Forms of gold occurrence at the Milin Kamak deposit, Western Srednogorie

Форми на присъствие на златото в находище Милин камък, Западно Средногорие

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Introduction

The Milin Kamak gold-silver deposit belongs to the Western Srednogorie zone in Bulgaria – part of the Upper Cretaceous Apuseni-Banat-Timok-Srednogorie (ABTS) magmatic and metallogenic belt (Popov et al., 2002). The deposit is located 50 km west of Sofia and 2 km south of the town of Breznik in the Bardoto locality. The area has been explored by Trace Resources Ltd. between 2004 and 2012 with100 trenches and 121 drill holes. Eight ore zones of almost identical mineral composition have been established. Based on the results, probable reserves and resources at a cutoff grade of 2 g/t have been estimated. The average content of gold is 5.04 g/t and of silver – 13.01 g/t.

Geology and mineralization

The Milin Kamak deposit is hosted by altered trachybasalt to andesitic trachybasalt volcanic and volcanoclastic rocks with Late Cretaceous age, products of the Breznik paleovolcano. A part of them is overlain by Paleogene and Neogene sediments. Sericitic, argillic, advance argillic and propylitic types of hydrothermal alteration occur in the deposit. Major NW-striking faults parallel to paleo-subduction direction of Western Srednogorie zone, and secondary NE- and E-W-striking crosscutting normal faults and shear zones are discovered in the area. The ore mineralization is associated with the E-W-striking faults. Eight ore zones, containing epithermal veins and many apophyses have been outlined. They have a varying length from 400 to 1000 m, width from several cm to 3–4 m, rarely to 10–15 m, an average 80–90 m depth (a maximum to 200 m) and dip steeply to south. The ore-forming process has been developed in 3 ore stages: quartz-pyrite, quartz-polymetallic, and carbonate-gold. Quartz-pyrite stage is characterized by quartz, euhedral to subhedral pyrite, and rare pyrrhotite. Because of the high oxidation potential in the upper levels of the deposit, hematite is deposited instead of pyrite. Quartz-polymetallic stage is represented by major anhedral pyrite, galena, sphalerite; minor chalcopyrite, tennantite, bournonite, tellurides and electrum; and trace pyrrhotite, arsenopyrite, marcasite. The sequence of deposition is: pyrite → galena with electrum and tellurides → sphalerite → tennantite and bournonite → chalcopyrite. The gangue minerals are quartz and carbonates. The last ore stage is carbonate-gold, defined by deposition of carbonate minerals and barite with native gold and stibnite. The supergene alteration is scarce and represented by sulphate and oxide-hydroxide minerals.

Methodology

Samples were collected from 12 drill holes intersecting 5 mineralized zones at the Milin Kamak. Mineral relations were examined in polished sections by optical microscopy. Microprobe (EPMA) analyses were performed using SEM JEOL JSM 6310 equipped with an Oxford Link ISIS EDX system and a Microspec WDX system at the Institute of Earth Sciences, University of Graz, Austria. Analyses were carried out at 20 kV accelerating voltage, 6 nA probe current, and 100 s counting time for EDX spectra using the following standards: $CuFeS_2$ (S, Fe, Cu), metallic Mn, ZnS (Zn), Pd_3As (As), CuSe (Se), metallic Ag, metallic Cd, NiSb (Sb), PbTe (Te, Pb), and Bi_2Te_3 (Bi). Trace element concentrations in pyrite were measured by LA-ICP-MS on polished sections at the Geological Institute, Bulgarian Academy of Sciences. The analyses were made using the PerkinElmer ELAN DRC-e ICP-MS equipped with a New Wave UP193-FX excimer laser ablation system. NIST SRM 610 glass was used as external standard. The laser system was operated at constant 10 Hz pulse rate; laser energy was 10.10 J/cm^2 on SRM 610 glass and 1.90–3.06 J/cm^2 on sample. Spot size was 50 μm in diameter. A total of 92 analyses were made and 48 isotopes were monitored. Acquisition dwell time for all masses was set to 0.01 s. Data reduc-

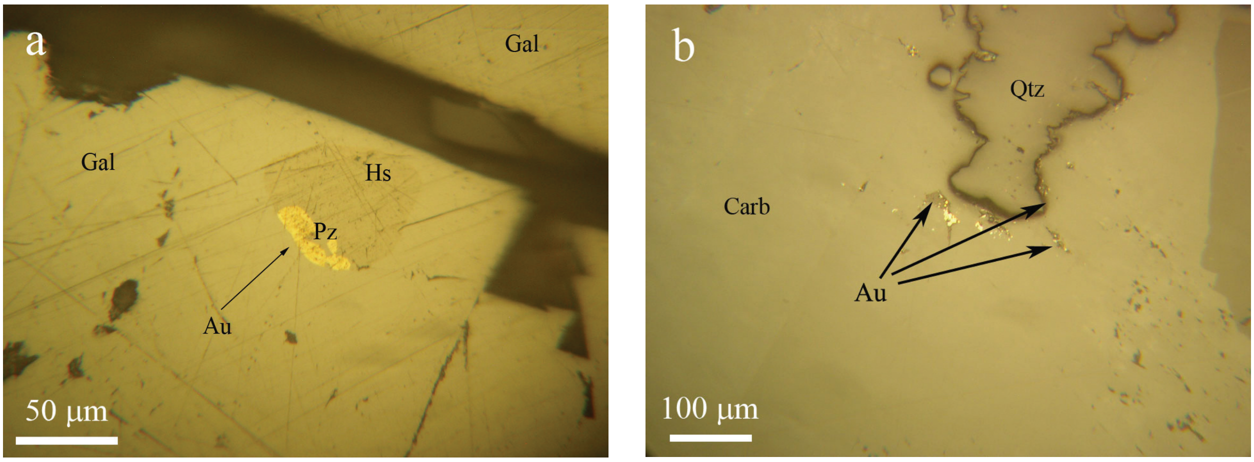

Fig. 1. Visible gold at Milin Kamak deposit: *a*, composite blebs of electrum, hessite (Hs) and petzite (Pz) in galena (Gal) in quartz-polymetallic stage at depth of 115.9 m; *b*, native gold grains in carbonate-gold stage at depth of 92.5 m

tion was undertaken using SILLS ver. 1.1.0 software (Guillong et al., 2008) and Fe as internal standard.

Forms of gold occurrence

Microprobe analyses indicate that gold occurs as discrete grains of electrum in quartz-polymetallic stage and as native gold in carbonate-gold stage. Electrum is identified at depths of 115.9 m together with hessite and petzite as composite blebs in galena (Fig. 1a). It is deposited also in the fractures and cleavage planes in galena but always in close spatial relation with telluride minerals. The morphology of electrum grains varies according to the shape of fracture or cavity they infill. Most often electrum occurs as irregular, elongated, rarely as oval and drop-like grains. Electrum in the blebs has size up to 40–50 µm, but mostly is hard to distinguish (3–5 µm). Chemical composition corresponds to electrum with 20.70–21.03 wt% Ag and gold fineness 724–729. The silver is the most significant trace element.

Native gold occurs at depths of 92.5 m and associates with stibnite and barite in carbonates (Fig. 1b). It is observed mostly as free grains with equant sections and oval forms up to 7 µm in size in carbonates, and very often on the phase boundary with quartz. The gold is with high fineness (838–854). Electron microprobe analyses indicate trace elements as Ag (6.25–7.78 wt%), Pb (5.64–6.23 wt%), Fe (0.25–0.41 wt%), and Cd (0.73 wt%). The high fineness of gold in the latest ore stage suggests redeposition of gold and removal of silver.

Gold concentrations from not detectable to 40.65 ppm (average 4.07 ppm) were determined by LA-ICP-MS in pyrite. In LA-ICP-MS depth spectra Au shows individual peaks suggesting the presence of microscopic inclusions of gold or gold-containing minerals, deposited in pores and micro fractures in pyrite. Arsenic also has prominent concentrations in pyrite – up to 14454.76 ppm. A positive correlation between Au and As is observed. The presence of As is usually considered as a major factor for incorporation of Au in pyrite crystal structure. Based on the time resolved spectra, can be suggested that gold could be also chemically bound but more definite proofs need to be obtained.

Gold was identified by EMPA in several other minerals, including pyrite (0.47–1.13 wt%), sphalerite (0.66–0.70 wt%), tennantite (0.60 and 0.63 wt%), hessite (0.92 wt%), and stibnite (0.50–0.69 wt%).

Conclusions

This study revealed three major modes of occurrence for gold at the Milin Kamak gold-silver deposit: 1) microscopically visible discrete grains of electrum (up to 40–50 µm) in galena and native gold (up to 7 µm) in carbonates; 2) invisible gold as micro-sized gold particles and gold-containing minerals in fractured and porous pyrite; and 3) gold as trace element in other minerals. Pyrite is the major ore mineral and is considered as the most important carrier of gold in the deposit. The most common mode of occurrence of gold in the Milin Kamak deposit appears to be the invisible gold as micro inclusions in pyrite.

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