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Magmatic Preservation Versus Hydrothermal Overprint: REE Systematics in the Saint-Honoré Carbonatite Complex (Quebec, Canada)

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Carbonatites and associated alkaline intrusions record mantle–crust interactions and commonly host critical metal deposits, including rare earth elements (REE). The Neoproterozoic (ca. 582–565 Ma; Néron et al., 2028) Saint-Honoré complex (Grenville Province, Saguenay Graben) exhibits concentric zoning from outer syenites to inner calciocarbonatite, magnesiocarbonatite, and central ferrocarbonatite hosting the Niobec Nb–REE deposit. Previous studies (Legros et al. 2025) propose a hybrid magmatic–hydrothermal model for REE mineralization, involving early magmatic crystallization followed by late hydrothermal remobilization in brecciated zones.

This study investigates mineralogical variability across a 113–1254 m depth profile using 14 samples from the deepest borehole within the ferrocarbonatite. Hierarchical cluster analysis of quantitative X-ray diffraction (QXRD) data identifies three mineralogical facies based on multivariate phase associations: (1) carbonate-dominated ferrocarbonatite (dolomite–ankerite 52–97%); (2) Ba-rich carbonate assemblages; and (3) locally REE-enriched assemblages characterized by elevated monazite (≤10%) and fluorapatite (≤25%). These facies reflect primary magmatic compositional variability within the ferrocarbonatite, including localized incompatible-element concentration in REE-rich domains. Ba-rich assemblages likely record magmatic barite crystallization with possible later fluid modification. Hydrothermal alteration—expressed by kaolinite, annite, quartz, and calcite—variably overprints these primary magmatic facies rather than defining a distinct stratigraphic unit. Although cluster membership is not strictly depth-controlled, the highest abundances of REE-bearing phases occur within the deeper portion of the profile (≈968–1254 m), indicating preferential preservation or development of REE enrichment at depth within an otherwise heterogeneous system.

QXRD via Rietveld refinement quantifies systematic mineralogical variations, including dominant dolomite–ankerite with siderite (0–23%) and minor calcite; REE-bearing phases (fluorapatite ≤25%, monazite ≤10%, bastnäsite ≤6%, fluocerite ≤1%, allanite ≤3%); and baryte (≤34%), lueshite (≤1%), pyrite, and hematite. X-ray fluorescence (XRF) data corroborate ferrocarbonatite compositions (LOI 19–49%; CaO 15–28%; MgO 4.5–16%; Fe_2O_3 6–21%) and steep LREE-enriched patterns (ΣLREE oxides up to ~9%) with HREE concentrations largely below detection limits, while Nb_2O_5 remains low (<0.3%) and decoupled from LREE. Together, these QXRD–XRF results support heterogeneous REE distribution consistent with magmatic preconcentration variably modified by hydrothermal processes.

The integrated QXRD–XRF workflow provides rapid, quantitative mineralogical–geochemical characterization, enabling efficient depth profiling and improved targeting in critical-metal carbonatite systems.