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GEOLOGY

A New Type of Gold–Platinum–Copper Mineralization in Northern Transbaikalia

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The northern Transbaikal region situated at the southwestern margin of the Aldan Shield incorporates a unique ore district (Fig. 1). Giant ore deposits, such as Udokan (copper, silver), Chinei (iron, titanium, vanadium, copper, and noble metals), and Katun (rare metal and rare earth elements), are located 30–100 km south of the Novaya Chara station along the Baikal Amur Mainline [2].

Despite unfavorable natural mining–geological and technological features of the Udokan copper deposit, its exploitation in the nearest future is inevitable [7]. Therefore, solution to problems related to enhancement of the efficiency of raw mineral mining in the deposit and ore district has become a crucial issue. This district is characterized by juxtaposition of two large deposits (Udokan and Chinei). Moreover, these deposits are superlarge (giant) objects with respect to resources of major metals (Cu and V). This fact is of paramount significance in the strategy of economic development of northern Transbaikalia. Extraction of associated ore components and elucidation of new types of complex ores are essential for enhancement of the efficiency of future mining–metallurgical plants in the region. In this respect, assessment of the genesis, abundance, and scale of gold–platinum–copper mineralization, which was first found in the Udokan–Chinei ore district, is very important.

Quartz veins with noble metals and copper were detected in the nearest framing of the Chinei Massif and the Pravoingamakit deposit. The Pravoingamakit deposit was exploited for cupriferous sandstones by the Udokan Expedition in the 1960s. However, we scrutinized ores of this deposit in 2004–2006 and revealed that its structure is more complicated and differs significantly from that of the standard cupriferous sandstone deposit (Udokan). Orebodies of the Pravoingamakit deposit are hosted in terrigenous–carbonate rocks of the middle section of the Chitkanda subformation of the Lower Proterozoic Udokan Formation. The discontinuous cupriferous horizon is traced as a NW-striking (dip azimuth 350, dip angle 65°–70°) zone extending over nearly 10 km on the surface and 400–500 m along the dip. Economic grade mineralization is developed over 4.5 km. The deposit includes orebodies of two types: (1) veins and lenses of milky white massive quartz with stringers and patches of sulfides (Fig. 2); (2) echelon of massive sulfide bodies surrounded by dissemination of pyrite and chalcopyrite. Quartz veins (0.3–1 m thick) extend along the strike over a few tens of meters. Sulfide bodies are 3–5 m thick and 300–440 m long. The orebodies are characterized by significant content of Cu (0.47–2.5 wt %) and very high variation of the Cu/Ni ratio (from 10 to 700 in various sectors).

Ores are represented by the pyrite–chalcopyrite varieties with typical stringer and breccia structures (Fig. 2). The maximal concentration of Ni in quartz veins is related to high contents of nickel minerals (millerite and pentlandite). The quartz vein ore is also enriched in noble metals (g/t): Pt 0.1–2.2, Pd 0.9–6.2, and Au 0.1–0.4. The ore includes fine (up to 10 μm) inclusions of clausthalite $Pb_{1,00}(Se_{0,78}S_{0,22})_{1,00}$, hessite $Ag_{1,98}Te_{1,02}$, bravoite $(Ni_{0,73}Fe_{0,30})_{1,03}S_{1,97}$, bogdanovichite $AgBiSe_2$, and palladium intermetallides, the composition of which could not be determined precisely because of their small dimension (a few micrometers). The major ore minerals in these sectors are characterized by high concentrations of Ni and Co. In particular, their concentrations in pyrite are as much as 1.75 and 1.48 wt %, respectively (Table 1).

In Cu-rich massive sulfide ores, the concentration of the majority of noble metals is appreciably higher (Pt 0.04, Pd 0.6, and Au 0.4 g/t) than in veins. However, the Ag concentration is maximal in the vein ore (as

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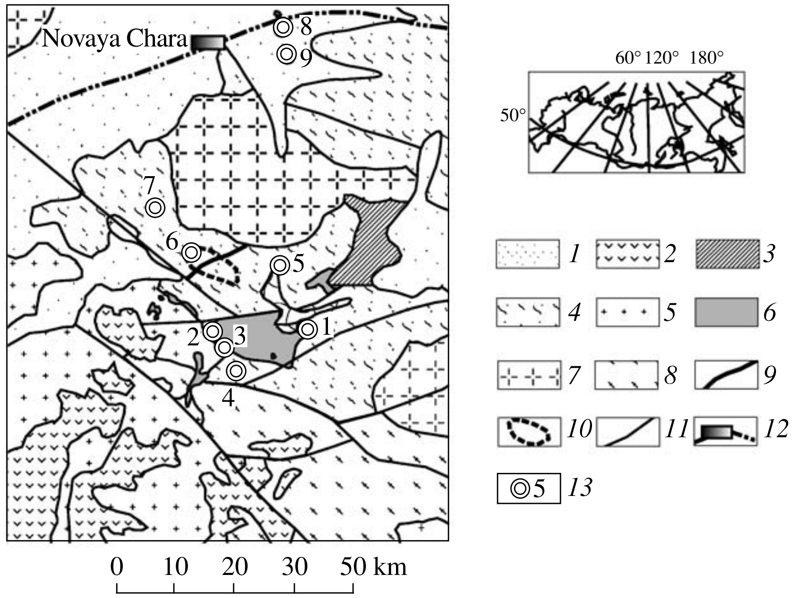

Fig. 1. Schematic geological map of the Kodar–Udokan district. (*1*) Quaternary sediments; (*2*) Neogene–Quaternary volcanic rocks; (*3*) Vendian–Cambrian sedimentary rocks; (*4*) Lower Proterozoic carbonate–terrigenous rocks of the Udokan Group; (*5*) granitoid rocks of the Ingamakit Complex; (*6*) gabbroids of the Chinei Complex; (*7*) granitoids of the Kodar Complex; (*8*) granitoids of the Kuanda Complex; (*9*) Major dike of the Udokan deposit; (*10*) cupriferous sandstone horizon of the Udokan deposit; (*11*) tectonic dislocations; (*12*) Baikal–Amur Mainline with station Novaya Chara; (*13*) deposits: (1) Rudnoe, (2) Kontaktovoe, (3) Skvoznoe Chinei Massif, (4) Pravoingamakit, (5) Sakin, (6) Udokan, (7) Klyukvennoe, (8) Luktur, (9) Unkur. Inset shows the position of the Kodar–Udokan district in the map of Russia.

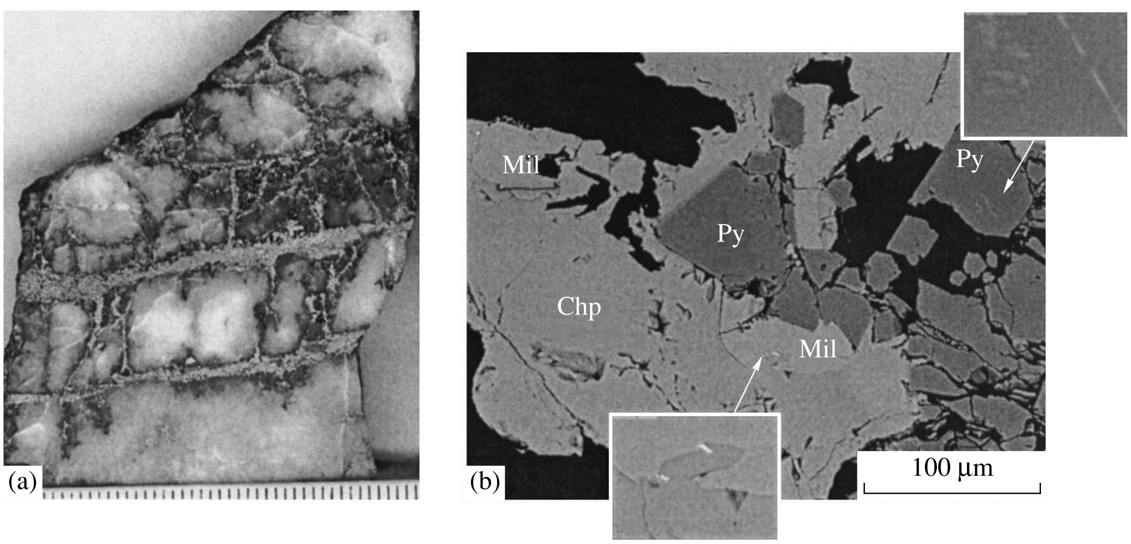

Fig. 2. Millerite–pyrite–chalcopyrite ores of the Pravoingamakit deposit. (a) Sample 45-3, (b) the same, photomicrograph. Insets show fine phases (a few micrometers) of clausthalite, hessite, and bogdanovichite.

much as 371 g/t in some specimens). The major minerals of this ore type are characterized by lower contents of Ni and Co.

Gold–platinum–copper ores of the Pravoingamakit deposit are different from copper ores of the Udokan deposit and are similar to outer contact ores of the Rudnoe deposit in the Chinei Massif [3, 4]. The Udokan deposit is composed of monometal (copper) ores represented by the major bornite–chalcocite and subordinate chalcopyrite varieties. Ag and Au are insignificant. The Au content is 0.3 g/t in crosscutting veins, 0.1 g/t in substratiform lenses, and 0.01 g/t in dissemination in sandstones.

Composition of the major ore-forming minerals in quartz–sulfide veins of the Pravoingamakit deposit, wt %

Ord. no.	S	Fe	Ni	Co	Cu	Total	Mineral
1	34.38	30.08	–	–	35.93	100.39	Chalcopyrite
2	34.72	29.18	–	–	35.60	99.50	The same
3	34.53	30.24	0.32	0.21	35.61	100.91	"
4	34.39	30.32	–	0.05	34.48	99.24	"
5	34.13	30.47	–	0.06	34.53	99.17	"
6	34.20	30.55	–	0.05	34.65	99.45	"
7	33.84	30.39	–	0.06	34.60	98.89	"
8	34.01	30.47	–	0.05	34.64	99.17	"
9	34.22	30.27	–	0.06	34.47	99.02	"
10	52.50	45.37	0.84	0.41	–	99.12	Pyrite
11	52.84	45.01	1.75	0.27	0.38	100.25	The same
12	53.05	46.22	0.87	0.35	–	100.48	"
13	52.27	45.16	0.43	1.12	–	98.98	"
14	53.32	44.01	0.51	1.27	–	99.10	"
15	52.67	46.38	0.31	0.36	0.01	99.73	"
16	52.60	46.05	0.38	0.75	0.13	99.91	"
17	52.59	46.46	0.29	0.30	0.18	99.82	"
18	52.49	46.54	0.39	0.32	0.26	100.00	"
19	52.68	46.29	0.44	0.41	0.10	99.92	"
20	53.04	46.23	0.38	0.40	0.17	100.22	"
21	52.80	46.39	0.21	0.65	0.20	100.25	"
22	52.43	45.70	0.32	0.91	0.19	99.55	"
23	52.93	46.60	0.10	0.73	0.00	100.36	"
24	53.08	45.54	0.08	1.48	0.01	100.20	"
25	32.99	23.51	42.58	0.28	–	99.36	Pentlandite
26	34.98	2.15	62.45	–	–	99.58	Millerite
27	35.34	1.90	62.20	–	0.41	99.85	The same
28	35.20	0.87	63.98	–	0.30	100.35	"
29	34.45	1.99	62.02	0.13	0.01	98.60	"

Note: Analyses were performed with a SX 100 (Cameca) microprobe at the Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow (N.N. Kononkova, analyst). (–) Below the detection limit.

As in the Pravoingamakit deposit with quartz veins, outer contact ores of the Chinei Massif occur in sandstones. The Chinei Massif typically encloses millerite–chalcopyrite veins and lenses of massive sulfides with an aureole of pyrrhotite–chalcopyrite dissemination. The subhorizontal ore zone is 3–65 m thick and 1–2 km long. Copper is the major metal, while Pt, Pd, Au, Ag, Ni, and Co are associated components. The ores are mainly characterized by a patchy–disseminated texture. Stringer and breccia-type textures are less common. The outer contact zone includes vein and lenticular bodies at the intersection of differently oriented fractures with anomalously high concentrations of noble metals (g/t): Pt 15, Pd 124, Au 14, and Ag 345. These elements do not correlate with Cu [9].

The fluid composition was determined in the quartz-hosted inclusions in vein ores. In the brecciated quartz with a matrix of a pyrite–chalcopyrite aggregate (Fig. 2), we detected primary, pseudosecondary, and secondary two-phase fluid inclusions of both negative and irregular crystal shapes (1–20 μm in size). The two-phase inclusions homogenize into the liquid phase at 222–192°C and contain an aqueous solution with a salt concentration of 2.7–2.6 wt % NaCl equiv. Solutions in such inclusions are mainly composed of sodium and magnesium chlorides (eutectic temperature varies from –43 to –38°C). The density of the fluid is 0.86–0.90 g/cm^3. Fluid inclusions from the outer contact ore of the Rudnoe deposit in the Chinei Massif also have similar values of eutectic temperature and density [6].

The magmatic nature of sulfur in sulfide minerals is indicated by its isotopic composition determined at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (L.P. Nosik, analyst). The $\delta^{34}S$ value varies from –2 to +7‰.

The geological position and specific features of tectonic events and magmatism of the Udokan–Chinei ore district suggest that metallogenic specialization of this marginal part of the Aldan Shield can be related to processes of multistage tectonomagmatic reactivation. The first stage (~2 Ga ago) was marked by the formation of the Kodar–Udokan Trough with both sedimentary and synsedimentary hydrothermal sulfide mineralizations. Development of sedimentary hydrothermal mineralization in sedimentary basins has been recorded in various geotectonic settings, including the unique Witwatersrand Basin [8]. The second stage (~1.8 Ga ago) was related to ultramafic–mafic magmatism, the formation of the Chinei Pluton with magmatic ores, and the development of postmagmatic hydrothermal polymetallic mineralization. This stage was undoubtedly associated with the abyssal fluid-magmatic system. The possibility of the formation of gold–PGM ores in the course of remobilization of older ores has been demonstrated for the Bushveld Massif [6]. However, mineralization discussed in the present paper corresponds more to autonomous ore-forming systems.

The spatial juxtaposition of copper deposits developed in various environments (sedimentary and magmatic rocks) is related to long-term evolution of the Udokan–Chinei geochemical system. Consequently, the system was characterized by manifestations of the synsedimentary hydrothermal, magmatic, and postmagmatic stages of ore formation. Copper and noble metals were introduced at these stages. Superposition of late processes on the older mineralized rocks fostered the formation of unusual quartz–sulfide ores.

Tectonic displacements and significant erosion of the southern Siberian Craton after the Proterozoic period were responsible for the exhumation of blocks with various components composed of layered massifs of the Chinei Complex. These processes promoted the formation of magmatic deposits of sulfide ores, hydrothermal copper deposits in their framing, and sedimentary copper deposits in the distal zone.

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