

Critical Mineral Formation in Carbonatite From the Rocky Boy Stock, Bears Paw Mountains, Montana

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The Rocky Boy stock is the largest alkaline intrusive body in the Bears Paw Mountains, Montana. A calciocarbonatite-silicocarbonatite occurrence hosts several REE minerals including ancylite, synchysite-parasite, lanthanite, as well as calkingsite $[(\text{Ce}, \text{La})_2(\text{CO}_3)_3 \cdot 4\text{H}_2\text{O}]$ and burbankite $[(\text{Na}, \text{Ca})_3(\text{Sr}, \text{Ba}, \text{Ce})_3(\text{CO}_3)_5]$, for which the stock is the type locality. Burbankite pseudomorphs in the central portions of the carbonatite dike are replaced by combinations of ancylite, synchysite-parasite, barite-strontianite, and lanthanite-calkingsite. The carbonatite dike also hosts a pyrochlore-group + zircon + fluorapatite assemblage in banded zones proximal to biotite-phlogopite selvages along contacts with alkaline silicate units. This study investigates the petrography, crystallization history, and petrogenetic significance of this HFSE+P assemblage, with emphasis on the evolution of the carbonatite melt–fluid system and interaction with silicate wall rocks. Mineral textures and compositions were characterized using backscattered electron imaging, optical cathodoluminescence (CL), electron probe microanalysis, X-ray fluorescence mapping, and LA-ICP-MS. Light stable isotopic compositions for biotite-phlogopite and in-situ Sr isotopic compositions were determined for fluorapatite and calcite to assess fluid involvement.

Pyrochlore crystals show complex concentric and patchy zoning, commonly ranging from betafite to pyrochlore. Fluorapatite exhibit blue-violet cores and yellow rims in CL. Some crystals have minor oscillatory zoning between blue-violet and yellow as well as yellow zones along fractures. A depletion of LREEs over middle and HREEs from the blue-violet cores to the yellow zones of fluorapatite suggest increased fluid-driven, metasomatic processes. Late-stage calcite has higher $^{87}\text{Sr}/^{86}\text{Sr}$ ratios compared with earlier fluorapatite, which suggests greater melt-wall rock interaction with time. The degree of interaction between wall rock and carbonatite melt affects the enrichment of REE and HFSE in the residual melt. We hypothesize that removal of F and H_2O during crystallization of biotite–phlogopite and fluorapatite destabilized HFSE–fluoride complexes within the carbonatite melt/fluid, triggering crystallization of pyrochlore-group minerals and, with Si derived from wall rocks, zircon.