

## Insights into Zonation Within the Olympic Dam Cu-U-Au-Ag Deposit from Trace Element Signatures of Sulfide Minerals

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LA-ICP-MS analyses of Cu-(Fe) sulfides (chalcocite, related  $\text{Cu}_{2-x}\text{S}$  phases, bornite, chalcopyrite) and pyrite were made on a sample suite representative of vertical and lateral zonation in the Olympic Dam Cu-U-Au-Ag deposit. The deposit is characterized by zoned mineralization (chalcocite, chalcocite-bornite, bornite-chalcopyrite, and chalcopyrite-pyrite zones, respectively, outward from the deposit core and also downward, and the boundary between hematite-stable and deeper magnetite-stable assemblages at ~1,600-m depth in the SE lobe). Sampling also included mineralization at the edges of the host Olympic Dam Breccia Complex, granite-hosted satellite mineralization, mineralization associated with dolerite dikes and mafic volcanic rocks, polymetallic (sphalerite- and/or tennantite-bearing) ores, mineralization from as deep as 2,000 m, and exotic lithologies such as possible BIFs entrapped within granite, in which interconversion between Fe oxides is distinct from other parts of the deposit.

Geochemical trends for each mineral define a series of signatures influenced by factors including protolith, spatial position, extent of superimposed overprinting by later fluids, and the presence/absence of coexisting minerals. Inherited signatures, distinct from those hosted within hematite breccias or granites, are recognized in sulfides hosted by carbonaceous metasedimentary units or mafic volcanic rocks. Sulfides are broadly enriched in a range of “granitophile” elements (Sn, Mo, chalcophiles, chalcogens), emphasizing the likely role played by hydrothermal fluids associated with host granite. The role of mafic rocks as a source can be tracked by the presence of Cr, Ni, and Zn at detectable concentrations in sulfides within and approaching dikes, and in late veins. The polymetallic signature, exotic in IOCG terms, can be attributed to signatures inherited from mafic (dike and volcanic) protoliths. Although some metal contribution from the mafic dikes is seen from trace element signatures of chalcopyrite, this is only one among many signatures defining overall hydrothermal evolution.

Trace element data are concordant with primary vertical zonation in which temperature gradient is the main controlling factor. Despite variation within and between samples, Cu-(Fe) sulfides broadly contain more Bi and less Te toward deeper levels. Mineralogical and geochemical vertical zonation patterns are not contradictory to formation of the orebody within an active breccia system. The dominant type of fluid-rock interaction is replacement via coupled dissolution-reprecipitation reaction. Such replacement drives confined reaction within cm-, dm-, and m-scale intervals, resulting in overall zonation across the ~2-km vertical extent of the orebody. Open-fracture fluid circulation is restricted to superimposed events, expressed as sequential vein generations.

Where coexisting, Ag is partitioned into chalcocite, and Bi into bornite. Chalcopyrite and pyrite are only significant Ag-Bi hosts where bornite and/or chalcocite are absent. Whereas Bi is readily locked in and retained within sulfides, LA-ICP-MS maps show subsolidus grain-scale remobilization of Ag, carrying implications for deposit-scale spatial vectors involving Ag. Arsenic, Co, and Ni occur mostly in pyrite; LA-ICP-MS maps depict cycles of oscillatory zonation during growth and brecciation.

Results carry implications for understanding deposit evolution in terms of superimposed events and underlying reasons for deposit-scale zonation. “Trace element-in-sulfide” signatures should be useful

in developing vectors for reconnaissance exploration elsewhere in the district if mineral associations are well characterized in terms of primary versus overprint character.