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Mineral and geochemical compositions, regularities of distribution, and specific formation of ore mineralization of the Rogovik gold–silver deposit (*northeastern Russia*)

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Abstract

New data on the mineral composition and the first data on the geochemical composition of ores of the Rogovik gold–silver deposit (Omsukchan ore district, northeastern Russia) have been obtained. Study of the regularities of the spatial distribution of ore mineralization shows that the deposit ores formed in two stages. Epithermal Au–Ag ores of typical poor mineral and elemental compositions were generated at the early volcanic stage. The major minerals are low-fineness native gold, electrum, acanthite, silver sulfosalts, kustelite, and pyrite. The typomorphic elemental composition of ores is as follows: Au, Ag, Sb, As, Se, and Hg. The content of S is low, mostly ≤1%. Silver ores of more complex mineral and elemental compositions were produced under the impact of granitoid intrusion at the late volcanoplutonic stage. The major minerals are high-Hg kustelite and native silver, silver sulfosalts and selenides, fahlore, pyrite, chalcopyrite, galena, and sphalerite. The typomorphic elemental composition of ores is as follows: Ag, As, Sb, Se, Hg, Pb, Zn, Cu, and B. The content of S is much higher than 1%. The ores also have elevated contents of Mo, Ge, F, and LREE (La, Ce, and Nd). At the volcanoplutonic stage, polychronous Au–Ag ores formed at the sites of the coexistence of silver and epithermal gold–silver mineralization. Their specific feature is a multicomponent composition and a strong variability in chemical composition (both qualitative and quantitative). Along with the above minerals, the ores contain high-Hg gold, hessite, argyrodite, canfieldite, orthite, fluorapatite, and arsenopyrite. At the sites with strongly rejuvenated rocks, the ores are strongly enriched in Au, Ag, Hg, Cu, Pb, Zn, Ge, Se, La, Ce, Nd, S, and F and also contain Te and Bi. The hypothesis is put forward that the late silver ores belong to the Ag–complex-metal association widespread in the Omsukchan ore district. A close relationship between the ores of different types and their zonal spatial distribution have been established. In the central part of the Rogovik deposit, epithermal Au–Ag ores are widespread in the upper horizons, Ag ores are localized in the middle horizons, and rejuvenated polyassociation Au–Ag ores occur at the sites (mostly deep-seated) with ore-bearing structures of different ages.

Keywords: gold–silver deposit; ores; mineral composition; geochemical features; stages of formation

Introduction

The research was carried out in the area of the Rogovik epithermal gold–silver deposit. The deposit is located in the Magadan Region, on the left bank of the Kolyma River, 180 km northeast of Seimchan Village and 200 km northwest of Omsukchan Village. It lies in the Omsukchan ore district, one of the known gold- and silver-richest ore districts. The deposit was opened by V.M. Kuznetsov in 1971 as a result of geological surveys at a scale of 1:200,000 under his guidance.

Data on the geologic structure, structure-tectonic position, and mineral composition of rocks and ores of the deposit are scarce (Kuznetsov, 2011; Kuznetsov and Livach, 2005; Kuznetsov et al., 1992). The prospecting and assessment works performed by Dukat Geological Survey Company (LLC "DGSC", Magadan) in 2010–2012 in order to explore the deposit at the closed sites and to a depth greatly expanded the existed concepts of its geologic structure, petrologic composition, and specifics of evolution.

Based on our numerous detailed investigations, we have determined for the first time the geochemical composition of the deposit ores and obtained new data on their mineral composition. The identified mineral and geochemical assemblages made it possible to classify the ores by petrologic composition. The regularities of the areal distribution of

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mineralization of different types have been established. The conclusion is drawn that the Rogovik gold–silver deposit formed in two stages.

Methods

More than 100 specimens of the host rocks and ores and 750 geochemical samples were taken from different sections and horizons of the Rogovik deposit. Eighty bulk mineralogo-geochemical samples (crush rocks) up to 10 kg in mass were taken from the ore intervals. About 100 thin sections and polished sections were prepared and examined. Sampling and sample treatment were performed following the generally accepted technique (Instruction..., 1983).

Spectral approximate quantitative analysis (SAQA) of all samples for a wide range of elements was carried out on an STE-1 Polyus-2 spectrograph in the Analytical Laboratory of the Baikal Branch of the Sosnovgeologiya Enterprise (Irkutsk), using the spilling method (analyst M.S. Malyugin). Other analyzes were performed in the laboratories of the Institute of Geochemistry, Irkutsk.

Sample control was made by approximate quantitative atomic-emission spectral analysis (AQAESA) for 50 chemical elements. The samples were completely evaporated from a carbon electrode channel and were examined using DFS-458S and STE-1 spectrographs, DG-2 arc generator, and PS-18 spectral projector (Vasil'eva et al., 1997) (analyst N.E. Smolyanskaya).

Analysis for Au was carried out by atomic-absorption spectroscopy with its pre-extraction with oil sulfides (Torgov and Khlebnikova, 1977). Measurements were made on an M503 Perkin Elmer spectrometer (analysts V.N. Vlasova and T.S. Krasnoshchekova).

Analysis for Hg was performed by acid digestion (A User's..., 2004). Measurements were made on an atomic-absorption spectrophotometer with Zeeman background correction of nonselective absorption (analysts L.D. Andrulaitis and O.S. Ryazantseva).

For detailed study of ore material, we selected 60 of 80 bulk mineralogo-geochemical samples (crush rocks). Besides the above-mentioned elements, the contents of S, Se, Te, F, W, and REE were determined.

The total content of S was measured by the iodimetric method (Instruction..., 1965) (analyst T.N. Galkina). Analysis for Se was performed by the fluorimetric method (Instruction..., 1979), and that for Te, by the direct atomic-absorption method (Vorob'eva et al., 1987) (analyst N.N. Bryukhanova).

Analyses for F and W were carried out by the quantitative atomic-emission method on a setup including DFS-8 (inverse linear dispersion 0.2 nm/mm), DFS-13 (0.4 nm/mm), and PGS-2 (0.27 nm/mm) spectrographs with recording units of a multichannel analyzer of emission spectra (Chumakova, 2009) (analysts N.L. Chumakova and O.M. Chernysheva).

The contents of REE (first of all, Ce, La, Nd, and Yb) were measured by atomic-emission spectroscopy (Chumakova and Smirnova, 2011). Measurements were made on DFS-8 and DFS-13 spectrographs with recording units of a multichannel analyzer of emission spectra (analyst N.L. Chumakova).

The mineral composition of ores was studied with a POLAR-3 microscope and JXA-8200 (JEOL Ltd, Japan) microprobe. Probe microanalysis was performed by the techniques of Pavlova and Paradina (1990) for the precise identification of minerals, determination of the composition of microinclusions, and detection of trace elements. The mineral surfaces were examined with a scanning electron microscope in the scattered-electron regime and from the pattern of X-ray radiation intensities of elements (mapping) in order to detect inclusions and microinclusions containing ore elements. The composition of these inclusions was identified with an EX-84055MU (JEOL Ltd., Japan) energy dispersive spectrometer. The recording of spectra and conversion of the intensities of lines into element concentrations were made using the microprobe software.

Geological description

The study area, where the Rogovik Au–Ag deposit is located, lies in the central part of the Okhotsk–Chukchi volcanogenic belt, in the northern closure of the Omsukchan (Balygychan–Sugoi) trough, at the site of its intersection by the W–E-striking Ust'-Sugoi fault (Fig. 1*a*).

The evolution and metallogeny of this rift trough were considered in more detail earlier (Kuznetsov, 2006; Kuznetsov and Livach, 2005; Sidorov et al., 2009, 2011, 2013). Note that this regional structure resulted from the Late Mesozoic tectonomagmatic activity and is unique in its silver metallogenic specialization. It encloses the world-largest Dukat Au–Ag deposit, whose ores contain >14,000 tons Ag and 40 tons Au (Konstantinov et al., 2003; Struzhkov and Konstantinov, 2005). This deposit was described elsewhere (Konstantinov and Sidorov, 1985; Konstantinov et al., 1998, 2003; Kravtsova, 2010; Kravtsova and Zakharov, 1996; Natalenko et al., 1980; Raevskaya et al., 1977).

Along with Au–Ag deposits (Dukat, Lunnoe, Rogovik, Irguchan, Barguzin, Krasin, etc.), there are widespread Ag–complex-metal (Gol'tsovoe, Mechta, Tidit, Arylakh, and Piritovoe) and Sn–Ag (Novodzhagynskoe, Malokenskoe, and Akhtan) (Kalinin et al., 1984; Konstantinov et al., 2003; Kravtsova et al., 1996, 1998) deposits and ore occurrences.

The area of the Rogovik deposit is made up of the volcanosedimentary Omsukchan Formation of Lower Cretaceous age, composed mainly of mudstones, volcanomict sandstones, rhyolite tuffs, and polymict breccias (Fig. 1*b*). It is highly tuff-covered. Most of the area (up to 70%) is covered with deluvial-solifluction loams. Therefore, the deposit had been poorly studied before the prospecting and assessment works were performed by the "DGSC" in 2010–2011. In recent years, comprehensive studies of the deposit have been carried out owing to global drilling. The explored area is about 2000 m along the strike of ore zones and a little more than 400 m in dip. Nevertheless, the total sizes of the ore field and