

The Fe and Ca isotope systematics of alkaline and carbonated magmas discriminate between mineral assemblages in their mantle sources

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The chemical and mineralogical heterogeneities of Earth's mantle are imprints of extensive processes involving silicate and carbonate magmas driven by plate tectonics. Geochemical indicators including Fe and Ca isotopes in mantle-derived magmas have been used to decipher mantle heterogeneity and thus mantle dynamics, revealing contributions from metasomatized lithospheric mantle, subducted oceanic crust, and recycled sedimentary carbonates in their sources. However, due to lack of understanding of how mineralogical variations influence isotope fractionation, the extent to which the geochemical signatures of mantle-derived magmas reflect the mineralogical heterogeneity remains controversial.

To address this, we present Fe isotope analyses of ~1.4 Ga olivine lamproites, 590–555 Ma ultramafic lamprophyres (UML) and carbonatites, and 142 Ma nephelinites from Aillik Bay on the margin of the North Atlantic Craton, integrating with previously reported Ca isotope data. These magmas were formed by melting of MARID-type metasomes, carbonated peridotites, and wehrlites during rifting, respectively, without a clear involvement of recycled crust. The $\delta^{56}\text{Fe}$ values (0.15 to 0.18 ‰) of the 1.4 Ga olivine lamproites slightly higher than MORBs ($0.103 \pm 0.07\text{‰}$), which we attribute to a phlogopite-enriched source. Metasomatic phlogopites are characterized by low $\delta^{44/40}\text{Ca}$ values (0.58 to 0.66 ‰). The 590–555 Ma UMLs are primitive SiO_2 -poor magmas showing MORB-like $\delta^{56}\text{Fe}$ values from 0.08 to 0.15 ‰. Carbonatites of the same Neoproterozoic age display highly variable $\delta^{56}\text{Fe}$ values (-0.25 to 0.35‰) due to post-magmatic processes. The Cretaceous nephelinites exhibit homogeneous (MORB-like) $\delta^{56}\text{Fe}$ values ($0.11 \pm 0.03\text{‰}$), resembling those of the UMLs. These observations indicate that mantle-derived carbonate-rich magmas exhibit MORB-like Fe isotope compositions but slightly lower $\delta^{44/40}\text{Ca}$ compositions (0.74 ‰). We suggest that the high $\delta^{56}\text{Fe}$ (up to 0.29 ‰) and low $\delta^{44/40}\text{Ca}$ (as low as 0.49 ‰) compositions of OIBs and continental basalts cannot be explained by metasomatic phlogopite and carbonate in their mantle sources but instead require recycled eclogite and sedimentary carbonate components (0.44 to 0.77 ‰ $\delta^{44/40}\text{Ca}$) at depth. We conclude that the Fe-Ca