GEOLOGY, MINERALOGY AND FLUID INCLUSION STUDIES OF THE CHERTOVO KORYTO DEPOSIT, NORTH TRANSBAIKAL, RUSSIA

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ABSTRACT

This investigation presents and interprets the results of petrographic-mineralogical and thermobarogeochemical studies of ores of new gold deposit named Chertovo Koryto (North Transbaikal, Russia). Chertovo Koryto deposit is located in the north of the Patom Upland in the basin of the river Bolshoy Patom and relates to black shale type.

Mineral diagnostics was conducted by using optical and X-ray spectroscopic methods. Sulfide generations are identified on the basis of typomorphic properties - crystal morphology, thermal electromotive force, microhardness, reflectivity, microelements. Determination of temperature, pressure, composition of liquid and gaseous phases of ore-forming fluids was performed by thermobarogeochemical methods, which include microthermometry, Raman spectroscopy and gas chromatography. Mineral assemblages were specified in accordance with the detected sulfide generations, their structural correlation with other minerals and thermobarogeochemical data.

Paragenetic and textural studies have established that ores of the deposit are formed by five mineral assemblages. Four types of fluid inclusions are recognized from quartz and calcite: (1) liquid-rich inclusions; (2) CO2-aqueous inclusions; (3) vapor-rich inclusions; (4) daughter mineral-bearing inclusions. The research has shown that earlier mineral assemblages (I and II) are formed within the temperature range of 400...360 °C from light-salinity fluids (6...15 wt% NaCl equiv.) of Na specialization within pressure range of 150...300 MPa. Productive Au-bearing mineral assemblages (III, IV) are formed at active participation of CO2, CH4 and, partly, N within the temperature range of 350...180 °C from fluids containing Na, Mg with saltiness to 12,5...21 wt% NaCl equiv.. Pressure changes within the limits of 60...200 MPa. The V mineral assemblage has been crystallized from light-salinity fluids (5...8 wt% NaCl equiv.) of sodium specialization at temperatures not exceeding 130 °C within the pressure range of 40...50 MPa. The results of this study provide an assessment of the P-T conditions and mineral-fluid evolution and suggest exploration potential for Au mineralization at Chertovo Koryto deposit.

Keywords: fluid inclusions, mineralogical and paragenetic studies, black shales, Au deposit.
INTRODUCTION

Chertovo koryto deposit (North Transbaikal) relates to black shale type. It is known that such objects (Sukhoy Log, Muruntau, Natalkinskoye, etc.) are considered in comparison to mesothermal deposits, located in crystalline substance (Irokinda, Berikulskoye, etc.) [1, 2], though, both types of deposits have a genetic homogeneity in accordance with the composition of ores, sequence of mineral crystallization, physical, chemical and thermodynamic conditions [3]. However, accumulation of data on new objects, confirming or denying such judgment is reasonable.

The results of mineralogical, petrographic, mineragraphic and thermobarogeochemical analysis of ore samples of new gold deposit named Chertovo Koryto are presented in the article.

GEOLOGICAL SETTING OF THE DEPOSIT

The deposit is a part of Artemyevskoye gold ore field of Kevaktinsky ore cluster, located in the north of the Patom Upland in the basin of the river Bolshoy Patom, 100 km to the north of large deposit Sukhoy Log. Ore shoot is located in carboniferous slate of Mikhalovsky formation of Early Proterozoic with the capacity of 1200 meters, which is formed by hydrothermally altered slates and metasomatites of phillie and propyritic facies. The shoot is confined to the side wall of folded and fault area of NNW-trending (350°), in which the upthow steeping to the West-South-West (60°) feathers Amarkand deep-seated fault. Sulfide mineralization is concentrated in hydrothermally altered barren rocks and metasomatites. Pyrite, arsenopyrite, pyrrhotite prevail; galena, sphalerite, chalcopyrite, cobaltine, native lead, ullmannite, tellurobismuthite participate as non-essential contaminant in sulfide-quartz systems. Sporadically sulfides can be found in quartz veins and veinlets. Native gold prevails in quartz. Tabular and subtabular masses of diorites, diorite porphyries and metadolerites with the capacity from 0.2 to 15 m [4, 5] are described in the ore body.

METHODS OF INVESTIGATION

Mineral diagnostics was conducted by using optical and X-ray spectroscopic methods. Sulfide generations are identified on the basis of typomorphic properties – crystal morphology, thermal electromotive force, microhardness, reflectivity, microelements. Determination of temperature, pressure, composition of liquid and gaseous phases of ore-forming fluids was performed by thermobarogeochemical methods, which include microthermometry, Raman spectroscopy and gas chromatography. Mineral assemblages were specified in accordance with the detected sulfide generations, their structural correlation with other minerals and thermobarogeochemical data.

RESULTS

Paragenetic and textural studies have established that ores of the deposit are formed by five mineral assemblages. (Table 1).
Minerals of early assemblage (Stage I) form large metasomatic cap, embedded in terrigenous rocks, earlier metamorphically altered at the stage of amphibole-tourmaline-

Table 1. Paragenetic sequence for mineral assemblages of Chertovo Koryto deposit. The thickness of the horizontal bars is related to the relative abundance of the mineral.

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Stage I pyrite-rutile-pyrrhotite</th>
<th>Stage II arsenopyrite-pyrite-pyrrhotite-quartz</th>
<th>Stage III arsenopyrite-pyrite-quartz</th>
<th>Stage IV galenite-chalcopyrite-sphalerite</th>
<th>Stage V quartz-carbonate</th>
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<tbody>
<tr>
<td>Quartz</td>
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<td>Sphalerite</td>
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<td>Galenite</td>
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muscovite-biotite paragenesis, corresponding to epidote-amphibolite facie. The minerals of this assemblage participates in the carboniferous (quartz I, ilmenite, sericite, rutile, pyrrhotite I, pyrite I, ankerite I, albite, epidote, chlorite I, kerogen), chloritic (quartz I, sericite, rutile, pyrrhotite I, pyrite I, ankerite I, ankerite I, epidote, chlorite I), albite (quartz I, sericite, rutile, apatite, pyrrhotite I, pyrite I, ankerite I, albite) and phillic (quartz I, sericite, rutile, apatite, ankerite) areas of metasomatic cap.

The earliest and most hyperthermal newly formed mineral is ferriferous magnesian ripidolite (chlorite I), which replaces original biotite at the stage of previous local metamorphism. Fine grain sericite, replacing chlorite, is formed with rutile and leucoxene. Rutile and leucoxene are often developed pseudomorphically, under ilmenite plates, forming skeleton forms. Ilmenite is presented by isometric grains, oriented in accordance with cleavage, 0.02...0.05 mm in size. Original feldspar is noted to be intensively replaced by newly formed albite in inner areas. Epidote can be found very seldom, and, like albite, is a product of replacement of calci-alkaline feldspars. Metasomatic ankerite I in rear areas forms metacrystals in the form of rombohedrons, and is traced in carboniferous area in the form of small poke holes and lenticules.

Pyrite I is the earliest sulfide, which can be seen in the carboniferous area in the form of dust-like impregnation of microinlets, oriented in accordance with cleavage. It is characterized by hole-type conductivity and medium value of microhardness - 15 kN. Then pyrrhotite I is formed in the carboniferous area in the form of “striae” parallel to cleavage, in the peripheral zone of which chalcopyrite I is often well-developed.
There is not much metasomatic quartz I – it mostly forms microlenses interticed with sulfides or flame-shaped forms around the latter. Single inclusions, presented by highly aqueous formations of later superimposed solutions. Homogenization temperature, which was over 400°C, has been established by single pseudo-epigenetic inclusions, preserved in the inclusions, have slight degree of salinity – 6...8 wt% NaCl equiv.. In accordance with numerous literature data [6], and pressure, altering within the range of 250...300 MPa, is supposed with the assistance of chlorite-sulfide geothermometers.

The second mineral assemblage (Stage II) is presented by quartz II, chlorite II, pyrite II, arsenopyrite II, pyrrhotite II, chalcopyrite II, sphalerite I and ankerite II. During the formation of this stage there happened multiple quartz II deposition, accompanied by sagging, crystallization and recrystallization, which is confirmed by the presence of a great number of secondary liquid-rich fluid inclusions, located along the cured fissures. Syngenetic inclusions occur seldom and are presented by carbon-aqueous formations. Correlation of carbon-dioxide and water-salt phases is 20:80. Salinity lies within the range of 10...21 wt% NaCl equiv. The eutectic temperature is (-36...28) °C, what is typical for Na-bearing solutions. Inclusions are homogenized into liquid phase within the temperature range of 420...365°C. Pressure parameter is evaluated under syngenetic CO2-aqueous and liquid-rich inclusions and equals to 150...230 MPa.

Pyrite II is the earliest among the sulfides, which is developed in the rock mass in the form of chain aggregates of crystals from 0,02 to 1 cm in size, confined to quartz-carbonate veinlets. It is characterized, like pyrite I, by hole-type conductivity. Microhardness is higher than of pyrite I, and equals to 15,8 kN in average. Native gold I is found in the form of mechanical impurity. Its content varies within the range of 1,1...4,8 g/t.

Arsenopyrite is developed in carbon-dioxide area of metasomatic cap in the form of metacrystals of short-domatic, less frequently of linear-domatic, form. Isomorphic mixture of CO and Ni, the presence of which preconditions electronic conductivity type. Microhardness of the mineral alters within the range of 10,6...12,7 kN. Native gold I, presented by mechanical impurity of particles from 0,08 to 0,5 in size, is found with the arsenopyrite I. Its content varies from 1,2 to 8,0 g/t (average – 6,3 g/t). In accordance with the X-ray spectroscopic analysis, gold I contains Ag and it is the finest one (886,5 ...922,9 %). Flame-shaped buildup of chlorite II, included into ripidolite area in accordance with its composition, like chlorite I, but different by high concentration of Mg, are developed around arsenopyrite.

Pyrrhotite II is represented by consolidated pocket impregnations in quartz-carbonate veinlets; it is a recent mineral in relation to pyrite II and arsenopyrite I, as it grows them. Sphalerite II and chalcopyrite II, developing at the peripheral part of granular aggregates of pyrrhotite II without any signs of corrosion that reflects recent time of their crystallization, are noted in the assemblage with pyrrhotite II. Rare mineral ullmannite (NiSbS) has been found in the assemblage with pyrrhotite II. The most recent mineral is ankerite II, crystallizing in the vugs in the form of rhomb-shaped crystals.
The products of the third mineral assemblages (Stage III) are located in the central part of the ore body in relatively massive quartz-carbonate veins and are presented by quartz III, chlorite III, pyrite III, arsenopyrite III, gold II and carbonate III.

Quartz III, forming the veins, has not one generation that is reflected in various colour and morphological characteristics. Grey quartz IIIa with a coarse-crystalline structure with a block-structured type of extinction was the earliest. It is characterized by the presence of great quantity of fluid inclusions of primary and secondary genesis. Syngenetic inclusions are CO₂-aqueous and gas-rich, when CO₂-aqueous inclusions are two-phase (water-salt solution + liquid CO₂). Correlation of CO₂ and water-salt phases in the inclusions varies from 20:80 to 60:40. The presence of mixture of CO₂ and low-boiling gases (CH₄ and N₂) is often found as well. In accordance with Raman spectroscopy the composition of gaseous phase of inclusions is represented by CO₂ (41,24...97,56 mol. %), CH₄ (0...58,76 mol. %) and N₂, which is found in several inclusions (up to 9 mol. %). High gaseous inclusions at 90...100% are represented by a bleb, there are CO₂ and CH₄ inclusions with low content of N₂ are among them. The quantity of CO₂ varies within the range of 0...50,63 mol. %, CH₄ – 28,24...100 mol. %, N₂ – 0...2,83 mol. %. Homogenization temperature of CO₂ inclusions with a prevailing quantity of liquid phase varies within the range of 390...205 °C. Salinity of the solutions is high and equals to 10... wt% NaCl equiv.. In accordance with the eutectic temperature - (36...28) °C, it was found that Mg and Na are present in the content of the solutions. The presence of daughter mineral-bearing inclusions, containing water solution, bleb and halite cubic crystals is found in quartz III. They are related to pseudoepigenetic inclusions.

More recent light-grey quartz IIIb with a close-grained structure and lower quantity of inclusions is also found in the assemblage with quartz IIIa. Mostly CO₂-aqueous inclusions are noted in it. In accordance with the X-ray spectroscopic analysis they consist primarily of CO₂ with a tributary quantity of CH₄ (up to 15 mol. %). Homogenization temperature and salt content lies within the range of 390...205 °C and 10...21 wt% NaCl equiv. correspondingly. The pressure of ore-forming fluid was calculated with the help of inclusions, it equals to 140...200 MPa.

Chlorite III is developed in quartz veins in the form of flakes of saturated green colour and corresponds to the ferrian variation – brunsvigite. Pyrite III is an early sulfide, like in the Stage II, which is very seldom and forms crystalline aggregates in quartz III. It is characterized by a great variety of morphological crystal forms and a mixed conductivity type with altering parameters. In accordance with the data of atomic emission spectroscopy high content of Co and Ni (Co – 150,0...205,0 g/t; Ni – 370,7...514,6 g/t) was found in pyrite III. Electronic conductivity type of pyrite III gives a reason to believe that Co and Ni are included in to the crystalline grid of the mineral. Low microhardness (up to 14,0 kN) in comparison to pyrite I and II serves as a confirmation to this fact. Then arsenopyrite is occured in the form of accumulation of crystals or large crystal sorting of short domatic habitus in quartz veins and veinlet with crystals or large crystal sorting of short domatic habitus in quartz veins and veinlet with a distinguished cataclastic texture. Presence of Co and Ni in the form of isomorphic impurity preconditions electronic type of conductivity. Microhardness of mineral varies with the range of 0,93...0,98 kN, that differs arsenopyrite I from II. Gold II with lower fineness (874,0...907,15 %) in comparison to gold I, and Ag with impurities
were found in the assemblage with sulfide. Ankerite III fills in the cavities in quartz veins, forming large pocket segregations.

The fourth mineral assemblage (Stage IV) is locally joined with the third one. Quartz IV, galena, sphalerite, pyrrhotite III, chalcopyrite III, gold III and carbonate IV are the primary minerals. Quartz IV, in comparison to the previous generations, is light-grey, clear and homogenous. It is characterized by undulating extinction, has massive homogenous composition and contains a significant number of primary fluid inclusions. Syngenetic inclusions are presented by CO₂-aqueous and gas-rich inclusions formations. CO₂-aqueous inclusions contain water-salt solution and liquid carbon dioxide. Correlation of carbon-dioxide and aqueous phases in the inclusions varies from 20:80 to 60:40. Constant presence of mixture of CO₂ and low-boiling gases (CH₄ and N₂) is noted. In accordance with X-ray spectroscopic analysis data, the composition of gaseous phase is represented by CO₂ (50,87...80,42 mol.%), CH₄ (19,58...49,13 mol.%). Highly gaseous inclusions are represented by a bieb at 90...100%. The quantity of CO₂ varies within the range of 0...95,24 mol. %, CH₄ - 4,76...100 mol. %, N₂ - 0...24,37 mol. %. Homogenization temperature of CO₂-aqueous inclusions with a prevailing quantity of liquid phase alters within the range of 210...110 °C. The salinity of solutions is medium and equals to 8...16,5 mass equivalent % of NaCl. With the help of eutectics temperature ≈(38...34) °C it was found, that Mg and Na are present in solutions. The pressure parameter, which equals to 60...140 MPa, was estimated with the help of inclusions.

Galenite in the form of pocket segregations up to 2 cm in size is observed in the assemblage with quartz IV. It is characterized by impurity Ag – 0,2...0,37 wt.% and Bi – 0,28...0,68 wt.%. Sphalerite II, like galenite, is noted in the form of bunches up to 2 cm in size and was probably formed a bit earlier than the latter. Fe – 6,92...7,23 wt.% and Cd – 2,99...3,26 wt.% were detected in the form of isomorphic impurities. Native gold III is related to sulfides in the form of mechanical impurity. The grade of this gold is the lowest at the deposit (786,0...790,3 %). Pyrrhotite III forms pocket segregations, separated from other sulfides. Cu (0,03 %) and Ni (0,02...0,11 %) were detected in it in the form of impurities; their concentration is significantly lower, than in pyrrhotite of the I and II generations. Chalcopyrite III, developed at the peripheral part, is present in the assemblage with pyrrhotite. Ankerite IV fills in the cavities in quartz veins and if often related to galenite and pyrrhotite III.

Ore formation is completed by crystallization of quartz-carbonate mineral assemblage (Stage V), presented by narrow veinlets, crosscutting early formations. Syngenetic liquid-rich inclusions, represented by single-phase aqueous or two-phase formations are developed in quartz and carbonates. Correlation of liquid and gas alters from 20:80 to 60:40. Salt content is not high and equals to 4,5...9 wt% NaCl equiv. Inclusions are homogenized into the liquid phase at 80...130 °C. The presence of pressure not exceeding 40...50 MPa is supposed [6].

**DISCUSSION OF THE RESULTS AND CONCLUSION**

The results obtained are compared to the data on Irokindinskoye and Berikulskoe deposits, located in crystal substrate, and to Sukholozhskoe deposit occurred in black shale strata. The conclusion is made on substance and genetic homogeneity of gold deposits in both systems.
REFERENCES


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