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Platinum metals on the Bam gold ore deposit of the Upper Amur region

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Abstract. The problems of complex extraction of noble metals (Ru, Rh, Pd, Ag, Os, Ir, Pt, Au) during the development of gold-silver deposits have recently acquired increasing practical importance and relevance, due to the clear tendency to exhaust the base of available ores, their concentration of useful components and deterioration of mining processing conditions. The aim of the work was an additional study of platinum mineralization in ore objects at the large Bam gold ore deposit of the Upper Amur region and obtaining estimates of noble metal contents by atomic absorption, electrochemistry and chemical analyzes. It is shown that industrial concentrations for mining are gold and silver, and platinum metals are present at concomitant concentrations and do not reach the values required for cost-effective industrial processing. The revealed peculiarities of the Bam deposit are superposition of high-temperature and low-temperature stages of mineralization of precious metals within the ore columns, which leads to averaging of general geochemical regularities and leveling of characteristic local differences. It is noted that platinum mineralization increases with depth and proximity to the source of volcanic heat, just like the relative sample of gold.

Keywords: geochemistry, noble metals, distribution, Bam gold ore deposit

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Introduction

In September 2014, the government of Russian Federation recommended to start exploitation of previously explored but suspended Bam gold-ore deposit provided that suitable technology is chosen. This non-placer was discovered by V.V. Domchak's expedition in 1979 basing on analysis of lithochemical flows of Ag and Au dissemination in bottom deposits of right tributaries of the Chul'bangro River. Before, minor placer ore-occurrences had been exploited. They had genetic connection with the continental drift material in Bam gold-ore deposit, which was characterized by a certain set of geochemical elements. Later, in the deposit, secondary geochemical dissemination aureole was explored, the ore body was opened with trenches and concomitant elements such as Cu, W, Pb, Bi, Mo, Sb and Hg were determined. At first, the deposit was estimated as medium-size in terms of gold concentration. However, after additional exploration (mostly by drilling) in 1990-2013, gold reserves amounting 107.5 tonnes were proved. The latter enabled us to classify the deposit as large (Moiseenko, Eirish, 1996; Stepanov et al., 1998). In Amur region gold- and platinum-bearing areas are detached into 46 gold-bearing and 7 potentially platinum-bearing placer deposits, where there have been cases of by-production of platinum group minerals up to 3 mm in size (Moiseenko et al., 2004). So, there is a necessity to additionally investigate the content of all group of noble metals (NM), which, apart from gold, includes silver and platinum-group metals (PGM). Silver is present in minerals of nuggets and their mineralization is often studied jointly, whereas PGM mineralization is less clear (Radomskii, Radomskaya, 2017).

The aim of the work was an additional study of platinum mineralization at the large Bam gold deposit and evaluation of possibility to complexly extract the whole group of noble metals.

Materials and Methods

Sampling of ore material was conducted according to the guidelines from Central Research Institute of Geological Prospecting for Base and Precious Metals (TSNIGRI). Analytical procedures were performed in accordance with the III category of accuracy. General analytical target profile was the following: total error band in terms of correctness, accuracy and reproducibility was ≤ 30%. Control of the obtained results was performed with the help of certified reference

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materials (CRM) – nickel concentrate NC-1 No.1702-86 and concentration tailings XO-1 CRM No.1703-86 (Radomskii, Radomskaya, 2017).

We analyzed averaged quartered samples of 14 ore columns (34 samples) and 18 samples of host and developed rock. The analysis of noble metal group (Ru, Rh, Pd, Ag, Os, Ir, Pt and Au) was made in accordance with SS R 52599-2006[1] (silver – IS No.130 VIMS NSAM 2010, and gold – IS No.131 VIMS NSAM), platinum group metals – SS R 55558-2015[2]. Quantitative estimation of gold and silver concentrations was performed after sample annealing at 650ºC during 1.5 hours. Batches of 5-10 grammes were treated with solution of HCl and HNO_3 in the ratio 3:1. Gold and silver were identified by atomic absorption method after extraction: gold – in solution of 0.05M dibutylsulphide in methylbenzene; silver iodide – in solution of 3-methylbutanol-1 (Radomskaya et al., 2005; Radomskii, Radomskaya, 2017).

Analysis of PGM was performed in accordance with SS R 55558-2015 and its further supplements and changes. Method of determination of PGM involved concentrating of elements from a 10-gramme batch by preliminary alloying on nickel matte. The matte was dissolved in hydrochloric acid deluged with distilled water in ratio 1:1. Insoluble sediment of PGM was detached. The sediment was alloyed with sodium peroxide. After dissolution of the alloy, a solution of platinoids was obtained. Subsequently, aliquots were taken from the solution in order to differentiate the metals separately. An aliquot was transferred into a 0.1M acetic solution to identify osmium and into 2-3M HCl solution to analyze other PGM. Contents of ruthenium, osmium and iridium were estimated with kinetic, catalymetric and photocolorimetric methods respectively. Secondary concentrating of platinum, palladium and rhodium was conducted with extraction method using mixture of 0.025M solution of di-2-ethylhexyl-phosphoric acid and iodide complexes of silver in a solution of 3-methylbutanol-1. Analyses were performed on atomic absorption spectrometer "Hitachi 180-50" and "SOLAAR M-6" in the mode of electrothermal atomization (Radomskii, Radomskaya, 2017). Performance of atomic absorption method was controlled within-laboratory with inversive electrochemistry analysis with sensitivity of detection NM 0.001 ppb while 1 g sampling batch was used (Kolpakova, 2004).

Distribution of NM in natural environment is unequal. So, while their part and behaviour in geochemical processes is being studied, their trace amounts should be accurately estimated. For this purpose representative value and efficient schemes of analysis, which require previous preparations, separation of groundmass and concentrating, are used. The latter eliminates matrix effect and significantly increases ratio signal/noise (Kolpakova, 2014; Radomskaya et al., 2005; Radomskii, Radomskaya, 2017).

Results of the study

First reports about platinum mineralization in Bam gold deposit appeared in 1998. Presence of PGM with maximum concentrations was determined in 14 samples taken near ore occurrence in Nevachansk intrusion (Stepanov et al., 1998; Moiseenko et al., 2004). Estimated total concentrations of NM in ores, host and developed rocks is shown in Table 1. Concentration Clarkes (CC) of NM in the deposit ores in relation to NM Clarkes in the earth's crust according to K.H. Wedepohl (Wedepohl, 1995) amount: Ru – 110; Rh – 50; Pd – 55; Ag – 257; Os – 440; Ir – 340; Pt – 950; Au – 3000. Row of CC in ores of Bam gold deposit is following: Au>Pt>Os>Ir>Ag>Ru>Pd>Rh, and it is identical to NM distribution in biogeochemical components of natural environment of Upper and Middle Amur within Amur region (Radomskii et al, 2008). However, the row of CC in host and developed rock is different Au(236)>Pt(325)>Os(140) >Ir(60)>Ag(11)>Ru(60) >Pd(15)>Rh(33) and changes insignificantly in alloys. Correlation relationships of NM with wide range of chemical elements having metal and non-metal origin have values close to perfect, they

Element	Ore columns 34 samples	Host rocks 18 samples	Clark in the Earth crust (Wedepohl, 1995)
Ru	0,010 – 0,012 / 0,011	0,001 – 0,010 / 0,006	0,0001
Rh	0,002 – 0,004 / 0,003	0,001 – 0,003 / 0,002	0,00006
Pd	0,020 – 0,024 / 0,022	0,004 – 0,008 / 0,006	0,0004
Ag	1,00 – 35,00 / 18,0	0,50 – 0,98 / 0,74	0,07
Os	0,018 – 0,026 / 0,022	0,006 – 0,008 / 0,007	0,00005
Ir	0,010 – 0,024 / 0,017	0,002 – 0,004 / 0,003	0,00005
Pt	0,22 – 0,54 / 0,38	0,12 – 0,24 / 0,13	0,0004
Au	1,00– 14,00 / 7,5	0,22 – 0,96 / 0,59	0,0025

Table 1. Total concentrations of NM in ores, host and developed rocks in Bam gold deposit, numerator – interval of estimated concentrations, denominator – mean value, ppm

[1] State Standard R 52599-2006 Dragotsennye metally i ikh splavy. Obshchie trebovaniya k metodam analiza [Precious metals and their alloys. General requirements for methods of analysis]. Moscow: Standartinform Publ., 2007, 10 p. (In Russ.)

[2] State Standard R 55558-2015 Ruda sul'fidnaya medno-nikelevaya. Mass-spektrometricheskiy metod opredeleniya soderzhaniya platiny, palladiya, rodiya, ruteniya, iridiya i zolota s predvaritel'nym kollektivirovaniem na nikelevyy shteyn [Copper-nickel sulfide ore. Mass spectrometric method for determining the content of platinum, palladium, rhodium, ruthenium, iridium and gold with preliminary collectivization on nickel matte]. Moscow, Standartinform Publ., 2015, 36 p. (In Russ.)

are heterogeneous and were thoroughly described earlier (Moiseenko et al., 2004).

Discussion

Bam gold deposit, approximately 400 sq. km in area, is located in western part of North-Stanovoy metallogenic zone, in gold-bearing province of Amur, which is dating Late-Mesozoic period. It belongs to volcano tectonic high of central type, consisting of subvolcanic intrusions and dikes of Early Cretaceous period. Its frame consists of granitoids from Chubachinsk massif of Proterozoic period, which contain gneiss xenolith and crystalline schists of Archaean period (Stepanov, 2000). Abnormal geochemical fields of Bam ore cluster according to A.A. Danilov (1998) are presented in Fig. 1 (Stepanov et al., 1998). To the south-east of Bam deposit, located 55º58’41’’N 123º53’6’’E, in the river heads of Upper and Middle Larba in the central part of Bam ore field, there are numerous explored occurrences, like Des, Apsakan, Dominikan, Normandia and others. The occurrences are similar in metallogenic features, geology, morphology of ore body, developed rock, composition of ores, purity of gold to Bam deposit and differ only in set and content of concomitant elements in natural minerals (Eirish, 2002). To the south-west there is Nevachansk subvolcanic intrusion of quartz syenite-porphyry, which gradually moves to the east at an angle 30° to the edge of Bam fault, called Bam bypass. Mineralization is intermittent and is mostly developed in the bottom layer of Bam fault (Moiseenko, Eirish, 1996).

Bam deposit belongs to hydrothermal group, igneous class, oxide-sulphide ore. The deposit has paragenetic relations with volcano-plutonic and paleovolcanic structures and occurrences of subvolcanic intrusions in Nevachansk pluton-related complex, dikes, acidic and moderately acidic sills. Bam ore cluster represents volcano-plutonic high of central type which is characterized by distinct geophysical and geochemical fields (Fig. 1). Bam deposit is a zone of fine quartz veinlets with gold and silver mineralization belonging to the similar-named ore fault. According to geological data, Early Cretaceous age of the deposit is proved by Rb-Sr method on ore-accompanying minerals at the interval 129±3,6 mln years (Stepanov, 2000).

Ore bodies represent mineralized zones of crushing and brecciation, they cross the structures of host composite gneiss, which is characteristic feature of friable rather than lamellated deformation. That proves hypabyssal type of mineralization. Morphological ore bodies represent ribbons and lenses complicated by monoclonal folds along strike and down-dip. Zones of concentrated mineralization are called ore columns, which are prolonged along down-dip.

Ore columns have specific south-eastern decline and tend to geometric and concentration changes with distance from the central igneous high. With distance from Nevachansk intrusion productivity and volume of ore columns are weakening. In general ore-bearing structure is treated as the zone of straddles in the bottom layer of Bam fault at the angles 40-50° (Eirish, 2002).

Ore bodies mostly consist of adularia-carbon-quartz rocks affected by low-temperature hydrothermal changes. Ore bodies represent veins of quartz and sulfide dissemination containing gold and silver amounting up to 160 ppm and 450 ppm in ore columns respectively. Wall rock alterations occur with beresitization, kalifeldsparization and argillization of host rock. Ore minerals are presented by sulfides amounting 5-10%, the main ones are pyrite, chalcopyrite, galena, faded and sulfosalts. Among other minerals gold, scheelity, tellurides, selenides and cinnabar are present.

Among barren metals quartz, calcite, ankerite, sericite, fluorite and barite exist. Gold and silver are the main value of the ore, they exist in the ratio 1/3 to 1/5 with absolute concentration 6.1 and 18.4 ppm respectively. Fine free gold with mostly low purity 550-950‰ makes associations with sulfides, tellurides, selenides of silver, antimony and mercury, which shows different stages of ore-forming processes (Stepanov et al., 2008).

In Bam deposit, 14 ore bodies have been identified, their industrial boundaries have been determined by sampling data and often coincide with quartz and quartz-carbon lodes, though more often ore bodies are represented by elongated mineralized zones with fracture pattern, crush zones, as well as granite, gneiss-granite, migmatite, gneiss brecciated zones. The latter are deeply changed, contain numerous diversely oriented narrow and short veinlets of quartz and carbo-quartz. Geochemical aureole alter dissemination aureole and are concomitant with aureole of hydrothermally changed rocks belonging to beresite formation. Width of dissemination aureole of single vein does not exceed several metres. Average chemical composition of deposit ores in %: SiO_2 – 73.05; TiO_2 – 0.13; Al_2O_3 – 7.60; Fe_2O_3 – 3.01; FeO – 0.66; MnO – 0.18; MgO – 4.13; CaO – 3.25; Na_2O – 0.77; K_2O – 2.76; P_2O_5 – 0.06; CO_2 – 2.41; C_{org} <0,1; S_{com} – 1,20; ∑ – 99,21 (Stepanov et al., 1998; Eirish, 2002).

Proximity to the source of volcanic heat revealed in vertical and horizontal zonality of NM in the deposit. In vertical zonality, the amount of gold increases, whereas the amount of silver decreases with depth. In horizontal zonality, high-temperature association Au-Mo-W changes into Au-multimetal one, and subsequently, into low-temperature association Au-Ag-Sb-Bi. Also, volcanic heat contributed to relocation of ore-bearing fluid into near-surface zone, crushing of the flow into different parts and further deposition and redeposition of ore matter due to redox potential of NM

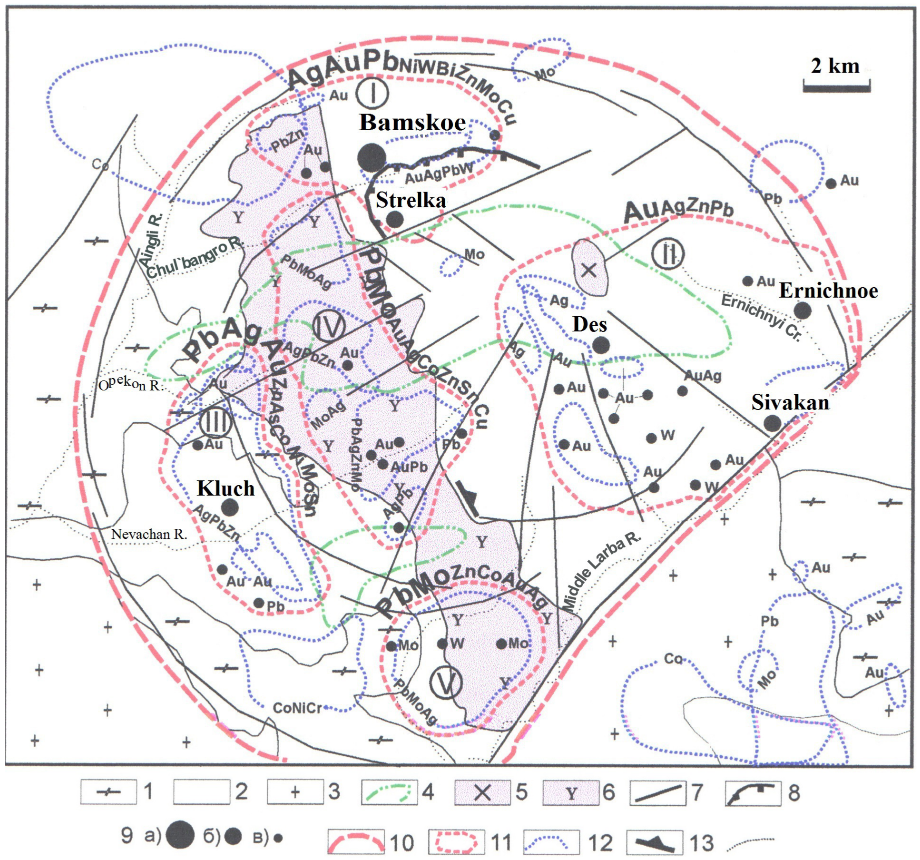

Fig. 1. Anomalous geochemical fields of the Bam ore cluster according to A.A. Danilov (1998). 1 – Archean gneisses and crystalline schists; 2 – granitoids of the Early Proterozoic Chubachi complex; 3 – granitoids of the Tynda-Bakaran complex of the Late Jurassic – Early Cretaceous; 4-6 – Early Cretaceous intrusive formations: 4 – areas of development of medium-sized dikes, 5 – intrusion of quartz monzodiorite, 6 – Nevachanskaya intrusion of quartz syenite and quartz syenite-porphyry; 7 – faults; 8 – Bam Mine Control Reset; 9 – deposits (a), manifestations (b), mineralization points (c); 10 – ore cluster border; 11 – borders of anomalous geochemical fields and their geochemical specialization (I – Bamskoe, II – Desovskoye, III – Kluchevskoy, IV – Central Nevachanskoe, V – South Nevachanskoe; 12 – areas of distribution of anomalous streams of elements scattering; 13 – elements of the occurrence of the Nevachanskaya roof intrusions.

in certain acid-base data of host medium (Radomskii, Radomskaya, 2010; Radomskii, Radomskaya, 2013; Radomskii, Radomskaya, 2015). Fixed points at the early stages are Au-Bi correlations, at the later stages – Ag-Sb correlations. In Bam deposit, they are significantly mixed. So, relative geochemical rows of dissemination aureole of NM as well as base metals for all biogeochemical components are different. Most correlations vary within values describing mean range of similar variations from one ore column to another, then, changing and varying further through the whole Bam deposit and its ore field (Fig. 1). Discrepancy of gold and silver concentrations in ore columns is over standard and highly irregular. Approximately 11-13% of ore belongs to primary gold concentrate and contains 13-15 ppm of gold, whereas the rest majority amounting 87% contain 1-5 ppm of gold. Approved gold and silver cut-offs in the ores of the deposit are 1ppm. According to gravity-flotability scheme NM are extracted as follows: 95.3% gold and 87.8% silver from primary ores and 88.6% and 68.8% respectively from oxidized ore (Moiseenko, Eirish, 1996). Characteristic element of ore columns, which makes the deposit different from other Amur deposits, is Sb, besides, low concentration of As in ores (less than 100 ppm), relieves some environmental restrictions and requirements necessary for NM mining companies.

Conclusion

1. Mass content of platinum in Bam deposit is concomitant with gold and silver content and does not reach the values required for industrial processing.

2. The peculiarities of Bam deposit are superposition of high-temperature and low-temperature stages of mineralization within the ore columns, which results in averaging of general geochemical regularities and leveling of characteristic local differences.

References

Danilov A.A. (1998). Geochemical characteristics and zonality of gold mineralization of the Bam field of Upper Amur region. *Avtoref. Diss. kand. geol.-min. nauk* [Abstract Cand. geol. and min. sci. diss.]. Blagoveshchensk.

Kolpakova N.A. (2014). Determination of platinum metals in mineral raw materials by the method of inversion voltammetry (review). *Zavodskaya laboratoriya. Diagnostika materialov,* 80(9), pp. 5-13. (In Russ.)

Moiseenko V.G., Eirish L.V. (1996). Zolotorydnye mestorozhdeniya vostoka Rossii [Gold-ore deposits of the Russian Far East]. Vladivostok, Dalnauka Publ., 352 p. (In Russ.)

Moiseenko V.G., Stepanov V.A., Eirish L.V., Melnikov A.V. (2004). Platinonostnost' Dal'nego Vostoka [Platinum Far East]. Vladivostok, Dalnauka Publ., 176 p. (In Russ.)

Radomskaya V.I., Radomskii S.M., Piskunov Yu.G., Kuimova N.G. (2005). Biogeochemistry of noble metals in water streams of the Amur River Basin. *Geoekologiya, inzhenernaya geologiya, gidrogeologiya, geokriologiya = Environmental Geoscience*, 4, pp. 317-322. (In Russ.)

Radomskaya V.I., Radomskii S.M., Pavlova L.M. and Kulik E.N. (2015). Biogeochemical response of landscape on open pit mining impact evidence from Albynskoe gold field of Amur River Region. *Ekologicheskaya khimiya*, 24(4), pp. 207-218. (In Russ.)

Radomskii S.M., Radomskaya V.I., Moiseenko N.V., Moiseenko V.G. (2008). Noble metals in landscapes of the Amur-Zeya plain in Priamurye. *Doklady Earth Sciences*, 423(1), pp. 1250-1252. https://doi.org/10.1134/S1028334X0808014X (In Russ.)

Radomskii S.M., Radomskaya V.I. (2010). Equilibrium operation factors of noble metals in oxidated process. *Estestvennye i tekhnicheskie nauki*, 49(4), pp. 166-170. (In Russ.)

Radomskii S.M., Radomskaya V.I. (2013). The ratio of ion and metal forms of noble metals at gold-silver layer Pokrovskoe (Upper Amur region). *Gornyj informatsionno-analiticheskiy bulleten' = Mining informational and analytical bulletin*, 1, pp. 128-134. (In Russ.)

Radomskii S.M., Radomskaya V.I. (2015). Balance of noble metals' forms in gold layer Pokrovskoe (Upper Amur region). *Georesursy = Georesources,* 63(4-1), pp. 85-89. http://dx.doi.org/10.18599/grs.63.4.14 (In Russ.)

Radomskii S.M., Radomskaya V.I. (2017). Platinum mineralization on Malomyr gold-ore deposit of Amur Region. *Izvestiya Sibirskogo otdeleniya sektsii nauk o Zemle RAEN. Geologiya razvedka i razrabotka mestorozhdeniy poleznykh iskopaemykh,* 40(4), pp. 30-41. DOI: 10.21285/2541-9455-2017-40-4-30-41 (In Russ.)

Stepanov V.A., Strikha V.Ye., Cheremisin A.A., et al. (1998). The Bam gold-ore deposit (geology, mineralogy and geochemistry). Vladivostok, Dalnauka Publ., 209 p. (In Russ.)

Stepanov V.A. (2000). Geologiya zolota, serebra i rtyti. Ch. 2. Zoloto i rtyt' Priamyrskoy provintsii [Geology of Gold, Silver and Mercury. Part 2. Gold and Mercury of the Priamurye Province]. Vladivostok, Dalnauka Publ., 161 p. (In Russ.)

Stepanov V.A., Melnikov A.V., Vakh A.S., et al. (2008). Priamurskaya zolotorudnaya provintsiya [Priamurian gold province]. Blagoveschensk, Izd. Amur State University Publ., 232 p. (In Russ.)

Eirish L.V. (2002). Metallogeniya zolota Priamur'ya (Amurskaya oblast', Rossiya) [Metallogeny of gold of Priamurye (Amur region, Russia)]. Vladivostok, Dalnauka Publ., 194 p. (In Russ.)

Wedepohl K.H. (1995). The composition of the continental crust. *Geochemica et Cosmochimica Acta*, 59(2), pp. 1217-1232. https://doi.org/10.1016/0016-7037(95)00038-2

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