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New genetic and timing constraints

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MIOCENE MAGMATISM AND ORE FORMATION IN THE SOUTH APUSENI MOUNTAINS, ROMANIA: NEW GENETIC AND TIMING CONSTRAINTS

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ABSTRACT: The South Apuseni Mountains mineral district ("Golden Quadrilateral"), Romania, hosts some of the largest porphyry Cu-Au and epithermal Au-Ag vein deposits in Europe. This study provides the first high-precision U-Pb dating of Miocene magmatic and hydrothermal events in the central (Barza magmatic complex) and northern (Rosia Poieni-Rosia Montana-Bucium) sectors of the district. In the Barza complex mineralised intrusions are spatially associated with coeval barren subvolcanic bodies. Based on field relationships, whole rock major and trace element geochemistry, U-Pb dating on magmatic zircons, and zircon trace element, REE and hafnium geochemistry, we propose geochemical and time constraints on the porphyry ore formation (Valea Morii porphyry Cu-Au deposit) within one of the most intensively mineralised magmatic structures in the district.

The neighbouring Rosia Poieni porphyry Cu-Au and Rosia Montana epithermal Au-Ag deposits, located in the northern part of the "Golden Quadrilateral" are the largest operating mines in the South Apuseni Mountains. Rosia Montana is a breccia-hosted low- to intermediate-sulphidation epithermal system, related to strong phreatomagmatic activity due to shallow emplacement of a dacitic dome structure. The Rosia Poieni deposit, situated about 4 km NE of Rosia Montana, is a porphyry copper system with a high-sulphidation epithermal overprint. Together with the existing ^{40}Ar-^{39}Ar data, the new results show clearly that the two deposits belong to two separate magmatic-hydrothermal systems, the porphyry copper system of Rosia Poieni being about 3 Ma younger than the nearby Rosia Montana epithermal deposit.
Epsilon hafnium signatures of magmatic zircons from the South Apuseni Mountains are indicative of mixed crustal-mantle origin of the magmas with progressively increasing mantle component with time.

INTRODUCTION

Calc-alkaline Miocene magmatism in the South Apuseni Mountains was related to transtensional and rotational tectonics. The magmatic activity was focused within NW-SE oriented extensional basins and developed mainly between 14.7 and 7.4 Ma (Rosu et al, 2004). These structures host some of the Europe's largest porphyry Cu-Au and epithermal Au-Ag deposits, both associated with shallow subvolcanic intrusions. One of the particularities of the South Apuseni district (also called "Golden Quadrilateral") consists of the common spatial association between porphyry Cu-Au and epithermal deposits. Some recent studies (Alderton and Fallick, 2000; Wallier et al, 2006) demonstrated that the mineralizing fluids in both systems have a dominantly magmatic origin, however a direct genetic link between the large porphyry and associated epithermal deposits in the area is still controversial.

This study is focused on two magmatic structures in the South Apuseni Mountains – the Barza magmatic complex and the Rosia Montana-Bucium volcano-intrusive structure (Fig. 1), hosting different styles of hydrothermal systems. We studied mineralised and barren intrusions from the Barza magmatic complex (one of the most intensively mineralised magmatic centres in the district), where based on field relationships, whole rock major and trace element geochemistry, U-Pb dating on magmatic zircons, and zircon trace element, REE and hafnium geochemistry, we propose geochemical and time constraints on the porphyry ore formation.

The second task of this study was to highlight the temporal and genetic succession of magmatic and hydrothermal events within the Rosia Montana-Bucium volcano-intrusive structure in the northern part of the district, hosting the largest operating mines in the South Apuseni Mountains – Rosia Poieni porphyry Cu-Au deposit and Rosia Montana breccia-hosted epithermal Au-Ag deposit (Fig. 1). Bucium-Tarnita is a porphyry stock cut by epithermal veins, located in the southernmost part of the structure (Fig. 1).

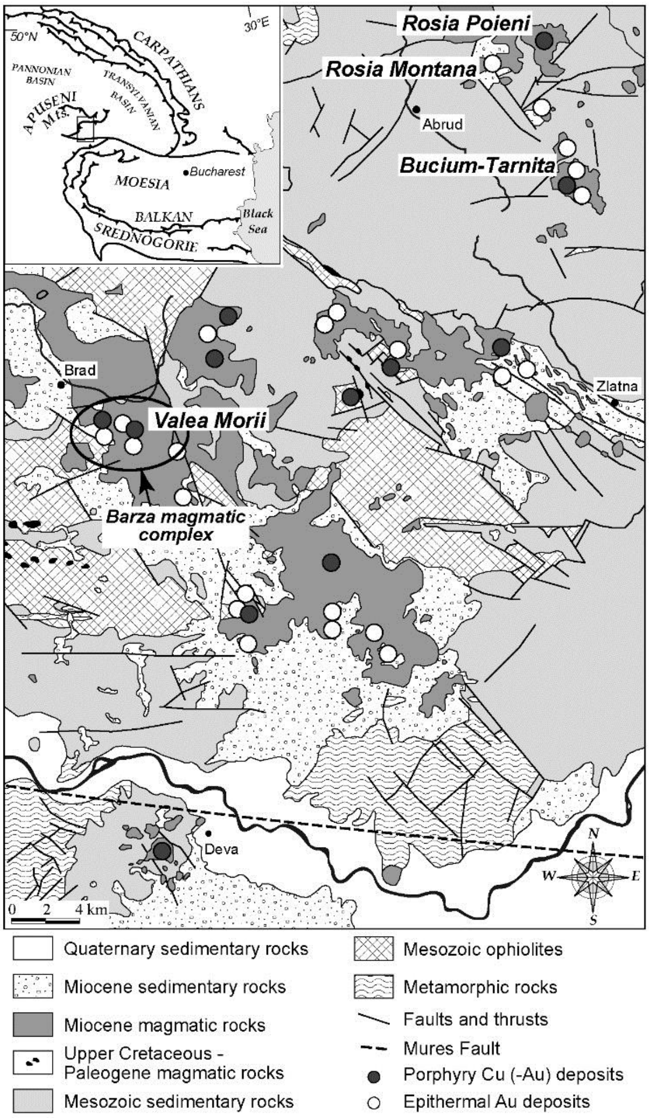

Figure 1. Simplified geological map of the South Apuseni Mountains mineral district. Location of Valea Morii, Rosia Poieni and Rosia Montana deposits is indicated as well (after Bostinescu, 1984, modified).

GEOLOGICAL SETTING

Porphyry and epithermal deposits in the "Golden Quadrilateral" are spatially and genetically associated with Miocene calc-alkaline and alkaline magmatic rocks, cropping out either in intra-mountain basins, or in clusters of magmatic bodies that are oriented roughly NW-SE (Bostinescu, 1984; Rosu et al., 2004; Fig. 1). Although a subduction geochemical signature has been demonstrated for these rocks, some authors (e.g., Seghedi et al., 1998; Rosu et al., 2004) have suggested that these magmas were generated in response to extension of the lithosphere.

The Barza magmatic complex (~8 km in diameter; Fig. 1) is situated in the central part of the district, as part of the Zarand-Brad Basin. The basement in the area consists of Mesozoic island arc volcanics (basalts, basaltic andesites, andesites and rhyolites) and diorite-granodiorite subvolcanic intrusions, and Upper Cretaceous-Paleocene sediments. These rocks are covered by Miocene sedimentary and volcano-sedimentary (Badenian) formations. The magmatic complex itself is build up by Sarmatian-Pannonian volcanic and subvolcanic rocks. Volcanic rocks consist of pyroclastics and flows. Subvolcanic intrusions have mainly andesitic composition with different proportions of the rock-forming minerals: amphibole-pyroxene-, amphibole-biotite-quartz andesites etc. In the central part of the complex the porphyry Cu-Au deposit of Valea Morii is hosted by a relatively small dioritic stock (Fig. 1). The porphyry mineralisation is overprinted by epithermal Au vein formation, which is extensively developed to W and NW, crosscutting the subvolcanic intrusion of Barza.

The Rosia Montana-Bucium volcano-intrusive structure occupies the northern sector of the district (Fig. 1). The Rosia Montana deposit is intimately related to a diatreme breccia complex associated with two dome-like dacitic bodies. The Rosia Poieni deposit is hosted by the Poieni diorite porphyritic stock, about 4 km NE of Rosia Montana. Rotunda type volcanic andesites and their pyroclastic derivates, cropping out in the area between the two deposits and also east and south of Rosia Poieni, have a subhorizontal basis and they cover the volcanoclastic breccia and dacites from the Rosia Montana structure, as well as earlier folded Cretaceous sedimentary rocks.

SAMPLING AND GEOLOGICAL SETTING

Twenty-six unaltered rock samples from the Barza magmatic complex and 28 samples from the Rosia Montana-Rosia Poieni sector have been studied for major and trace elements. Five carefully selected samples from each structure have been used for U-Pb dating, including samples from barren and mineralised magmatic host rocks, as well as intramineralization dykes.

Major elements on whole rock samples were analyzed by X-ray fluorescence (XRF) at the University of Salzburg, Austria. Trace elements and rare earth elements (REE) were analyzed by laser-ablation inductively-coupled-plasma mass-spectrometry (LA-ICP-MS) on molten lithium-tetraborate pellets at ETH, Zurich, Switzerland.

Conventional U-Pb single grain zircon dating was used to determine the crystallization ages of the studied magmatic rocks, as this method combines the relative resistance of zircons to hydrothermal overprint with the high precision of the ID-TIMS (Isotope Dilution – Thermal Ionization Mass Spectrometry) technique. Analyses were performed at ETH, Zurich. Hafnium isotope ratios in zircons were measured on a MC-ICP-MS at ETH, Zurich. Time correction of the ε_{Hf} was made using present day chondritic ratios of 0.28286 ($^{176}Hf/^{177}Hf$) and 0.0334 ($^{176}Lu/^{177}Hf$) and an average $^{176}Lu/^{177}Hf$ ratio of 0.005 for all zircons.

LA-ICP-MS analyses of zircons were applied in order to study variations in REE and trace elements. Scanning electron microscopy-cathodoluminescence (SEM-CL) images of zircons helped the interpretation of the U-Pb zircon data and contributed to the understanding of the compositional variations.

RESULTS

Major and trace element analyses show normal calc-alkaline character of magmas from the Barza complex. Studied magmatic rocks have mostly andesitic composition. Just two samples plot into the dacite field. All rock samples are medium-K in composition. Incompatible element abundances normalised to the primitive mantle show well expressed depletion in Nb and Ta and enrichment in LILE and Pb, characteristic features of subduction-related magmas. Sr content is usually low and no adakitic tendency has been observed. REE patterns are also very similar for mineralised and barren intrusions. They do not show a Eu anomaly.

Magmatic rocks from the Rosia Montana-Rosia Poieni area also show normal calc-alkaline signature. They are more evolved at Rosia Montana, where they have dacitic composition, compared to Rosia Poieni, where the compositions plot within the andesitic field. Samples from Rosia Poieni intrusion and related volcanics display "adakitic-like" signatures (Rosu et al., 2004). Samples from Rosia Montana show a small Eu anomaly, not detectable in the Rosia Poieni samples.

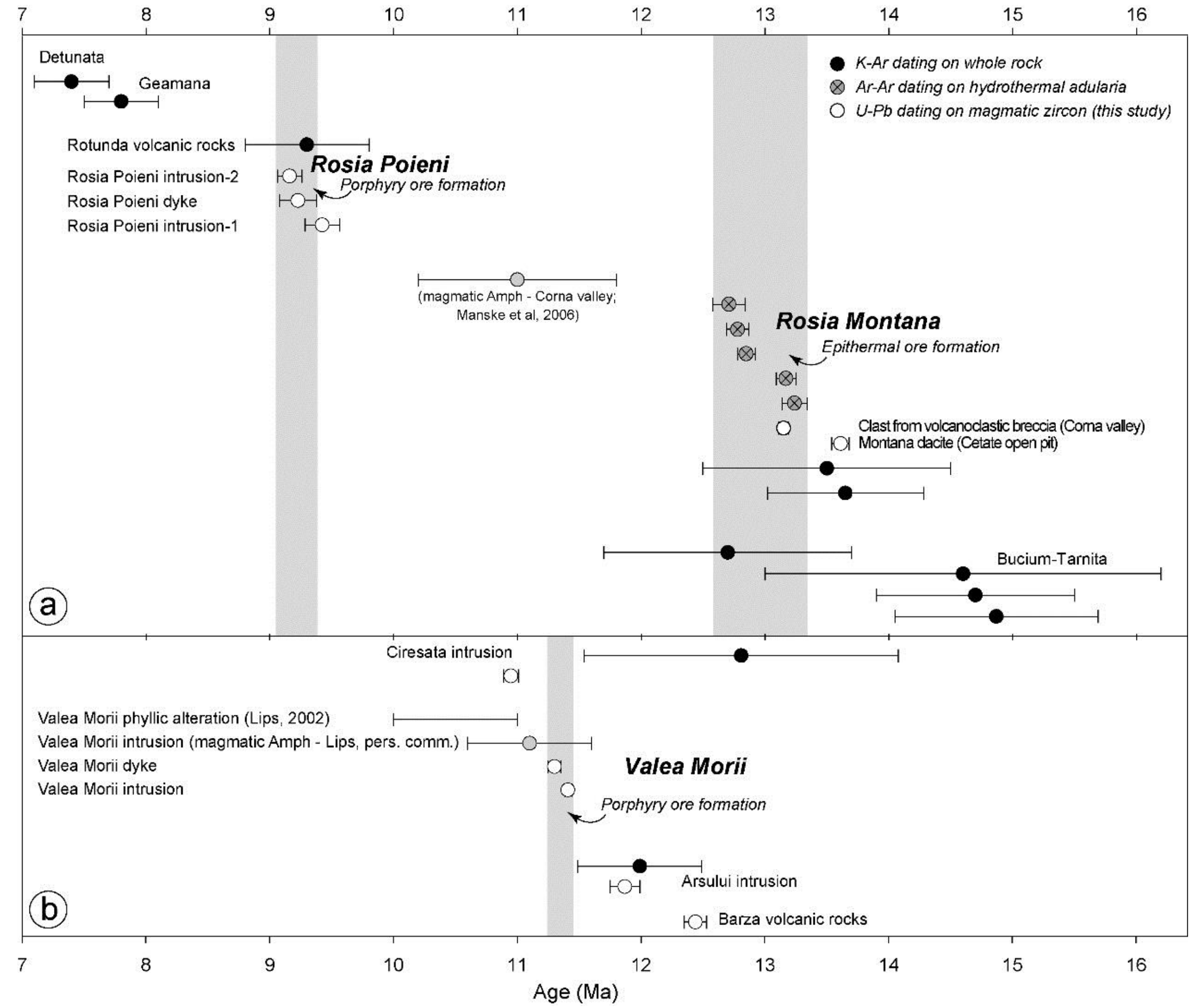

Figure 2. Summary diagram for the timing of magmatism and mineralisation in the Rosia Montana-Bucium volcano-intrusive structure (**a**) and the Barza magmatic complex (**b**), including the U-Pb dating on magmatic zircons from this study, as well as published K-Ar dating on whole rock samples (Rosu et al., 2004) and Ar-Ar dating on hydrothermal minerals (Lips, 2002; Manske et al., 2006; Wallier et al., 2006).

Figure 2 is a summary diagram for the timing of magmatism and ore formation in the Rosia Montana-Bucium volcano-intrusive structure and the Barza magmatic complex, summarising the existing Ar-Ar and K-Ar data and the U-Pb dating from the present study. Bracketing the timing of porphyry ore formation at Rosia Poieni and Valea Morii was possible by dating the main host intrusions and intramineralisation dykes. The timing of magmatism and related porphyry mineralization at Rosia Poieni ranges within the narrow interval of 9.42-9.16 Ma. ^{40}Ar-^{39}Ar dating of the high-sulfidation epithermal veining overprinting this porphyry system is in progress.

The magmatic activity in the Rosia Montana area took place in the time interval 13.6-13.2 Ma and was immediately followed by the economic hydrothermal mineralization (13.24-12.71 Ma; Fig. 2a).

Porphyry ore-formation at Valea Morii occurred between 11.41 and 11.30 Ma, about 1 Ma after the main volcanic activity (Fig. 2b). Magmatic activity continued during and after the porphyry ore-formation. The Ciresata intrusion which is clearly post-dating the porphyry formation at Valea Morii by about 0.5 Ma is cut by epithermal Au-bearing veins, thus confirming the possible timing of the white mica alteration accompanying the epithermal mineralisation at 10-11 Ma (Lips, 2002).

Zircons from all studied samples show extremely consistent chondrite-normalised REE patterns. A small Eu anomaly is present in samples from Barza and Rosia Montana. Slight increase of the Eu/Eu*, Nb/Ta and Th/U ratios has been recorded as a function of the crystallisation age of zircons. These data suggest a slightly increasing mantle component of the magmas with time. A positive Ce anomaly is considerably higher for the mineralised Valea Morii intrusion and the intramineralization dyke, compared to the samples from barren intrusions in the Barza complex, suggesting a higher oxidation state of the parental magma during the stage of porphyry ore-formation.

Epsilon hafnium signatures of zircons also show a progressive increase with time (Fig. 3).

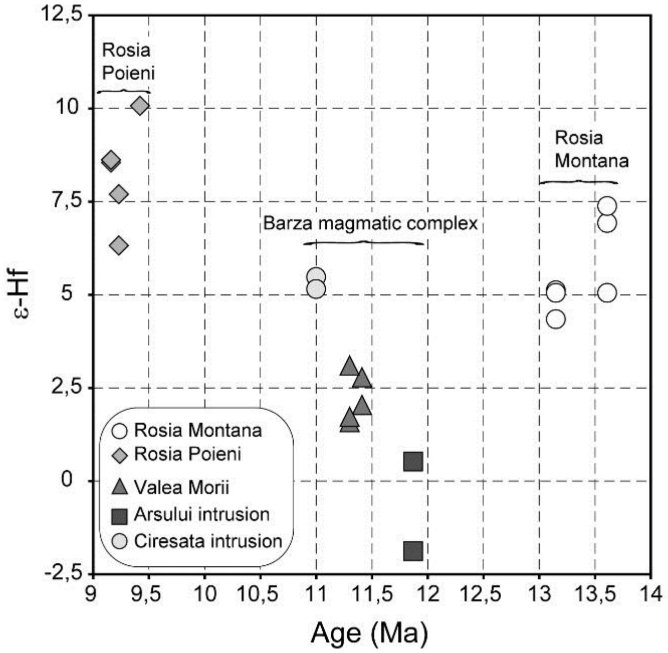

Figure 3. Epsilon Hf values of zircons from mineralised and barren intrusions from the Barza magmatic complex and magmatic rocks from the Rosia Poieni and Rosia Montana deposits versus U-Pb zircon ages.

Different ε-Hf values for zircons from the central and northern part of the district could be due to differences in the basement and different degree of basement assimilation. Rosia Poieni-Rosia Montana samples display increased mantle component signatures compared to the Barza samples.

CONCLUSIONS

This study provides the first high-precision U-Pb dating of Miocene magmatic and hydrothermal events in the South Apuseni Mountains. The results show clearly that despite their proximal location, and the magmatic character of the mineralizing fluids in both, the Rosia Montana and Rosia Poieni deposits belong to two separate magmatic-hydrothermal systems. The porphyry copper system at Rosia Poieni is about 3 Ma younger than the neighbouring Rosia Montana epithermal deposit, which is much longer than the thermal lifetime even of a very large upper-crustal magma chamber.

Despite the similarities observed for major and trace element distribution between mineralised and barren intrusions from the Barza magmatic complex, some small but crucial differences in zircon geochemistry (trace elements, REE and hafnium isotopes) could help for better understanding the magmatic and geochemical factors controlling the porphyry ore formation in this magmatic structure. The mineralised Valea Morii intrusion crystallised clearly in more oxidised conditions compared to the surrounding barren intrusions.

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