NEW MINERALOGIC AND GEOCHEMICAL DATA ON THE NATALKA, VETREN, AND IGUMEN Au QUARTZ DEPOSITS IN THE UPPER-KOLYMA REGION, RUSSIAN NORTHEAST

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ABSTRACT

Different ores sampled from the Natalka, Igumen, and Vetren lode gold deposits were examined under electron microscope and with microprobe. Minerals and compounds, which are considered not typical for this deposit type were found: monazite, zircon, cassiterite, vanadium oxides, cobalt and nickel sulphoarsenides, loellingite, pentlandite, Ag-pentlandite, breithauptite, greenockite, hessite, sylvanite, acanthite, native silver, maldonite, Au-Bi sulphide, bismuth sulphotellurides and tellurides and others. PGE concentrations were determined by NAA, but PGE minerals were not established.

Some of these minerals, such as monazite, zircon, and cassiterite, are interpreted to result from sedimentary processes. Co and Ni sulphoarsenides, and pentlandite are interpreted to have formed during regional metamorphism of primary sulphides. Loellingite, maldonite, Au-Bi sulphide, and bismuth sulphotellurides and tellurides are interpreted to have formed during alteration due to magmatic intrusions or to contact metamorphism processes superimposed upon the ores. Hessite, sylvanite, acanthite, and native silver are interpreted to result from retrograde metamorphism, or as having been formed in a zone of cementation.

A complicated process of gold mineralization resulted in complex polycomponent ores.

INTRODUCTION

The Natalka, Vetren, and Igumen Au-quartz deposits occur in the southwestern part of the Yana-Kolyma auriferous belt that is interpreted as forming during accretion of the Kolyma-Omolon superterrane to the North-Asian craton during the Late Jurassic to Early Cretaceous time (Parfenov et al., 1993). These lode deposits belong to the Au-quartz deposit type and have a significant commercial potential for gold. Some other metals including platinoids (PGE) may also be present, which justifies new detailed mineralogic and geochemical studies. New mineralogic data obtained will also provide for a better understanding of the genesis of these lode deposits.

GEOLOGIC SETTING AND ORE BODIES

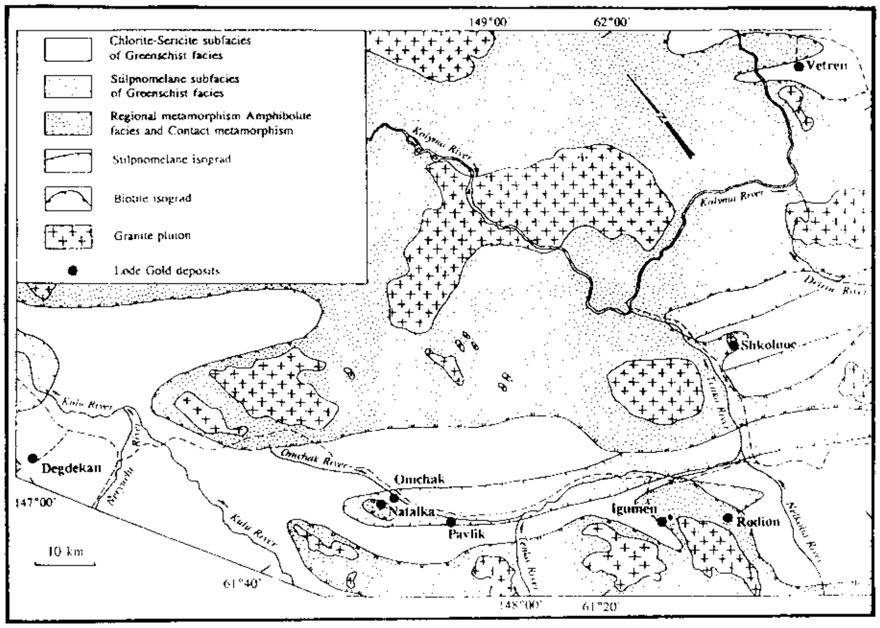

Fig.1. Simplified map of regional prograde metamorphism and occurrences of the lode gold deposits (modified from M.L.Gelman, M.P.Krutous, A.U.Filippov, and O.G.Epshtein, 1976 unpublished map).

The Natalka and Igumen deposits are hosted by Permian metasedimentary carbonaceous rocks; the Vetren deposit is hosted by Jurassic metasedimentary carbonaceous rocks. These rocks are metamorphosed to varying degrees (Fig. 1).

The Au-quartz deposits occur near the biotite isograde. Igneous rocks consist of Late Jurassic pre-mineral rhyolite and spessartite dikes, which are not wide-spread. Ore bodies of the Igumen deposit are cut by Cretaceous granitoids and subject to contact metamorphism.

Ore bodies of the Natalka deposit are mainly complex linear zones of subparallel quartz stringers along steep joints. Ore bodies of the Vetren deposit consist of saddle veins hosted in fold hinges, also cross-cutting veins and shear zones. Ore bodies of the Igumen deposit consist of persistent veins and veinlets, which have well-defined linear contacts, steep dips and a length of several kilometers.

The most typical wall rock alterations include silicification, carbonation, sulphidization, feldspar alteration and albitization. Usually, several types of alteration are combined. The main gangue mineral is quartz; carbonates and feldspars are subordinate. Ore minerals in all deposits consist of arsenopyrite and pyrite (95-99%), with a predominance of arsenopyrite. Such minerals as pyrrhotite, sphalerite, chalcopyrite, galena, native gold, scheelite, ilmenite, and rutile are ubiquitous but scarce. The total content of ore minerals is not more than 1 percent for the Vetren and Igumen deposits and is 1-3 percent, sometimes to 5 percent, for the Natalka deposit. Gold fineness is 730-790 for the Natalka deposit, 860-890 for the Vetren deposit, and 650-950 for the Igumen deposit.

ANALYTICAL METHODS

Polished sections were used to examine sulphide relations. Mineral monofractions were taken by means of a binocular microscope from concentrates washed in bromoform. Silicate matrix was dissolved in hydrofluoric acid in order to extract ore minerals for a morphology study. A scanning electron microscope with a "Kevex" device was used to qualitatively examine minerals at the United Institute of Geology, Geophysics and Mineralogy of the Russia Academy of Sciences Siberia Branch (Novosibirsk). A microprobe study of sulphides was performed by means of "Camebax-304" at the Northeast Interdisciplinary Research Institute of the Russia Academy of Sciences Far East Branch (Magadan) and "Camebax" SX-50 at the "Gintsvetmet" Institute (Moscow).

Neutron activation analyses were performed to determine the platinum group elements content (PGE). Lead fire assay of noble metals was used to obtain lead-silver bullion with subsequent incomplete cupellation in magnesite cupels. The neutron activation analysis was carried out in the Laboratory of Activation Analysis of the Institute of Nuclear Physics, the Uzbekistan Academy of Sciences, Tashkent. Samples were exposed to neutron total radiation, density 10^{14} n/cm^2, in the VVR SM reactor radiation hole. Determinations were made for platinum and palladium using the IAEA standards for the comparison. The sensitivity of determinations was different for each sample exposed to radiation due to a significant influence of gold present and ranged from 0.1 to 4.0 g/metric ton for platinum and palladium.

RESULTS

The presence of such minerals as monazite, cassiterite, breithauptite, millerite, cobaltite and Ag-pentlandite is established for the Natalka deposit. Monazite is wide-spread in alluvium of Geologichesky Creek, that cuts through the ore bodies in the northwestern part of the deposit. It is grey and forms ellipsoid-shaped grains up to 1 mm in size. Under a microscope, the monazite matrix is porous and contains silicate inclusions as quartz, feldspar and biotite. The lanthanum content of monazite ranges from 4 to 19 weight-percent, cerium from 22 to 39 weight-percent, neodymium from 8 to 25 weight-percent, praseodymium 2 to 4 weight-percent, yttrium is less that 1 percent, and the thorium content is 2.87 percent for one grain. At the Natalka lode deposit, monazite occur as irregularly shaped micro-inclusions in pyrite and arsenopyrite; as these inclusions are very small, monazite is only qualitatively established under a scanning electron microscope. Breithauptite and cassiterite occur as separate very small grains (<0.01 mm) in altered metasediments. Co, Ni and Fe sulphoarsenides of changing composition and Ag-pentlandite also occur in altered metasediments in association with arsenopyrite, pyrrhotite, chalcopyrite, and sphalerite. Small inclusions of cobalt and nickel minerals (0.001 mm) are consistently present in arsenopyrite and pyrite. The composition of major inclusions is represented by formulas: $Co_{0,81}Fe_{0,13}Ni_{0,09}As_{0,95}S_{1,03}$ and $Co_{0,66}Fe_{0,17}Ni_{0,18}As_{0,91}S_{1,09}$. Millerite occurs as solitary grains in mineralized spessartite dikes and has the following composition: $Ni_{0,99}Fe_{0,03}S_{0,99}$.

High grade of platinum group elements were found at the Natalka deposit in 1991 (Sidorov et al., 1994). About 120 neutron activation analyses were carried out in order to determine the presence of PGE and some atomic absorption and atomic emission analyses were also performed. The obtained results were mathematically processed and PGE-bearing ores were distinguished into several geochemical types. "High-grade" gold-platinum-palladium mineralization is represented by massive and brecciated arsenopyrite-quartz veins (Au - 40, Pt - 10, Pd - 9 g/metric ton). "Mean-grade" mineralization is represented by zones of sulphide-quartz veinlets (Au - 2.4, Pt - 0.5, Pd - 0.6 g/metric ton). "Low-grade" mineralization is also represented by zones of veinlets (Au - 0.3, Pt - 0.4, Pd - 0.6 g/metric ton). The local (point) contents of Pt - 0.9 and Pd - 0.1 wt. percent were established by microprobe analysis of a lead-silver bullion obtained from lead fire assay of a high-grade sample. Nevertheless, platinoid minerals are not found and platinum and palladium are not present as an admixture to other ore minerals.

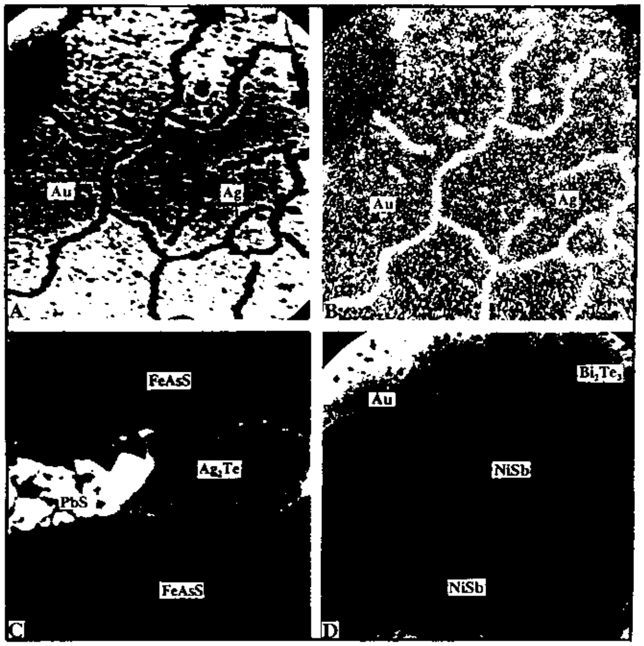

Fig. 2. Backscattered-electron and X-ray images of thin sections from the Vetren deposit. A. Native gold with native silver veinlets. Width of photomicrograph = 0.1 mm. B. X-ray image for Ag-$L\alpha$ of the same area as (A). C. Broken arsenopyrite (FeAsS) with hessite (Ag_2Te) and galena (PbS) in fractures. Width of photomicrograph = 0.03 mm. D. Native gold with breithauptite (NiSb) and tellurobismuthite (Bi_2Te_3) inclusions. Width of photomicrograph = 0.04 mm.

The presence of breithauptite, tellurobismuthite, tetradymite, greenockite, native silver, hessite, sylvanite and, acanthite is established for the Vetren deposit. Breithauptite is present as oval-shaped inclusions in gold not more than 0.01 mm in size (Fig. 2). The composition of breithauptite is $Ni_{4.98}Sb_{5.02}$. According to X-ray examination by microprobe, nickel and antimony minerals have a uniform distribution in breithauptite inclusions. Breithauptite forms intergrowths with gold and tellurobismuthite. Tellurobismuthite and tetradymite occur as micro-inclusions after cleavage cracks in galena and have an admixture of antimony. The average composition of tellurobismuthite is $Bi_{1.87}Te_{3.02}Sb_{0.11}$ (n=7), and tetra-dymite is $Bi_{1.87}Te_{1.99}S_{1.06}Sb_{0.08}$. The formation of tellurobismuthite always precedes that of tetradymite (Fig. 3).

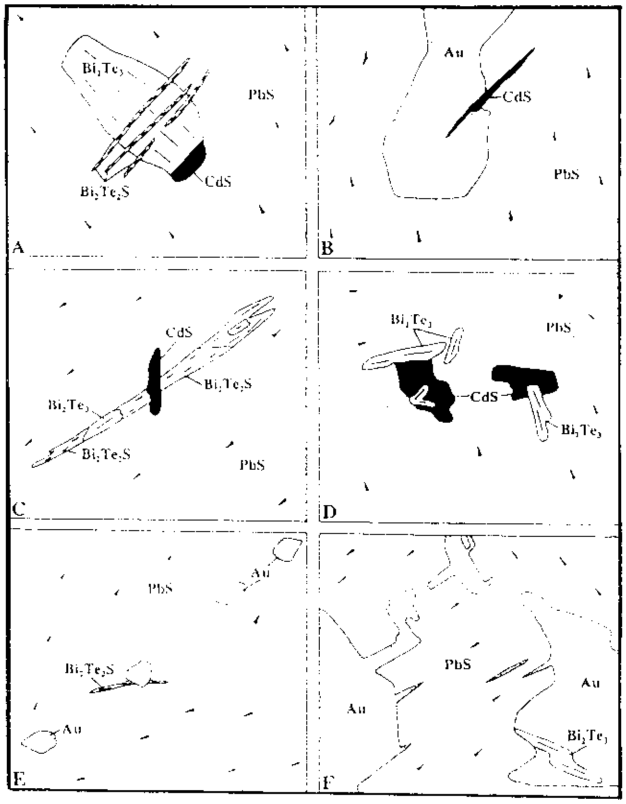

Fig. 3. Drawing of photomicrographs of thin sections from the Vetren deposit. A. Replacement of tellurobismuthite (Bi_2Te_3) by tetradymite (Bi_2Te_2S). Width of drawing = 0.02 mm. B. Intergrowths of native gold crystals (Au) and greenockite (CdS) in galena (PbS). Width of drawing = 0.02 mm. C. Intergrowths of tellurobismuthite (Bi_2Te_3), tetradymite (Bi_2Te_2S), and greenockite (CdS) in galena (PbS). Width of drawing = 0.03 mm. D. Intergrowths of tellurobismuthite (Bi_2Te_3), and greenockite (CdS) in galena (PbS). Width of drawing = 0.03 mm. E. Native gold (Au) grains along galena (PbS) cleavage. Native gold is intergrown with tetra-dymite (Bi_2Te_2S). Width of drawing = 0.02 mm. F. Galena (PbS) with native gold (Au) in cleavage cracks. Native gold is intergrown with tellurobismuthite (Bi_2Te_3). Width of drawing = 0.04 mm.

Greenockite is present as inclusions after cleavage in galena in association with tetradymite, tellurobismuthite, and gold. It is often represented by chains of oval grains and has a stoichiometric composition $Cd_{0.99}S_{1.01}$ (n=6). The antimonial phase may sometimes be present at the ends of elongated crystals, but its diagnosis is difficult due to its small size. The formation of greenockite was probably simultaneous with the formation of tellurobismuthite and tetradymite, and subsequent to the formation of native gold (Fig. 3). Native silver is present as fine irregular veinlets (0.001-0.003 mm) in native gold having a high fineness (Fig. 2). Hessite, sylvanite, and acanthite occur in galena-anglesite veinlets hosted by arsenopyrite (Fig. 2). These minerals are not more than 0.02 mm in size. The composition of sylvanite is $Au_{0.98}Ag_{0.95}Te_{4.1}$, and hessite is determined by means of scanning electron microscope.

According to PGE analysis for quartz and quartz-sulphide massive and brecciated veins at the Vetren deposit, the content of platinum is 0.1-0.7 g/metric ton, palladium 0.4-2.1 g/metric ton, and gold 0.1-6.3 g/metric ton. The highest platinum content, i. e. 1.2 g/metric ton, is characteristic of significantly altered sediments of the vein footwall, where the content of palladium is 0.7 g/metric ton and gold 0.5 g/metric ton. The content of palladium is 0.6 g/metric ton, platinum 0.4 g/metric ton and gold 1.5 g/metric ton in sediment-hosted zones of sulphide-quartz veinlets. The content of palladium is 0.8 g/metric ton, platinum 0.2 g/metric ton and gold 0.15 g/metric ton for carbonaceous shaly tectonites. The platinoid content of non-altered coaly shales is below the analysis sensitivity, and gold is 0.03 g/metric ton. Platinoid minerals are not found.

Table 1. Microprobe analyses of Bi-bearing minerals from Igumen lode gold deposit

Ag	Pb	Bi	Au	Te	S	Total	Formula
Schirmerite							
7.9	21.1	55.7	-	-	15.6	100.3	$Ag_{2.68}Pb_{3.73}Bi_{9.76}S_{17.82}$
6.7	39.5	38.5	-	0.1	15.4	100.2	$Ag_{2.30}Pb_{7.06}Bi_{6.82}S_{17.79}Te_{0.03}$
5.0	47.4	30.6	-	0.9	14.4	98.3	$Ag_{1.80}Pb_{8.86}Bi_{5.67}S_{17.40}Te_{0.27}$
6.1	40.4	36.8	-	0.5	15.5	99.3	$Ag_{2.10}Pb_{7.25}Bi_{6.54}S_{17.96}Te_{0.15}$
Joseit B							
-	0.1	78.7	-	20.0	2.3	101.1	$Bi_{4.35}Te_{1.81}S_{0.83}$
0.1	0.2	78.9	-	18.3	2.4	99.9	$Bi_{4.42}Te_{1.68}S_{0.88}$
-	0.3	75.8	0.1	19.9	3.0	99.1	$Bi_{4.13}Te_{1.78}S_{1.07}$
-	0.3	74.6	0.1	20.7	3.0	98.7	$Bi_{4.06}Te_{1.85}S_{1.07}$
-	1.0	77.3	-	19.2	3.2	100.7	$Bi_{4.14}Te_{1.68}S_{1.12}$
-	1.0	77.6	-	18.1	3.0	99.7	$Bi_{4.25}Te_{1.62}S_{1.07}$
Au - Bi sulphide							
-	1.6	76.4	13.5	-	8.2	99.7	$Bi_{5.24}Pb_{0.11}Au_{0.98}S_{3.67}$
-	1.5	76.4	14.3	-	8.4	100.6	$Bi_{5.17}Pb_{0.10}Au_{1.03}S_{3.70}$
-	1.7	76.0	13.6	-	9.3	100.6	$Bi_{4.97}Pb_{0.11}Au_{1.01}S_{3.90}$
-	1.0	76.3	14.5	-	9.1	100.9	$Bi_{5.02}Pb_{0.07}Au_{1.01}S_{3.90}$
-	1.9	75.7	14.2	-	8.8	100.6	$Bi_{5.05}Pb_{0.13}Au_{1.00}S_{3.82}$

The Igumen deposit has a rare assemblage of bismuth minerals including schirmerite, bismuthine, joseite-B, maldonite, gold-bismuth sulphide ($AuBi_2S_4$), native bismuth, and native gold (Table 1). Schirmerite forms irregular spotted aggregates in native gold hosted by arsenopyrite. Schirmerite has a changing lead-to-bismuth ratio, whereas their sum remains the same. Bismuthine, joseite-B, gold-bismuth sulphide, native bismuth, and native gold make up an intergrowth without well-defined age dependencies between minerals. Maldonite and native bismuth may sometimes be present as oval inclusions in native gold. The composition of maldonite generally remains the same and has the formula $Au_{2.03}Bi_{0.97}$ (n=5). Native gold from this mineral assemblage has a fineness of 910-970. Intergrowth-hosting quartz is significantly recrystallized.

DISCUSSION OF RESULTS

The Natalka, Veticn, and Igumen deposits generally feature approximately the same ore composition, but differ in their rare minerals content. This is due to different host rocks and their alterations, as well as, to a different influences of post-mineral processes, including metamorphism and oxidation.

The formation of such minerals as monazite and cassiterite from the Natalka deposit was related to sedimentary processes. Grey monazite (kularite) has a chemogenic-sedimentary nature (Nekrasova and Nekrasov, 1983 and Nekrasova, 1990). Cassiterite is interpreted as a relict mineral resulting from the destruction and removal of remote bedrock sources, probably in old volcanics. The formation of framboidal pyrite, which is seldom preserved in metamorphic rocks, was also related to the processes of sedimentation. It seems that carbon was important in that case, and also for the primary concentration of noble metals.

The mobilization of main ore components was related to the progressive metamorphism of sedimentary rocks. During this stage, pyrite underwent recrystallization with idiomorphic metamorphic pyrite, which formed earlier, and then altered to pyrrhotite under high-temperature conditions (Voroshin et al., 1993). During the regressive metamorphism stages, the main mineral assemblages including pyrite-arsenopyrite, sulphides of base metals, and suphosalt-stibnite formed. Such minerals as cobalt and nickel sulphoarsenides, breithauptite, and pentlandite formed during the same period.

Contact metamorphism of ores is most significantly expressed in the Igumen deposit (Tyukova, 1989) and resulted in the formation of new sulphide assemblages including, firstly, an arsenopyrite-lollingite assemblage. There are also rare assemblages of bismuth minerals related to anomalous local physico-chemical conditions caused by metamorphism of initial isolated sulphide associations in quartz veins. Low-temperature contact metamorphism is also expressed in the Vetren deposit, where it resulted in the formation of tetradymite and tellurobismuthite.

The formation of gold and silver tellurides, native silver, acanthite and, probably, greenockite is interpreted as related to the cementation zone. This proposal is supported by that the fact that these minerals co-occur with sulfates in veinlets. The processes of oxidation are most significant at the Vetren deposit at a depth of about 200 m (Kalinin, and Panychev, 1974), where these minerals are the most wide-spread.

Despite of the great number of positive analyses for platinoids, the forms of these elements in ores is not clear. Therefore, it is difficult to discuss the genesis of platinum mineralization, associated with gold lode deposits in black shales. Like gold and silver, platinum group elements manifest a chemical affinity with carbon-bearing matter of sedimentary rocks (Ermolaev et al., 1992). However, appearance of modern ore was formed as a result of prolonged pre-ore regrouping of metals. If all precious metals were accumulated initially in sea environments in black shale strata, then the question arises: at what stage does the division in geochemical evolution of gold and silver with the elements of platinum group take place? Yet, in modern ores, gold and silver are present as large independent minerals. Platinoid minerals, if they are present, are very small inclusions or an admixture in other minerals. Platinoid localization as complex compounds with carbon matter of the rocks, is also possible (Varshal et al., 1994). The latter proposal may explain the absence of platinum and palladium minerals in ores of the Natalka and Vetren deposits.

CONCLUSIONS

According to the results obtained through repeated study of the mineralogy of well-known mineral deposits, they may differ significantly for subordinate and rare ore minerals. Such differences are due to local conditions under which mineral deposits formed. This factor may sometimes become important from the viewpoint of exploration activities and ore processing technology. In addition, the established high PGE content of ore, even though these high PGE contents are difficult to fully explain, actually makes it important to revise the potential of many Au-quartz deposits, including the utilized ore processing techniques.

ACKNOWLEDGMENTS

The authors wish to thank the Laboratory of Activation Analysis of the Institute of Nuclear Physics, the Uzbekistan Academy of Sciences, Tashkent for the neutron activation analysis carried out by analysts Drs. E.S. Flitsian and N.S. Osinskaya and T.N. Velikoda who translate the paper.

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