

Crustal Thickness as a First-Order Control on Copper Deposit Styles in Evolving Arcs

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Copper systems in magmatic arcs display systematic lithogeochemical variations linked to crustal maturity, expressed through calc-alkalinity and redox state. Porphyry systems are associated with thick crust, hydrous and oxidized magmas, and large magmatic volumes, whereas other arc-related systems (e.g., VMS, IOCG, Sn–Cu veins) reflect distinct tectono-magmatic conditions along this evolutionary spectrum.

This study integrates more than 20,000 whole-rock geochemical analyses from modern and fossil arcs (44 deposits) to evaluate the role of crustal thickness in controlling magmatic and hydrothermal characteristics. A multielement proxy is used to estimate crustal thickness, while stochastic modeling evaluates the coupling between magmatic volume, system duration, and redox state. A magma–crust density contrast model further constrains emplacement depths under typical conditions and identifies anomalous behaviors related to geodynamic controls.

Results show that copper systems evolve with increasing crustal thickness (CT), which systematically modulates calc-alkalinity (Rb/Sc) and redox state (FMQ). VMS deposits form in primitive arcs ($CT \leq 25\text{--}30\text{ km}$), characterized by low Rb/Sc (0.2–1) and moderately oxidized conditions ($\Delta\text{FMQ} + 0.1$). IOCG systems occur in thicker crust ($\sim 30\text{--}35\text{ km}$), with intermediate Rb/Sc (2–4) and near-neutral redox conditions ($\Delta\text{FMQ} \approx 0$). In sub-mature arcs ($\sim 38\text{--}45\text{ km}$), Cu–Au porphyries dominate, showing higher Rb/Sc (7–10) and increased oxidation ($\Delta\text{FMQ} + 0.7$). In mature arcs ($\sim 48\text{--}55\text{ km}$), Cu–Mo porphyries exhibit high Rb/Sc (10–20) and strongly oxidized conditions ($\Delta\text{FMQ} + 0.9$). In super-mature crust ($\geq 55\text{--}60\text{ km}$), Sn–Cu systems develop under very high Rb/Sc (20–30) and reduced conditions ($\Delta\text{FMQ} - 2.0$).

The stochastic FMQ–volume–Cu relationship indicates that redox defines a critical efficiency threshold, with optimal conditions near $\Delta\text{FMQ} + 1$. However, model results suggest that supergiant deposits are primarily associated with flux–time conditions. Notably, porphyry deposits in the Chilean Andes are emplaced at shallower levels than predicted by the magma–crust density model. This deviation is likely related to geodynamic conditions involving prolonged crustal thickening followed by gradual tectonic relaxation, which may sustain high magmatic fluxes and long-lived systems, favoring the formation of supergiant copper deposits.