Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35355

Insights into the sub-volcanic plumbing system of the South Apuseni Mts., (Romania) – a magmatic enclave perspective

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Minerals and their inclusions provide a powerful archive of the temporal, thermal, and chemical evolution of magmatic systems, particularly where bulk-rock compositions obscure deep crustal processes. We investigate basaltic to basaltic-andesitic magmatic enclaves hosted in Neogene andesites from the South Apuseni Mountains (western Romania), a segment of the Carpathian orogenic belt, characterized by calc-alkaline to locally adakitic magmatism. Using an integrated mineralogical approach combining major- and trace-element mineral chemistry, thermobarometry, zircon geochronology, and melt inclusion analysis, we reconstruct the evolution of a deep crustal magmatic system recorded by enclave-hosted mineral cargo.

The enclaves exhibit simple, cumulate-like mineral assemblages dominated by plagioclase, amphibole, and accessory zircon, apatite, and oxides. Bulk-rock compositions show systematic enrichments in certain trace elements (e.g. Ti, Zn, Sc, V) indicating crystal accumulation rather than quenched melt compositions. Despite their plagioclase-rich modal mineralogy, some of the enclaves display pronounced negative europium anomalies (Eu/Eu* = 0.5-0.6 in some samples, compared to 0.8-0.9 in others and in the host andesite), correlated with elevated Y and MREEs. These relationships require early plagioclase-dominated crystallization and segregation from a mafic parent melt, leading to Eu depletion of the residual melt prior to the formation of the cumulate sampled by the enclaves.

Plagioclase exhibits normal zoning from An_{75-90} cores to An_{45} rims, while amphibole cores of tschermakitic composition are overgrown by magnesio-hornblende rims. Amphibole thermobarometry indicates crystallization of cores at ~9-10 kbar and ~900 °C, consistent with formation in a deep crustal reservoir, whereas thin rims record equilibration at ~3-4 kbar and ~700 °C. Zircon U-Pb ages from the enclaves overlap with emplacement ages of the host andesite, indicating a cogenetic relationship. Silicate melt inclusions in zircon record highly evolved melt compositions (up to ~ 70-75 wt.% SiO_2), and acicular zircon morphologies indicate rapid crystallization from locally differentiated interstitial melts.

Together, these mineralogical records support a multi-stage model involving early plagioclase segregation, formation of plagioclase and amphibole cumulates at lower-crustal depths, and mechanical entrainment of crystal-rich mushes during ascent in an extensional setting.