

Refining the Magmatic–Hydrothermal Evolution of the Altar Cu-(Au-Mo) Porphyry System: Insights from High-Precision Geochronology and Zircon Geochemistry

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The province of San Juan, Argentina, hosts some of the world's largest Cu resources associated with numerous undeveloped Cu–Au porphyry-epithermal deposits. However, their precise temporal evolution remains poorly constrained, as few studies rely on high-precision geochronology, which is critical for understanding mineral deposit formation processes.

The Altar Cu-(Au-Mo) porphyry deposit provides an opportunity to address this gap in our understanding. It comprises three main mineralized centers (Altar Central, Altar United, and Altar East), hosting ~2.4 Gt of measured and indicated resources (0.42% Cu, 0.07 g/t Au, 1.22 g/t Ag, 42 ppm Mo) and ~1.2 Gt of inferred resources (0.37% Cu, 0.04 g/t Au, 1.25 g/t Ag, 45 ppm Mo). This study presents an integrated framework combining high-precision geochronology (CA-ID-TIMS U-Pb in zircon; ID-N-TIMS Re-Os in molybdenite) with zircon trace-element geochemistry (LA-ICP-MS).

New U-Pb ages reveal three pulses of porphyry emplacement at ~11.59 Ma, ~11.36 Ma, and ~10.41 Ma, assigned to the Upper Subvolcanic Suite (USS; middle-late Miocene), with the first two associated with the main mineralization stage. These intrusions are hosted by volcanic wall-rocks of the Pachón Formation (~22.16 Ma; early Miocene), mineralized only when spatially close to the aforementioned porphyry centers. Rhenium-Os geochronology identifies two stages of molybdenite precipitation (~11.0 Ma and ~10.4–10.0 Ma). Mineralization lasted ~1.7 Ma and developed episodically, with progressive downward migration of the mineralized centers.

Zircon geochemistry indicates USS magmas were hydrous ($\text{EuN}/\text{Eu}^* > 0.4$), oxidized ($\Delta\text{FMQ} > +1$), and underwent deep-level differentiation (high $(\text{EuN}/\text{Eu}^*)/\text{YbN}$), consistent with fertile magmas. In contrast, Pachón Formation magmas were drier, less oxidized, and differentiated at shallower crustal levels.

Our results reconstruct the magmatic–hydrothermal evolution of the Altar system at high temporal resolution, providing new exploration criteria based on timescales of metals precipitation, physicochemical conditions, and magmatic fertility signatures derived from zircon geochemistry.