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Hydrothermal modification of detrital apatite as a record of saline brine–rock interaction and aquifer fertility in sediment-hosted copper systems

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Sediment-hosted copper deposits form through circulation of saline basinal brines through permeable aquifer units, yet mineral-scale records of these fluid–rock interactions are rarely preserved. We evaluate whether apatite, a common detrital resistate mineral, records systematic chemical modification during hydrothermal alteration and can therefore serve as a proxy for fluid composition, redox evolution, and aquifer fertility.

Approximately 200 samples from the Central African Copperbelt and related basins were characterized using automated mineralogy, cathodoluminescence (CL), EPMA, and LA-ICP-MS (~2500 apatite analyses). Two apatite populations are consistently distinguished. Detrital apatite (CL-blue, rounded) exhibits variable LREE-enriched patterns and pronounced negative Eu anomalies consistent with igneous to metamorphic provenance. In contrast, CL-green apatite—commonly inclusion-rich and texturally associated with hydrothermal alteration—is characterized by systematic LREE depletion, lower La/Gd ratios, subdued to locally positive Eu/Eu*, elevated Sr, and commonly low U/Pb ratios.

These geochemical shifts indicate interaction between detrital apatite and saline basinal brines capable of preferentially mobilizing LREE relative to MREE–HREE. Elevated Sr and modified Eu anomalies are consistent with fluid–rock interaction involving feldspar breakdown and redox-controlled Eu behavior. In stratigraphically constrained transects (e.g., Kamoa-Kakula), hydrothermal apatite compositions vary predictably relative to redox interfaces, with progressive decreases in V, As, Sr, and Ba from basin center toward basin margin. Comparisons between mineralized systems and failed prospects show that intensely mineralized aquifers are associated with more pronounced hydrothermal apatite signatures (low La/Gd, higher Eu/Eu*), whereas barren systems retain predominantly detrital-like compositions.

We interpret hydrothermal apatite as the product of coupled dissolution–reprecipitation and trace-element exchange during brine infiltration under low-grade conditions. Because apatite is mechanically and chemically robust, these signatures may survive burial and mild metamorphism, providing a durable archive of basinal fluid evolution and sedimentary basin fertility.