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Using pyrite composition to track the multi-stage fluids superimposed on a porphyry Cu system

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Abstract

The Yulekenhalasu porphyry Cu-Mo deposit (0.2 Mt Cu at 1.04 wt% and 0.012 Mt Mo at 0.06 wt%) is located in the Devonian Halasu copper belt, East Junggar block, northwest China. At Yulekenhalasu, Cu and Mo mineralization commonly occurs as disseminated sulfides or veinlets in porphyry-related alteration zones. Five alteration stages have been identified, including porphyry-type alteration, i.e., sodic-calcic (stage I), potassic (stage IIa), propylitic (stage IIb), and phyllic (stage III) alteration, and widespread late Cu sulfide-bearing veins (stage IV) cross-cutting porphyry-type alteration, plus a post-ore fault-controlled argillic alteration (stage V). Stages IV and V have overprinted porphyry-type alteration (stages I–III).

Anomalous concentrations of trace elements in stage IIb pyrite (e.g., Ti, Zr, Gd, and Hf) are due to the presence of micro-inclusions (e.g., zircon and rutile) in the low-temperature (~200 °C) propylitic zone. Cu, Ag, Co, and Mn, occurring as stoichiometric substitutions or as tetrahedrite inclusions in overprinting stage IV pyrite, were sourced directly from the primary hydrothermal fluid. The enrichment of distal pathfinder elements (e.g., Cr, Au, and Tl) in overprinting stage V pyrite was caused by a low-temperature (~160 °C) hydrothermal event related to regional orogenic Au mineralization. The spatial variation of Se/S in pyrite among various paragenetic stages were influenced by changes in the hydrothermal fluid composition and temperature, with the latter having the effect of decreasing pyrite Se/S. Lower Se concentrations in pyrite of stages IIb and III close to the orebody are explained by relatively higher temperatures in the locus of mineralization. This may provide a potential vectoring tool to mineralization using pyrite geochemistry in porphyry deposits.

Systematic thermodynamic calibrations were applied to pyrite compositions to fingerprint the corresponding Se/S and Co/Ni ratios of fluids and further to develop a complete metallogenic model for Yulekenhalasu. The Devonian diorite porphyry generated fluids that produced the early porphyry-type alteration. High Co/Fe (average ~1×10^{-4}) and Ni/Fe (average ~3×10^{-6}) ratios of fluid for late Cu sulfide-bearing veins, combined with higher Se/S (average ~6×10^{-7}) than orogenic Au deposits (average ~3×10^{-8}), indicate that the fluids possibly derived from a Late Devonian-Carboniferous mafic intrusion. Argillic alteration assemblages forming at ca. 280 Ma host pyrite relatively enriched in Au (average 0.1 ppm, with native gold inclusions). Therefore it is likely related to a regional orogenic gold mineralizing event in the Early Permian that overprinted Devonian mineralization. Although spatially contiguous, hydrothermal alteration and hypogene mineralizing stages identified herein represent discrete episodes of hydrothermal activities at Yulekenhalasu. The multi-stage alteration features observed at Yulekenhalasu may provide insights into the complete evolutionary history of Paleozoic porphyry Cu deposit systems in the Central Asian orogenic belt. This study contributes to a better understanding of the metallogenic and exploration models of porphyry Cu deposits overprinted by multi-stage hydrothermal events, which is economically important in Phanerozoic orogenic belts.

Keywords: Central Asian Orogenic Belt, Yulekenhalasu, porphyry Cu-Mo deposit, pyrite composition, superimposed alteration and mineralization