New Data on the Formation Conditions of the Dyvok Ore Occurrence (South Yakutia, Russia)

Veronika Kardashevskaya 1, Galina Anisimova 1
1 Diamond and Precious Metal Geology Institute, SB RAS, 39, Lenina pr., Yakutsk, 677900, Russia
kardashevskaya92@mail.ru

Abstract. The article presents new data on the mineralogical and thermobarogeochemical research of Dyvok ore occurrence. The aim of the research is to learn about the mineral-geochemical characteristics of the ore occurrence as well as about the formation of auriferous mineralogical associations at the occurrence. At the moment, Verkhnealgominsk auriferous area consists of several ore occurrences and a deposit. The area is located within famous Stanovaya auriferous area, South Yakutia. Dyvok ore occurrence is subjected to the influence of Tyrkandinski fault. The host rocks are Early-Archaean K-spar-quartz metasomatites, beresited and argillated rocks with sulphide-quartz veins and mineralised zones of beresited rocks with sulphide and quartz-sulphide mineralisation. Now, there are 3 productive ore zones at the ore occurrence. We found mineral associations that contain native gold and described the variety of its forms, seize and composition. The mineral associations are 1) gold-arsenopyrite-pyrite-quartz; 2) gold-sphalerite-chalcopyrite; 3) quartz-boulangerite; 4) quartz-telluride. We carried out thermobarogeochemical investigation of fluid inclusions in quartz to learn about the formation conditions of productive mineral associations, the quartz was extracted from gold-arsenopyrite-pyrite-quartz, gold-sphalerite-chalcopyrite and quartz-telluride associations. Microanalyses helped to discover monophase, diphase and three-phase inclusions. Early association had the temperature of 270-335°C. The rated pressure is 0.4 kbar. The inclusions contain carbon dioxide, water, methane and carbonate ion. The solid phase contains dawsonite and native sulphur. The deposition temperature of gold-sphalerite-chalcopyrite association is 186-219°C, and the one of quartz-telluride association is 199-200°C. The pressure of the latter two associations remains unknown due to the lack of coexisting three-phase inclusions. Raman spectroscopy showed the presence of carbon dioxide and methane in early association, as well as of carbon dioxide, methane and nitrogen (impurity) in late-phase quartz. Therefore, we claim that all the associations in question were formed in shallow- and mid-depth and oxidizing conditions with the involvement of deeper sources for the ore constituents.

1. Introduction
By the present time, no hydrothermal deposits or gold occurrences of rare-metal mineralization have been discovered in Stanovaya auriferous area, it could nevertheless be interesting to study them in order to deepen the knowledge of regional patterns of ore formation. Dyvok ore occurrence is located in Stanovaya auriferous area, 300 km away from Neryungri. In 2005, Yakutskgeologia investigated the area to find ore and alluvial gold. The ore occurrence, as well as Bodorono gold-quartz deposit, is situated in Verkhnealgominskii auriferous zone. This article is the first attempt to present our data on composition of auriferous mineral associations in this deposit as well as on their formation conditions.
2. Geological setting

Dyvok gold deposit is located close to Tyrkandinskiy fault and is related to cretaceous granite-porphyry stock [1]. The enclosing rocks are Early-Archaean K-spar-quartz metasomatites, beresited and argillated rocks. There are quartz, quartz-sulphide, quartz-carbonate-barite and carbonate-barite veins. Numerous faults reach along the latitudes and meridians to the North-East and North-West. Today, there are 3 ore zones which are considered the most productive ones with the vein thickness varying from 0.1 to 0.4 m.

Figure 1. The location (a) and the geological map (b) of Verhnealgominsk auriferous area (simplified and specified) according to [2]. I – ore occurrence; II – railway station «El’ga»; III – railway «Ulak-El’ga»; IV – geological camps; V – winter road; VI – territory of geological work of the Verkhnealgominsk party. 1 — metamorphic formations of Precambrian basement with various extent of granitisation and complicated location; 2 — terrigenous-carbonate sedimentary formation of The Ediacaran Period and The Cambrian Series 2; 3 — terrigenous partly volcanogenic and carboniferous sediments of Jurassic and Early Cretaceous Periods; 4 — Mesozoic volcanogenic and intrusive rocks of Aldan complex.
3. Methods
Mineragraphic analysis of the composition was carried out with ore microscope Jenavert JL 100, then we studied the chemical composition of the minerals with the use of scanning electron microscope JEOL JSM-6480LV and energy dispersive spectroscopy system Energy 350 of Oxford Instruments (the analyses performed by S. Popova). Detection limit is — ? The optical tests of the polished wafers were performed with microscope AxioScope 40A equipped with camera AxioCam ICc3 as well as with microscope Olympus BX–53. We performed microthermometric analysis (the analysis of the homogenisation temperature) of fluid inclusions in the laboratory of the department of geology survey in North-Eastern Federal University with the use of temperature controlled stage, Linkam LNP95 Liquid Nitrogen Pump (the temperature ranges from -196 to +600°C) and microscope AxioScope A1 (to within 0.1°C), as well as in St. Petersburg State University resource centre Geomodel with the use temperature controlled stage Linkam THMSG 600. Raman spectroscopy (spectrometer Lab Ram HR800) was used to study the composition of the inclusions’ gas phase (St. Petersburg State University resource centre Geomodel, the analyses performed by V. Bocharov).

4. Results and discussions
Vein quartz is milk-white with transparent spots and fine-grained texture. The ore minerals are pyrite, arsenopyrite, sphalerite, chalcopyrite, galenite, and the more rare ones are pyrrhotite, molybdenite, boulangereite, native gold; altaite, volynskite, hessite, melonite, merenskyite and rucklidgeite are also sporadically present. Vein minerals other than quartz are ankerite, calcite, siderite, accessory minerals are ilmenite, monazite, rutile, fluorapatite, chlorapatite and zircon. Supergene minerals are anhydrite and goethite.

There are four mineral associations at the Dyvok ore occurrence: 1) gold-arsenopyrite-pyrite-quartz (fig. 2A); 2) gold-sphalerite-chalcopyrite (fig. 2B); 3) quartz-boulangerite (fig. 2C); 4) quartz-telluride. Typomorphic minerals are arsenopyrite and pyrite with arsenopyrite being non-stoichiometric and having Co (till 5%) and Pb (0.16%) impurities. Pyrite contains As (till 3%) and Pb (0.43) impurities. Native gold is attested as minor inclusion in arsenopyrite and pyrite.

Figure 2. Mineral associations of Dyvok ore occurrence. A – gold-arsenopyrite-pyrite-quartz; B – gold-chalcopyrite-sphalerite; C – quartz-boulangerite. Qtz – quartz, Py – pyrite, Apy – arsenopyrite, Au – native gold, Sp – sphalerite, Bln – boulangereite.

**Pyrite** is the main fore mineral forming spots and veins of the size up to 3 mm. It is attested in interstratified enclosing rocks, vein quartz and as arsenopyrite inclusion in the form of idiomorphic cubical precipitations and metacrysts.

**Arsenopyrite** is also a rather frequently attested mineral forming idiomorphic rhombic crystals in quartz and enclosing rocks with the grains reaching 2 mm. There are also some arsenopyrite-pyrite clots.
**Sphalerite** forms allotriomorphic grains attaching to pyrite and arsenopyrite and reaching 4 mm having some pyrrhotite and chalcopyrite inclusions.

**Chalcopyrite** is a rare sulphide attested attached to sphalerite with the precipitations being rather small and of irregular form.

The aggregates of **boulangerite** are of irregular needle shapes and with the size reaching 0.1 mm. They are most often attested as a free element in quartz but also coalesces with galenite.

**Gold** is mostly concentrated in arsenopyrite and pyrite but is also attested as a free element in quartz associating with sphalerite. According to nuclear absorption analysis Au concentration is <20 (10) g/t with the gold grains ranging from 0.01 to 0.04 mm. The form of the grains varies from rounded to elongated. The fineness of gold ranges from 715 to 750%.

The microbore analysis helped us to find Pd, Ni, Bi, Pb and Ag tellurides. There are six mineral phases within the telluride mineralization, hessite, altaite, volynskite, merenskyite, melonite, and rucklidgeite.

To learn about the conditions of the mineral formation we studied fluid inclusions (FI) in the vein quartz of the three productive associations. For optical and thermometric tests, we made two-sided high-polished wafers with the thickness of 0.5 mm. The primary inclusions are equally distributed in all the host mineral growth zones and the secondary ones are close to the quartz wedge cracks.

The quartz of the **gold-arsenopyrite-pyrite-quartz association** has translucent milk-white aggregates with some transparent spots. The size of inclusions ranges from 5 to 350 μm. We found the following types of inclusions at the room temperature (fig. 3).

![Figure 3. Fluid inclusions of auriferous-arsenopyrite-pyrite-quartz association of Dyvok ore occurrence. A – monophase; B – diphas; C – three-phase.](image)

1) Monophase inclusions are gas inclusions containing 100% of CO₂ gas phase volume and being of 5-300 μm in size and most often of elongated form. They could occur single as well as in groups (fig. 3A);

2) Diphasic inclusions have gas and liquid phases. The average size ranges from 10 to 350 μm. Gas bubble makes more than 20-30 % of the vacuole volume. The form of vacuoles is isometric with negative faces (fig. 3B). The inclusions contain water and CO₂ gas phase;

3) Three-phase inclusions (CO₂ gas + CO₂ liquid phase + H₂O liquid phase) are carbon dioxide and water rounded or elongated inclusions with negative faces and the size of 10-250 μm. The gas bubble makes around 15-20% of the volume (fig. 3C). The solid phases of three-phase FI contain dawsonite
NaAl(CO$_3$)(OH)$_2$ and native sulphur. Water solution constantly includes carbonate ion. Carbon dioxide prevails in gas phase with only rarely attested 3% traces CH$_4$.

The homogenization temperature of diphase inclusions ranges from 300 to 310°C. We measured the pressure while there were syngenetic gas-liquid and carbon-liquid water inclusions. The homogenization temperature is 26-27°C, carbon dioxide density is 0.7 g/cm$^3$ (according to Amagat’s table). The estimated pressure is 400•10$^5$ Pa.

Quartz of **gold-sphalerite-chalcopyrite association** forms transparent and translucent grains. The size of the primary inclusions ranges from 5 to 300 μm. The inclusions are of negative cryst form (fig. 4).

**Figure 4.** Fluid inclusions of auriferous-sphalerite-chalcopyrite association of Dyvok ore occurrence. A-C – diphase.

Transparent quartz that makes up most of the vein mass has the following types of inclusions.

Type 1. Monophase mostly gas inclusions, which contain CO$_2$.

Type 2. Diphase gas-liquid inclusion, which contain water, liquid CO$_2$, and gas CO$_2$ (fig. 4A-C). Gas bubble makes up 20-30% of the vacuole volume.

The homogenization temperature of gas-liquid inclusions is 202-213°C. The pressure has not been estimated due to the lack of three-phase inclusions.

Quartz of **quartz-telluride association** has transparent and translucent aggregates. The size varies from 5 to 200 μm with the grains being of irregular form. At the room temperature we found the following types of inclusions (fig. 5A-C).

**Figure 5.** Fluid inclusions of quartz-telluride association of Dyvok ore occurrence. A-C – diphase.

Type 1. Monophase mostly gas CH$_4$ inclusions.
Type 2. Diphase gas-liquid inclusions with the gas bubble making up 20-30% of the volume. In the inclusions of this type there are CH\textsubscript{4} and H\textsubscript{2}S impurities in the gas bubbles. Raman spector shows CH\textsubscript{4} - 2911 cm\textsuperscript{-1}, N\textsubscript{2} - 2331 cm\textsuperscript{-1} [3].

The homogenization temperature of the diphase inclusions in quartz is 199-200°C. The pressure has not been due to the lack of three-phase inclusions.

5. Conclusions

The studies at Dyvok ore occurrence allows us to draw conclusions about the fact that the gold-arsenopyrite-pyrite-quartz association was formed at temperature of 305°C and the pressure of 0.4 kbar. Carbon dioxide is a major element in the gases, and taking into consideration the density of CO\textsubscript{2} in gas bubble of the three-phase inclusions, we can claim that there are two types of fluid inclusions in this quartz, with the density of 0.33 g/cm\textsuperscript{3} and with the one of 0.19 g/cm\textsuperscript{3}. All things considered the solution was oxidative or neutral as there is native sulphur in it. The gold-sphalerite-chalcopyrite association forms at the temperature of 213°C. The gases mostly contain CO\textsubscript{2}. The quartz-telluride association forms at the temperature of 200°C with the gases mostly containing CH\textsubscript{4} or — less frequent — N\textsubscript{2}. The fact of the telluride existence implies that there is epithermal telluride mineralization within the occurrence [4]. Thus, we can conclude that the associations were formed formed in shallow- and mid-depth and oxidizing conditions while the presence of carbonates in the solution implies oxidizing conditions.

Acknowledgments

We would like to thank Ye. V. Badanina, associate professor at the Department of Geochemistry in St. Petersburg State University, for the help with thermobarogeochemical research. The reported research was funded by Russian Foundation for Basic Research and the government of the region of the Russian Federation, grant № 18-45-140045 and work is done on state assignment of DPMGI SB RAS.

References

[1] G. S. Anisimova, E. P. Sokolov and V. N. Kardashevskaya, “Gold-rare metal (Au-Mo-Bi-Te) mineralization of the Upper Algominsk gold deposit zone (Southern Yakutia),” Otechestvennaya Geologia, i. 5, pp. 12-22, 2017.

[2] A. V. Molchanov, A. V. Terekhov, V. V. Shatov, O. V. Petrov, K. A. Kukushkin, D. S. Kozlov and N. V. Shatova, “Gold ore districts and ore clusters of the Aldanian metallogenic province,” Regionalnaya Geologia i metallogenia, i. 71, pp. 93-111, 2017.

[3] M. L. Frezotti, F. Tecce and A. Casagli, “Raman spectroscopy for fluid inclusions analysis,” J. of Geochem. Explor., vol. 112, pp. 1-20, 2012.

[4] L. I. Rogulina and G. B. Molchanova, “Noble-metals and nickel-telluride mineralization of the Berezitovoye gold ore field (Upper Amur region),” Zapiski RMO, vol. 140, i. 1, pp. 90-101, 2011.