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Timing of Magmatism and Mineralization in Southeastern Europe

Albrecht von Quadt,[1,]* Daniela Gallhofer,[1] Stoyan Georgiev,[2] and Irena Peytcheva[1,2]

[1]Institute of Geochemistry and Petrology, ETH Zurich, 8092 Zurich, Switzerland
[2]Institute of Geology, Bulgarian Academy of Science, Sofia, Bulgaria

*E-mail, albrecht.vonquadt@erdw.ethz.ch

The Alpine-Balkan-Carpathian-Dinaride belt is one of the world's oldest mining areas and has played a major role in the history of European civilizations. Today, it is Europe's premier Cu-Au(-Pb-Zn-Ag) province, especially for gold-rich deposits associated with calc-alkaline magmatism. The latter is exposed in three main magmatic and metallogenic belts with specific deposit types and productive time windows.

The Apuseni-Banat-Timok-Srednogorie Late Cretaceous magmatic arc in the Carpathian-Balkan orogen formed on the European margin during closure of the Neotethys Ocean. Trace element and isotopic signatures of the magmas indicate a subduction-enriched source and variable contamination by continental crust. Extensive U-Pb zircon dating combined with reliable published data suggest magmatic activity at a continental margin for 25 m.y. (~92–67 Ma) related to oblique subduction and slab steepening. Ore mineralization is related to porphyry systems and includes world-class porphyry Cu-Au-(Mo) deposits, proximal and distal intermediate- and high-sulfidation epithermal deposits, and sediment-hosted and carbonate-replacement deposits that formed during an economically important window of 6 to 8 m.y. (92–86 Ma or 86–78 Ma in the different segments). Predating tectonics and stratigraphy played a particularly important role for the location and grade of mineralization. The Apuseni-Banat-Timok-Srednogorie was subsequently deformed into a complex orocline by continental collisions.

The Serbo-Macedonian-Rhodope belt is directly connected to postcollisional episodes of back-arc extension related to slab break-off and asthenospheric upwelling and delamination (60–40 Ma) and the formation of metamorphic core complexes (MCCs)—the North Rhodope MCC (38–25 Ma) and South Rhodope MCC (after 23–22 Ma). The magmatism preserves largely subduction related features as sourced in the subcontinental mantle lithosphere and lower crust that were enriched during previous subduction. Several isolated time windows of ore-forming processes are obtained in the Apuseni-Banat-Timok-Srednogorie belt, partly using U/Pb zircon ages but also published Ar-Ar and K-Ar data: 43 to 39 Ma, sparse epithermal and intrusion-related Au-Ag to Au-W deposits in the western Rhodopes; 38 to 32 Ma, epi- to mesothermal Pb-Zn(-Ag-Au) vein and carbonate replacement deposits from Bosnia (e.g., Trepca) through Serbia-Macedonia-Greece and southern Bulgaria; 32 (30) to 24 Ma and 23 to 18 Ma (porphyry Cu-Au-(Mo) and epithermal Au), connected with the extensional magmatism following the MCC formation; and, finally, 12 to 1.8 Ma for several epithermal and Carlin-type Au deposits—e.g., the Alshar deposit.

The "gold quadrilateral" of the Apuseni Mountains, also known as the Transylvanian gold province, includes a cluster of large, low-sulfidation epithermal Au-Te vein deposits including Sacarimb and Rosia Montana, which is probably Europe's largest gold resource. The epithermal veins are spatially and temporally associated with small- to medium-sized porphyry-style Cu(-Au) deposits in calc-alkaline intrusive centers of Miocene age. Magma generation and the emplacement of numerous intrusive stocks are probably related to extensional accommodation of major strike-slip motions, associated with the northeastward incursion of the Adriatic-Pannonian microcontinent. The time of ore formation of the most

important deposits of the Apuseni Mountains includes a window of 4 m.y. between 13.5 and 9.1 Ma, using recent U/Pb zircon ages.