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GEOLOGY

Copper–Gold–Palladium Mineralization in Ultrabasic Rocks of the Polar Urals

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The northern Ural region incorporates several large ultrabasic massifs (Voykar-Osa, Rai-Iz, and Syum-Keu) confined to the Polar Ural ophiolite belt. The massifs enclose chromite deposits. The ultrabasic rocks are characterized by high concentrations of refractory platinoids (PGE) of the Ru–Os–Ir composition and the subordinate role of Pt, Pd, and Rh. Laurite, erlichmanite, cuproiridsite, irarsite, ruarsite, hollingworthite, sperrylite, and other mineral phases are subordinate [1–4 and others]. Native gold, silver, copper, and iron are also found in these massifs.

Recent detailed investigations of the Polar Urals have made it possible to discover a low-sulfide copper ore occurrence on the right bank of the Dzelyatyshor Creek (left tributary of the Malaya Kharamatalou River). We have detected for the first time gold and silver associated with palladium, bismuth, and tellurium in the copper ore. The Ozernoe copper–gold–palladium occurrence is located in the northeastern area of the Voykar-Osa ultrabasic massif associated with the Kershor plutonic complex of probably Devonian age. The Kershor Complex—the middle (gabbroic) part of the Rai-Iz–Voykar-Osa ophiolite association—includes a sequence of diverse polychronous gabbroic and ultrabasic rocks. They are characterized by rhythmic intercalation of dunites, wehrlites, clinopyroxenites, and episodic plagioclase-bearing gabbronorites.

The Ozernoe ore occurrence includes two NE-oriented zones of sulfide (mainly, bornite–chalcopyrite) mineralization confined to the layered rock complex. The sulfide zones are developed in clinopyroxenites, their olivine varieties, and wehrlites 120–150 m above the contact of layered rocks with dunites. The first (southeastern) zone is approximately 3.5 km long and 40–50 m thick. The second (northwestern) zone is approximately 2 km long and 10–15 m thick. Both ore zones demonstrate a southeastern dip at 60°–70°.

The ore zones are characterized by a complex structure with irregular distribution of the sulfide mineralization. The ores have the following composition: Cu 0.1–1.4 wt %, Au up to 2.2 g/t, Pd up to 1.7 g/t, and Pt up to 0.3 g/t. The highest metal concentrations are confined to olivine rocks at the base of rhythms.

Ore-enclosing rocks contain magnetite dissemination of several generations. Relatively large heteroge-

Table 1. Composition of gold, gold–copper, gold–palladium–copper, and gold–silver phases in the Ozernoe ore occurrence, wt %

Mineral	Au	Ag	Cu	Pd	Te
Cu-gold (cuproauride)	58.9	5.5	17.3	2.8	–
The same	61.2	6.4	18.5	3.2	–
"	55.5	2.5	29.3	1.6	–
"	49.7	–	38.2	3.8	–
Auricupride	44.7	8.3	41.3	–	–
The same	44.3	–	54.0	2.1	–
"	39.7	1.3	53.5	6.0	2.0
Au–Pd–copper	7.9	1.4	63.5	16.4	–
The same	5.5	–	64.3	16.2	–
"	7.5	1.5	64.3	17.2	–
"	9.1	2.2	65.7	16.9	–
Au–silver	14.6	80.7	1.2	1.0	–
The same	15.9	83.3	0.9	–	–
Au–silver (küustelite)	34.6	62.7	0.8	–	–

Note: Analyses were carried out at the Institute of Geology, Komi Scientific Center (Syktyvkar), using a JSM-6400 scanning electron microscope equipped with a Link energy-dispersive spectrometer.

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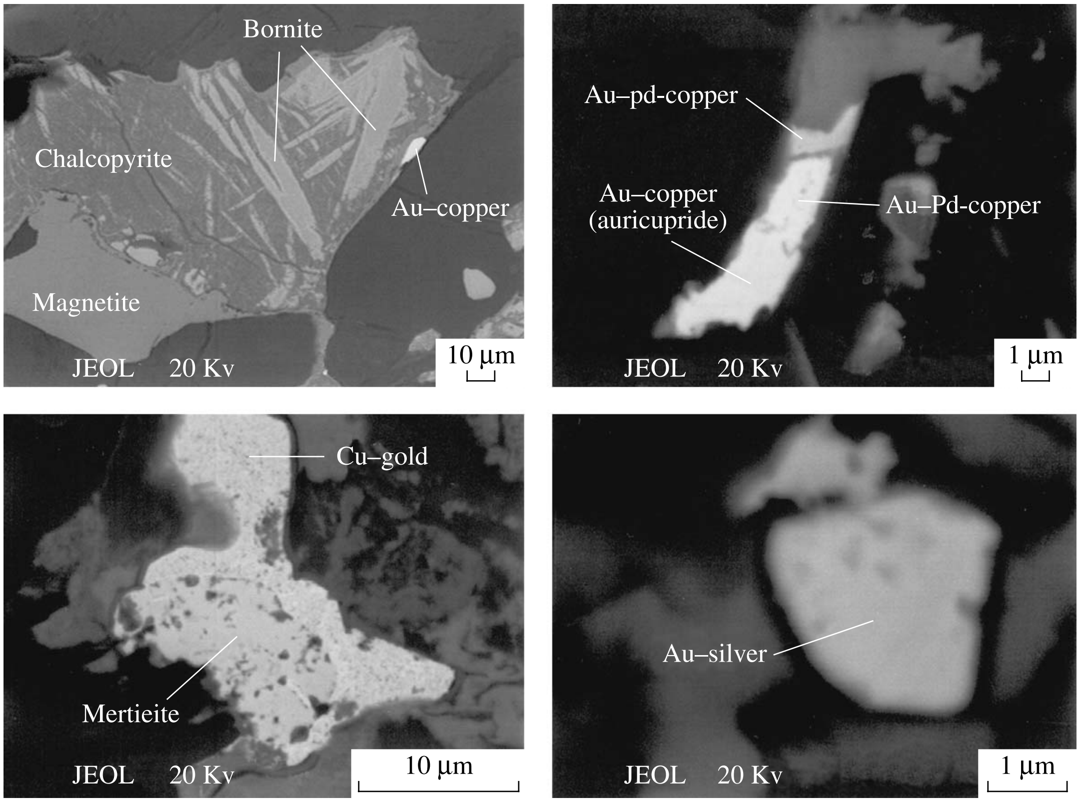

Fig. 1. Gold, palladium, and copper minerals in copper–gold–palladium ores of the Ozernoe ore occurrence. Back-scattered electron images.

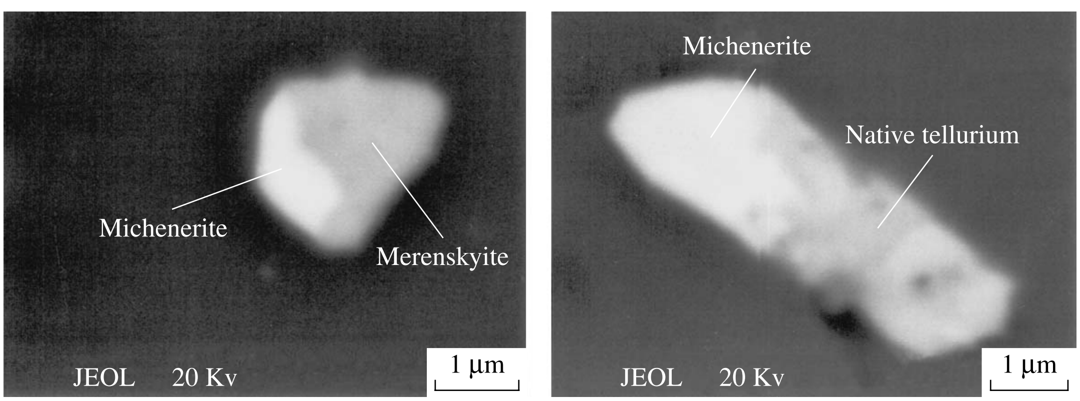

Fig. 2. Fine grains of palladium, tellurium, and bismuth minerals in copper–gold–palladium ores of the Ozernoe ore occurrence. Back-scattered electron images.

neous magnetite grains with regular distribution of spinel and ilmenite inclusions formed at the late magmatic stage. Smaller homogeneous magnetite grains formed at the subsequent stages of rock transformation.

Sulfide minerals usually make up fine dissemination. Sulfide patches up to 4–5 mm in size are less common. The sulfides are mainly represented by chalcopyrite and bornite. Their subgraphic intergrowths probably related to exsolution are less common. In some places, chalcopyrite makes up intergrowths with pyrrhotite, cubanite, and pentlandite. The pentlandite is enriched in Co (up to 10 wt %). Pyrite occurs at margins of ore zones. Bornite and chalcopyrite are often replaced by covellite and chalcocite.

Minerals of noble metals developed as very fine segregations in association with copper sulfides can only be detected at high magnification under an electron microscope. They are represented by intermetallides of Au–Cu, Au–Pd–Cu, and Au–Ag systems, and compounds of Pd with Te, Bi, and Sb.

Table 2. Compositions of palladium, tellurium, and bismuth minerals in the Ozernoe ore occurrence, wt %

Mineral	Pd	Te	Bi	Cu	Sb	Crystallochemical formula
Mertieite	62.1	–	–	2.8	25.5	$(Pd_{4.89}Cu_{0.36})_{5.25}Sb_{1.77}$
The same	66.9	–	–	2.6	28.8	$(Pd_{4.86}Cu_{0.32})_{5.18}Sb_{1.83}$
Merenskyite	25.8	52.6	–	–	–	$Pd_{1.06}Te_{1.94}$
The same	21.4	56.0	–	–	–	$Pd_{0.94}Te_{2.05}$
Michenerite	21.5	29.1	37.1	–	–	$Pd_{0.99}Bi_{0.88}Te_{1.12}$
The same	24.5	25.3	42.8	–	–	$Pd_{1.09}Bi_{0.92}Te_{0.94}$
Native tellurium	5.9	78.4	–	–	–	Te

Gold–copper, gold–palladium–copper, and gold–silver phases occur as fine isometric, extended, or irregular grains (up to 10–15 μm across) in intergrowths with copper sulfides or as inclusions therein (Fig. 1).

The composition of gold–copper minerals varies from Cu-gold to Au-copper (Table 1). Contents of Au and Cu are equal to 39.7–61.2 and 17.3–54.0 wt %, respectively. The minerals always contain Ag and Pd (up to 8.3 and 6.0 wt %, respectively). Tellurium (2.0 wt) was detected in one grain. Recalculation of analytical compositions to crystallochemical formulas shows that the gold–copper phases virtually overlap the entire series ranging from cuproauride (CuAu) to auricupride (Cu_3Au).

The ore occurrence contains a specific Au–Pd copper with the following stable composition (wt %): Cu 63.5–65.7, Pd 16.2–17.2, Au 5.5–9.1, and Ag up to 2.2.

Minerals of the Au–Ag are represented by the native Au–silver with the following composition (wt %): Ag 81–83, Au 15–16, Cu 1, Pd 1. In some places, the Ag content drops to 63 wt %, while the Au content rises to 35 wt %. This composition fits küstelite (Ag_3Au).

Mertieite (~10 μm in size) occurs as intergrowth with Cu-gold and has the following composition (wt %): Pd 62.1–66.9, Sb 25.5–28.8, and Cu 2.6–2.8 (Table 2).

Minerals of the Pd–Te–Bi system make up two phases of microscopic grains with an intricate heterogeneous structure (Fig. 2). The first (Bi-free) phase corresponds to palladium telluride with the formula matching $PdTe_2$ (Table 2) and the composition matching merenskyite $Pd(Te,Bi)_2$. The second phase with stoichiometric proportions of Pd, Te, and Bi corresponds to michenerite PdBiTe. Native tellurium with traces of Pd was detected in one grain.

The copper–gold–palladium mineralization in the Polar Urals represents the latest stage of ultrabasic magmatism. This unique mineralization could have been developed with the participation of regional dislocation metamorphism and metasomatism that promoted the mobilization and concentration of Cu, Au, PGE, and other ore components. The significant extension and thickness of ore zones, as well as the relatively high contents of Cu, Au, and Pd, indicate that new complex deposits associated with ultrabasic rocks can be discovered in the Polar Urals.

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