
Apatite Petrochronology and Geochemistry – Tracking Mineral System Evolution at the Ernest Henry Iron Oxide-Copper-Gold (IOCG) Deposit, Northwest Queensland, Australia

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Understanding multistage alteration and mineralization in iron oxide-copper-gold (IOCG) systems remains an attractive topic in economic geology. Geochronology without sufficient mineralogical context can limit petrologic interpretations. Our study employs integrated apatite petrochronology with detailed geochemistry at the Ernest Henry deposit (NW Queensland) to provide both temporal and chemical constraints on fluid evolution. As one of the most economically significant IOCG deposits in Australia with exceptional preservation and exposure, Ernest Henry serves as a global type locality offering critical insights into IOCG formation processes worldwide.

Petrographic observations, in situ U-Pb geochronology, and compositional analyses reveal distinct apatite populations correlating with multiple hydrothermal events. Early regional Na ± Ca alteration (dated at ~1570-1560 Ma) produced Apatite-1 with high Na and Cl content, reflecting element remobilization/leaching by acidic fluids. Apatite-2 from the Inter-Lens (a pre-mineralization structure located at depth) is petrogenetically and geochemically similar to Apatite-1 but with elevated F, S, and As. Apatite associated with pre-ore K-Fe-(Mn) alteration is influenced by regional post-peak metamorphism, while pervasive K-Fe alteration within the ore breccia produced apatite displaying magmatic-like REY signatures and enrichment in F and S. Ore-stage apatites (dated at ~1529-1521 Ma) have the highest As and F contents, documenting continued fluid evolution and mineralization.

Apatite groups also exhibit compositional variations corresponding to their spatial distribution, notably increasing F, S, As, Mn, Cu, Fe, and Ba concentrations coupled with decreasing Na and Cl from distal areas (>2 km from the orebody) toward mineralized zones. Such spatially and temporally resolved geochemical trends can serve as effective proxies for identifying and distinguishing between regional and ore-forming processes within a long-lived mineral system. The integration of apatite petrochronology and mineral chemistry not only illuminates the formation framework of this IOCG deposit, but also contributes to a holistic methodological approach for investigating complex, multistage mineral systems globally.