formation model of the deposits during the convergence of the plate margins [Groves et al., 2007]. According to this model, the ore-forming structure of the Kumtor deposit is confined to a continent-continent collision zone and was formed in the Late Paleozoic (Upper Carboniferous to Early Permian) orogenic stage of the evolution of the region. That period was characterized by the renewal of the movements of the Ishim-Central Tien Shan microcontinent toward the Kyrgyz-Kazakh continent. At the same time, the crust of the Paleoturkestan Ocean was actively subducted under Ishim-Central Tien Shan microcontinent and the latter was compressed from the south.

This model assumes the ultra-metamorphic transformations of the rocks at the depth. Under conditions of the pressed wedge and bilateral pressure, the melting of the lithospheric fragments at the depth and uplift of the asthenospheric boundary in this place are suggested. All these may explain the peculiarities of ore composition of the Kumtor deposit, in particular, abundant newly formed carbonates. According to the model, ore-forming components originate from a zone of reworking of the lithosphere blocks and significant amounts of CaO and CO_2 are resulted from the thermal dissociation of sedimentary carbonates.

In accordance with a model of Groves et al. [2007], the small multiphase intrusive bodies were intruded at initial collision stage along the suture zone at the boundary of two continents. In our case, this is the Nikolaev Line and monzonite, monzogranite and monzogabbro intrusions of the Middle to Late Carboniferous Songkul-Kensoo complex. The skarn and porphyry Cu-Bi-Au-Mo-W occurrences and deposits (Kumbel, Kensu, etc.) are known to be related to these intrusions. They were described in a structure of the Au-Cu-Mo-W Songkel-Kensoo ore belt [Kudrin et al., 1990]. Many geologists relate the formation of the Kumtor deposit to the intrusions of this complex.

In our opinion, the Kumtor deposit was formed far southward this belt. The major ore-forming processes occurred at the depth in the central part of the Central Tien Shan structure under conditions of the Late Paleozoic thrusts system, dynamothermal metamorphism, and multistage hydrothermal activity. The close modern location of the deposit from the Nikolaev Line (~5 km) is related to the moving up of the ore-bearing zones along the thrusts to the north and northwest during the Alpine tectonic stage. The Alpine deformations have complicated the postorogenic structure of the region and, probably, significantly displaced it relative to the primary position.

References

Anikin, S.I. Geology and mineralogical-geochemical features of gold-tellurium rare-metal mineralization in the Vendian carbonaceous rock sequences at the Kumtor ore field (Central Tien Shan) // Extended abstract of PhD Thesis. Bishkek, BPI, 1992 [in Russian].

Bogdetskiy, V.N. et al. Geological position of gold-tungsten mineralization in carbonaceous schists on the example of one of the Tien Shan deposit // Stratiform deposits of non-ferrous and rear-earth metals in black slate formations. Frunze: FPI, 1981. P. 101–105 [in Russian].

Groves, D.I., Bierlein F.P. Geodynamic settings of mineral deposit systems // J. Geol. Soc., London. Vol. 164, 2007. P. 19–30.

Kudrin, V.S., Soloviev S.G., Stavinskiy V.A. et al. Gold-copper-molybdenum-tungsten ore belt of the Tien Shan // Geol. Ore Dep., 1990. No. 4. P. 13–26.

Maslennikov, V.V., Large R.R., Shevkunov A.G., Simonov V.A. Evolution of the Sukhoi Log and Kumtor gold ore giants // Abstract of CERCAMS14 & MDSG's34 Annual Meeting, 2011. Section XIII. P. 4–5.

V.A. Simonov[1], V.V. Maslennikov[2], A.V. Kotlyarov[1]

[1] Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, simonov@igm.nsc.ru
[2] Institute of Mineralogy UB RAS, Miass, Russia

PHYSICO-CHEMICAL CONDITIONS OF MAGMATIC AND HYDROTHERMAL SYSTEMS OF THE PALEOZOIC "BLACK SMOKERS" FROM THE RUDNY ALTAI, NORTHEAST KAZAKHSTAN

Исследования расплавных и флюидных включений позволили выяснить физико-химические условия процессов минералообразования, связанных с магматизмом и постмагматическими флюидными и рудообразующими гидротермальными системами палеозойских «черных курильщиков» Северо-Восточного Казахстана. Установлено, что кислые расплавы обладали повышенными содержаниями CuO (до 430 г/т) и воды (до 5.7 %). Выяснено, что постмагматические флюиды имели более высокие значения солености (до 8.8 %) и температур (до 288 °C) по сравнению с рудообразующими растворами – до 5.8 % и до 160 °C.

The representative samples of sulfide ores and host rocks from the massive sulfide deposits of the Rudny Altai (northeast Kazakhstan) were collected during the joint field works of specialists from the Urals and Siberian Branches of Russian Academy of Sciences. The analysis of morphology of orebodies and distribution and correlation of ore facies allowed construction of the morphogenetic range of the deposits from the sulfide mounds to the bedded massive sulfide deposits. A finding of fragments of the Paleozoic black smoker chimneys was the major achievement of the field works. This finding unequivocally indicates that deposits were formed in a similar manner to the modern black smokers with related abundant biota [Maslennikov et al., 2007; Maslennikov, Simonov, 2012].

Here, we report on new results of formation conditions of the Paleozoic black smokers in the northeast Kazakhstan based on melt and fluid inclusion study. The study of melt inclusions allows us to find out the features of the magmatic systems directly affected the hydrothermal ore-forming processes at the massive sulfide deposits from the Rudny Altai. The investigation of the fluid inclusions makes possible to identify the physical and chemical parameters of postmagmatic fluids and hydrothermal systems, which produced the sulfide mounds at the same deposits of the northeast Kazakhstan. The melt and fluid inclusions were studied on the specially designed devices at the Institute of Geology and Mineralogy SB RAS (Novosibirsk) [Simonov, 1993; Sobolev, Danyushevsky, 1994].

The melt inclusions, reflecting the magmatic system, were studied in quartz from the fine-grained quartz porphyric rocks of the Nikolaevskoe massive sulfide deposit. The samples were taken from the intrusive body 5–10 m thick at the bottom of the open pit in the immediate vicinity of the sulfide ore. The primary melt inclusions 10–50 μm in size are regularly distributed in the quartz phenocrysts. The one-phase inclusions filled with a pure homogeneous glass are dominant. Some inclusions contain the gas bubble, ore phases, and light crystals or a great amount of small dark phases in a glass. The majority of melt inclusions is depressurized during the high-temperature heating stage that indicates significant fluid pressure. The temperatures of homogenization of stable inclusions were ~1080 °C.

According to the chemical composition of glass, the melt inclusions (with alkali contents up to 5.3 wt %) correspond to the rocks of normal alkalinity and belong to the low-alkali rhyodacites. On the FeO/MgO–SiO_2 diagram, the data points of composition of melt inclusions fall to the area of the tholleiitic rocks. The decrease in TiO_2 (from 0.27 to 0.09 wt %), Al_2O_3 (from 11.8 to 9.9 wt %), Fe_2O_3 (from 2.1 to 1.6 wt %), and CaO (from 1.43 to 1.1 wt %) with simultaneous increase in Cl (from 0.11 to 0.23 wt %) is registered during the evolution of the acid melts (with increase of SiO_2 content). The characteristic decrease in Al_2O_3 content points to the fractionation of plagioclase during the differentiation of the magmatic systems.

Comparing these results with our data on melt inclusions in quartz from effusive rocks of other massive sulfide deposits, we can conclude that these melts are similar to acid magmas from the Yubileinoe deposit in the Rudny Altai and Yaman-Kasy deposit in the South Urals in TiO_2, Al_2O_3, MgO, CaO, and Na_2O contents. The content of the majority of oxides from our study also shows similarity with previously published data on melt inclusions in quartz of porphyry rocks from the Pamyatnik hill directly associated with the Nikolaevskoe deposit [Mergenov, 1987].

The microprobe analysis has shown the notable CuO content (up to 430 ppm and up to 640 ppm in single analyses) in melt inclusions from the Nikolaevskoe deposit. The copper accumulates during the fractionation of acid melts with increase in FeO/MgO ratio and chlorine content.

The ion microbe analyses of melt inclusion in quartz have revealed the increased H_2O contents (2.4–5.7 wt %) in magma of the Nikolaevskoe deposit comparable with those from the Yubileinoe (up to 4.30 wt %) and Yaman-Kasy (2.7–5.2 wt %) deposits. Based on ion microbe analyses, the REE distribution in the studied melt inclusions is similar to that from the felsic volcanic rocks of island arcs. In the LREE area, they coincide with data on melt inclusions from the Yubileinoe deposit and rhyolites of the Kuril-Kamchatka island arc. The acid melts from the Yaman-Kasy deposit with typically lower REE contents are obviously distinct. All REE spectra are characterized by the clear Eu minimum, which indicates the magma differentiation during the fractionation of plagioclase.

The physical and chemical parameters of postmagmatic fluids are based on the fluid inclusion study of melt-bearing quartz phenocrysts from quartz-feldspar porphyry rock closely associated with sulfide ores of the Kamyshenskoe massive sulfide deposit. The fluid inclusions 3–15 μm in size are located as chains in quartz. The two-phase (light transparent liquid and gas bubble) inclusions are dominant.

The freezing temperature of the fluid inclusions is –35 – –40 °C. The eutectic temperatures vary from –23 to –26 °C, indicating dominant NaCl admixed with KCl. The final melting temperature includes two groups of values (–0.9 – –2.5 °C and –3.2 – –5.8 °C) that indicates two groups of salinity: 1.4–3.8 wt % and dominant 5.0–8.8 wt % NaCl-equiv. (up to 13 wt % in some cases). Three temperature ranges are typical of the studied fluid inclusions: 134–190, 204–250 and 272–288 °C.

The correlation of homogenization temperatures and salinity gives two groups of inclusions, which are overlapped with those from the Yaman-Kasy porphyry rocks. The low-temperature (to 190 °C) group is characterized by considerable salinity (up to 13 wt % NaCl-equiv.) that is comparable with data on quartz from the porphyry rocks of the Kyzyl-Tashtyg deposit. At the same time, inclusions with elevated temperature (up to 288 °C) are characterized by the lower salinity (up to 8.8 wt % NaCl-equiv.). It should be noted that homogenization temperature and salinity directly correlate in both groups of inclusions.

The formation conditions of the ore-forming hydrothermal system from the feeder channels to the top of the sulfide mound were studied in fluid inclusions in barite from sulfide ores of the Artem'evskoe massive sulfide deposit.

The fluid inclusions in barite from the feeder channels are 3–15 μm in size. They are mostly regular distributed in the crystals or confined to the numerous intercrossed healed fractures. Three types of co-existing fluid inclusions may be distinguished: (I) dominant one-phase liquid inclusions, (II) abundant two-phase inclusions with a light liquid and round gas bubble, and (III) vapor inclusions. This is similar to the fluid inclusions from the feeder channels of the Valentorka massive sulfide deposit in the North Urals.

The freezing temperature of the two-phase inclusions ranges from –35 to –40 °C. The eutectic temperatures vary from –24.5 to –26 °C that points to the presence of NaCl and KCl in the fluids. The final melting temperature of –0.15 – –3.7 °C corresponds to the salinity of 0.2–5.8 wt % NaCl-equiv. In most cases, the salinity is below that of seawater. The homogenization temperatures vary from 114 to 160 °C.

The homogenization temperatures and salinity of the studied fluid inclusions are similar to the low-temperature group of inclusions in barite from the Yaman-Kasy deposit. It should be noted that studied fluid inclusions are characterized by significant range of salinity at narrow temperature range. At the same time, fluid inclusions in barite from the Yaman-Kasy deposit and sulfide mounds from the Manus back-arc basin are characterized by the higher homogenization temperatures.

Thus, out studies of melt and fluid inclusions allowed us to identify the physical and chemical conditions of related processes of mineral formation at massive sulfide deposits of the Rudny Altai (northeast Kazakhstan) similar to the modern black smokers and to find the consecutive change of the magmatic systems by postmagmatic fluids and ore-forming hydrothermal systems. It was established that acid melts of normal alkalinity, corresponding to low-alkali rhyodacites in composition, have increased CuO (to 430 ppm) and H_2O (to 5.7 wt %) contents. The postmagmatic fluids are characterized by higher salinity (up to 8.8 wt % (rarely up to 13 wt %) NaCl-equiv) and elevated temperatures (up to 288 °C) in comparison with those of ore-forming hydrothermal solutions (up to 5.8 wt % NaCl-equiv and up to 160 °C).

The work is supported by the project of joint researches of the Siberian and Urals (no. 12-C-5-1010) Branches of the Russian Academy of Science.

References

Maslennikov, V.V., Simonov, V. A., Zhukov, I.G., Tretyakov, G. A., Herrington, P., Maslennikova, S.P., Kanygin, A.V. First findings of sulfide chimneys of the Paleozoic "black smokers" in the Central Asia // Geology of the seas and oceans: Materials of XVII International scientific conference (School) on the sea geology. Vol. II. M: GEOS, 2007. P. 47–49 [in Russian].

Maslennikov, V.V., Simonov, V.A. Some problems of near-hydrothermal fauna developed in the zones of activity of the Paleozoic "black smokers" of the Rudny Altai // Metallogeny of ancient and modern oceans-2012. Hydrothermal fields and ores. Miass: IMin UrB RAS, 2012. P. 65–68 [in Russian].

Mergenov, V.M. Physico-chemical features of formation of porphyry rocks and ores of the Nikolaevskoe deposit (Rudny Altai) // Geology of ore deposits, 1987. No 1. P. 59–65 [in Russian].

Simonov, V.A. Petrogenesis of ophiolites (thermobarogeochemical researches). Novosibirsk: UIGGM SB RAS, 1993. 247 p. [in Russian].

Sobolev, A.V., Danyushevsky, L.V. Petrology and Geochemistry of Boninites from the North Termination of the Tonga Trench: Constraints on the Generation Conditions of Primary High-Ca Boninite Magmas // J. Petrol., 1994. Vol. 35. P. 1183–1211.

I.V. Sinyakovskaya[1, 2], V.V. Zaykov[2, 1]

[1] National Research South Ural State University, Chelyabinsk, Russia, sin@mineralogy.ru

[2] Institute of Mineralogy, Urals Branch of RAS, Miass, Russia,

GEODYNAMIC TYPES OF THE PYROPHYLLITE DEPOSITS

Пирофиллитовое сырье относится к сравнительно редким видам нерудных полезных ископаемых. По геологической позиции и условиям образования месторождения подразделены на 5 типов. Первые два связаны с гидротермально измененными породами в вулканогенных толщах кислого и среднего составов. К третьему типу относятся месторождения метаморфогенно-метасоматического генезиса. Проявления четвертого типа приурочены к низко- и среднетемпературным стадиям образования гидротермальных жил среди вулканических и метаморфических толщ. Пятый тип - это пирофиллитсодержащие коры выветривания по метаморфическим толщам и метасоматитам. Условия образования и размещения месторождений пирофиллитового сырья в складчатых поясах определяются геодинамической обстановкой формирования.

Pyrophyllite is a comparatively rare economic mineral. Basic consumers of raw pyrophyllite are ceramic and fire-resistant industries. It is also used for manufacture of fillers for paper, cardboard, rubbers, plastic, insecticides, technical ceramics, and in the electro technical industry. Monomineral pyrophyllite is used in high-pressure apparatus to manufacture synthetic diamonds and also as a material for stone culling (agalmatolite). Zaykov et al. [1988] proposed typification of the deposits. We adopt the scheme and relate it to a modern geodynamic scheme (table).

Deposits in metasomatic rocks of intra-continental and marginal-continental volcanic zones (Type I). Host rocks of this type deposit are typically calc-alkaline andesitic to rhyolitic lavas, which are enriched in potassium or sodium and potassium. The pyrophyllite deposits are associated with volcanogenic metasomatic rocks of the "secondary quartzites - pyrophyllites" series, and they are commonly found in ancient rifling zones on platforms and on active continental margins. Pyrophyllite deposits on Precambrian platforms are found in Ukraine, Sweden, South Africa, USA, Canada and Brazil. In contrast, pyrophyllite deposits in Middle Asia, Kazakhstan and Australia are distributed in Paleozoic active continental margins. Pyrophyllite deposits occur at Mesozoic-Cenozoic active continental margins in USA, Canada, Morocco, China, New Zealand, Korea, Japan, Vietnam, Georgia and Azerbaijan.

Pyrophyllite deposits in metasomatic rocks in island arcs and Paleozoic and Cenozoic marginal seas (Type II). In folded Paleozoic island-arc system there are pyrophyllite deposits, which occur in bimodal volcanogenic series. This type of deposit is widespread in the Ural folded Paleozoic island-arc system, where pyrophyllite-bearing metasomatic rocks of sericite-quatrz formations accompany massive sulfide mineralization [Udachin, Zaykov, I994]. Pyrophyllite mineralizalion in folded structures of Cenozoic age is known in "green tuff" region of Japan, the Bolnis area of Southeast Georgia and the Panagursko zone in Bulgaria.

Pyrophyllite deposits in metamorphosed terrigenous-argillaceous strata of Paleozoic and Mesozoic age, containing pyroclastic material and coals seams (Type III). Pyrophyllite deposits in Paleozoic beds in passive continental margins and interior seas and coal-bearing depressions occur in