

The role of exhumation in generating high-grade copper deposits: From the Andes to Arizona

Frances Cooper^{1,2}, Byron Adams^{1,2}, Simon Dahlström², Ehlers Todd³, Matthijs van Soest⁴, Kip Hodges⁴, Brian Jicha⁵, Bradley Singer⁵, Jasmin Bower¹, Thomas Lamont⁶, Rebecca Perkins⁷, Adam Gorecki⁸, Jaime Cortes Yañez⁹

¹University College London, London, United Kingdom, ²University of Bristol, Bristol, United Kingdom, ³University of Glasgow, Glasgow, United Kingdom, ⁴Arizona State University, Tempe, USA, ⁵University of Wisconsin-Madison, Madison, USA, ⁶University of Nevada, Las Vegas, USA, ⁷BHP, London, United Kingdom, ⁸BHP Legacy Assets, Tucson, USA, ⁹Camino Las Flores, Santiago, Chile

Porphyry copper deposits (PCDs) are notoriously high-tonnage and low-grade, making extraction and processing inefficient and environmentally destructive. With global demand set to double within a decade, it is ever more important to locate the most concentrated, least damaging deposits. The exhumation history of a PCD plays an important role in determining copper concentration. During initial hypogene mineralization, rapid exhumation is required to advect heat toward the surface, allowing metal-carrying magmas and fluids to transport their cargo into the shallow crust. To achieve maximum ore grade, exhumation must then slow to allow sufficient time for secondary supergene enrichment driven by meteoric water close to the surface. Tracking spatial-temporal variations in exhumation can thus provide a critical tool to narrow search space for high-grade PCDs, particularly in the preliminary, high-risk, terrane-scale phase of exploration.

However, constraining precise and accurate exhumation histories in magmatically-active regions is challenging. They are typically derived from rock cooling histories, but these can be severely disrupted by magmatic heat. To address this, we track exhumation by combining zircon U-Pb crystallization ages and biotite ⁴⁰Ar/³⁹Ar, zircon (U-Th)/He, and apatite (U-Th)/He cooling ages with a thermokinematic model that includes magmatic heat. Independent geobarometric emplacement depth constraints provide an important check on model results, ensuring that predicted exhumation histories are geologically plausible.

To test this approach, we applied it to a ~300 km segment of the Middle Eocene-Early Oligocene copper belt in northern Chile between the Chuquicamata and Queen Elizabeth PCDs. The results reveal multi-step exhumation histories that vary considerably along the belt, but generally show that hypogene mineralization coincided with the phase of fastest exhumation before slowing prior to surface exposure. Applying the same approach to the Laramide Porphyry Belt in Arizona, we are currently investigating the extent to which variations in exhumation might explain spatial-temporal variations in copper grade.