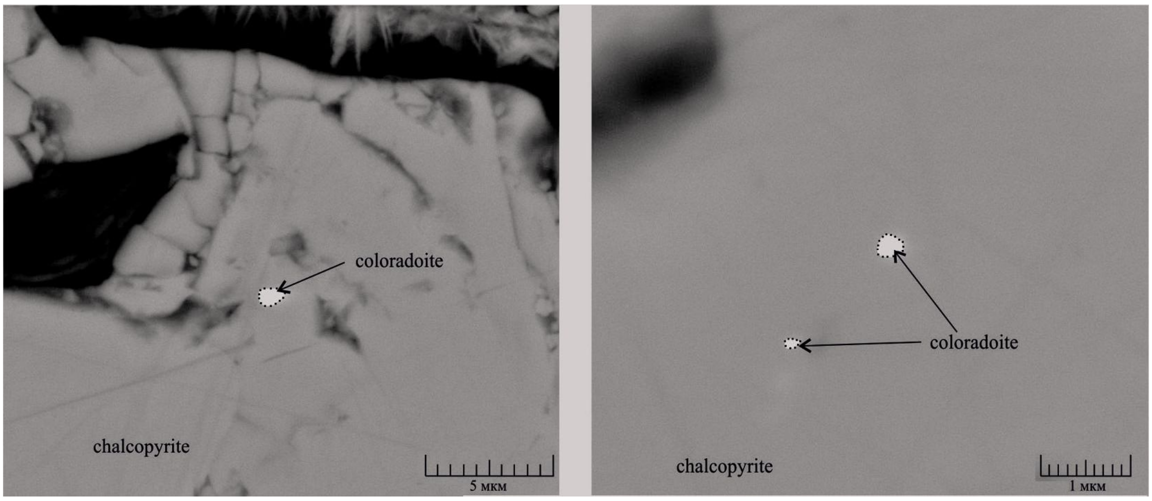

Fig. SEM image of coloradoite in chalcopyrite.

Thus, the chemical composition of coloradoite reflects the specific formation conditions under low- and medium-hydrothermal process in the quartz-chalcopyrite veinlets.

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FORMATION CONDITIONS AND DYNAMIC OF THE DEVELOPMENT OF THE OROGENIC ORE-FORMING SYSTEM OF THE KUMTOR GOLD DEPOSIT, CENTRAL TIEN SHAN

Месторождение Кумтор является одним из крупных золоторудных объектов Тянь-Шаня. Рудные зоны локализованы в породах черносланцевой формации в амагматичной пологозалегающей структуре. Отличительными особенностями месторождения в ряду золоторудных объектов, локализованных в черносланцевых толщах, являются преобладание руд пирит-(полевошпат)-карбонатного состава и практическое отсутствие в рудах мышьяка. Месторождение Кумтор – типичный представитель месторождений орогенного типа.

The Kumtor deposit situated in the Republic of Kyrgyzstan is one of the large gold deposits of the Tien Shan. The deposit is located in the Kumtor fold zone (flat (25°–45°) amagmatic tectonic structure) and is hosted in phyllites of the Vendian Dzhetymtau Group [Bogdetskiy et al., 1981]. The origin of gold mineralization of the Kumtor deposit is related to the metamorphic-hydrothermal-metasomatic activity occurred in the lens of metamorphic rocks (chlorite-sericite subfacies of the greenschist facies). The Kumtor deposit is an example of As-free gold deposits of the black shale type. Native gold, Au-Ag tellurides, scheelite, hematite and pyrite are typical ore minerals of the deposit. The main three groups of pyrite may be distinguished: sedimentary (PY1), metamorphic (PY2), and so called ore pyrite (PY3). Up to 90% of all Au-bearing minerals and mineral assemblages are related to PY3 [Anikin, 1992]. The sedimentary and metamorphic pyrite is broadly developed at the deposit without economic value.

The ore-bearing zones at the Kumtor deposit represent an alternation of intense stockwork zones in various phyllites and altered phyllites. The stockworks usually compose the peripheral parts of theorebodies. They consist of compact veinlets subconformable with foliation, crosscutting along the fracture cleavage system, and making the breccia-like structures. The various kinds of metasomatites compose the cores of orebodies.

The sericitolite haloes and quartz-potash-feldspar metasomatites were formed at the initial stage of the ore-forming process during alteration (bleaching) of phyllites, burning-out of the organic matter, and corrosion of primary pyrite. The pyrite-carbonate-albite stockworks and metasomatic bodies were formed after in more local zones. The pyrite-carbonate veinlets and microbrecciated-banded pyrite-carbonate (pyrite-dolomite or pyrite-ankerite-calcite) metasomatites (milonites, cataclasites) are overprinted on potassic-feldspar and albite metasomatites. The host rocks also bear the traces of dynamometamorphic transformations of the great depths with typical microtextures and structures of blastocataclasites, blastomilonites, and phyllonites. The thickness of pyrite-carbonate ores is up to 10 m and more. The orebodies usually have tectonic boundaries. Locally, they are banded pyrite-carbonate bodies similar to pyritized sedimentary calcarenites with fine dissemination of the rounded scheelite grains and metasomatic pyrite (Fig.). They are gradually replaced by carbonaceous carbonate phyllites and both form the mesofolds.

The ore-bearing zones are accompanied by Au, W, Te, Hg, Sb, Sr, Ag, Ba, and Pb endogenic haloes. As, Cu and Zn form the removal haloes. In the ore-bearing zones, Au has a significant positive correlation with Te, Ag, Cu, Hg, Sb, As, Sr and Zn, and weak correlation with Bi, Pb, and W. The Au + Te + Hg + Ag + W group is a root geochemical association of gold ores. All these elements form their proper minerals and occur as traces in other minerals. Arsenic forms no significant contents (<50 ppm) and occurs as admixture in tennantite and tetrahedrite or some pyrite types. The microinclusions of arsenopyrite rarely occur in grains of arsenic pyrite.

The ore pyrite (PY3) is characterized by anomalous contents of Au and is strongly distinct in geochemistry. It has high and intermediate contents of Au, Ag, Te, W, Cu, Zn, Sb, Hg, and Se. The broad dispersion of their contents and ore study indicate that these elements occurs as microinclusions of ore minerals, whereas Se is incorporated into a crystal lattice. The scanning of the PY3 surface has shown that Au, Ag, and Mn are evenly dispersed in the grains.

Among the sedimentary pyrite, the framboidal pyrite (PY1f) is characterized by the highest contents of Au, Ni, Co, As, Mn, Pb, Sb, Ba, Mo, Ag, Cu, Te, Se, Bi, Cd, Tl, and Hg. The formation of this pyrite was related, in a certain degree, to the biogenic sedimentation processes and we may suggest that the high content of these elements is a result of biochemical processes.

The subsequent transformation of the rocks leads to recrystallization of the primary pyrite, reconstruction of the internal structure, and strong decrease of the contents almost of all trace elements [Maslennikov et al., 2011].

The thick intervals (>100 m) of microcrystalline pyrrhotite-bearing schists of chlorite-biotite subfacies are found in the hanging wall of the ore-bearing Central area at the deposit. Pyrrhotite has replaced the early sedimentary, diagenetic and metamorphic pyrite that typically occurs at intensification of the metamorphic degree. At temperature higher than 400 °C, pyrrhotite replaces PY1 that is accompanied by release of S, As and other elements: $FeS_2 \rightarrow Fe_{1-x}S + S_{1+x}$.

The late metamorphic pyrite (PY2mt) is formed at the expense of the released sulfur in assemblage with pyrrhotite. The latter hosts the most part of Ni, while PY2mt contains almost all released As, which does not participate in the further migration. Thus, S, Au, Ag, Te, Pb, Sb, Mn, Mo, and Tl should easily migrate from the composition of PY1 owing to the intensification of the metamorphic

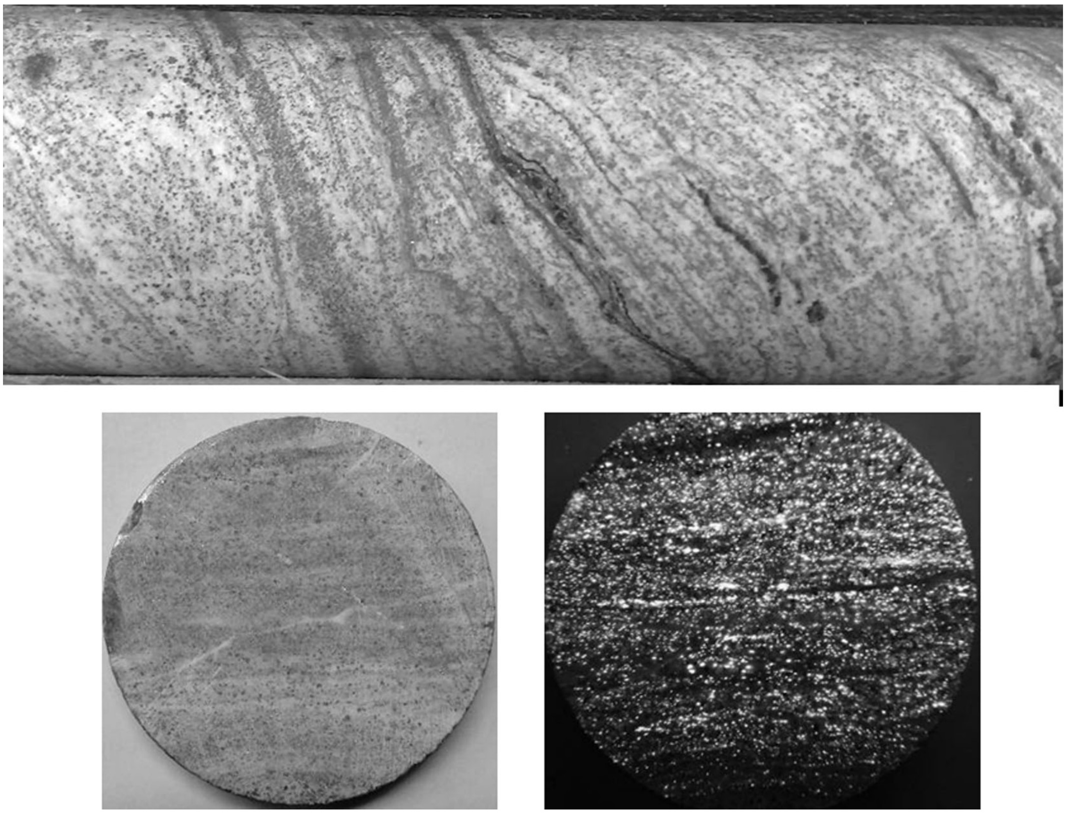

Fig. Banded calcite rock (limestone-calcarenite?) with interlayers of carbonaceous phyllite and dissemination of metasomatic pyrite (top photo, core fragment, actual size); transverse cross-section of this core fragment (bottom left photo) and the same under UV-rays (right photo; white is scheelite). Kumtor deposit, Central area, Stockwork ore body.

degree from the greenschist up to biotite facies. Most of these elements govern the ore geochemistry of the deposit.

However, this model characterizes only processes occurred in the rocks of the hanging wall, at a distance of 100–200 m and more from the ore-bearing structure. No pyrrhotite is observed closely to the ore-bearing structure. Two points of view on the pyrrhotite occurrence at the deposit are known: (i) continuous sequence of rocks in the overturned bedding and (ii) pinching out of the thrust sheet of more metamorphosed and pyrrhotitized rocks from the deeper parts of the deposit. At the current stage of research, both models are acceptable.

Two evolution ranges of metamorphic and hydrothermal-metasomatic alterations of the primary pyrite and position of ore pyrite are clearly evident from the geological evolution of the Kumtor structure. One of them is traced in the rocks of the hanging wall of the ore-bearing structure (I) and the second one is typical of the ore-bearing structure (II):

$$[(\mathrm{PY1s+PY1f+PY1sf}) \rightarrow \mathrm{PY1sfp} \rightarrow \mathrm{PY1mt}] \leftrightarrow [\mathrm{POmt} + \mathrm{PY2mt}] \leftrightarrow [\mathrm{PY3}] \qquad (\mathrm{I})$$

$$[(\mathrm{PY1s+PY1f+PY1sf}) \rightarrow \mathrm{PY1sfp} \rightarrow \mathrm{PY1mt}] \leftrightarrow [\mathrm{PY3}] \quad (\mathrm{II})$$

The first range may serve as a part of the model of formation of the primary ore-bearing fluid composition because of the fragment of the deeper parts in the section of the deposit. The second range shows the model of the transformation of the primary pyrite in the major ore-bearing structure and probability of additional enrichment of the intruded fluid in ore trace elements from the primary pyrite.

The endogenic high-temperature fluid has gained CaO, MnO, SrO, CO_2, CO, S, Au, W, and Te from the ultra-metamorphic zone into the ore-locating structure. The main stages of ore deposition occurred under conditions of thrust stress deformations without visible intrusive rocks and are mostly related to the mobilization of water and rock-forming components (Na_2O, SiO_2, MgO, BaO, Fe^{2+}, Fe^{3+}) from the host rocks.

All above mentioned geological-structural features allow us to refer the Kumtor deposit to the orogenic gold deposits. The location of the Kumtor deposit well corresponds to the certain part of 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.

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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