Copper isotopic vectors to supergene enrichment: Leached cap isotopic footprint of the Quellaveco porphyry copper deposit, southern Peru

Corresponding author: David P Braxton, Anglo American, dave.braxton@angloamerican.com

Co-authors:
Ryan Mathur, Juniata College, MATHURR@juniata.edu

Superior copper grades developed by the processes of supergene enrichment represent one of the most fundamental determinants of value of a porphyry copper mining operation. In porphyry exploration, effective vectoring toward and early identification of significant copper enrichment may dramatically enhance a project’s economic profile. Interpretation of limonite species in surficial weathering profiles has long been practiced to evaluate the potential for underlying supergene copper enrichment in porphyry environments, with varying degrees of success. Recent studies highlighting potential exploration applications of copper isotopes within porphyry supergene environments prompted detailed copper isotopic analysis of 222 leached cap iron oxides and supergene copper sulfides from the weathering profile of the Quellaveco porphyry deposit in southern Peru. The study revealed a broad range of $\delta^{65}$Cu copper isotopic values for supergene phases between -27 and +6 per mil, representing the largest degree of fractionation measured in one deposit to date. Significantly, copper isotope values from Quellaveco’s leached-cap iron oxides display systematic variation as a function of the supergene geological context and maturity of the underlying supergene enrichment.

Limonites from Quellaveco showing weak isotopic depletion ($\delta^{65}$Cu -5.0 to -1.0 per mil) correspond to areas of the leached cap overlying zones of moderate-strong copper enrichment, while those showing strong isotopic depletion ($\delta^{65}$Cu < -5 per mil) correspond to areas of the leached cap the pyritic halo to the system. Leached cap limonites from Quellaveco showing moderate to heavy isotopic values ($\delta^{65}$Cu >> +1 per mil) overlie zones where the sulfide enrichment blanket has been incised by erosion, and has experienced physical and isotopic re-working by two or more cycles of supergene enrichment. Leached cap limonites showing negligible copper isotopic depletion ($\delta^{65}$Cu -1.0 to +1.0 per mil) overlie late-mineralization or post-mineralization intrusions, or to areas well beyond the limits of the porphyry system, and thus suggest insignificant enrichment potential.

Experimental studies show that isotopic fractionation during low-temperature oxidative leaching and dissolution of copper sulfides favors partitioning of the heavier copper isotope into the aqueous phase. The copper isotopic patterns observed for leached cap limonites from Quellaveco are consistent with Rayleigh models describing leaching of variable amounts of copper from a hypogene ($\delta^{65}$Cu near 0 per mil) or enriched ($\delta^{65}$Cu > +2 per mil) copper sulfide zone. The isotopically lightest values ($\delta^{65}$Cu as low as -27 per mil) characteristic of limonites overlying the pyritic (5-10% pyrite) halo reflect near-complete leaching of copper, a process consistent with the elevated acid-generating capacity that would logically attend the weathering of such material. The study results suggest that copper isotope analysis of supergene limonites represents a complement to, and an improvement upon, the traditional limonite-species-focused methods of leached cap interpretation when exploring for supergene-enriched zones.