

A Multi-Proxy Isotope and REE Analysis of the Neoproterozoic Marine Carbonates Hosting Cu Mineralization: Implications for Fluid Sources and Alteration Footprint at the Nifty Deposit in the Yeneena Basin, Western Australia

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The REE composition of carbonate-hosted mineral systems provides insights into depositional environments, fluid-rock interactions, and diagenetic/hydrothermal overprinting. This study examines REE concentrations, along with stable and radiogenic Sr, C, and O as well as elemental ratios isotopes, in dolomitic shales from the Neoproterozoic Broadhurst Formation at the Nifty copper deposit, Western Australia. The findings highlight hydrothermal fluid influence, paleo-redox conditions, and help to constrain the plausible sources of mineralizing fluid(s) and the geochemical/isotope evolution of this sedimentary carbonate-hosted Cu ore system.

Positive Eu/Eu* anomalies in the studied dolomitic shales suggest increased inputs of hydrothermal fluids enriched in Eu, likely due to high-temperature (>250°C) fluid-rock interactions releasing Eu from plagioclase. These anomalies correlate spatially with sulfide-rich (Cu-bearing) zones, supporting the role of hydrothermal fluids in Cu mineralization. Ce/Ce* anomaly data, with some samples present slightly positive, indicate anoxic to sub-oxic conditions. Elemental proxies reveal complex diagenetic or fluid-rock interaction histories. The studied carbonates exhibit high Mn/Sr ratios, particularly in the Nifty Carbonate Member, where elevated Eu/Eu* anomalies further corroborate hydrothermal alteration.

As to isotope proxies, $\delta^{13}\text{C}$, and $\delta^{18}\text{O}$ exhibit progressively negative trends with an increasing depth, which might be attributed or linked to post-depositional processes involving organic matter oxidation, CO_2 release, and subsequent formation of isotopically light carbonates. The observed $\delta^{13}\text{C}$ values at mineralization depths are more negative than typical Neoproterozoic marine carbonates or paleo-seawater (-2‰ to 6‰), pointing to the effect of secondary processes and overprinting by non-marine, diagenetic, or mineralizing fluids. To further assess the degree of alteration of the studied Neoproterozoic carbonates, we also employed radiogenic and stable Sr isotopic tracers ($^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{88}\text{Sr}$). Briefly, the $^{87}\text{Sr}/^{86}\text{Sr}$ ranged from ~0.7259 to ~0.7621, thus highly radiogenic

compared to the Neoproterozoic seawater values (~0.7055 to 0.7060), indicating involvement of non-marine, crustal-derived fluids, or radiogenic lithologies within the Broadhurst Formation. The stable Sr isotope values are also highly variable, ranging from $\delta^{88}\text{Sr}$ signatures as low as -0.2‰ up to 0.45‰. We hypothesize that large variations in $\delta^{88}\text{Sr}$ values are linked to post-depositional carbonate dissolution/precipitation as well as the impact or isotope overprinting by non-marine diagenetic/mineralizing fluids.