Co-Ni Mineralization in the Albazino Gold Ore Deposit (Khabarovsk Krai, the Mongol-Okhotsk Orogenic Belt)

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Abstract. The gold-sulfide impregnated deposits occupy one of the leading positions in terms of gold reserves, both in Russia and in the world. The article presents the results of a study of Co-Ni mineralization at the Albazino gold ore deposit (Khabarovsk Krai, the Mongol-Okhotsk orogenic belt). Arsenides of Co, Ni, Fe are represented by arsenopyrite, alloclasite, glaucodot, while the ones of Co and Fe are represented by cobaltite and gersdorffite. Typomorphic features of this group of minerals of the association are: the presence of increased concentrations of nickel (for example, in alloclasite, glaucodote, and cobaltite), Co (arsenopyrite, gersdorffite), Sb (arsenopyrite, gersdorfite, cobaltine), Se (galena), As (pyrite), and Fe (sphalerite). Gold is mainly finely dispersed and, belongs to low fine one (with Au – 74–76 wt%, Ag 26–24 wt%) in terms of its chemical composition. The revealed typomorphic features of the material composition of ores and the geological structure of the deposit allows attributing this object to the gold-sulfide impregnated type.

1. Introduction

Giant gold-sulfide impregnated deposits (GSID) are known to be found in various age metallogenic provinces (from Precambrian to Pliocene [10, 11, 12]). As a rule the objects of this type are localized in terrigenous and terrigenous-carbonate carbonaceous strata, which are characterized by “invisible” gold contained in sulfides or found in free form [12]. It’s the presence of gold in sulfides that provides the ores with refractory properties. Basically, sulfides form fine impregnation or dissemination in sheeted and brecciated rocks [12]. GSIDs bear significant world reserves of Au, in recent years, about 12-15% of the total production volume has been mined in our country from this type of deposits recently (for example Olympiada, Mayskoe and Albazino gold ore deposits [10, 11, 12].

The identification of both the mineralogical-geochemical features of GSID ores and distribution of gold and associated minerals-satellites in those deposits plays a significant role in establishing the typomorphic characteristics and informational affiliation (identity) of the last ones, which is an ultimate and necessary source for the development of rational schemes of enrichment of this type of ore.

2. The research subject

The Albazino gold ore deposit is one of the largest and most prospective areas in the Khabarovsk Krai. It is located approximately in 780 km to the north-east of Khabarovsk and in 440 km from Amurusk. This deposit is a part of the gold ore cluster of the same name and which is localized in
the Nizhne-Amur zone of the Sikhote-Alin gold-bearing province on the left bank of the estuary of the Amur river of the Mongol-Okhotsk orogenic belt [5, 7].

The Albazino gold ore deposit is one of the largest objects with an approximate reserve of Au constituting about 100 tons. [10, 11]. The most ancient formations of the studied area are terrigenous deposits of the Jurassic, which are broken through by late Cretaceous intrusive and subvolcanic bodies of diorites, granodiorite-granite-porphyry and extrusive rhyodacites [5, 7]. Several ore areas with industrial gold mineralization are identified here, they are as follows: Anfisinskaya, Olginskaya and Ekaterininskaya [7, 9].

We carried out research in the Olginskaya zone which is the most prospective one at the territory of this gold ore field.

At this site gold mineralization is concentrated mainly in the metasomatically altered Jurassic siltstone and late Cretaceous dacite-rhyodacite formations and microdiorite dikes. Mineralization is represented by vein-disseminated and disseminated mineralization, where hurricane Au contents do not have a clear spatial pattern. The eruptive and brecciated areas (including the breccias themselves) include the hurricane Au. Most often, eruptive brecciation is observed at the contacts of both dacite – rhyodacite formations and andesite – microdiorite ones. The host hornfelsed terrigenous rocks are intensely faulted and cataclastic in the zones of dike impact, and the Au content in them varies from insignificant to high.

The Olginskaya ore-bearing area has a strike length of 1000 m and a width of 60 to 90 m. The site is localized in a veinlet-metasomatic zone of sub meridian strike, superimposed on a dike of complex configuration with numerous branches and apophyses of dacite composition, breaking through the Jurassic sandstone strata (mass). The dike, which controls the ore-bearing structure with an outcropping width of 20–40 m, has a northwest strike and falls to the east at an angle of 30–45°. The lying wall of the dacite body is broken through by a series of close, thin, microdiorite dikes of a similar direction. Within the ore-bearing zone, dacites and partially Jurassic sandstones tend to have the most intense transformations from both hanging and lying walls (about 10–20 m). The last one is characterized by a thin vertical metasomatic zoning, which means it has a discontinuous subzone consisting of pyrite-arsenopyrite-quartz veinlets, alternated by a subzone of quartz veinlets. The lower part of the section is dominated by carbonate veinlets. Areas of hydrothermal brecciation (including breccias themselves) often coincide to the contacts of dacites and, to a lesser extent, to the ones of granodiorites and granites. The matrix of hydrothermal breccias is characterized by uneven sulfide impregnation both throughout its entire mass and in the form of veins.

3. Main research results and discussion

Two methods of investigation were used for our researches, they are as follows: the X-Ray micro-spectral analysis which was conducted on the four-channel microanalyzer JXA 8100 by the analyst G.B. Molchanova and microscopy that was carried out on the Axioplan 2 microscope. Co – Ni mineralization was identified in the ores of the Albazino deposit (Olginskaya zone). Ore minerals are dominated by sulfides (pyrite, arsenopyrite, less often pyrrhotite, chalcopyrite, galena, and sphalerite), arsenides of Co, Ni, Fe are represented by rhombic and pseudo-rhombic segregations of arsenopyrite, alloclazite, glaukodot, as well as by cubic and pseudocubical grains of Co and Fe (cobaltite and gersdorffite), sulfoantimonite Cu (tetrahedrite), sulfoarsenide of lead (zugarite, rarely), together with fahlore, coloradaite (rare), native gold and silver. This type of represented in the form of disseminated impregnation among sulfide arsenopyrite-pyrite ores, as well as in breccia-like hydrothermal formations.

Group of sulfide minerals:

Pyrite is one of the main sulfide minerals. It forms disseminated impregnation in the form of single crystals (0.5–1 mm) and the intergrowths of the last ones, less often it forms nests (10–20 mm) and makes microveins (10–50 mm). Its content in rocks and quartz veins ranges from proportions of a percent to tens of percent of the total sulfide content. The grains of this mineral
are represented by idiomorphic cubic forms, characterized by zonal structure and heterogeneous composition. The inclusions of sphalerite, galena, arsenopyrite, and native gold were found in pyrite. The pyrite grains contain impurities of arsenic (from 0.47 to 2.74 wt%) and nickel (from 0.7 to 0.98 wt%).

**Arsenopyrite** (FeAsS) is often found in the form of idiomorphic, allotriomorphic and acicular crystals or forms a border in the form of a thin rim along the periphery. Two generations were identified, they are as follows: an early one with an admixture of Co (from 1.8 to 2 wt%) and Ni (1.98 wt%), Sb (1.29 wt%), and a later one without admixtures. Arsenopyrite is characterized by intergrowths with pyrite and cobaltite.

**Sphalerite** (ZnS) is less common than pyrite and arsenopyrite. It forms micro-veins and inclusions in pyrite and arsenopyrite. The size of the grains is equal to 1 - 15 microns. Sphalerite contains inclusions of native gold. Sphalerite is characterized by an impurity of Fe equal to 2.35–7.84 wt. %.

Galena is a rare mineral which is found to be an inclusion in pyrite. The size of the grains is from 1 to 10 microns. The impurity of Se contained in it varies from 1.36 to 2.32 μm (microns).

**Chalcopyrite** (CuFeS2) is rarely found. It forms micro-veins in pyrite and arsenopyrite, as well as intergrowths with sphalerite, galena and arsenopyrite.

**Alloclazite** (Co, Fe) AsS forms grains in arsenopyrite, ranging in size from 1 to 5 μm, and also occurs in paragenesis with glaucodote, cobaltite, and gersdorffite. The presence of Ni impurities (from 8 to 11 wt%) is a specific feature of alloclazite.

**Glaucodot** (Co, Fe) AsS forms rhombic grains with a size ranging from 2 to 5 μm. It is found in paragenesis with alloclazite, cobaltite, and gersdorffite and is characterized by an impurity of Ni ranging from 9 to 13 wt%.

**Cobaltite** (CoAsS) is a rare mineral that occurs in the form of round and cubic precipitates ranging from 5 to 50 microns in size. It forms both independent grains in quartz and intergrowths with arsenopyrite and glaucodot. Cobaltite contains impurities of Fe (from 1.85 to 2.3 wt%), Ni (from 1.16 to 7.02 wt%), and Sb (from 2.03 to 3.36 wt%). Based on the studies carried the content of the main chemical elements of Co, As, S, and impurity ones of Fe, Ni and Sb have been established to be variable.

**Gersdorffite** (NiAsS) is found in the form of cubic and round crystals varying from 5 to 60 microns in size. It forms independent crystals in quartz and is fixed in intergrowth with dolomite. The specific feature of gersdorffite is the presence of isomorphic impurities of Fe (varying from 6.19 to 7.65 wt%), Co (2.97 wt%), and Sb (varying from 1.72 to 2.6 wt%).

**Sulfoantimonite** of Cu (tetrahedrite), sulfoarsenide of lead (tsugaruite), as well as fahlore and coloradaite (rare one) are rare and are characteristic mainly of the gold-silver-base metal association.

**Native gold** (Au) is found in the form of inclusions in pyrite, arsenopyrite, and rarely in sphalerite. It forms a round or elongated forms varying from 1 to 10 microns in size. Native gold composition is as follows: Au – 74–76 wt%, Ag 26–24 wt%. %.

**Native silver** (Ag) was found in quartz in the form of single grains, ranging from 1 to 5 μm in size. The chlorine impurity with a dimension of 0.3 wt% was found to be contained in it.

As a result of the studies carried out in the Olginjskaya area of Albazino gold ore deposit, the following mineral associations are distinguished: (1) arsenopyrite-pyrite-quartz with native gold and cobalt-nickel mineralization, (2) gold-silver-base polymetallic ones(native gold and silver, sulfoantimonite of Cu (tetrahedrite), the lead of the sulfoarsenide (tsugaruite), as well as fahlore and coloradaite).

The constant impurities of Ni (for example, in alloclazite, glaucodote, and cobaltite), Co (arsenopyrite, gersdorffite), Sb (arsenopyrite, gersdorffite, cobaltite), Se (galena), As (pyrite), and Fe (sphalerite) are typomorphic feature of the studied mineralization. The absence of pure cobaltite is characteristic, with a predominance of Ni, Sb and Fe-Ni-cobaltite, which suggests significant concentrations of Ni, Sb in mineral-forming media.
According to N.V. Petrovskaya’s classification [8] native gold belongs to the finely dispersed and low-grade type.

4. Conclusion

As a result of the studies, pyrite and arsenopyrite were established to be crystals grains the main minerals-concentrators of gold, less often the last one is fixed in sphalerite. Gold is mainly finely dispersed and belongs to low fine one (with Au - 74–76 wt%, Ag 26–24 wt%) in terms of its chemical composition.

The cobalt-nickel mineralization revealed in the Olginskaya zone of the gold ore field is represented by arsenides of Co, Ni, Fe (arsenopyrite, alloclasite, glaucodot), as well as by Co and Fe (cobaltite and gersdorffite). Co-Ni mineralization is more typical for gold-bismuth (gold-rare metal) type of deposits [2,4,6]. However, this type of mineralization can also occur in orogenic gold-sulfide disseminated deposits [11, 12]. The mineral-forming source must have been enriched with Ni and Co, which caused Co-Ni mineralization at the Albazino deposit.

The features of the gold-silver epithermal type of mineralization is also characteristic for the deposits and are expressed in the presence of coloradaite, native silver, accompanied by a constant admixture of Sb in arsenopyrite, cobaltite, gersdorffite, and one of Se in galena in the ores. Earlier, [9] the low-temperature minerals (cinnabar, antimonite) which are characteristic for the epithermal type of mineralization and high concentrations of Au, Ag, As and Sb [9] were recorded to be present in the ores.

According to its typomorphic characteristics (geological structure, mineral composition of ores, size and fineness of native gold), the Albazino gold ore deposit belongs to gold-sulfide impregnated ones with epigenetic root systems. Gold-sulfide disseminated type of mineralization is problematic in mining, due to factors, they are: ores have refractory properties and the gold is finely dispersed; but, at the same time, it is characterized as very productive in terms of the amount and reserves of gold. The geodynamic setting producing the Carlin type occupies the leading position among the deposits of the gold-sulfide disseminated type nevertheless, the orogenic tectonic-magmatic one (TMT) is no less productive and also deserves a special attention [10, 11, 12]. The fact that the Albazino gold ore deposit was formed in the conditions of an orogenic TMT serves as the evidence of this statement.

Based on the typomorphic features revealed, the Albazino gold ore deposit is comparable to the largest gold-sulfide disseminated deposits both in the North-East of Russia (Mayskoye, Tumnannoie, Olimpiada, etc.) [2, 3, 10, 11] and Australia [1].

5. References

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