In-Situ Geochemical Signatures of Apatite in Carbonatite-Related REE Deposits: Insights into Magmatic Sources and Fluid Overprints

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Carbonatite-associated rare earth element (REE) deposits commonly form in tectonically active settings, with both primary magmatic processes and post-magmatic hydrothermal events contributing to ore formation. Apatite, a key accessory mineral in most carbonatites, serves as a sensitive record of these events. This study integrates cathodoluminescence (CL) imaging with in-situ trace element and Sr-Nd-O isotopic analyses of apatite from three large carbonatites that host significant REE mineralization: Bayan Obo (China), the Gifford Creek Carbonatite Complex (GCCC, Australia), and Miaoya (China).

Apatites from each carbonatite show diverse CL textures, from oscillatory zoning to mottled or patchy overgrowths, which correlate with differences in REE and Sr contents and help to distinguish magmatic from hydrothermal generations. Magmatic apatites show near-CHUR to slightly enriched isotopic signatures. When integrated with isotopic studies from other global ore-hosting carbonatites, these results suggest that crustal material may have contributed to ore formation in these systems, but only to a limited extent.

Hydrothermal apatite generally shows elevated $\delta^{18}O\_SMOW$ values, consistent with the involvement of ^{18}O-enriched metamorphic fluids. Sr and Nd isotope signatures, however, vary with fluid chemistry. The hydrothermal apatite that displays minimal isotopic change from the associated magmatic apatite suggests interaction with inert CO_2-rich fluids, while the hydrothermal apatites that display a wide range of $^{87}Sr/^{86}Sr$ ratios indicates interaction with F- or Cl-bearing fluids capable of mobilizing Sr. Bayan Obo and GCCC, both of Mesoproterozoic age, display a broader range of εNd(t) values than the younger Miaoya deposit, likely due to Sm/Nd fractionation during fluid-mediated REE redistribution. Although $^{143}Nd/^{144}Nd$ ratios remain robust, variation in Sm/Nd can bias age and source interpretations. Collectively, these results offer insights into the role of multiple fluid events in shaping REE mineralization within carbonatite deposits.