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Ore and Silicate Magnetic Pellets as Indicators of Structure and Fluid Regime, as well as Mineral and Ore Formation in the Present-Day Baranskii Hydrothermal System, Iturup Island

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Abstract—Ore and silicate spheric globules found in the present-day high-temperature Baranskii (Iturup Island) and Mutnovskii (Southern Kamchatka) hydrothermal systems are discussed. Using mineralogical, microprobe, and x-ray powder data, we identified the pellets of native iron, magnetite, Fe-Ti-Mn silicates (shorlomite-type garnet), and zonal aggregates with iron cores rimmed by magnetite and iozite. The pellets contain traces (up to 5%) of Ni, Mn. Ti, and Cu: they are regularly shaped, often hollow, and highly porous, ranging in size from less than 0.1 to 1.7 mm. All the pellets are magnetic to a variable degree. It is assumed that the pellets are transported from a depth of >1.5-2.0 km to metasomatites by a “dry” reduced fluid with a temperature not lower than 500-600°C. The pellets are probably derived from a subintrusive diorite body or peripheral magma chamber feeding the hydrothermal system. The spheric globule occurrences mark the position of the heat-conducting fault zones (as deep as 1.5 km) in horsts. Having high gas content, the hydrothermal fluid influences the geological structure of the system: the hydrothermal breccias form in zones of hydrothermal solution boiling along the contacts with the subintrusive bodies. The fluid introduces Fe, Mg, Mn, Ti, Cr, Cu, Pb, Au, Ag, As, Al, Si, K, Na, Ca, etc. into the wall rocks. Concentrations of these and some other elements steadily increase from early to late stages of hydrothermal deposit formation. Apparently, the present-day high-temperature volcanogenic hydrothermal systems correspond to the first stage of epithermal ore deposit formation.

INTRODUCTION

The problem of sources of ore material is most important in the theory of the origin of hydrothermal ore deposits. The solution of the problem depends upon the degree of investigation; it is not always possible even for the well-studied deposits (for example, by intense drilling), as each subsequent stage of ore formation eliminates the mineralogical and geochemical evidence of earlier stages as a result of recurrence of mineralogical and geochemical processes. The investigation of the early stages of hydrothermal mineral and ore formation is a principally different approach to the solution of the problem. In studying the present-day high-temperature hydrothermal systems, we can reveal the genetic relations between magmatic and hydrothermal ore-forming processes.

Ore pellets composed of native metals, solid solutions, or intermetallic compounds have been found in different-type sediments or rocks and in various geological positions (Kukharenko, 1961; Yudin, 1969; Tyan *et al.,* 1976; Glavatskikh, 1990). Such aggregates frequently occur in hydrothermal ores (Novgorodova, 1983; Nikol’skii, 1987). Ore and silicate pellets from metasomatites of the present-day hydrothermal systems are poorly studied. Only findings of native iron of primary magmatic origin are known (Karpov *et al.,* 1984). At the same time, the ore and silicate pellets carry essential information on temperature, composition, and other parameters of the endogenic fluid and on the structure-forming processes in the earth’s interior and at the surface of the systems. We have separated and studied in detail pellets from the present-day high-temperature Baranskii hydrothermal system (central part of the Iturup Island). The data on the composition of ore pellets from one deep (up to 1.6 km) section across the Mutnovskii system (Southern Kamchatka) were also obtained.

GEOLOGICAL SETTING AND GENERAL DATA ON THE HYDROTHERMAL SYSTEM

The following questions were considered in previous papers: (1) geological structure of the Central Iturup hydrothermal region, the hydrothermal system of the Baranskii volcano and its central part—the Okeanskoe hydrothermal deposit (Zlobin, 1989; Zlobin and Znamenskii, 1991; Rychagov, 1993) and the composition of thermal solutions and hydrothermal rocks (Znamenskii and Nikitina, 1985; Znamenskii, 1991); (2) the mineralogy, geochemistry, and temperature distribution in the interior of the hydrothermal system; these data are derived from the study of the secondary mineral formation (Rychagov *et al.,* 1993; Rychagov *et al.,* 1994); some specific features of the permeability at the Okeanskoe deposit (Rychagov and Stepanov, 1994); and (4) the block structure and intensity of the hydrothermal-metasomatic alteration of rocks (Ladygin and Rychagov, 1995). Below, we give general data concerning the transport mechanism, distribution, and behavior of ore and silicate magnetic globules within the structure of the hydrothermal system.

The hydrothermal system is located on the southwestern slope of the Late Quaternary Baranskii andesitic volcano at the center of the Middle-Late Pleistocene (?) Kipyashchaya caldera. The caldera overlaps the volcanic domelike uplift of the Groznyi ridge that strikes along the general Kurile-Kamchatka direction and includes several volcanotectonic structures of 12-18 km across and present-day volcanoes (Fig. 1): Rebunshiri, Ivan Groznyi, Drakon, Machekha, Teben'kov, and Baranskii (Gorshkov, 1967; *Geologo-geofizicheskii atlas* ..., 1987).

The lower part of the geologic section is composed of psephite-psammitic and agglomeratic andesitic tuffs and andesitic and andesibasaltic lavas (the Parus Formation, N_2pr). Rare thin layers of rhyolitic tuffs also occur, which consist of flattened fragments of pumice and volcanic glass. The boreholes cross the upper 600-m part of the sequence. The rocks of the Parus Formation are overlain without apparent angular unconformity by fine- to coarse-clastic tuffites, pumice tuffs, and andesitic lavas of the Lebedin Formation (N_2-Qtlb), with the tuffaceous sedimentary rocks predominating. The thickness of the sequence is about 400 m. The Middle-Late Quaternary andesibasaltic to andesidacitic lavas, tuffs, and tuff breccias are likely to be erupted under the subaerial conditions during the uplift of the Groznyi Ridge. The total thickness of the Middle-Late Quaternary sequence is no less than 100-150 m. Like the Parus and Lebedin rocks, the deposits are substantially altered by the hydrothermal-metasomatic processes. The present-day rocks comprise the unaltered massive andesitic and andesidacitic lavas and unconsolidated coarse-clastic talus-proluvial sediments up to 30 m thick within local depressions.

The size, thermal energy, age, temperature of the solutions, and some other parameters of the hydrothermal system are controlled by intrusive magmatism. The subvolcanic shallow-level magmatic bodies comprise dikes and sills of andesibasalts and basalts 0.15-17.0 m thick, the extrusions of andesidacites, and thin (1-5 m) microdiorite lenses. Groups of dikes and sills lie along the lithologic and stratigraphic boundaries, for example, along the boundary of the Parus and Lebedin formations. The roof of a large diorite body is supposed to be at a depth of 1000-1500 m. It is evidenced from the occurrence of the rocks of a peculiar kind—intrusive tuffs or intrusive (automagmatic) breccias, which usually compose the exocontact zones of gabbrodiorite to granodiorite bodies (*Struktura* ..., 1993). The thickness of this zone within the Okeanskoe deposit is 500-800 m, similar to that within Mutnov and Paratun deposits of Kamchatka, which were crossed by the deep boreholes (Kiryukhin *et al.,* 1991; *Struktura* ..., 1993). Within the hydrothermal systems, the temperature distribution and ore location are governed by the position of the exocontact zones of the subintrusive bodies (Rychagov, 1989; Kiryukhin *etal.,* 1991; *Struktura* ..., 1993).

The tectonic structure of the hydrothermal system is controlled by the block structure of the territory (Rychagov, 1993). The Kipyashchaya Rechka and Starozavodskoe Pole horsts, a relatively subsident block, and several tectono-magmatic uplifts are distinguished (Fig. 1). The blocks are isometric or radially elongated relative to the volcano summit. The rocks of the relatively subsident block and tectono-magmatic uplifts are significantly less dislocated than the rocks of the horsts. Horsts are characterized by the maximum heat flow (up to 71 000 kcal/s) at the surface (Pchelkin, 1988). The boundaries of large blocks and zones of faults that break the rocks of horsts into the smaller block-slabs are the main heat-conducting structures.

The deep and distal zones of the assumed essential heat source—the diorite body and, presumably, peripheral magma chamber (Zlobin and Znamenskii, 1991)—are characterized by the abundance of the sodium chloride-carbonate-nitrate neutral thermal solutions with low gas content and salinity of 0.5-3.0 g/1, but high content of Rb, Cs, K, and Ga (Pchelkin, 1988). The steam-condensate in the deposit corresponds to the hydrosulfide-carbonate-sulfate water with a salinity of 0.15-2.0 g/1. The springs from the upper aquifer are hydrosulfide, weak acid, or subneutral. The waters of the hydrosolfatara fields are predominantly sulfate, neutral to acid with a temperature of 80°C. The acid waters are enriched in Al and Fe and locally (the Kipyashchaya Rechka area), in As and Ba. The hydrotherms of the Okeanskoe deposit have a relatively high hydrogen content (Znamenskii and Nikitina, 1985). The temperatures of the steam-hydrotherms, determined by well thermologging and the study of gas-liquid inclusions in the secondary minerals, are in the range from 180-200 to 300-350°C, depending on the position in the geological section.

The rocks (excluding the Late Quaternary unfractured andesibasalts) that accommodate the hydrothermal system are altered in a variable degree by the hydrothermal-metasomatic processes. The bottom of the section (the Parus Formation) consists of medium- to high-temperature quartz-chlorite-albite-mica propylites with epidote, zeolites, carbonates, and sulfides. According to O.P. Goncharenko, the temperature of the propylite formation is 350-470°C (Rychagov *et al.,* 1993). These propylites are assigned to the exocontact zone of the assumed diorite body. Low- to medium-temperature (180-300°C) quartz-chlorite-calcite-zeo-

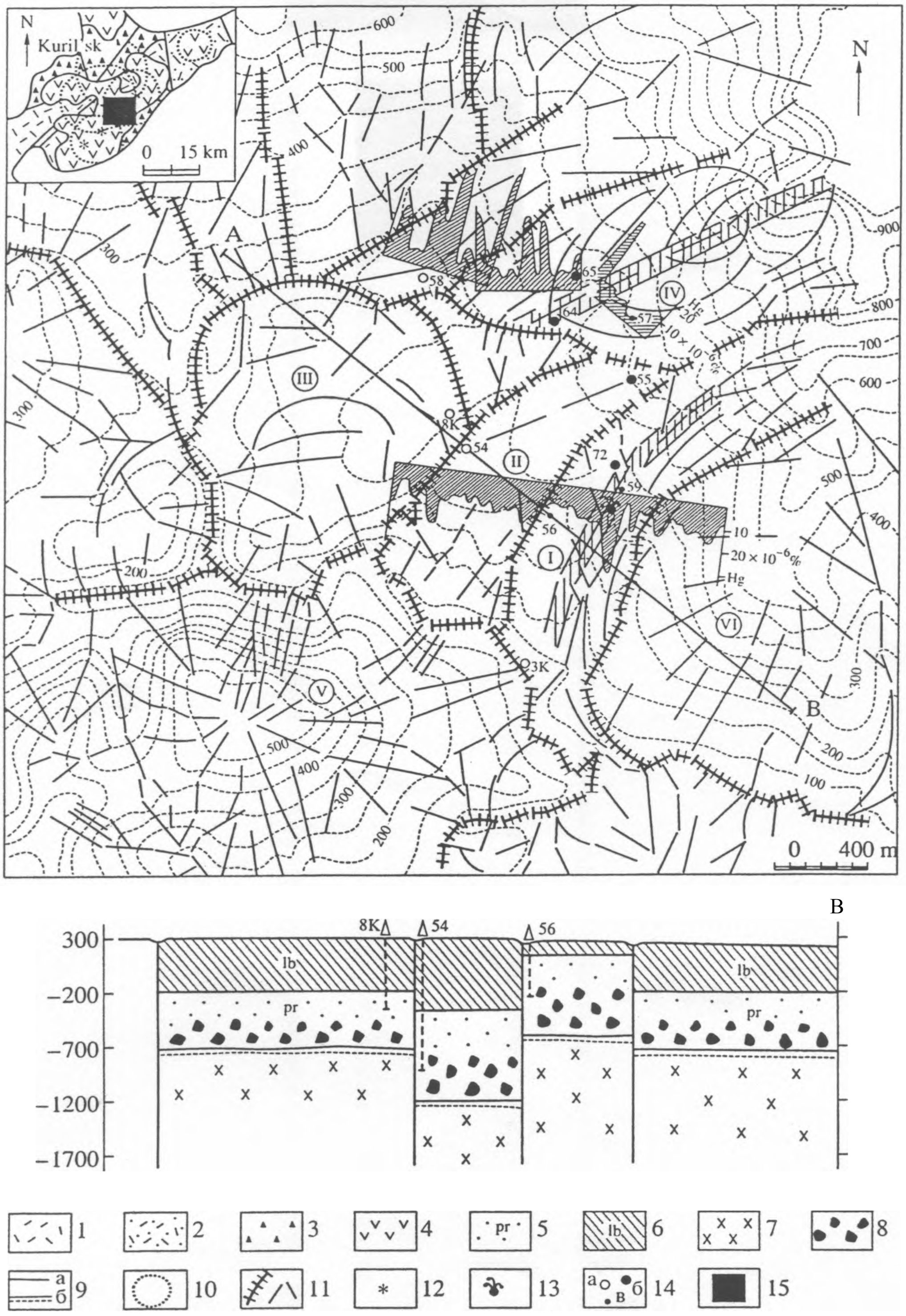


Fig.31 Scheme of the present-day tectonic structure of the Baranskii hydrothermal system.
(1 -4) Geological complexes (on the inset map based on *Geologo-geofizicheskii atlas....* 1987): (1) Middle Miocene-Pliocene volcanogenic silicic-diatomic. (2) Middle Miocene-Pliocene volcanogenic (predominantly silicic) rocks, (3) Middle Miocene-Pliocene andesibasaldc, (4) Quaternary andesitic: (5) the Parus Formation; (6) the Lebedin Formation; (7) diorites; (8) intrusive tuffs (intrusive or automagmatic breccias); (9) contacts; (a) lithologic and (b) intrusive; (10) volcano-tectonic structures; and (11) faults and boundaries of tectonic blocks: (1) the Kipyashchaya Rechka horst, (II) relatively subsided block, (III) tectono-magmatic (magmatic?) uplift, (IV) the Starozavodskoe Pole horst. (V) tectono-magmatic (magmatic?) uplift—the subvolcanic extrusive Kupol complex, and (VI) presumably as (V) in the lower stream of the Semaya River; (12) volcanoes (from SW to NE): Ivan Groznyi, Teben'kov. Baranskii: (13) the *Coluboe o zero* hot spot; (14) boreholes: (a) with ore and silicate pellets, (b) without ore and silicate pellets, and (c) boreholes without representative samples; and (15) figure area on the inset map. The axial parts of horsts and mercury geochemical profiles are hatched in different patterns.

lite propylites with hydromicas, anhydrite, epidote, and sulfides occur in the depth interval from 0 (in horsts) to 500 m. Low-temperature (100-200°C) quartz-calcite-zeolite-hydromica propylites with chlorite-smectite minerals generally replace the tuffites of the Lebedin Formation and Quaternary tuffs, pumices, and fractured lavas. The "cap" of opal-kaolinite-alunite rocks of the zone of sulfuric acid leaching and the products of hydrochloric-carbonic acid leaching (smectites), which overlie all other neomorphous rocks, is 50-225 m thick, in general, and up to 400-500 m thick along some faults. Due to their high viscosity and low porosity, the opal-kaolinite-alunite metasomatites and smectites serve as the upper confining bed for steam-hydrotherms.

COMPOSITION AND STRUCTURE OF THE PELLETS

Spheric mineral aggregates were separated during the analysis of panned samples of the core and mud from boreholes 55, 64, 65, and 72, which were drilled in the central parts of the Baranskii and Mutnovskii (borehole M-18) hydrothermal systems. The pellets are black or steel gray colored, and have a perfectly smooth surface with glassy luster or a rough surface with dull or metallic luster. The grain size ranges from less than 0.1 to 1.7 mm. Often, they are regularly rounded; more rarely, oval, drop-shaped, flattened out two-sides, botryoidal; etc. (Fig. 2). All the pellets are magnetic to variable degrees. Many pellets are hollow with one or two holes (Fig. 3). They are homogeneous or have one or several cores with high reflectivity. The cores are composed of native iron or hematite filling the cavities (Fig. 4, Table 1). Thin shells on the surface of some pellets consist of aggregates of hematite crystals (Fig. 5). The pellet composition is determined using a Camebax microprobe (Tables 2 and 3) and x-ray powder method (Table 4, DRON-2 automated diffractometer, CoK_x-radiation, 30 kV, 30 mA). The following varieties of ore and silicate magnetic pellets are found: (1) native iron; (2) magnetite; (3) Fe-Ti-Mn silicate (shorlomite-type garnet); (4) zonal pellets with iron cores containing up to *5%* Ni, Mn, and Cu and rims of magnetite and iozite. X-ray powder data indicate the existence of Fe-trevorite (Ni, Fe)Fe_2O_4, magnesioferrite $MgFe_2O_4$, chromite $FeCr_2O_4$, cuprospinel $CuFe_2O_4$, donathite (Fe, Mg)(Cr, Fe)$_2$O$_4$, and quandilite Mg_2TiO_4. Magnetite pellets are most abundant, and other main varieties occur in equal amounts.

Magnetite pellets are usually perfectly rounded and black with a dull surface and various internal structure. The hollow pellets (with one or more cavities) dominate, whereas the homogeneous massive varieties are rare. Occasionally, reticulate, laminar or lattice exsolution textures, and polygonal or skeletal crystal growth habits are observed in reflected light. The exsolution textures are not always discernible by microprobe due to the similarity of phase compositions (magnetite-trevorite-magnesioferrite-chromite-cuprospinel-...) but can be distinguished by x-ray powder method (Table 5). In grains with a skeletal texture, the crystal cores (light phase) are composed of magnetite, while the interstitial space and rims (dark phase) around the cores consist of shorlomite.

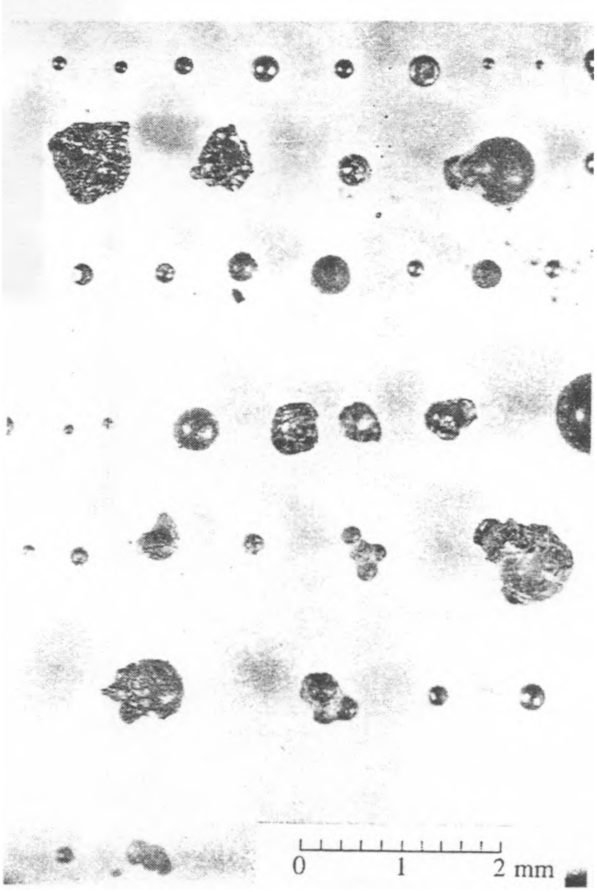


Fig. 2. Pellet morphology. Reflected light image, MPSU-1 microscope, xlOO.

Fe-Ti-Mn silicate pellets are black-colored and weakly magnetic, they have a smooth surface with glassy luster, and the lowest reflectivity. The rounded pellets are the most abundant, and ellipsoidal or other varieties are less typical. Most pellets have homogeneous and massive structure, whereas the finely porous aggregates are uncommon. Fe-Ti-Mn silicate pellets fit Mn-shorlomite in composition.

Native iron pellets are characterized by steel gray color and rough surface; they are highly magnetic, forgeable, and sometimes coated with a thin crust of limonite.

Zonal pellets are the most typical and simple variety, having cores of magnetite and rims of magnetite with iozite, trevorite, and other minerals of similar composition. Pellets with a complex textural relationship between mineral phases are rare. Zonal pellets are very similar to magnetite ones in appearance.

Table 1. Exsoiution textures in hematite from the magnetite pellets

Oxides, wt %	Borehole 65, 570 m		Borehole 64, 70 m		Borehole 72, 220 m	
	magnetite	hematite	magnetite	hematite	magnetite	hematite
SiO_2	–	–	–	–	–	–
TiO_2	–	–	–	–	–	–
Al_2O_3	–	–	–	–	–	–
FeO	69.28	–	68.19	–	69.04	–
Fe_2O_3	31.17	99.98	30.69	97.98	31.05	101.11
Cr_2O_3	–	–	–	–	–	–
MgO	–	–	–	–	–	–
CaO	–	–	–	–	–	–
Na_2O	–	–	–	–	–	–
K_2O	–	–	–	–	–	–
MnO	–	–	–	–	–	–
NiO	–	–	–	–	–	–
ZnO	–	–	–	–	–	–
Total	100.44	99.98	98.88	97.98	100.10	101.11

Note: Minerals are analyzed by S.V. Moskaleva using a Camebax microprobe (Institute of Volcanology, Far Eastern Division, Russian Academy of Sciences).

Table 2. Chemical composition of the magnetic ore and silicate pellets

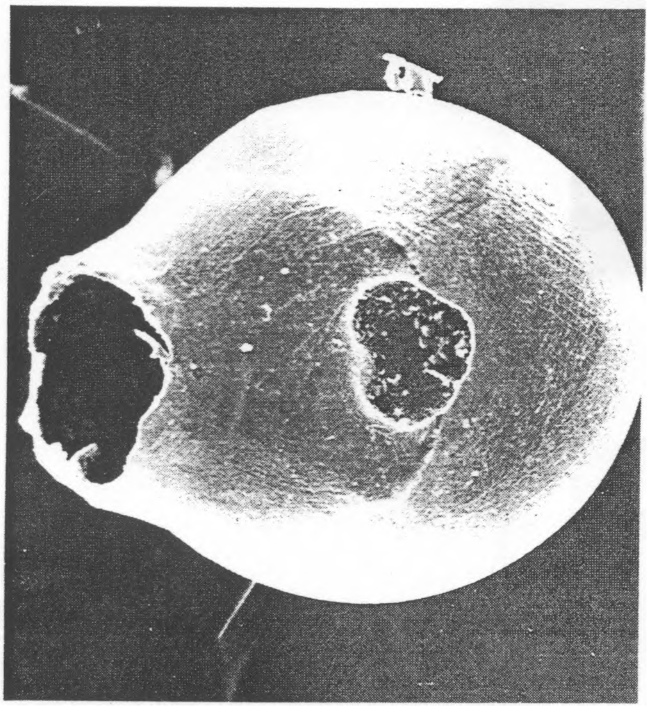
Oxides, wt %	Magnetite		Shorlomite		
	72-14	65-36	65-38	65-39	M-18
	320 m	440 m	540 m	570 m	370 m
SiO_2	0	0	18.96	13.27	12.91
TiO_2	0.01	1.75	38.20	35.91	48.15
Al_2O_3	0	0.22	7.44	7.23	2.14
Fe_2O_3	68.63	64.81			
FeO	30.79	31.53	9.84	24.33	6.33
Cr_2O_3	0	0	0.09	0	0
MgO	0	0.15	6.14	5.95	3.04
CaO	0	0	0.36	2.24	10.56
Na_2O	0	0	1.89	0	0.01
K_2O	0	0	2.43	0.05	0.68
MnO	0.10	0.67	14.47	11.06	15.43
NiO	0	0	0	0	0
ZnO	0	0	0	0	0
Total	99.53	99.13	99.82	100.04	99.24

Note: Microprobe analyses are conducted by T.M. Filosofova and S.V Moskaleva (Institute of Volcanology, Far Eastern Division, Russian Academy of Sciences).

Table 3. Chemical composition of the native iron spherules and cores of magnetite pellets

Elements, at. %	M18, 120 m	M18, 485 m	M18, 485 m	72-14, 320 m	72-14, 320 m
	1	2	3	4	5
Pb	0	0	0	0	0
Cu	0	0.30	0.14	0	0
Ni	0.02	1.91	0.85	0	0.18
Fe	99.97	97.68	98.98	100.0	99.80
Mn	0.01	0.10	0.02	0	0.03
Ti	0	0	0	0	0
Sn	0	0	0	0	0
Co	0	0	0	0	0
Total	100.0	100.0	100.0	100.0	100.0

Note: 1 and 4—native iron pellets; 2, 3, and 5—cores of magnetite pellets. Analysts: T.M. Filosofova and S.V. Moskaleva.



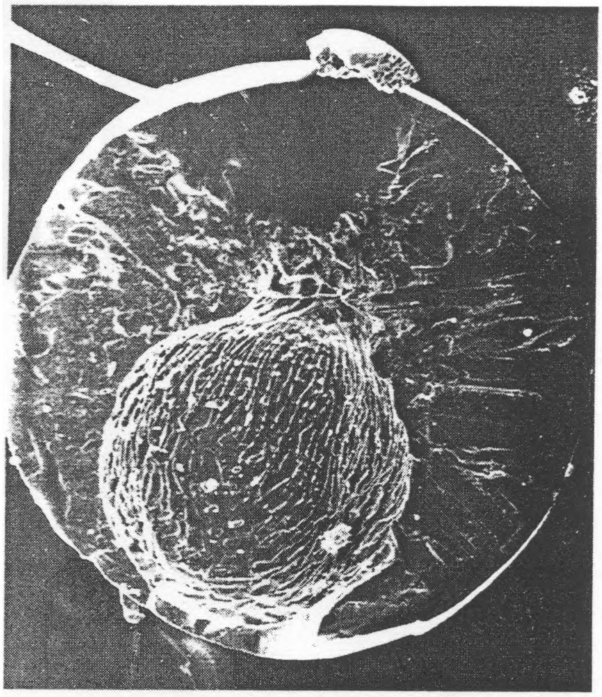


Fig. 3. A hollow pellet with central and side holes SEM image. x250.

Pig. 4. A massive ore pellet with hematite filling a cavity, SEM imaae. x220.

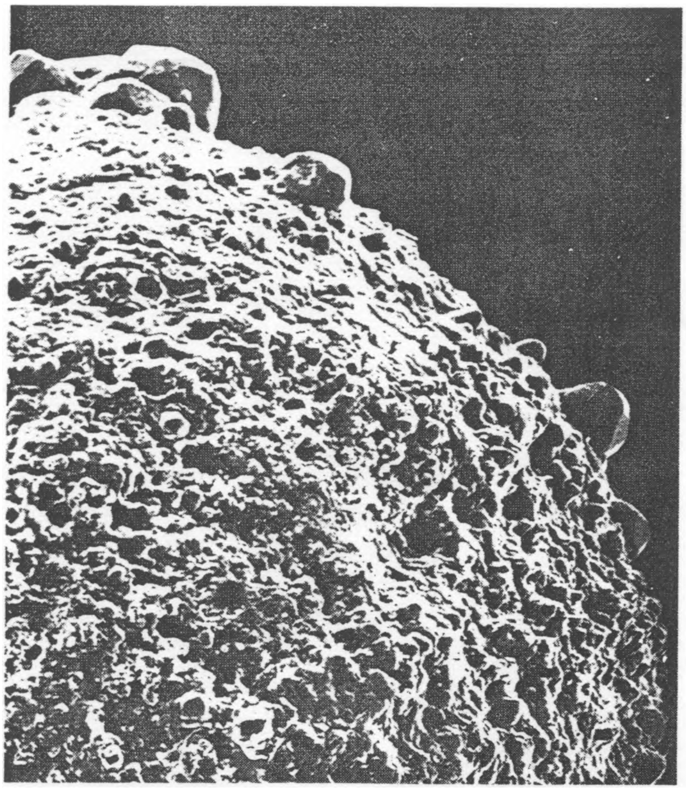


Fig. 5. Hematite shell on an ore pellet. SEM image. x600.

Table 4. Mineral composition of the magnetic pellets

Sample no.	Depth, m	Mineral		ASTM standard	
		I	*d/n*	*I*	*d/n*
		Native iron		6/696	
72-12	220	10	2.021	10	2.028
		3	1.434	2	1.435
		3	1.169	3	1.171
		1	1.014	1	1.014
65-36	440	10	2.024	10	2.028
		3	1.434	2	1.435
		3	1.170	3	1.171
		2	1.011	1	1.014
		Iozite		6/615	
72	100–400	10	2.524	10	2.532
		4	2.098	2	2.096
		3	1.611	4	1.613
		4	1.483	5	1.482
		2	1.091	1	1.092
		Magnetite		19/629	
65	250–950	4	4.857	1	4.854
		2	2.964	3	2.967
		10	2.521	10	2.532
		3	2.099	2	2.096
		2	1.614	4	1.613
		3	1.482	5	1.482
		Shorlomite		1/70390	
72	100–400	1	2.206	1	2.205
		2	1.974	2	1.964
		1	1.859	1	1.865
		10	1.611	10	1.614
		3	1.518	3	1.512

Table 5. Composition of extra mineral phases from the magnetite pellets

Sample no.	Depth, m	Mineral		ASTM standard	
		I	*d/n*	*I*	*d/n*
		Magnesioferrite		36/398	
72-3	100–400	10	2.524	10	2.532
		4	2.098	2	2.096
		3	1.611	3	1.615
		4	1.483	4	1.484
		1	1.282	1	1.280
		2	1.091	1	1.093
		Donathite		22/349	
65	250–950	2	2.964	3	2.967
		3	2.100	2	2.101
		2	1.614	3	1.618
		3	1.482	4	1.486
		1	1.092	1	1.094
		1	1.050	1	1.050
		Fe-trevorite		23/1119	
72-3	100–400	3	4.830	3	4.831
		5	2.954	5	2.959
		10	2.524	10	2.525
		4	2.098	4	2.092
		4	1.483	6	1.480
		2	1.091	3	1.092
		Cuprospinel		25/283	
72-3	100–400	10	2.524	10	2.519
		4	2.098	3	2.101
		3	1.611	4	1.616
		4	1.483	5	1.479
		Quandilite		25/1157	
72-3	100–400	10	2.524	10	2.532
		4	2.098	2	2.101
		4	1.483	4	1.486
		1	1.282	1	1.282
		1	1.049	1	1.050

Note: for Tables 4 and 5, the x-ray powder analyses are performed by S.G. Kokorev at the Institute of Volcanology, Far Eastern Division, Russian Academy of Sciences.

PELLETS AS INDICATORS OF GEOLOGICAL STRUCTURE, FLUID REGIME, AND MINERAL AND ORE FORMATION IN THE HYDROTHERMAL SYSTEM

A study of the distribution of ore and silicate pellets within the present-day hydrothermal system shows that they are characteristic of the zones of ascending hydrothermal fluxes represented by marginal, and particularly, axial, parts of horsts (Fig. 1). The axial parts represent the fault zones that are 100-200 m wide and at least 1.5-2.0 km deep (Rychagov, 1993). The hottest hydrothermal solutions with a temperature up to 320°C (based on direct measurements in boreholes) or up to 470°C (based on study of gas-liquid inclusions and mineral geothermometry data) rise along these zones (Rychagov ***etal.,*** 1993). Metasomatites along the entire vertical cross section (1000 m in boreholes 64 and 65) contain a large amount of pellets; they fill cavities and cracks and less frequently are included in the hydrothermal clay composed of the quartz-chlorite-hydromica aggregate that is in equilibrium with a solution. Contrarily, the pellets are absent within the subsident blocks—the feeding zones of the hydrothermal system—where the rocks are cooled by meteoric or exhausted thermal waters (Fig. 1). Apparently, the pellets of native iron, shorlomite, magnetite, and zonal varieties form at a temperature higher than 500-600°C and at a depth of >1.5-2.0 km near or within the subintrusive body (peripheral magma chamber?) and are transported to the surface by dry gas-rich fluid. The existence of reduced fluid (retention of high H_2/H_20, according to F.A. Letnikov in *Fluidnyi rezhim metamorfisma,* 1980) at the surface is supported by an intense hydrogen release from the *Golubye ozera* thermal springs within the Kipyashchaya Rechka horst (Znamenskii and Nikitina, 1985). Probably, the reduced gases are not oxidized because of a high ascent rate, shallow level of the magma chamber, or the possible presence of hetero-organic compounds in the hydrothermal fluid (Slobodskoi, 1977). This is evidenced from the high content of charred wood in the Lebedin Formation sediments, representing the first aquifer horizon of the hydrothermal system, where the fluid could react actively with organic matter. Probably, the complete fluid oxidation really does not occur during dynamic evolution of systems, including hydrothermal ones, as is believed by the authors of *Fluidnyi rezhim Zemli...* (1991).

Therefore, the occurrence of pellets of native iron, magnetite, and shorlomite, which are found within the progressively developing hydrothermal system, is indicative of a high temperature and high reducing degree (dryness) of the gas-liquid fluids and gives evidence of the permeability of the zones: the axial faults of the horst possibly reach the surface of the subintrusive diorite body or even the peripheral magma chamber. Within the cooling hydrothermal systems (such as Pauzhet; Paratun; etc., Southern Kamchatka), ore and silicate pellets have not been found in metasomatites, and any evidence of the reduced fluid is absent.

Moreover, the study of the pellets shows that the hydrothermal fluid has a high gas content and influences the geological structure of the system. This results in the formation of hydrothermal breccias in recent fault zones (of steam-dominated systems, according to N.S. Zhatnuev *etal.,* 1990) and polymictic complex breccias with sulfide mineralization in the brecciated shell of the diorite body. Generally, the pellets tend to concentrate in repeatedly brecciated rocks that represent the most permeable zones. This fact, being an indicator of the geological structure of the hydrothermal system, was also noted forepithermal ore deposits (Novgorodova, 1983).

It is accepted in the theory of the hydrothermal ore formation that, at the early stages of the evolution of the system, the quartz, chalcedony, sulfides, and other minerals contain fine-dispersed gold, whereas at the later stages, the gold particles become coarser, and ore-rich associations form. This tendency is also revealed for present-day hydrothermal systems and geothermal deposits. Fe, Mn, Mg, Ti, Cr, Al, Si, K, Na, and Ca are introduced with ore and silicate pellets into the system. Pyrite from the zones of hydrothermal flux ascent within the present-day high-temperature hydrothermal system contains noticeable amounts of Au, Ag, As, Hg, Pb. Cu, Mg, Mn, Mo, Co, Ni, Zr, V, Si, and Al in the range from 0.0001 to 3.2% (Rychagov *et al.,* 1995); this observation correlates with the composition of deep-level solutions (Pchelkin, 1988). Many of these elements are introduced into the system by deep-level fluid. Generally, the concentrations of these and some other elements increase from early to late stages of the geothermal deposit formation: sulfides and clays from the cooling Pauzhet steam-hydrothermal deposit contain up to 0.1 ppm Au, 0.5 ppm Ag, 300 ppm As, 60 ppm Sb; quartz-adular metasomatites contain up to 0.1 ppm Au, 0.0002% Ag, and 0.001% As (*Struktura ...,* 1993).

CONCLUSIONS

(1) Ore and silicate magnetic pellets of native iron, magnetite, shorlomite, and zonal aggregates of magnetite with iron, iozite, and shorlomite within the present-day hydrothermal system are typical of the zones of rising high-temperature flow of reduced gas-rich fluid.

(2) The pellet occurrences mark the position of fault zones (as deep as 1.5-2.0 km) in the axial parts of horsts.

(3) Fe, Mn, Mg, Ti, Cr, Al, Si, K, Na, and Ca are introduced with ore and silicate pellets into the hydrothermal system. The ore-bearing fluid is probably derived from the subintrusive diorite body or basic magma chamber.

(4) Present-day high-temperature geothermal volcanogenic systems are likely to correspond to the initial stages of the epithermal gold-sulfide deposit formation.

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