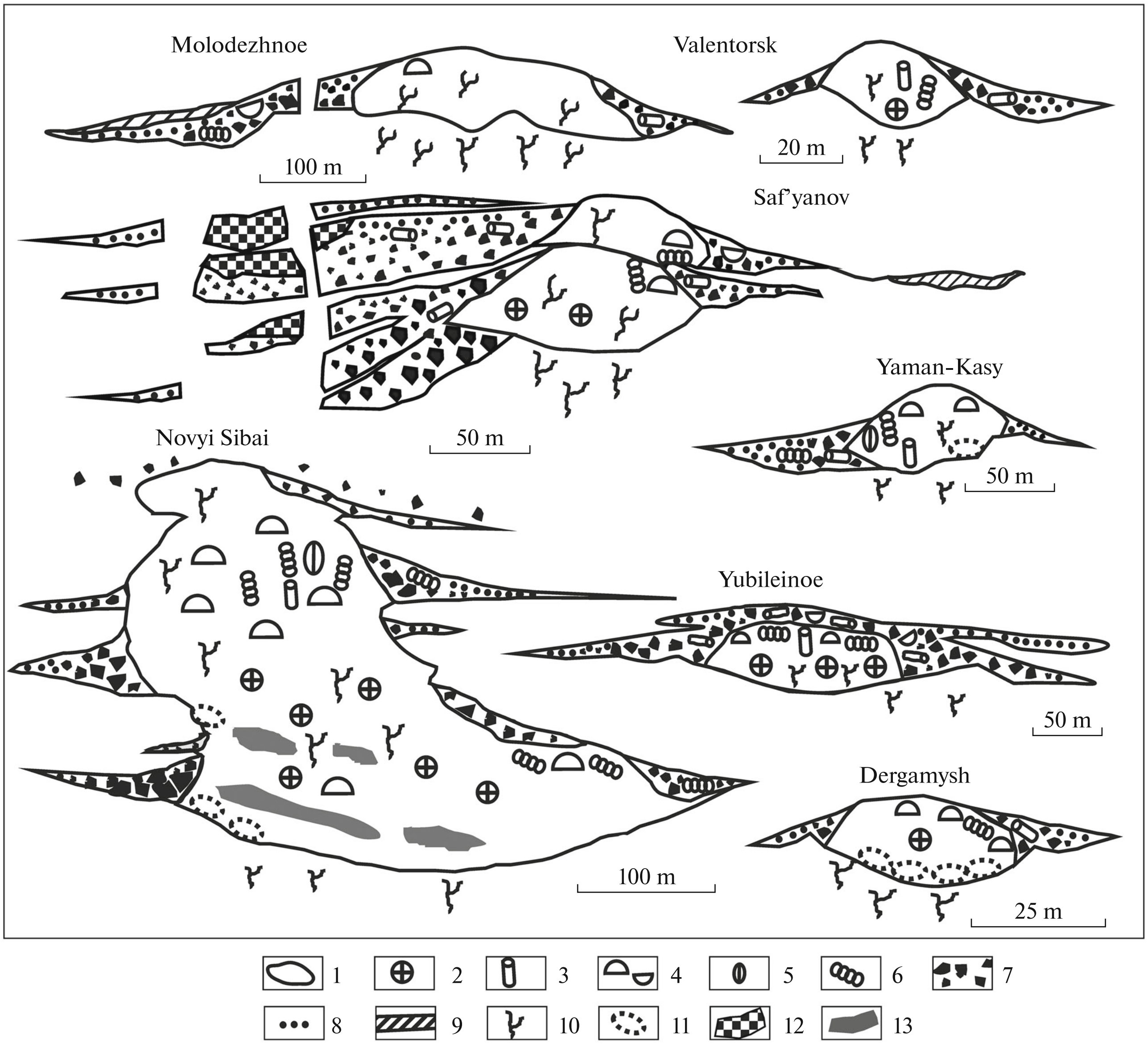

Fig. 3. Structure of ore bodies in the Uralian VHMS deposits and location of mineralized fauna therein. (1) Massive hydrothermal and hydrothermal-metasomatic ores; (2) hydrothermal conduits and diffusores; (3) vent chimneys inside paleosmokers; (4) colloform pyrite (hydrothermal crusts and overgrowths); (5) Bivalvia; (6) tubeworms; (7) sulfide breccia; (8) layered fine-clastic ores; (9) barite ores; (10) stockwork and disseminated ores; (11) hydrothermal-metasomatic ores formed after serpentinites (Dergamysh deposit) or basalts (Sibai and Yaman-Kasy deposits); (12) hydrothermal-metasomatic chalcopyrite ores replacing the primary hydrothermal and clastic sulfide deposits; (13) hydrothermal-metasomatic chalcopyrite–pyrrhotite ores.

(Fig. 2), making this deposit similar to the Ural type (subtype III) (Maslennikov et al., 2014).

Despite finds of the paleosmoker vent chimneys, reliable signs of mineralized macrofauna are lacking in the VHMS deposits associated with felsic volcanics (Uzel'ga-1, Uzel'ga-5, Oktyabr, Aleksandrinsk, Tash-Tau). These deposits are similar to the Kuroko-type deposits and sometimes assigned to the Baimak ore-formational type associated with the late felsic volcanism in ensimatic island arcs (Herrington et al., 2002; Prokin and Buslaev, 1999; Seravkin, 2010; Vikentyev, 2015a; Zaikov et al., 2001).

The massive sulfide-bearing volcanic sequences in the South Urals are marked by a wide development of jaspers (Maslennikov et al., 2012). In contrast, counterparts in the Central Urals are often distinguished by the development of carbonaceous aleuropelites ("black shales"). We only detected numerous pyritized tubeworms in sulfide mounds of the Saf'yanov VHMS lead–copper–zinc deposit (Fig. 4h) confined to a back-arc basin in the eastern Central Urals (Korovko et al., 1988; Maslennikov, 1999, 2006). This deposit can likely be assigned to the VHMS copper–zinc subtype of the Altai ore-formational type (Maslennikov

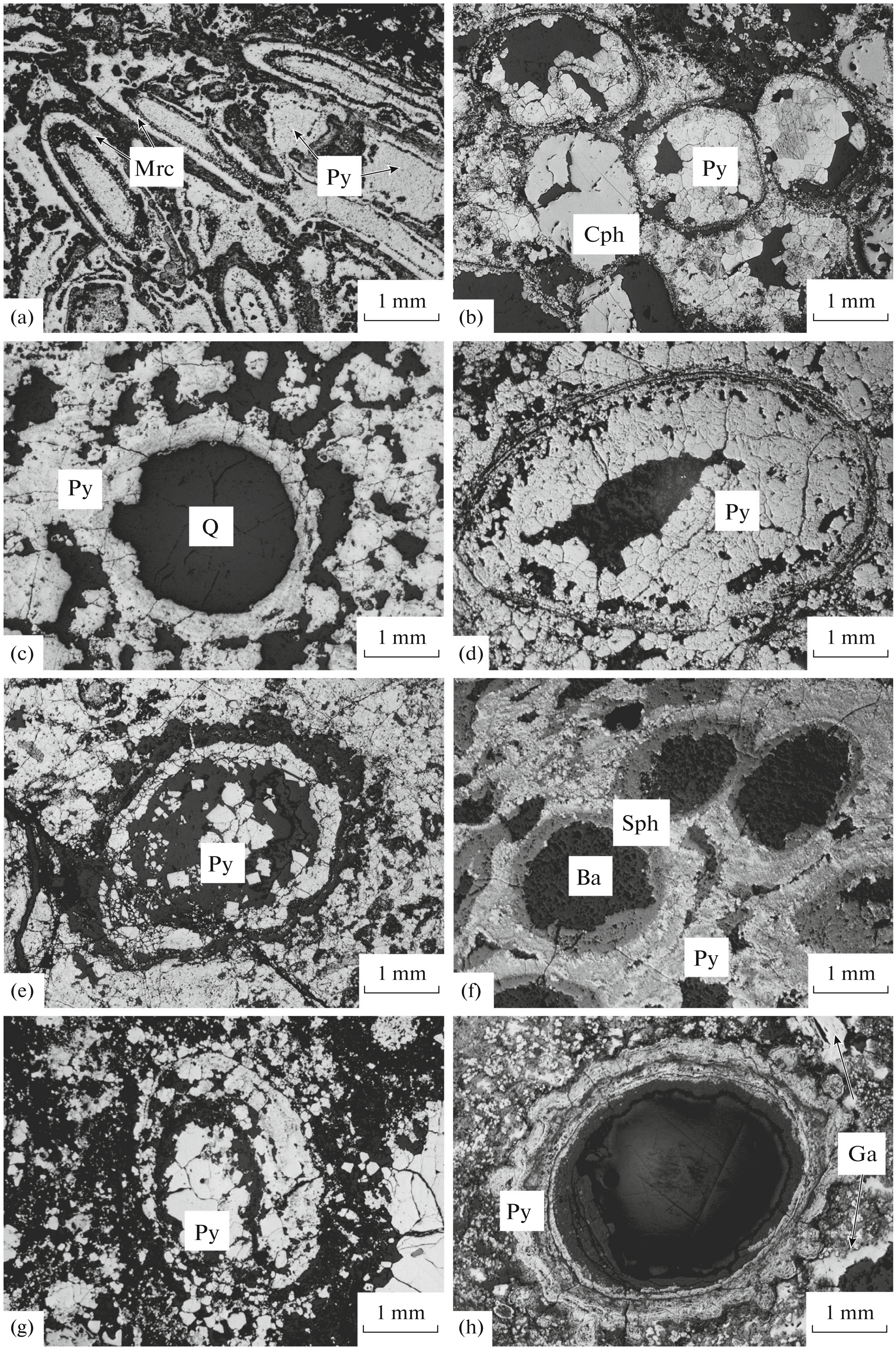

Fig. 4. Transverse sections of small pyritized tubeworms (Polychaeta) in the Uralian VHMS deposits. (a) Dergamysh, (b) Yubileinoe, (c) Priorsk, (d) Sultanov, (e) Blyava, (f) Molodezhnoe, (g) Valentorsk, (h) Saf'yanov. (Py) Pyrite, (Mrc) marcasite, (Chp) chalcopyrite, (Sph) sphalerite, (Ba) barite, (Ga) galena, (Q) quartz.

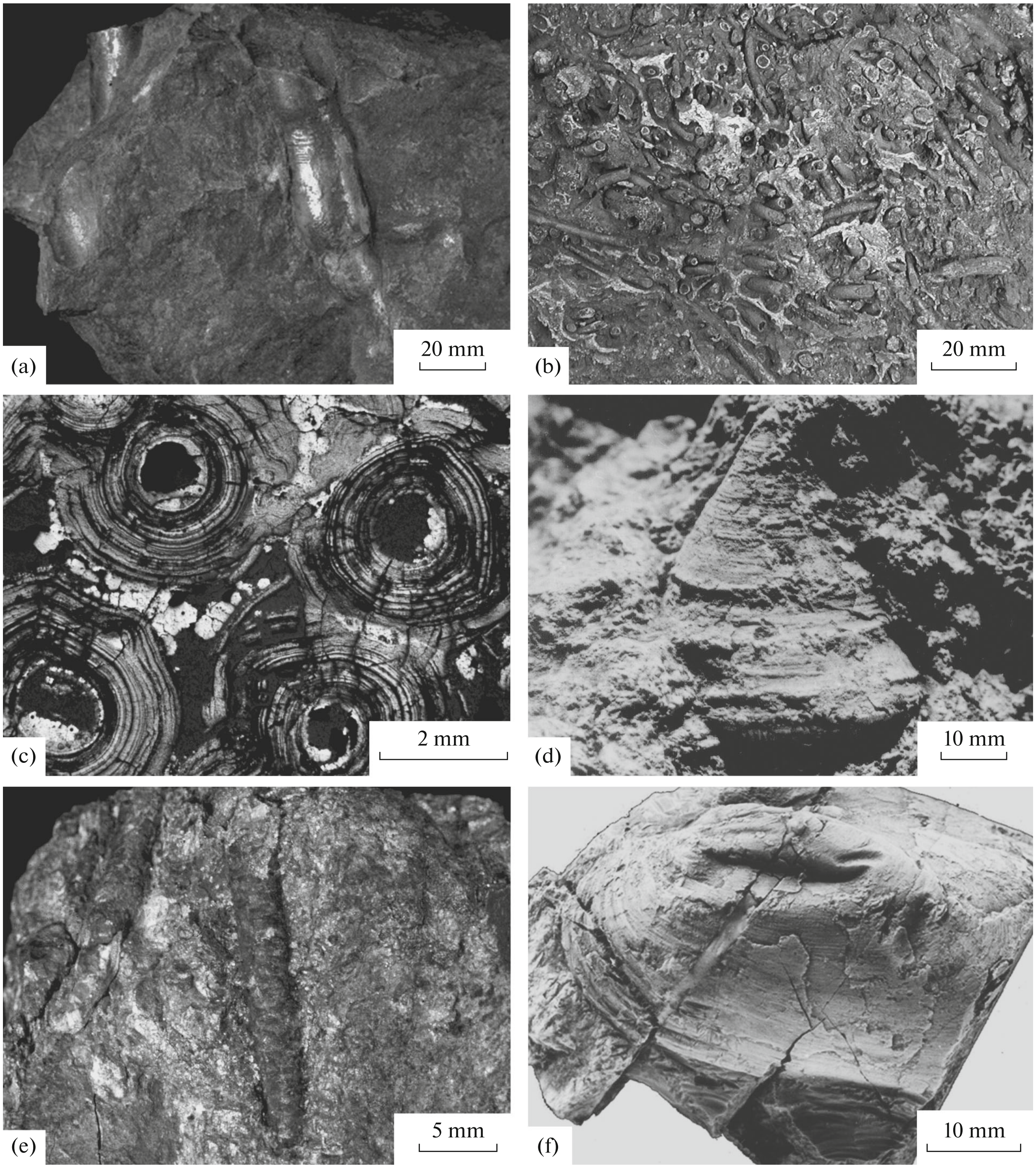

Fig. 5. Pyritized hydrothermal zone fauna in the Uralian VHMS deposits. (a) Vestimentifera, (b) Polychaeta, (c) Polychaeta (transverse section), (d) Monoplacophora, (e) Vestimentifera, (f) Bivalvia. Deposits: (a–d) Yaman-Kasy, (e, f) Sibai.

et al., 2014). We conditionally assign the stratiform VHMS deposits associated with black shales in the andesibasalt–andesite–dacite–rhyolite formation to the Central Ural type, which is similar to the Altai and Iberian ore-formational types. Reliable signs of mineralized fauna are usually lacking in these deposits that underwent the greenschist metamorphism (Vikentyev, 2015b). However, A.V. Gorokh found a single sulfidized tubeworm in the Krasnogvardeisk deposit located in the Tagil island-arc system (Ivanov, 1959).

ORE-FACIES CRITERIA

Mineralized fauna were found mostly in massive sulfide bodies (Dergamysh, Novyi Sibai, Yaman-Kasy, Molodezhnoe, Valentorsk, and Saf'yanov deposits) that are reconstructed as sulfide mounds (Fig. 3). Of particular interest for the search of hydrotherm-related macrofauna are the hydrothermal seafloor facies that include hydrothermal crusts, lenses, and plates along with diffusores and hydrothermal vents. These ore facies are confined mainly to the upper parts of sulfide mounds. Mineralized fauna are observed as fragments in colluvial sulfide breccias on the slopes of such mounds and are less often preserved in sulfide turbidites on the flanks of ore bodies.

In general, these fragments are pseudomorphoses of chalcopyrite or sphalerite after the pyritized fauna. Mineralized fauna are lacking in the massive hydrothermal-metasomatic chalcopyrite–pyrite, chalcopyrite and chalcopyrite–pyrrhotite, and siderite–chalcopyrite–pyrite ore facies that make up “cores” of the sulfide mounds, because massive ores are products of the hydrothermal alteration of rocks of the seafloor hydrothermal facies. Despite the mound-type shape of sulfide bodies and other favorable signs, abundance of the hydrothermally altered ores decreases probability of the detection of mineralized fauna in VHMS deposits, such as Uchaly, Novyi Uchaly, Ozernoe, Pyat’desyat let Oktyabrya, and Uzel’ga-4.

On the whole, the degree of mineralized fauna preservation and, correspondingly, the probability of their detection decreases from the weakly disintegrated hydrothermal sulfide mounds to the layered stratiform deposits that are composed of clastic sulfide ores and products of their submarine transformation. Mineralized fauna are almost absent in stratiform ore bodies (Vostochnyi Semenov, Vostochnoe Molodezhnoe, Degtyar, Voroshilov, Chusov, and others). In products of the submarine transformation of sulfide turbidites (ore clastic facies), fragments of the mineralized fauna and other sulfide fragments are replaced by authigenic minerals that camouflage the primary biomorphic structures. In products of the complete submarine oxidation of massive sulfide ores, researchers have unraveled tubular microfauna replaced by hematite, chlorite–hematite, quartz–hematite, and carbonate–hematite aggregates (Talgan, Molodezhnoe, Aleksandrinsk, and others) (Ayupova et al., 2016).

We have previously demonstrated that the degree of seafloor disintegration and transformation of sulfide mounds has a positive correlation with the ratio of the sedimentogenic/effusive facies in geological sections (Maslennikov, 2012). This is likely related to inverse correlation between the exposure duration of sulfide mounds on the seafloor and the intensity of effusive volcanism. Hence, finds of the mineralized fauna in the Uralian VHMS deposits depend on the relationship between the ore-associated, volcanosedimentary, and effusive facies (Fig. 6).

The plot shows that the mineralized fauna are usually found in ore bodies characterized by the L/M ratio less than 10, with a small amount of the volcanosedimentary and sedimentary rocks in the ore-overlying sequence. In contrast, sedimentogenic rocks are much more developed above the stratiform bodies. This relationship correlates with the ore-formational types of VHMS deposits. The morphogenetic series begins with the prevalence of the Cyprus- and Ural-type deposits (subtypes U-I and U-II) and ends with deposits of the Baimak and Central Ural (subtype U-II) types. Probability of the detection of mineralized fauna is low for stratiform ore bodies in the Besshi-type deposits. This statement is also valid for the Central Ural-type ore bodies that associate with andesi-dacites (their volcanosedimentary varieties included) and resemble the Besshi type (Prokin et al., 1998).

MINERALOGICAL CRITERIA

Each ore-formational type of VHMS deposits is characterized by specific assemblages of rare minerals (Eremin et al., 2007). Since a significant amount of rare minerals was formed during the epigenetic alteration of massive sulfide ores (Eremin, 1983; Vikentyev, 2004), they can serve as indicators of the physicochemical ecosystem constraints related to the hydrothermal activity. However, syngenetic mineralization in the hydrothermal paleosmoker chimneys and synchronous veins is marked by specific features in different ore-formational types of VHMS deposits with distinctive values of bioproductivity (Table 1). Massive sulfide copper or copper–zinc paleosmokers and veins in the bioproductive VHMS deposits are characterized by the abundance of colloform pyrite, marcasite, isocubanite, and pyrite pseudomorphoses after the euhedral pyrrhotite, as well as the presence of pyrrhotite microinclusions in pyrite crystals. Among rare minerals, diverse sulfoarsenides and tellurides serve as indicators.

In contrast, these minerals are exceptionally rare in the base metal massive sulfide vents and veins of the Baimak-type VHMS deposits that commonly lack the fauna. In paleosmokers and veins of this type, euhedral pyrite, barite, bornite, and gold–gelenite–fahlore assemblage are much more common. Only some of these bodies contain the subordinate hessite and the rare altaite (Table 1).

MINERAL–GEOCHEMICAL CRITERIA

Concentrations of chemical elements in the hydrothermal sulfides of paleosmokers in the Uralian VHMS deposits show a correlation with bioproductivity (Tables 2–4).

Chalcopyrite. Chalcopyrite and isocubanite in paleosmokers associated with abundant mineralized fauna are enriched in Se, Te, Sn, Ag, and Co. In some places, however, they are depleted in Sb and As relative to paleosmokers in the majority of the Baimak-type VHMS deposits (Table 2) except for chalcopyrite in the Yaman-Kasy, Molodezhnoe, and Saf’yanov deposits, where the high As content is related to microincluions of both sulfoarsenides and fahlores.

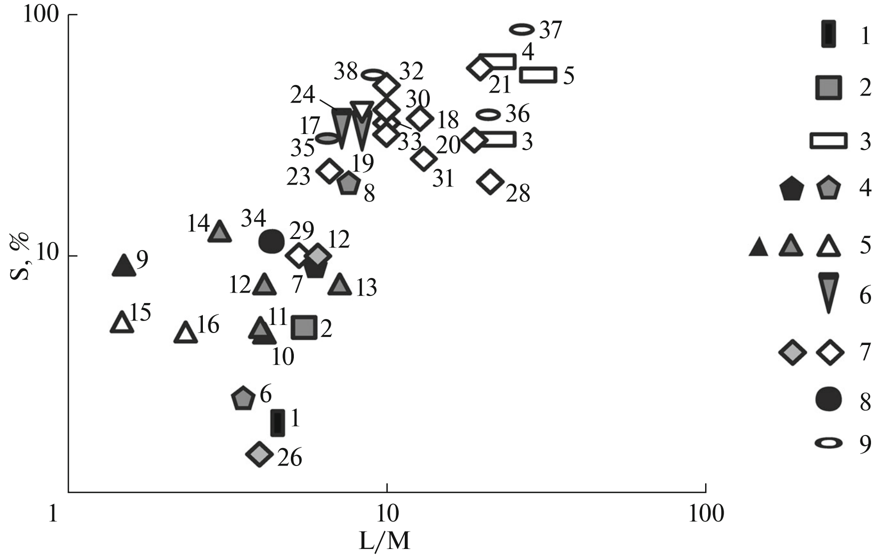

Fig. 6. Dependence of fauna from the disintegration degree of hydrothermal sulfide ore mound expressed as relationship between its length + width (L), thickness (M), and percentage of the volcanosedimentary rocks overlying the ores (S). Ore-formational types of the Uralian VHMS deposits: (1) Atlantic; (2) Cyprus; (3) Besshi; (4–6) Ural subtypes: (4) U-I, (5) U-II, (6) U-III; (7) Baimak and Kuroko; (8) Altai; (9) Central Ural. Here and in Fig. 7, black color designates abundant fauna; gray color, episodic finds of fauna; and white color, lack of fauna or problematic find. Deposits: (1) Dergamysh, (2) Buribai, (3) Letnee, (4) Osennee, (5) Mauk, (6) Priorsk, (7) Yubileinoe, (8) Sultanov, (9) Sibai, (10) Yaman-Kasy, (11) Shemur, (12) Blyava, (13) Uchaly, (14) Komosomol'sk, (15) Ozernoe, (16) Pyat'desyat let Oktyabrya, (17) Molodezhnoe, (18) Chebach'e, (19) Uzel'ga-4, (20) Uzel'ga-1, (21) Talgan, (22) Makan-2, (23) Oktyabr, (24) Podol'sk, (25) Devyatnadtsatyi Parts"ezd, (26) Valentorsk, (27) Barsuchii Log, (28) Dzhusa, (29) Tash-Tau, (30) Bakr-Tau, (31) Aleksandrinsk; (32) Maisk, (33) Vostochnyi Semenov, (34) Saf'yanov, (35) Krasnogvardeisk, (36) Tretii Internatsional, (37) Yuzhnoe, (38) Degtyar.

It is assumed that Co, Sn, and Ag can enter partly as isomorphous elements in chalcopyrite. In the Ural-type deposits, Ag occurs as admixture in hessite, whereas Co occurs as cobaltite and mattagamite microinclusions (Maslennikov et al., 2009). In the Saf'yanov deposit, chalcopyrite includes the glaucodote–hessite assemblage. Contents of Se and Te commonly display a positive correlation: their concentration in chalcopyrite paleosmokers decreases in the ore-formational series of VHMS deposits with increase of the share of felsic volcanic rocks therein (Fig. 7a). Relative to smokers in deposits of other types, paleosmokers in the bioproductive Ural-type VHMS deposits are enriched in Te as numerous telluride microinlcusions. Some part of Te^{4+} in paleosmokers occurs as an isomorphous component of fahlores (Maslennikov et al., 2015).

The hydrothermal *sphalerite* in paleosmokers from VHMS deposits with abundant mineralized fauna are commonly enriched in Fe (>1 wt %), Sn (8.5–196 ppm), with strong variations of Co (from 3 to 1704 ppm) (Table 3) except for the Yubileinoe deposit with high contents of Fe and low contents of Co (0.01 ppm). High concentrations of Fe, Sn, As, Sn, and Se are typical of the hydrothermal sphalerite in the Saf'yanov deposit.

The hydrothermal sphalerite of VHMS deposits, which lack the mineralized fauna, are marked by a much lower Fe content of usually less than 1 wt % (Table 3, Fig. 7b). This sphalerite is commonly characterized by lower contents of both Co (0.001–4 ppm) and Sn (0.5–8.3 ppm). Despite the presence of quartzified tubeworms, the Valentorsk deposit is closer to the Baimak-type deposit with respect to contents of Fe, Sn, and Co in sphalerite. Other chemical elements (Cd, Mn, Se, Sb, Ag), which are isomorphous components of sphalerite (Table 3), are unrelated to the presence of mineralized fauna.

Colloform pyrite. In the colloform pyrite of VHMS deposits, which include the mineralized fauna, contents of Co are high and Co prevails over Ni in some places. Exceptions are the Sibai deposit, where Co is mainly concentrated in the euhedral pyrite (Maslennikov et al., 2014) and Valentorsk deposit, which represents a transition to the Baimak type. In the colloform pyrite of the Baimak-type VHMS deposits, Ni usually prevails over Co, which is commonly negligible (Table 4).

Low contents of As, Sb, Pb, and Tl are typical of the colloform pyrite in the bioproductive VHMS deposits (Figs. 7b, 7d). Their concentrations increase in the ore-formational series of VHMS deposits with increase of the share of felsic volcanic rocks therein (Maslennikov et al., 2014; Vikentyev, 2016). Contents of Pb and Tl are maximal in the colloform pyrite of the Baimak-type deposits (Fig. 7c). In the colloform

Table 1. Finds of the mineralized fauna and mineral composition of the hydrothermal vents and veins in ores of the Uralian VHMS deposits. Original data modified after (Herrington et al., 1998; Little et al., 1997, 1999a, 1999b; Maslennikov, 1999, 2006; Maslennikov et al., 2009, 2013; Maslennikova and Maslennikov, 2007; Prokin and Buslaev, 1999)

Deposits	Formation	Pyrite	Secondary and rare minerals	Fauna
Dergamysh	J-H	c, p, a, s, e, f	Chalcopyrite > sphalerite, marcasite, isocubanite, cobaltiferous pyrite, calcite, *pyrrhotite, electrum, tin sulfide, arsenopyrite*	P, ±V
Priorsk*	J-B	c, p, a, s, e,	Chalcopyrite > sphalerite, marcasite, pyrrhotite, *isocubanite, fahlores, molybdenite, arsenopyrite, galena, quartz*	P
Yubileinoe	J-RB-1	c, p, a, s, e	Chalcopyrite > sphalerite, talc, calcite, quartz, *pyrrhotite, arsenopyrite, tellurobismuthite, coloradite, hessite, native gold, tennantite, electrum*	P, ±V,
Sultanov	J-RB-1	c, p, a, s, e	Chalcopyrite > sphalerite, marcasite, isocubanite, *tellurobismuthite, altaite, hessite, native gold, quartz*	±V
Novyi Sibai*	J-RB-2	c, p, a, s, e	Chalcopyrite, sphalerite, pyrrhotite, marcasite, *tellurobismuthite, altaite, rucklidgeite, quartz, calcite*	V, P, Bv
Yaman-Kasy	J-RB-2	c, p, a, s, e	Chalcopyrite, sphalerite, marcasite, isocubanite, *quartz, pyrrhotite, frobergite, mattagamite, loellingite, cobaltite, altaite, tellurobismuthite,hessite, kervelleite, volynskite, native tellurium, barite, native gold, tennantite, tetrahedrite, goldfieldite*	V, P, Br, M, G
Molodezhnoe	J-RB3	c, p, a, s, e	Chalcopyrite, sphalerite, marcasite, *altaite, hessite, coloradite, tennantite, native gold, quartz, barite*	P
Uzel'ga-4	J-RB3	c, a, s, e	*Marcasite*, barite, *coloradite, tennantite-tetrahedrite, native gold, hessite*	±P, ±V
Uzel'ga-1		a, s, e	Sphalerite, chalcopyrite, tetrahedrite-tennantite, hessite, native gold, galena	–
Oktyabr	J-RB3	±c, a, s, e	Sphalerite > chalcopyrite*, barite, hessite, altaite, tennantite, native gold*	±P, ±Br
Valentorsk	J-BR	±c, a, s, e	quartz, *rucklidgeite-kochkarite, hessite, native gold, petzite, sylvanite, tennantite*	P
Tash-Tau	J-BR	a, s, e	bornite, *tennantite, galena, quartz, barite, native gold*	–
Aleksandrinsk	J-BR	a, s, e	barite, tennantite, bornite, *hessite, native gold, renierite*	–
Dzhusa	J-BR	a, s, e	barite, *galena, tennantite*	–
Saf'yanov	BR-U	c, p, a, s, e, f	marcasite, *glaucodote, arsenopyrite, tetrahedrite, enargite, tennantite, bismuth tellurides, hessite, native gold, stannite, quartz, barite*	P

(*) The general mineral composition of ores is given for the Priorsk, Novyi Sibai, and Krasnogvardeisk deposits; the composition of only hydrothermal vents is given for the remaining paleosmokers. *Formations:* (H) harzburgite, (B) basalt, (RB) rhyolite–basalt; (BR) basalt–rhyolite, (J) jasperous; (U) Uralian black shale. *Pyrite*: (c) colloform, (p) pseudomorphous after pyrrhotite, (a) anhedral, (s) subhedral, (e) euhedral, (f) framboidal. *Minerals:* secondary minerals are lowercased; rare minerals are italicized. *Mineralized fauna:* (P) tubeworms less than 0.5 cm in diameter (Polychaeta?), (V) tubeworms more than 0.5 cm in diameter (Vestimentifera?), (M) Monoplacophora, (Br) Brachiopoda, (G) Gastropoda, (Bv) Bivalvia; (±) uncertain fauna identification, (–) lack of fauna.

Table 2. Average contents of trace elements (ppm) and their standard deviation (σ) in the hydrothermal chalcopyrite from the Uralian VHMS deposits

Deposits	Co	Ni	As	Se	Ag	Sn	Sb	Te	Bi
Dergamysh (134)	2578	271	27	551	40	36	25	97	110
σ	3691	574	53	216	32	41	38	56	224
Buribai (25)	1	3	3	1536	89	4	10	75	2.7
σ	1	4	3	556	91	0	8	75	3.1
Sultanov (21)	2.7	3.3	29	363	502	94	31	430	60
σ	4.8	7.7	56	237	465	95	44	378	43
Yubileinoe (82)	1.0	0.2	3.4	261	34	17	4.9	16	3.3
σ	5.2	0.9	6.9	232	55	9.0	6.0	37	7.2
Sibai (34)	12	0.3	14	410	12	14	4.5	5.9	14
σ	37	0.4	58	325	8	35	5.4	7.9	25
Yaman-Kasy (136)	84	1.0	1069	60	570	58	358	5012	605
σ	481	2.7	2879	42	1122	130	754	12279	2902
Molodezhnoe (48)	311	1.4	813	499	138	225	48	3381	79
σ	412	2.6	1054	470	209	850	49	7140	152
Valentorsk (52)	0.2	1.8	27	139	70	37	5.6	138	3.7
σ	0.4	4.9	37	79	108	16	5.9	464	4.0
Uzel'ga-4 (20)	1.8	3.2	21	731	158	23	6.4	207	0.02
σ	7.9	14	54	449	354	5.1	21	519	0.08
Uzel'ga-1 (64)	1	0	26	120	8	55	25	6	8.1
σ	2	0	91	59	17	248	104	45	10
Oktyabr (22)	0.4	0.5	5.0	134	5.6	3.8	1.7	8.4	100
σ	1.4	1.4	4.1	50	14	0.4	1.7	18	333
Talgan (6)	0.1	0.1	20	21	14	11	13	1.5	31
σ	0.1	0.2	15	10	9.0	1.6	22	0.7	66
Tash-Tau (57)	0.1	0.4	9.0	84	22	3.4	1.3	1.1	1.3
σ	0.3	1.5	48	36	33	2.4	2.9	2.3	3.2
Aleksandrinsk (52)	0.0	0.4	243	23	7.5	6.1	90	6.8	2.7
σ	0.1	2.3	1427	40	6.2	6.3	542	23	5.8
Dzhusa (8)	0.7	0.2	88	8.5	4.3	80	11	0.05	0.001
σ	1.9	0.4	240	2.0	3.7	22	22	0.05	0.001
Saf'yanov (40)	43	0.2	113	909	132	489	35	22	35
σ	122	0.2	275	760	266	944	94	36	56

Deposits containing the mineralized fauna are boldfaced; deposits with episodic finds of fauna are italicized and boldfaced; deposits without or with problematic mineralized fauna are given in normal font. The number of samples is given in parentheses.

pyrite, Tl is likely concentrated in galena (George et al., 2015). Distortion of the positive correlation between Pb and Tl can suggest the presence of minerals like altaite (Molodezhnoe and Yaman-Kasy deposits). Positive correlation between As and Sb does not rule out the presence of fahlore microinclusions in the colloform pyrite. Total contents of Sb and As in the colloform pyrite of the Baimak-type deposits, which lack the mineralized fauna, are one to two orders of magnitude higher than in the colloform pyrite of the bioproductive VHMS deposits (Table 4).

DISCUSSION

Comparison of the recent and ancient ecosystems of VHMS deposits in hydrothermal activity areas revealed not only some similarities, but several dissimilarities of their specific features. The fauna is most abundant and diverse in the present-day World Ocean

Table 3. Average contents of trace elements (ppm) and their standard deviation (σ) in the hydrothermal sphalerite from the Uralian VHMS deposits

Deposits	Mn	Fe	Co	Cu	As	Se	Ag	Cd	Sn	Sb
Dergamysh (46)	1913	4.3	1704	1.6	18	161	44	0.1	196	1154
σ	1675	2.4	1530	1.5	21	177	54	0.03	204	1215
Buribai (7)	88	1.5	3	1.6	9	203	32	0.2	14	19
σ	14	0.5	3	1.1	8	126	24	0.01	19	20
Yubileinoe (34)	140	1.8	0.01	0.9	351	23	264	0.3	4.2	473
σ	93	0.9	0.01	1.1	521	16	326	0.0	3.3	626
Sultanov (8)	3	3.8	0.01	4.4	60	3.9	33	0.3	90	222
σ	7	1.0	0.01	1.1	99	1.9	40	0.0	88	409
Sibai (6)	90	3.0	0.13	0.4	85	1.0	115	0.1	83	198
σ	47	1.3	0.05	0.3	41	0.0	54	0.0	104	104
Yaman-Kasy (106)	56	1.9	18	1.1	1897	5.5	137	0.2	26	636
σ	58	1.8	27	1.1	1878	6.7	208	0.1	31	933
Molodezhnoe (46)	44	0.6	21	0.4	213	115	176	0.2	91	97
σ	43	0.7	42	0.7	741	109	384	0.0	124	289
Valentorsk (38)	171	0.7	0.06	0.7	102	56	49	0.2	4.2	44
σ	93	0.5	0.25	0.6	387	44	51	0.1	5.0	103
Uzel'ga-4 (16)	2	1.1	0.10	1.2	17	518	49	0.2	8.6	86
σ	1	0.7	0.23	0.8	27	524	70	0.0	4.6	230
Uzel'ga-1 (36)	40	0.1	0.1	0.3	1438	106	54	0.4	0.5	675
σ	103	0.2	0.1	6806	3759	73	158	0.03	1.0	1879
Oktyabr (25)	39	0.5	0.00	0.6	376	50	2697	0.3	1.0	585
σ	18	0.4	0.00	0.4	540	42	11160	0.0	0.5	740
Talgan (3)	14	0.7	0.01	0.1	217	9	297	0.2	2.9	990
σ	10	0.3	0.01	0.0	29	10	38	0.0	0.5	184
Tash-Tau (30)	17	0.4	0.15	0.4	79	55	134	0.4	5.5	356
σ	7	0.9	0.77	0.3	220	51	259	0.0	8.3	917
Dzhusa (9)	80	0.70	4	0.04	1.0	3.0	5.4	0.2	0.9	3.0
σ	20	0.08	2	0.02	1.1	2.0	3.3	0.01	0.9	3.1
Aleksandrinsk (52)	15	0.2	0.02	0.6	437	25	46	0.4	1.9	278
σ	19	0.2	0.04	0.7	1799	50	43	0.1	2.2	477
Saf'yanov (45)	4	2.6	0.81	3.2	1686	181	339	0.5	185	1299
σ	10	2.4	1.60	2.6	3992	177	463	0.1	213	2838

Legend as in Table 2. Contents of Fe, Cu, and Cd are given in wt %.

in fast-spreading areas of the eastern Pacific because of the formation of black smokers on basalts (EPR) or organic-rich sediments (Guaymas) (Galkin, 2002). The major finds of ancient fauna are confined mainly to the Cyprus-type deposits formed on basalts (Boirat and Fouquet, 1986; Haymon et al., 1989; Little et al., 1999a, 2002; Oudin and Constantinou, 1984). The abundance of fauna, whose vital activity is provided by thiotrophic endosymbionts, depends on the composition of the host substrate: hydrotherms in basalt complexes, with rare exceptions reported in (Lein and Ivanov, 2009), are dominated by H_2S (Perner et al., 2013). High and stable concentrations of hydrogen sulfide are indicated by abundant Vestimentifera colonies, which lack alternative nutrient sources except endosymbiotrophs with thionic bacteria (Gebruk et al., 2002). As the Dombarov-type deposits, layered ore bodies of the Besshi-type VHMS deposits in the Urals lack the mineralized fauna, probably, because of intense diagenetic and metamorphic transformations of the dominating sulfide turbidites (Safina et al., 2015). Only a few tubeworms and bivalves were found in the relict seafloor hydrothermal facies of the Cyprus-type Buribai deposit associated with both tholeiites and boninites at

Table 4. Average contents of trace elements (ppm) and their standard deviation (σ) in the hydrothermal-sedimentary colloform pyrite from the Uralian VHMS deposits

Deposits	Co	Ni	As	Ag	Sb	Te	Tl	Pb	Bi
Dergamysh (12)	3027	228	0.01	24	223	26	5.8	0.002	38
σ	1795	157	0.01	21	198	31	4.8	0.002	48
Buribai (18)	20	285	0.007	60	46	107	5	0.05	33
σ	10	79	0.003	21	13	37	5	0.02	10
Yubileinoe (35)	38	31	0.07	162	68	90	48	0.02	28
σ	85	19	0.05	116	52	82	79	0.01	26
Sultanov (9)	13	54	0.15	86	91	112	76	0.01	140
σ	17	21	0.02	96	57	114	48	0.01	139
Sibai (30)	0.07	36	0.18	135	343	1.3	10	0.01	0.07
σ	0.09	55	0.10	72	187	1.1	7.5	0.01	0.08
Yaman-Kasy (45)	65	19	0.34	923	714	**1282**	16	0.09	5.9
σ	146	30	0.38	2016	780	**1905**	18	0.21	10
Molodezhnoe (8)	725	29	0.60	1678	299	**1762**	7.8	0.17	59
σ	568	19	0.31	1110	353	**1133**	6.1	0.11	30
Uzel'ga-4 (12)	38	23	0.34	203	217	285	7.5	0.02	2.3
σ	47	21	0.27	89	227	244	17	0.01	2.7
Valentorsk (5)	0.4	11	0.2	139	38	233	9	0.06	120
σ	0.4	7	0.06	197	55	262	2	0.04	170
Talgan (7)	0.1	11	**1.99**	294	2926	22	43	0.03	114
σ	0.0	7.1	**1.15**	204	1518	8	27	0.02	69
Oktyabr (26)	4.1	356	0.45	2085	2970	**1000**	**1957**	0.21	15
σ	4.1	260	0.24	7561	2399	**4354**	**1666**	0.76	35
Aleksandrinsk (5)	4.7	300	0.74	152	456	52	**1282**	0.01	130
σ	2.9	185	0.30	103	399	41	**672**	0.01	120
Saf'yanov (24)	157	115	0.49	286	503	17	77	0.03	261
σ	217	130	0.38	289	555	17	101	0.03	417

Legend as in Table 2. Contents of As and Pb are given in wt %.

the basement of the West Magnitogorsk paleoisland arc (Seravkin, 2010).

As compared to the East Pacific, low-spreading rifts in the Atlantic and Indian oceans are marked by a lower diversity of the hydrothermal zone fauna (Mironov et al., 2002). Black smokers and diffusores in these oceans are formed on both basalts and serpentinites (Bogdanov et al., 2006, 2015). Ecosystems here are dominated by tolerant mixotrophs (e.g., Bathymodiolus) that are less sensitive to attenuation of the hydrothermal activity (Gebruk et al., 2002). Scarcity of fauna is likely related to the hydrogen sulfide deficit (Galkin, 2002). The content of hydrogen sulfide is lower in the mature hydrothermal systems that are typical of the Atlantic (Bogdanov et al., 2006, 2015). The hydrogen sulfide deficit is a characteristic feature of hydrothermal systems developed on serpentinites: relative to the migration of hydrothermal solutions across basalts, their percolation in ultramafic rocks is accompanied by the influx of a greater amount of H_2 and CH_4 and a lesser amount of hydrogen sulfide (Lein and Ivanov, 2009; Perner et al., 2013). Evidently, therefore, mineralized fauna have not been detected in the ancient VHMS deposits confined to serpentinites. So far, sole exception is the Dergamysh deposit (Urals), where we found numerous and variable size well-preserved tubeworms.

Hydrothermal systems of gray smokers in the West Pacific island-arc zone is characterized by a chaotic distribution of colonies of the hydrothermal zone fauna irrespective of the composition of host volcanics (basalts, dacites, rhyolites, andesites). The fauna are completely absent in some places. In other places near the foothill, bacterial mats include abundant Gastropoda and other organisms. In addition to hydrogen sulfide and methane symbiotrophs, specific nutrient sources (e.g., bacterial overgrowths) can be used by some of these organisms (Gebruk et al., 2002). Let us

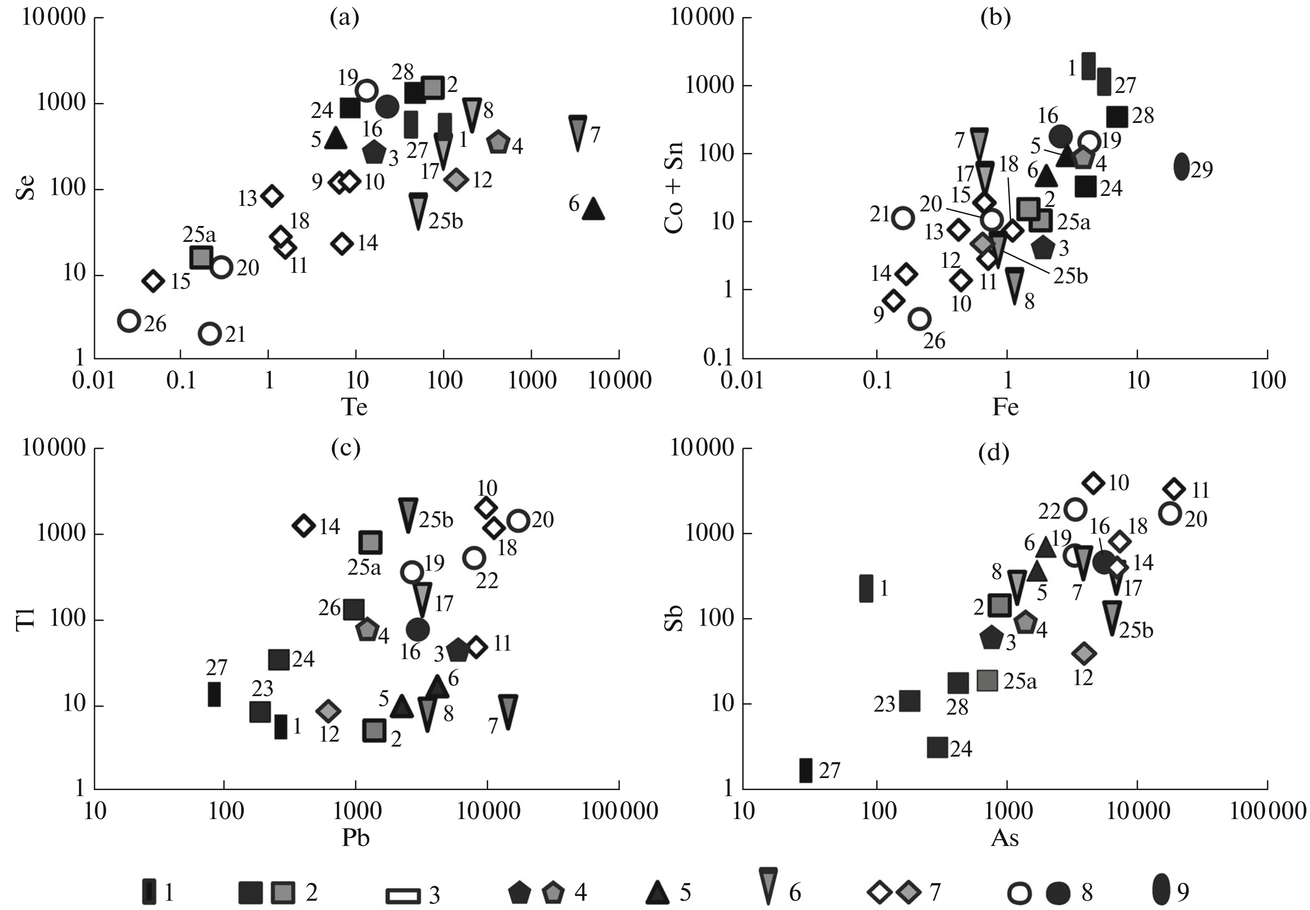

Fig. 7. Relationship between chemical elements in ore minerals in different types of VHMS deposits. (a) Se/Te in the hydrothermal chalcopyrite; (b) Fe/(Co + Sn) in sphalerite; (c) Tl/Pb in the hydrothermal-sedimentary colloform pyrite; (d) Sb/As in the hydrothermal-sedimentary colloform pyrite. Ore-formation types of VHMS deposits: (1) Atlantic; (2) Cyprus; (3) Besshi; (4–6) subtypes in the Ural type: (4) U-I, (5) U-II, (6) U-III and Pontid; (7) Baimak and Kuroko; (8) Altai; (9) Guaymas. (1–16) Uralian deposits: (1) Dergamysh, (2) Buribai, (3) Yubileinoe, (4) Sultanov, (5) Novyi Sibai, (6) Yaman-Kasy, (7) Molodezhnoe, (8) Uzel'ga-4, (9) Uzel'ga-1, (10) Oktyabr, (11) Talgan, (12) Valentorsk, (13) Tash-Tau, (14) Aleksandrinsk, (15) Dzhusa, (16) Saf'yanov. (17–23) Other regions: (17) Pontides (Lahanos, Killik, Kizilkaya, Cayely-Madenkoy, Kutlular), (18) Hokuroko (Matsumine, Ainai, Furutobe, Ezuri, Kosaka), (19–21) Rudnyi Altai (19) Nikolaev, (20) Artem'ev, (21) Zarechensk, (22) Iberian belt (Tarsis), (23) Cyprus (Skouriotissa). (24–29) Ore-formational types of black smokers and biographic zones in recent oceans: (24) East Pacific, (25) West Pacific: (25a) basalt, (25b) bimodal; (26) South Japan (Hakurei field, Okinawa trough), (27) Atlantic-1 (Rainbow), (28) Atlantic-2 (Broken Spur, Snake Pit, Menez Gwen, Lucky Strike), (29) Guaymas.

note the weak development of Vestimentifera and polychaetas-alvinellides near hot springs and the lack of fauna on walls of smokers and diffusores in the West Pacific, as opposed to the EPR (Desbruyeres et al., 1994). However, the hydrogen sulfide deficit likely plays the major role in this case as well. Contents of H_2S in the hydrothermal fluids of island-arc smokers are often lower than in the hydrotherms of MOR (Bogdanov et al., 2006; Lisitzin et al., 1997), while reduced gases often give way to oxidized varieties such as CO_2 and SO_2 (De Ronde et al., 2011). Bacterial vestimentiferan endosymbionts of the Palinuro Volcano (Mediterranean Sea) oxidize both hydrogen sulfide and H_2 (Thiel et al., 2012). In the case of deficiency of H_2S and HS^-, energy for the bacterial chemosynthesis could also be provided by thiosulfates (Gebruk et al., 2002; Lein, 2002). In the ore-formational series of the Uralian VHMS deposits, increase of the relative amount of felsic volcanic rocks is accompanied by decrease in probability of the detection of mineralized fauna. According to (Maslennikov, 2006; Revan et al., 2013), tubeworms are even more scarce in ores of the Pontian-type massive sulfide mounds (Cayely-Madenkoy, Lahanos, Killik, Kizilkaya, Kutlular) that are similar to the Ural type (subtype U-III).

Reliable finds of fauna, except (Nakajima et al., 1985), are lacking in ores of the ancient volcanic-hosted base metal sulfide deposits of the ore-formational series (Baimak, Kuroko, and Rudnyi Altai types) that are associated mainly with the felsic volcanics, although rare fragments of paleosmoker chimneys have been reported from some such deposits

(Maslennikov et al., 2010; Scott, 1981; Shikazono and Kusakabe, 1999; Shimazaki et al., 1990). Presumably, the biopotential of hydrothermal fluids, which are associated with the felsic magmatic-hydrothermal massive sulfide-forming systems, is lowest. Exception is the Saf'yanov deposit, where ores are marked by the abundance of tubeworm colonies. In the sequence underlying ores of this deposit, felsic volcanic rocks are supplemented with carbonaceous aleuropelites. It is believed that the organic sediments, which serve as conduits for the percolation of hydrothermal solutions, serve as a source of reduced gases (Maslennikov, 2013). It is known that the organic-rich sediments can deliver a great amount of thermogenic CH_4, which is consumed by the methanotrophic symbionts (Guaymas Basin) (Lein and Ivanov, 2009).

On the whole, fauna have mainly been detected in seafloor hydrothermal sediments of VHMS deposits that are reconstructed as weakly disintegrated sulfide mounds. Such mounds were preserved in the case of sufficiently intense volcanism. However, a significant portion of massive sulfide deposits, particularly in epicontinental island-arc basins, were mainly formed under weak volcanism. This is suggested by the prevalence of volcanosedimentary rocks over effusive rocks (Maslennikov, 2012). Detection of the mineralized fauna in such sulfide bodies is hardly probable because of the intense synsedimentary alteration of the fine-clastic layered ores.

Hydrothermal vents of the most bioproductive ancient and recent massive sulfide-forming systems have yielded pyrrhotite, pyrite, marcasite pseudomorphoses (after pyrrhotite and isocubanite), and abundant colloform pyrite. The presence of pyrrhotite and isocubanite testifies to intense reduction of hydrotherms (Afifi et al., 1988). Abundance of the colloform pyrite in vent chimneys and mineralized fauna indicates their rapid precipitation from the hydrothermal fluids enriched in both Fe^{2+} and H_2S. The colloform pyrite is involved in the fossilization of such fauna (Avdonin, 1996; Georgieva et al., 2015; Little et al., 1997; Maginn et al., 2002; Maslennikov, 2006), promoting their burial and good preservation. The colloform pyrite is rare in hydrothermal vents of the Baimak-, Kuroko-, and Altai-type VHMS deposits. It gives way to the euhedral pyrite, which likely grows at a slower rate from the low-saturated solutions (Large et al., 2009; Wohlgemuth-Ueberwasser et al., 2015). The appearance of abundant inclusions of barite, fahlores, enargite, or bornite in vent chimneys of the Baimak-, Kuroko-, and Altai-type deposits testifies to a partial oxidation of hydrothermal fluids.

High concentrations of Co, Fe, Sn, Se, and Te in the chalcopyrite- and sphalerite-rich black smokers of recent and ancient bioproductive massive sulfide-forming systems not only reflect the composition of host rocks (Maslennikov et al., 2010), but also suggests that hydrothermal fluids were represented by the high-temperature and intensely reduced varieties (Auclair et al., 1995; Butler and Nesbitt, 1999; Hannington et al., 1991). Low contents of Se and Te in the chalcopyrite of recent and ancient gray smokers (Maslennikov et al., 2016) (Fig. 7a), which are mainly associated with the felsic volcanics, can be related to both lower temperatures and higher reduction of the hydrothermal fluids (Maslennikov et al., 2010). As is known, resistance to reduction decreases in the following series: $H_2S > H_2Se > H_2Te$ (Ivanov, 1996). Paleosmokers of the Ural- and Pontian-type deposits dominated by tellurides occupy an intermediation physicochemical position (Maslennikov et al., 2013). Appearance of tellurides and native tellurium is related to some oxidation of the hydrothermal fluids that contain both Te^{2-} and Te_2 (Cook et al., 2009). However, the presence of the frobergite–altaite assemblage, for example, in the anomalously bioproductive Yaman-Kasy deposit, testifies to a weak oxidation of fluids (Maslennikov, 2012). In vent chimneys of the Baimak- and Kuroko-type deposits, only hessite is crystallized under the Te deficit because of the high affinity of Ag to Te (Eremin et al., 2007; Zaikov et al., 2001).

According to (Desbruyeres et al., 1994), the absence of fauna in some recent West Pacific hydrothermal fields is related to high contents of toxic elements, such as As and Pb. Indeed, colloform pyrite in the recent and ancient bioproductive systems of VHMS deposits are distinguished by lower average contents of As, Pb, Sb, and Tl (Figs. 7c, 7d). As is known, toxic elements are not particularly hazardous for many marine organisms (Francesconi and Edmonds, 1998). The mineralized microfauna is commonly absent or extremely rare in deposits with the maximal contents of As and Sb (0.7–3.6 and 0.1–1 wt %, respectively). Recent hydrothermal arsenic sulfide-bearing buildups are characterized by scanty macrofauna (Okinawa trough, Kaia Natai, Konikakh Seamount, Brothers, and other submarine volcanoes). The As-concentrating hydrothermal fluids destroyed the hydrothermal zone mats of fungal filaments and replaced them by orpiment (Dekov et al., 2013). As colloform pyrite in the recent MOR black smokers, its counterpart in the Uralian bioproductive VHMS deposits are characterized by low contents of Tl (<1000 ppm). If its content is higher (>1000 ppm), the distribution of biocoenoses in West Pacific hydrothermal products becomes chaotic. In the fauna-barren ores of the Altai-, Kuroko-, and Baimak-type deposits, the Tl content in the colloform pyrite does not exceed 1000 ppm.

CONCLUSIONS

1. The mineralized microfauna are abundant mainly in the hydrothermal massive sulfide mounds formed on the jasperous basalt and rhyolite–basalt. They are less common in the serpentinite complexes. In ore-formational series of the VHMS deposits,

probability of the detection of mineralized fauna decreases with increase of the relative amount of felsic volcanic rocks in the ore-underlying sequences.

2. This series also shows changes in the mineral composition of paleosmoker vent chimneys, testifying to a higher oxidation of hydrothermal fluids and, consequently, decrease of their potential bioproductivity. Contents of Fe, Co, Se, and Te in sulfides decrease in the same direction, while the share of toxic elements (Tl, Sb, As, Pb) increase.

3. Preservation of fauna degrades from the hydrothermal sulfide mounds to the stratiform clastic sulfide bodies because of more intense transformation of the layered fine-clastic ores, relative to the seafloor hydrothermal sediments. The degradation degree of sulfide mounds correlates with the attenuation of volcanism. This is reflected in the increase of sedimentary and volcanosedimentary rocks and decrease of effusive rocks in the geological sections.

4. The trends described above support our previous assumption that mineralized fauna of the ancient VHMS deposits belong to the biota of black smoker ecosystems.

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