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REE-enrichment pathway from melt immiscibility to carbohydrothermal processes during magma evolution in the Hongcheon Carbonatite, South Korea

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Carbonatitic alkaline melts, which are generated by extremely low degrees of partial melting and thus possess inherently high REE contents, undergo various enrichment processes during their evolution. We identified a unique two-step REE-enrichment pathway that occurred during the evolution of alkaline magma in the Hongcheon carbonatite, South Korea.

The first step in this REE-enrichment process was melt immiscibility, in which a phosphorus-rich melt separated from the carbonatitic magma. During this process, REEs migrated into the phosphorus-rich melt, where they exhibited high chemical affinity and were concentrated in fluorapatite (1.5–2.3 wt.% Ce; 0.8–1.2 wt.% La). This interpretation is supported by microtextural evidence showing that REE-enriched fluorapatite formed domains distinct from magnetite–dolomite domains.

The second step was a carbohydrothermal alteration stage, which occurred through interaction between the carbonatite and magmatic-carbohydrothermal fluids generated during cooling of the immiscible melts. During this stage, REEs hosted in fluorapatite were extracted, concentrated, and crystallized as monazite, a REE phosphate. This is supported by microtextural features indicating a sequential alteration process, including the development of a REE-depleted rim containing fine-grained monazite around REE-enriched fluorapatite, a fluorapatite pseudomorph replaced by fine-grained monazite, ankerite, and quartz during advanced alteration, development of a symplectic texture of monazite and quartz, crystallization of large monazite crystals from concentrated REEs, and formation of carbonate and quartz veinlets.

These observations confirm that enhanced REE enrichment was achieved through a two-step process: an initial magmatic stage (melt immiscibility) followed by a late- to post-magmatic carbohydrothermal stage.