Indications for colloidal origin of the bonanza of electrum millimetre-to-submillimetre-wide colloform-banded texture in the Khan Krum Au-Ag deposit, Eastern Rhodope Mountain, SE Bulgaria

Показатели за колоиден произход на богатата на електрум милиметрова до субмилиметрова коломорфно-ивичеста текстура в Au-Ag находище Хан Крум, Източни Родопи, ЮИ България

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Introduction

The millimetre-to-submillimetre-wide colloform-banded veinlets in the Khan Krum deposit (known also as Ada Tepe deposit) are composed mainly of adularia, quartz, and electrum of high grades (Marinova, 2009a). Marchev et al. (2004) have suggested a colloidal origin of gold-rich bands on the basis of a presence of opal and dendritic gold. Later, Marinova (2009b) has observed, besides dendrite-like electrum, in addition, spherical quartz micro-textures, poorly defined banding of diffuse boundaries, and pseudosedimentary textures. All these features of the millimetre-to-submillimetre-wide bands have been attributed to formation from a material of increased density, limited diffusion and gelatine-like consistency related most probably to extreme boiling of hydrothermal fluids. In this work, additional textural and morphological features indicating colloidal origin of the bonanza texture in the Khan Krum deposit are presented, and a brief reconstruction of the depositional environment is made.

Material and methods

The hand specimens of studied texture came from 10 high-angle veins on the summit of the Ada Tepe ridge, and were collected in 2007 and 2008. The studies were carried out by a stereomicroscope, a conventional polarizing optical microscope, and by Philips-515 SEM in secondary electrons. For identifying the silica phases, micro Raman spectra have been recorded by a LabRam Jobin-Ivon spectrometer equipped with an Olympus BX41 microscope and a He-Ne laser with an excitation wavelength of 633 nm. The beam power on the sample surface was 0.7 W. The spectral resolution was 2 μm.

Results and discussion

The micro-banding appears with contrast margins with the neighbouring macro-bands, which reflect its formation from an individual hydrothermal pulse. At the same time, the margins are uneven, without clear signs of partition.

Two types of orientation of the quartz and adularia crystals occur in the micro-bands: 1) randomly oriented grains both on the substrate (host rock or preceding band) and within the bands that characterizes the major part of the micro-banding, and 2) grains oriented approximately perpendicularly to a preceding band, thus forming a comb texture that plays a subordinate role. The first type is inconsistent with a crack-seal model of vein formation from true solutions, and suggests crystallization from a silicate gel. In the second type of orientation, a geometrical selection has acted, revealing that the crystals have been grown via direct crystallization.

Electrum in the bonanza micro-textures forms: 1) micron-sized, closely disposed oval aggregates with tree- and chain-like shapes, which are orientated most often transversely or obliquely to the banding and rarely along it; 2) relatively coarse clots along the banding, which at places reach sizes visible by naked eye; 3) disseminated micron-sized grains, and 4) dense sprinklings deposited in open space on the surface of micro-bands. The transverse electrum aggregates are predominantly located in the protruded parts of colloform micro-bands and everywhere intersecting only a few neighbouring micro-bands, never the entire banding, and without any feeding cracks. These observations allow one to conclude that the source of electrum is not external for the micro-banding, but is internal. In reflected light, it is visible that the micro-banding is breached transversely by material containing electrum dendrite-like aggregates. The absence of clear margins between the filling and the host micro-bands means that during breaching the matrix was not solidified, rather it was still viscous. The electrum clots, tracing the banding, occur as oval aggregates concentrated in a few neighbouring micro-bands. The largest clots are concentrated at the bottom of micro-bands. Somewhere, euhedral quartz crystals are covered by bended globular electrum aggregates, a fact suggesting that during the quartz crystallization the electrum aggregates were still viscous.

The micro Raman spectroscopy study of micro-bandings of anhedral adularia, apparently isotropic SiO_2, and dendrite-like electrum revealed almost identical spectra, typical of low-temperature α-quartz (Kingma, Hemley, 1994). Seven pronounced peaks at about 126, 204, 262, 353, 400, 463 and 511 cm^{-1} are presented in the 100–600 cm^{-1} spectral range, all they belonging to α-quartz. There is no evidence for low-crystalline or non-crystalline silica phases.

Secondary electrons images of veinlets with colloform micro-texture cut perpendicularly to the banding, exhibit alternation of clearly crystalline micro-bands and such which look like vitreous, denoted as crystalline and vitreous-like, respectively. The crystalline micro-bands are deciphered as cracks of syneresis lined with comb, relatively coarse quartz and adularia, while the vitreous-like – as former ore-silicate gel transformed into very fine-grained matrix of equigranular, anhedral quartz and adularia. Electrum is concentrated exclusively in vitreous-like micro-bands. The electrum aggregates, cut near their base, exhibit a lace-like texture due to the abundance of angular pores occupied by quartz and adularia. The afore-mentioned electrum sprinklings observed on the surface of individual micro-bands are obviously grown in open space with their bases onto the micro-band surface. Most likely, these sprinklings appeared as condensates of gasses separated during a boiling of fluids. Electrum liberated from the embracing matrix with HF, shows platy shapes with sharp edges, and uneven surface. At high magnifications, the surface of plates looks like dough with a lot of oval voids, which appears negative prints of the globular shape of a gel, and a lot of angular voids, being negative prints of quartz and adularia crystals.

Conclusions

1. The apparently isotropic SiO_2 in the studied texture corresponds to α-quartz, according to micro Raman spectroscopy data. Quartz and adularia display a random-grain fabric in the micro-bands, while the abundant micro-pores and longitudinal micro-cracks of syneresis are lined or infilled with relatively coarse comb quartz and adularia. Electrum forms dendrite- and chain-like aggregates oriented transversely to the banding, and oval clots oriented longitudinally. We relate this morphology to a reorientation of aggregated electrum globules, resulted from the huge difference between the specific weight of electrum, on one hand, and that of quartz and adularia, on the other hand, which has happened during the plastic deformation of an ore-silicate gel for the high angle of the veins. Electrum forms also sprinklings on the surface of some bands for which we presume a condensation of gaseous phase, separated during a boiling of fluids. **2**. The bonanza of electrum colloform micro-banding has formed under specific conditions: hydraulic fracturing of the already formed banded and massive veins probably related to a short-lived, high overpressure of fluids and to an extreme boiling of fluids resulted from a sudden drop of pressure, which have led to the formation of ore-silicate sol with relatively low water content. The coagulation of the sol results in the precipitation of a banded electrum-silicate gel from which, finally, crystallize very fine-grained quartz and adularia, and dispersed globular electrum. During the drying of the gel, micro-pores and micro-cracks of syneresis have been formed and lined or infilled with relatively coarse comb quartz and adularia deposited from separated true solutions passing through the gel like through a semi-permeable membrane. Among the fine matrix, there have formed also relatively coarse quartz and adularia via re-crystallization. Pores and cracks of syneresis are free of electrum because it was not in a soluble form, but most likely in the form of a sol. **3**. It is proposed that the process of extreme boiling of fluids has favoured the vigorous deposition of potassium feldspar and initial amorphous silica due to increase in pH, and of electrum due to loss of H_2S and destabilization of the complex compounds of gold and silver. **4**. We consider that the paleohydrothermal system was open or partly open during the formation of bonanza texture.

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