Refinement of the conceptual model for formation of bonanza electrum in steep sinusoidal-walled veinlets. Case study from the Khan Krum gold deposit

Уточняване на концептуалния модел за образуване на богати електрумни руди в стръмни синусовидни жилки в златното находище Хан Крум

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Introduction

Colloidal and physical transport textures exhibited by electrum in epithermal low-sulfidation ores are useful tool helping to understand the mechanisms of formation of the spectacular bonanza electrum ores worldwide. They appear as if are snapshots of a moving colloidal suspension and thus suggest a flow of electrum colloidal particles along cracks. Specific electrum distribution along such cracks infers an impact of both crack geometry and behavior of the flowing fluid (Saunders et al., 2011; Shimizu, 2014; Marinova, 2014, 2015). However, the textural analysis alone is unable to decipher the pattern of former colloidal flow – laminar or turbulent, one- or two-phase flow. Results of experiments and simulations of colloidal solutions flows along natural or artificial micro-cracks/micro-channels are required for reliable explanation of the mineral textures. In this work such an approach was employed.

Material and methods

Material is a sinusoidal-walled veinlet of bonanza electrum from the Khan Krum precious-metal deposit, Eastern Rhodopes Mountains, SE Bulgaria studied in reflected and transmitted light (Marinova, 2014). To explain the observed textural features results of experiments and simulations of flows of colloidal solutions along micro-cracks/micro-channels of similar geometry have been taken into account.

Results and discussion

The studied veinlet of bonanza electrum appears an alternation of narrow and thicker portions. The thicker portions begin with a throttle, then a thickening occurs, and then again a throttle section follows. The narrow portions are of two kinds: one appears necking between two thick portions; the other has a shape of long narrow portion. Electrum exhibits a pronounced enrichment only in the thicker portions, while the narrow portions are almost barren. The largest electrum agglomerations occur in the thickest sections. The narrow portions have widths from ~70 up to ~180 μm. The thicker portions are wide from ~260 up to ~350 μm (Fig. 1a). The thicker portions appear low velocity zones (Batchelor, 1970; Boutt et al., 2006) and thus places of slowing of colloidal particles as well as of relative enrichment of electrum in comparison with silicate particles. They have acted as trapping zones for the heavy electrum colloidal particles causing their collision, adhesion and agglomeration inherited during further coagulation and gel formation (Marinova, 2014). A question arises here: What pattern of the colloidal flow was mostly responsible for the pronounced electrum retention in the thickest portions? Marinova (2014) supposed that in the shelter sides of thicker portions a re-circulation of the flow has happed following the outcomes of Boutt et al. (2006) for colloidal transport in a single rough-walled fracture. Some experiments suggest that may be a transition of laminar flow into turbulent occurs in some thicker portions. Stanley et al. (1997) experienced the transition of laminar flow into turbulent regime. For two-phase (gas-water) flow at temperatures 20–70 °C, below a micro-channel width of 80 μm, the laminar regime was most dominant. Between 80 and 150 μm micro-channel width, the transition was seen to take place in varying degrees. Well defined transition occurred in micro-channels of width of 203 μm. For larger channels (170–260 μm wide), transition was seen to occur at large Reynolds number, i.e. for fluids with inertial forces highly dominating over the viscous forces. Campo-Deano et al. (2011) used a micro-channel of very high curvature to investigate flow of colloidal solutions. The micro-channel had a contraction (necking) with a hyperbolic

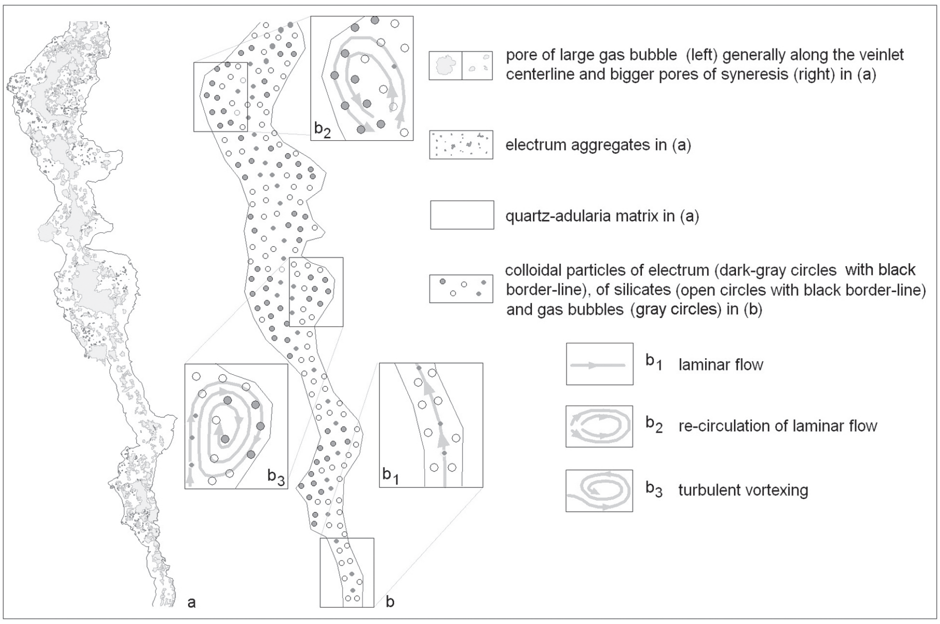

Fig. 1. Conceptual model for formation of bonanza electrum along sinusoidal-walled cracks: *a*, segment of the studied sinusoidal-walled veinlet (to scale); *b*, model of flow of boiling auriferous colloidal solution: inset b_1, geometry of site of expected laminar flow; inset a_2, geometry of site of expected re-circulation of laminar flow; inset b_3, geometry of site of expected transition of laminar flow into turbulent regime. Pronounced electrum enrichment associates with turbulent flow and re-circulation of laminar flow.

shape, followed by an abrupt expansion (thickening). The total width of the micro-channel was 400 µm and the minimum width of the contraction was 54 µm. These dimensions are of the same order as the ones of the studied micro-band. These authors used dilute suspensions at 20 °C at different weight concentrations, adding 1% (w/w) NaCl. The prepared fluids were seeded with fluorescent tracer particles to be sensitive to the fluorescence microscope used and injected up into the channel by a pump. Using CCD camera the authors visualized pronounced zones of vortexing just before or after the contraction with locations depending on the flow rate, viscosity, solution concentration, and the presence/absence of NaCl.

Taking into account the results discussed the author could conclude that the narrow barren portions of the studied veinlet were sites of laminar flow (Fig. 1b, inset b_1), while the thickest portions with abrupt expansion of the micro-crack were sites of turbulent flow (Fig. 1b, inset b_3). In some slightly widened portions in comparison with the next lower portions the author supposes that re-circulation of laminar flow has happened (Fig. 1b, inset b_2).

Conclusions

Integration of observations on natural bonanza electrum with experiments and simulations of flow of colloidal solutions along cracks/channels infers that in steep sinusoidal-walled joints the largest electrum agglomerations form in a turbulent flow of auriferous colloidal solution, followed by weaker electrum enrichment resulted from re-circulation of laminar flow, while the barren narrow portions form in a laminar flow.

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