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Replacive Magmatic Evolution as a Key Process in Ultramafic Alkaline–Carbonatite Complexes: The Kovdor Case

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Ultramafic alkaline–carbonatite complexes commonly display extreme petrographic and mineralogical diversity, yet the processes generating this variability remain debated. New field observations, petrography, mineral chemistry, and Sr–Nd isotope data from the Kovdor massif indicate that much of this diversity reflects pervasive replacive interactions among magmatic phases rather than independent crystallization of discrete rock types.

The 380–376 Ma Kovdor massif in the Kola alkaline province is a vertical stock (~9 × 7.5 × 12 km³) dominated by olivinite and clinopyroxenite, with twelve subordinate lithologies. Olivine compositions, trace-element systematics, and clinopyroxene–magnetite exsolution lamellae suggest initial crystallization from carbonate-rich melts comparable to those of ultramafic lamprophyres. Clinopyroxenite with Ti-augite and Mg-hastingsite represents another primary assemblage. These early rocks subsequently reacted with carbonatitic and melilitolitic melts, producing pronounced major- and trace-element zoning in olivine and clinopyroxene, monticellite coronas, veinlets and other abundant reactive microstructures. Monticellite veinlets trace intergranular migration of resorbing carbonatitic fluids. The degree of carbonatite replacement can be tracked by HREE enrichment in carbonates, which depends on the Carbonate/Clinopyroxene ratio. All batches of carbonatitic melt are Si- and P-bearing and contain diopside, Na-, Ba-, and Sr-rich olivine and phlogopite, forming a continuous transition to phoscorites. Rare-earth-element partitioning between calcite and apatite indicates that the carbonatite–phoscorite assemblages are magmatic. Whole-rock isotopic compositions (εNd = +2 to +6; $^{87}Sr/^{86}Sr$ = 0.7034–0.7040) indicate derivation from a depleted mantle source. Clinopyroxenites partly resorbed by carbonatites display marked Sr–Nd disequilibrium between relict pyroxene and replacing carbonate; the magnitude of this disequilibrium at the centimetre scale amounts to nearly one-third of the isotopic variability observed across the massif.

These observations demonstrate that a substantial proportion of ultramafic alkaline-carbonatite complexes, exemplified by Kovdor, form through percolation of reactive melts through earlier crystallized mineral frameworks. The resulting rocks represent frozen reaction fronts rather than equilibrium mineral assemblages and are best described as replacive magmatic lithologies. Geochemical interpretations that ignore textural context can therefore be misleading. Replacive magmatic reactions in these complexes should be regarded as a fundamental process, comparable in significance to subsolidus fenitization.



