

Hydrothermal HFSE(+HREE) mineralization in the Bear Lodge Alkaline Complex—a key to understanding the larger Hicks Dome critical mineral resource?

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Carbonatite critical mineral resources are invariably LREE-enriched. Some alkaline-carbonatite complexes also host veins or peripheral zones that are HREE-enriched. For most of these occurrences, HREE mineralization is attributed to LREE-HREE fractionation and late hydrothermal activity. We examine two alkaline-igneous centers in the United States that host similar HFSE(+HREE) mineral assemblages and propose models for their formation.

Hicks Dome is a cryptovolcanic structure that hosts a fluorite-barite resource in the Illinois-Kentucky fluor spar district. In addition to fluorite and barite, Hicks Dome is enriched in HREE and HFSE with an estimated 65.8 Mt area-wide resource averaging 15.8% fluorite, 4.8% barite, 1.3% TiO₂, 0.3% REY oxide, 0.2% Nb₂O₅, and 0.16% BeO, at a fluorite cut-off grade of 10%. The resource is associated with 271 Ma carbonate-rich, alkaline, lamprophyre dikes and diatremes of the Midwest Permian Ultramafic District. Critical minerals occur in fluorite-mineralized rock-flour-matrix breccia and solution-collapse breccia in Ordovician to Silurian platform carbonate rocks at depths of 700-1000 m.

The Eocene Bear Lodge alkaline complex hosts a large REE resource in a weathered, carbonatite dike swarm and vein stockwork. Carbonatites are LREE-enriched with Ca-REE fluorocarbonates as the principal ore minerals. A peripheral HFSE(+HREE) occurrence at Bear Lodge composed of anatase, xenotime-(Y), brockite, fluorite, zircon, and K-feldspar is enriched in a suite of elements similar to the Hicks Dome host breccia (HREE, Th, Ti, Nb, Be, P, F).

We present multielement data from more than 3,000 Hicks Dome drill-core samples, micro-XRF maps of the host breccia, results from mineralogical studies, and compare results with those from the Bear Lodge HFSE(+HREE) occurrence. Despite some major differences between the two critical mineral resources, their geochemistry and unusual mineralogy are remarkably similar. Chondrite-normalized REE profiles for both occurrences have convex patterns from Sm to Lu which crossover the associated alkaline igneous rock (carbonatite and lamprophyre) patterns between Nd and Eu (figure 1a,b). We discuss a model by which HFSE(+HREE) precipitate from highly fractionated fluids derived from carbonatite or carbonate-rich alkalic magmas and the role specific ligands (Cl, F, SO₄, HCO₃, CO₃) may have in the formation of these resources.

