GENESIS OF EPITHERMAL AU-MINERALIZATION AT ROZÁLIA MINE, BANSKÁ HODRUŠA, SLOVAKIA

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Abstract: This paper presents a new genetic model for the epithermal Au-mineralization based on new fluid inclusion and stable isotope data. The Au-mineralization occurs as subhorizontal veins at the base of pre-caldera stage andesites. It evolved during two stages, both associated with boiling fluids of low salinity (0-3 wt% NaCl eq.) and moderate temperatures (290 – 310°C). Variable pressure conditions (114 - 45 bars) indicate continuous opening of the system and transition from hydrostatic + lithostatic towards hydrodynamic conditions at shallow depths. $\delta^{18}O$ and δD values suggest mixing of magmatic fluids with meteoric waters that have intermediate composition between granodiorite-related and horst-related hydrothermal systems in the ore district. The pre-caldera stress field and related changes in hydrologic conditions due to caldera subsidence probably provided the structural framework for the Au-mineralization hydrothermal system. The shallow magma chamber of the volcano is the likely source of heat and magmatic components in the mineralizing fluids.

Key words: Štiavnica stratovolcano, hydrothermal system, stable isotopes, fluid inclusions, Tertiary

Introduction

Au-mineralization at the Rozália mine belongs to the Hodruša-Štiavnica ore district, situated in the central zone of the Štiavnica stratovolcano (16.3-10.5 Ma, Early Badenian to Late Sarmatian). The stratovolcano includes a large caldera 20 km in diameter and a late stage resurgent horst in its centre, exposing basement and extensive subvolcanic intrusive complex. The following stages of its evolution have been recognised (Konečný et al., 1995; Lexa et al., 1999a): (1) formation of a large px/hb-px andesite stratovolcano; (2) denudation, emplacement of a diorite intrusion with development of a *barren high-sulphidation hydrothermal system*; (3) emplacement of a large granodiorite bell-jar pluton within the basement associated with *magnetite skarns, stockwork base metal mineralization and* *advanced argillic alteration*; (4) emplacement of granodiorite/quartz-diorite porphyry stocks and dyke clusters with *Cu skarn-porphyry mineralization* around the granodiorite pluton; (5) caldera subsidence and its infill by bi-hb andesite volcanics, emplacement of quartz-diorite porphyry sills and dykes at subvolcanic level, *hot spring type advanced argillic hydrothermal systems* in the caldera infill; (6) renewed activity of andesites from dispersed centres on slopes of the volcano; (7) uplift of a resurgent horst accompanied by rhyolite volcanics and dykes and associated with an extensive system of *precious/base metal epithermal veins*.

The studied Au-mineralization was the most recently discovered type of mineralization, representing an unconventional type of Au-mineralization for the district, very different from the historically exploited epithermal veins. It does not have a clear relationship to the evolution of the stratovolcano. Lexa et al. (1999b) suggested a genetic relationship to the granodiorite pluton and the related base metal stockwork hydrothermal system, while Maťo et al. (1996) and Háber & Jeleň (2001) proposed a relationship to the system of horst-related epithermal veins.

Geology and mineralogy of the Au-deposit

The Au-mineralization at the area the Rozália mine is located at depth of 400 - 500m below surface. It occurs in the form of subhorizontal veins and veinlets with shallow dips to the S-SE (up to 30°). Veins are present in the environment of extensively altered pre-caldera stage andesites, not far from the roof of the granodiorite pluton. The mineralization is dismembered by a younger set of quartz-diorite porphyry sills, emplaced along the contact zone of the granodiorite pluton and andesites, mostly parallel to mineralized structures. The mineralization and sills are segmented by several generations of faulting, especially by steeply-dipping NNE-SSW oriented faults of the Hodruša-Štiavnica horst including the epithermal Rozália vein and parallel veinlets.

Mineralized andesites, apart from widespread propylitization, are pervasively silicified with disseminated pyrite and are locally altered to adularia and sericite close to veins (Maťo et al. 1996). Alterations and fracturing, typical for andesites hosting Au-mineralization, were not observed in the granodiorite nor in quartz-diorite porphyries. However, they are affected by fault tectonics of the Hodruša-Štiavnica horst and related younger epithermal mineralization.

The sub-horizontal extension-induced structures used by the Au-bearing mineralization required the same stress field as the emplacement of granodiorite by underground cauldron subsidence as well as the emplacement of post-mineralization porphyry sills by the ring-dyke mechanism. This stress field with δ_3 in the vertical direction was characteristic of the pre-caldera stage of the volcano due to the presence of a shallow magma chamber with differentiated magma of lower density than overlaying rocks (Lexa et al., 1999b). The resurgent horst and related system of epithermal veins was governed by the stress field characteristic of the post-caldera stage with the minimum stress δ_3 oriented in the NW-SE direction, with δ_1 variably oriented in the NE-SW or vertical direction (Nemčok et al., 2000).

The Au-mineralization is the result of two mineralization stages (Maťo et al., 1996; Lexa et al., 1999b). The first stage corresponds to the pervasive silicification/pyritization and formation of early subhorizontal veins with milky quartz and silicified breccias (Svätozár vein and parallel structures), accompanied by carbonate, pyrite, minor sphalerite and rare Au of high fineness. Banded veins and veinlets with quartz, rhodonite, rhodochrosite, adularia with minor pyrite, sphalerite, chalcopyrite and Au of moderate fineness are typical for the second stage. The thickness of these veins is 0.1 - 2 m and the gold content varies in the range 5 - 600 g/t (20 - 50 g/t in average), with Au/Ag ratio from 2:1 to 1:10 (Maťo et al., 1996; Šály & Veselý, 1997).

The Au-mineralization is crosscut (and partially remobilized – 3rd stage) by the younger, base metal, Rozália epithermal vein (and parallel veinlets), represented by quartz, carbonate, gypsum, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, polybasite, hessite and electrum (Maťo et al., 1996).

Fluid inclusions

Microthermometry has been performed on fluid inclusions in quartz, sphalerite and carbonate. Homogenisation temperatures (Th) were most often in the range 290-310°C and 280-300°C for the first and second stage of mineralization respectively, while the salinity usually varied in the range 0-3 wt% NaCl eq, independent of changes in Th values. These values are typical for Au-rich precious metal epithermal deposits (Hedenquist & Lowenstern, 1994). Both stages, but especially the second, were accompanied by extensive boiling of fluids, as suggested by the rare presence of associated high salinity inclusions with progressively lower Th values. First stage mineralization showed boiling at 293-307°C, the second at 292-300°C and 255-269°C. Rare presence of secondary inclusions with lower Th values probably represents lower temperature mineral assemblages (down to 183°C).

Fluid pressures, calculated for the boiling systems (assuming H_2O-CO_2-NaCl system; Wilkinson, 2001), are variable in individual samples. Pressures up to 114 bars were determined for the first stage and are probably the result of initial opening of host fractures, when the hydrothermal system contained a lithostatic in addition to the hydrostatic component. Local overpressure resulted in brecciation and silicification, as seen on the Svätozár vein and parallel vein structures. Substantially lower pressures during the later stage (up to 45 bars only) indicate continuous opening of the system and a transition towards dominantly hydrostatic (or more exactly hydrodynamic) conditions. The pressure decrease resulted in the observed extensive boiling, which in turn caused the precipitation of adularia, rhodochrosite and gold due to substantial decrease of their solubility with continuous boiling (Hedenquist & Arribas, 1999).

The microthermometry data obtained are in agreement with previous fluid inclusion studies from the deposit (Maťo et al., 1996; Jeleň & Háber, 2000). However, Maťo et al. (1996) regarded all Th values from boiling inclusions (including those with heterogenous trapping of vapour and liquid) for true trapping temperatures Tt. Based on this interpretation the authors labelled the Au-mineralization as “mesothermal“. This is in contrast to the present interpretation where just minimum values from a broad range of Th values from boiling inclusions were regarded as Tt.

In order to study the relationship of the Au-mineralization to the Rozália vein, some limited fluid inclusion studies were performed on samples from this vein at levels close to the Au-mineralization. Rozália vein has its own sequence of mineralization that consists of six mineral stages (Koděra, 1978). However, at the depth where Au-mineralization occurs, only the last 3 stages are present. The vein filling is of breccia type with the possibility of incorporating fragments of older Au-mineralization. Fluid inclusion data show two Th modes at around 285 and 187°C, both accompanied by salinity mostly in the range 1-4 wt% NaCl eq. The earlier Th mode is probably associated with the fragments of Au-mineralization and with sphalerite from the 4^{th} stage of the vein filling. The later Th mode is related to quartz from the latest stages of the Rozália vein. The data are consistent with the earlier preliminary fluid inclusion study on the Rozália vein from levels much above the Au-mineralization (Onačila et al., 1995; Jeleň & Háber, 2000).

Stable isotopes (O, H)

O and H isotope data from quartz and carbonate from Au-veins showed a surprisingly homogeneous fluid composition for both stages of mineralization (-2.7 to +1.0‰ $\delta^{18}O$, -78 to –62‰ δD) falling into the field of mixed magmatic and meteoric fluids. However, quartz from the Rozália vein had a relatively lighter fluid composition (-4.7 to +0.6‰ $\delta^{18}O$, -104 to –86‰ δD), while heavier end-member values result from incorporating quartz from breccia fragments of Au-mineralization. Isotopically homogeneous fluids related to Au-mineralization indicate mixing outside the zone of mineralization, excluding the possibility that granodiorite from the footwall of mineralization could be the source of magmatic fluids.

Compared to O, H data from other mineralization types from the ore district (Kantor et al., 1983; Koděra et al., 1999) Au-mineralization at Rozália mine plotted on the $\delta^{18}O_{fluid}$ vs. δD_{fluid} diagram occupies a specific position, located between two trends, each reflecting mixing of meteoric and magmatic fluids. One of the trends is related to Fe-skarns and base metal stockworks while the other is related to horst-related epithermal veins. The different position of the trends is probably related to changes in isotope composition of ancient meteoric waters that resulted from significant changes in climate (towards cooler and dryer) from Early Badenian to Late Sarmatian (Planderová et al., 1993). Consequently, the intermediate position of the data for Au-mineralization indicates their intermediate position in time-scale too.

Conclusions

Fluids responsible for the Au-mineralization were of low salinity, moderate temperature, and were subject to extensive boiling that resulted in Au-precipitation. These are characteristics typical of Au epithermal deposits (Hedenquist & Lowenstern, 1994). Changes in boiling temperature suggest significant changes in confining pressures related to continuous opening of the system and transition from hydrostatic + lithostatic towards hydrodynamic conditions. Corresponding minimum depths calculated for hydrostatic pressures (up to 500 m) suggest shallow position below the paleosurface or discharging of the shallow-dipping hydrothermal system in a deep paleovalley.

Stable isotope data and geological evidence suggest that the Au-mineralization is younger than the granodiorite and the base-metal stockwork hydrothermal system, but older than the sills of quartz-diorite porphyries and horst-related epithermal veins. The hydrothermal fluids related to Au-mineralization used the structures resulting from the pre-caldera stress field with lateral outflow of hydrothermal fluids. The shallow position of the hydrothermal system and the relative age of mineralization indicates that the system could be related to the hydrothermal activity of *hot spring type advanced argillic hydrothermal systems* in the caldera filling (e.g. now located at Červená Studňa). The present vertical distance between the Au-mineralization and the base of caldera filling is roughly 500 - 600 m if corrected for the thickness of post-mineral porphyry sills and displacement on younger faults. The caldera subsidence and related significant changes in hydrologic conditions could have establish new fluid flow paths using structures that originated before or and during the early stage of caldera subsidence. A source of heat and magmatic components for the fluids was probably within the deeper magmatic roots of the volcano (differentiating shallow magma chamber).

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