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GEOLOGY

Formation Conditions of High-Grade Tin–Copper Ores in the Churpun'ya Deposit (Yakutia)

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At present, only the Churpun'ya cassiterite–silicate–sulfide vein deposit is mined for tin ore in Yakutia. The present communication discusses the results of study of the metallogenic features of the ore district and thermobarogeochemical investigations of high-grade ores from the Churpun'ya deposit. The deposit is located in the Chokohur–Chokurdakh ore-bearing zone of the Northeast Yakutian metallogenic belt [1]. The ore-bearing zone extends in the meridional direction over 250 km and coincides in space with an intermittent chain of small uplifts among Cenozoic sediments of the Yana–Indigirka lowland (Fig. 1). Based on seismic exploration and prospecting drilling data, the friable sedimentary cover of the lowland is 60–110 m thick. The uplifts are composed of low-angle Jurassic flyschoid sediments and Late Jurassic–Early Cretaceous volcanosedimentary sequences. Their formation was related to the intrusion of granodiorite, subalkaline amphibole–biotite granite, and subvolcanic rhyodacite bodies. Volcanic rocks are located at the Svyatoi Nos termination of the Oloi volcanoplutonic belt [1].

The Churpun'ya deposit is confined to an eroded paleovolcanic edifice (Fig. 1). In terms of tectonics, the edifice is located at the junction of the sublatitudinal and NW-oriented faults subjected to repeated tectonomagmatic reactivation. They serve as auxiliary structures of the sublatitudinal Churpun'ya deep fault that governs the subvolcanic bodies and major orebodies of the Churpun'ya deposit. The faulting zone corresponds to the subvolcanic rhyodacite body in thickness (130–200 m).

The volcanoplutonic edifice is surrounded by nearly equant effusive fields n–110n m in thickness and 3.5 × 6.5 km in area. The base of the exposed section includes a sequence of stratificated tuffites of the neck facies, lahar breccia, and andesite lavas. The overlying sequence is composed of lava breccia, tuffites, tuffs, and tuffstones. Volcanosedimentary rocks are overlain by rhyodacite effusives and crosscut by explosive breccia and rhyodacite extrusion veins of the paleovolcanic neck facies. Based on results of the K–Ar biotite dating, rhyodacite bodies were emplaced 102–104 Ma ago. Intraore rhyolite and granite porphyry dikes postdated the rhyodacite bodies and predated the tin deposits [1].

Orebodies are represented by veins, mineralized crush zones, and stockworks. The Sn content is as much as 48% in quartz veins up to 1.5 thick. Therefore, the Churpun'ya deposit can be qualified as a unique body. High-grade ores of this deposit can be processed selectively, and they can be dressed up to the concentrate state by manual sorting. The deposit incorporates 35 orebodies (including 34 orebodies specialized in Sn and one orebody specialized in W) that can be grouped into three linear zones: Northern, Central, and Southern. The major explored Sn reserves (approximately 90%) are concentrated in the Central zone. Orebody 1 includes up to 70% of the Sn reserve [2]. The thickness of orebodies ranges from 0.7–1.0 to 2–3 m; the average Sn grade, from 1–2 to 2.5–5%. In addition, the deposit also incorporates two stockworks. The first stockwork (size 300 × 400 m, average Sn grade varies from 0.1–0.3 to n%) is located at a depth of 30–65 m. The second (smaller) stockwork is confined to similar depths [2]. The deposit is characterized by an abundance of hydrothermal-metasomatic rocks. Quartz–tourmaline rocks prevail, particularly in the central part of the volcanoplutonic complex of the neck facies. Effusive rocks are subjected to chloritization and carbonatization. Crush zones are marked by the development of sulfides (pyrite, marcasite, and arsenopyrite dissemination) and argillic alteration in some places. An effusive sequence at the western flank of the deposit hosts large-scale porphyry copper dissemination (>0.1% Cu). Reserves of the high-grade vein copper ore (up to 33.5% Cu) detected in this zone are insufficiently explored [3].

Orebodies of this deposit formed in two stages: the productive cassiterite–quartz stage and the sulfide pyrrhotite–chalcopyrite stage [1, 3]. Ores of the productive

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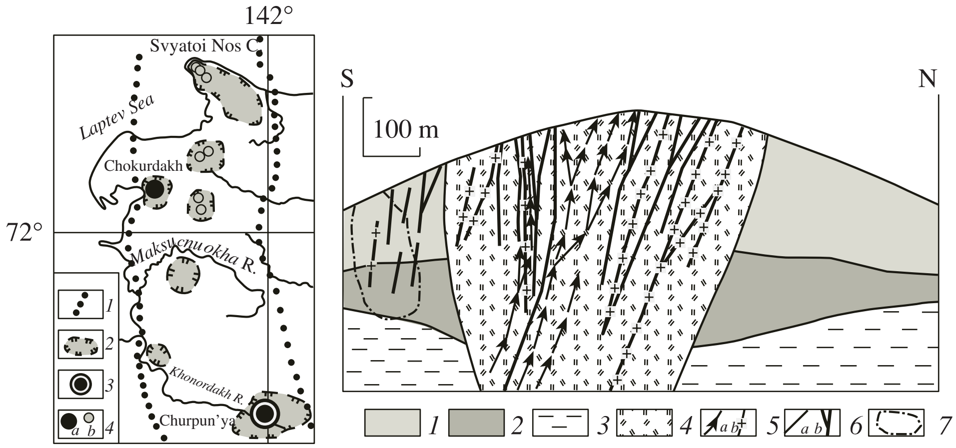

Fig. 1. Schematic geological section of the Churpun'ya deposit and its position (inset) in the Chokohur–Chokurdakh metallogenic zone. (*1*) Upper effusive member (rhyolite and rhyodacite lavas); (*2*) lower volcanosedimentary member (tuffs, tuffites, and tuffstones); (*3*) terrigenous basement (silty sandstones and siltstones); (*4*) subvolcanic dacite–rhyodacite body; (*5*) dikes of (*a*) rhyolite porphyres and (*b*) granodiorite porphyres; (*6*) geological boundaries (*a*) and orebodies (*b*); (*7*) Sn-bearing stockwork. Legend for the inset: (*1*) Boundary of the Chokohur–Chokurdakh metallogenic zone; (*2*) boundary of domes; (*3*) Churpun'ya deposit; (*4*) small deposits (*a*) and occurrences (*b*) of tin ores.

stage contain wolframite and bismuth minerals. The mineral assemblage of the sulfide stage is terminated by the sulfosalt–carbonate assemblage [1, 3]. The deposit is undoubtedly characterized by the superposition of copper and tin mineralizations developed at different stages. However, their temporal relationships remain unclear. The tin mineralization can be superimposed on the earlier copper mineralization that is widespread in the Oloi volcanogenic belt. The Churpun'ya deposit is confined to the western flank of the Oloi belt. In this belt, the porphyry copper mineralization is closely associated with Late Jurassic granitoids of the Egdegych Complex with an age of 141 Ma [4]. Tin mineralization is widespread in the Central Poluosnaya metallogenic zone and associated with Early Cretaceous leucocratic granitoids [1]. Hence, tin mineralization in the Churpun'ya deposit could overlap the early porphyry copper mineralization. The latter mineralization could undergo intense remobilization and redeposition in quartz–cassiterite orebodies with the formation of high-grade ore shoots. This assumption is supported by geoexploration data [3]. Complex ores of the Churpun'ya deposit are characterized by an essential mineralogical feature manifested as the absence of high contents of Ag. In contrast, many volcanogenic tin deposits of South America (e.g., Potosi district, Bolivia) contain bonanza silver ores of autonomous industrial significance [5]. The juxtaposition of tin and silver mineralizations is a characteristic feature of the Dukat and West Verkhoyansk districts in Northeast Russia [6]. The lack of silver mineralization in ores of the volcanogenic Churpun'ya deposit can be related to the specific feature of the preorogenic intermediate sources of ore material in this region.

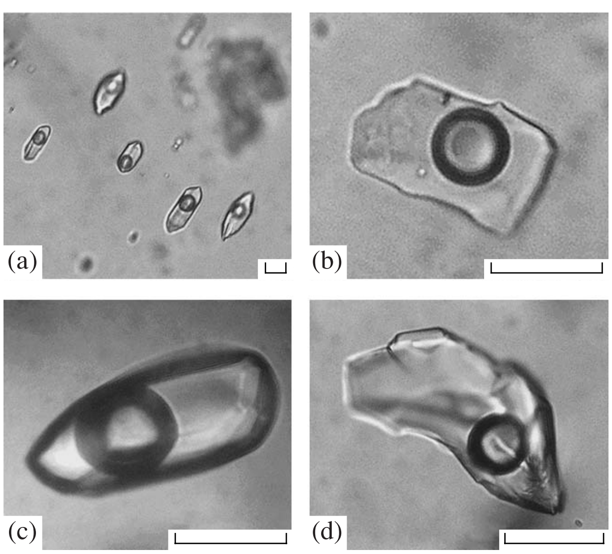

Fig. 2. Quartz-hosted two-phase fluid inclusions in high-grade ores of the Churpun'ya deposit. (a, b) Primary (the inclusion in 2b recorded at +10°C shows a salt crystal); (c) pseudosecondary; (d) secondary. Scale 20 μm.

Thermobarogeochemical investigation of cassiterite–quartz ores from orebody 1 of the Churpun'ya deposit was carried in specimens kindly placed at our disposal by B.V. Makeev. Quartz in these ores contains only two-phase (gaseous–liquid) inclusions (3–50 μm in size) of negative crystals (Fig. 2). The quartz grain also contains regular dissemination of primary inclusions. The gaseous phase in them accounts for 20–35 vol % of the vacuole. Some inclusions contain low-soluble anisotropic silicate (probably, mica) crystals of probably xenogenic nature. The inclusions can be divided into two varieties. The inclusions are primarily located in cracks confined to the grain boundaries (pseudosecondary inclusions) and the crosscutting cracks (secondary inclusions).

Microthermometric investigations of fluid inclusions (FI) were performed with a THMSG-600 (Linkam Company) device that makes it possible to measure phase transition temperatures ranging from –196 to +600°C and to check them at high magnifications. The salt concentration in the FI solution was estimated on the basis of the ice melting temperature using data from [7]. The salt concentration and water fluid density was estimated with a FLINCOR software package [8]. The table presents the results.

Primary FIs in quartz from the Churpun'ya deposit homogenize into the liquid phase at 423–341°C. Cryometric investigations revealed that the inclusions contain not only ice (homogenization at –18.5 to –1.9°C), but also salt crystals (homogenization at –25.5 to +18.3°C). The concentration of the water solution is estimated at 26.3–13.1 wt % NaCl equiv. Based on the eutectic temperature (from –42 to –29°C), the FI solution is dominated by sodium and magnesium chlorides. The fluid density is 0.74–0.92 g/cm^3.

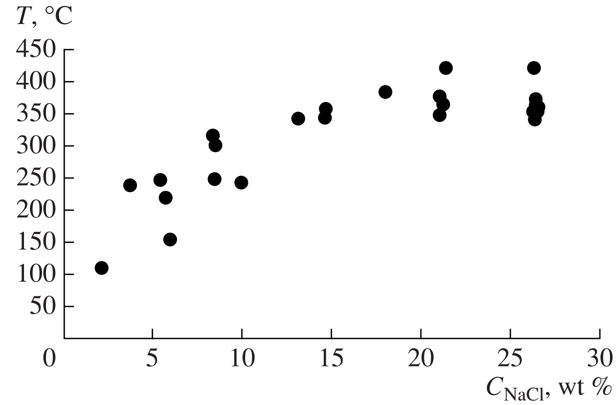

Fig. 3. Temperature vs. concentration diagram for relicts of ore-forming fluids in the Churpun'ya deposit.

Pseudosecondary FIs homogenize into the liquid phase at 316–243°C and contain a water solution with

Results of the thermo- and cryometric investigations of individual quartz-hosted inclusions in high-grade ores of the Churpun'ya deposit

Inclusion no.	Mineral, inclusion type	n	T_{hom}, °C	T_{eut}, °C	$T_{i.m.}$, °C (of crystal)	C_s, wt % NaCl equiv	d, g/cm^3
1	Quartz P	3	423	–40	–17.3 (1.6)	26.2	0.84
2	The same	6	422	–39	–11.9 (–25.5)	21.3	0.80
3	″	3	385	–33	–14.2	18.0	0.78
4	″	5	378	–42	–18.1	21.0	0.85
5	″	3	374	–51	–18.5 (5.4)	26.3	0.90
6	″	5	367	–43	–17.8 (7.9)	26.3	0.91
7	″	17	367	–38	–8.5 (–25.0)	21.2	0.86
8	″	11	363	–29	–1.9 (16.7)	26.4	0.91
9	″	6	356	–38	–10.6	14.6	0.79
10	″	3	353	–32	–2.4 (18.3)	26.4	0.92
11	″	6	353	–42	–10.7 (3.9)	26.2	0.81
12	″		348	–42	–18.1	21.0	0.88
13	″	15	345	–42	–10.6	14.6	0.82
14	″	5	343	–35	–9.2	13.1	0.79
15	″	3	341	–38	–6.5 (7.5)	26.3	0.74
16	Quartz PS	3	316	–37	–5.3	8.3	0.78
17	The same	3	301	–36	–5.4	8.4	0.81
18	″	2	247	–36	–5.4	8.4	0.88
19	″	8	246	–32	–2.3	5.4	0.86
20	″	3	243	–38	–6.5	9.9	0.90
21	Quartz S	6	238	–30	–2.2	3.7	0.85
22	The same	2	220	–33	–3.5	5.7	0.89
23	″	4	153	–26	–3.6	5.9	0.96
24	″	2	109	–30	–1.2	2.1	0.97

Note: Fluid inclusion type: (P) primary, (PS) pseudosecondary, (S) secondary; temperature: (T_{hom}) homogenization, (T_{eut}) eutectic, ($T_{i.m.}$) ice melting.

a salt concentration of 9.9–5.4 wt % NaCl equiv. The solution in these inclusions is also dominated by sodium and magnesium chlorides (eutectic temperature ranges from –38 to –32°C). The fluid density is 0.78–0.90 g/cm^3.

Secondary FIs homogenize into the liquid phase at 238–109°C and contain water solution with a salt concentration of 5.9–2.1 wt % NaCl equiv. The solution in these inclusions is also dominated by sodium and magnesium chlorides (eutectic temperature ranges from –33 to –26°C). The fluid density is 0.85–0.97 g/cm$_3$.

Comparative analysis of the results obtained with data on other tin deposits suggests the following conclusion: relative to the FIs from the Deputat deposit [9], various quartz-hosted inclusions in the high-grade cassiterite–quartz ores of the Churpun'ya deposit are characterized by a lower range of homogenization temperatures that matches the temperature range recorded in deposits of the Sikhote Alin region [10]. Ores of the Churpun'ya deposit also differ from other deposits in terms of the temperature–concentration relationship [9, 10].

The temperature–concentration plot shows a distinct positive correlation of salt concentration in the FI solution with temperature (Fig. 3). This pattern of salinity variation can be related to the dilution (synchronously with a decrease in temperature) of the strongly mineralized deep fluid by the weakly mineralized meteoric waters. According to Borisenko et al. [9], the formation of cassiterite–silicate–sulfide ores is accompanied by the automatic dilution of the strongly concentrated fluids due to condensation of a paragaseous phase at lower temperatures. The dilution is distinctly recorded along both vertical and lateral directions in the Deputat deposit. This pattern is also observed in other large tin deposits [10]. However, the dilution was only recorded in one sample in our case. Therefore, we assume that high-grade ores of the Churpun'ya deposit formed in the mixing zone of the deep (magmatic) concentrated fluid and meteoric waters. Unfortunately, we failed to scrutinize the formation conditions of copper mineralization. Nevertheless, we can assume that disseminated and vein copper ores of the Churpun'ya deposit represent the apical part of the magmatic copper porphyry system.

Thus, both high-grade cassiterite–silicate–sulfide and porphyry copper ores of the Churpun'ya deposit formed in a single ore-bearing structure at the same depth.

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