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Calcium-isotopes as a robust tracer of magmatic differentiation

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The large mass difference (~10%) between the two most abundant isotopes of calcium, ^{40}Ca and ^{44}Ca, gives Ca great potential in tracking mass-dependent fractionation during magmatic processes. Resolvable Ca-isotope fractionation during fractional crystallization of magma, particularly by feldspar in evolved melts, has been theoretically inferred but not robustly tested in nature. We studied the late-Permian alkaline igneous suite of the øyangen Caldera, Oslo Rift, Norway, consisting of volcanic and intrusive units ranging from basaltic to rhyolitic compositions. Major and trace element variations and modeling demonstrate that the main series of samples (*N*=20), including basalts, ring dykes, and central domes, likely document a co-genetic and closed-system fractional crystallization sequence. Our data show minimal $\delta^{44/40}$Ca variation (< 0.05‰) in the intermediate magma and a marked increase in $\delta^{44/40}$Ca in the felsic magma of the øyangen Caldera (from 0.62 ± 0.02‰ to 1.15 ± 0.03‰ relative to Ca standard, SRM915a). The systematic increase is best explained by equilibrium isotopic fractionation dominated by alkali feldspar in the mineral assemblage. This is further supported by strong correlations between $\delta^{44/40}$Ca, CaO, and Eu/Eu* in the main-series samples. Implementing a Monte Carlo approach, isotopic modeling of the liquid line of descent using Rayleigh fractionation resolves high consistency with the observed Ca-isotope evolution. For the first time, we confirm prominent Ca stable isotope fractionation in felsic-stage differentiation of alkaline magma and constrain the isotope fractionation factors of plagioclase and K-feldspar. Integrated with extant estimations on mineral fractionation factors from the literature, our results suggest increasing fractionation effects of rock-forming minerals with decreasing Ca content. The affirmation of significant Ca-isotope fractionation in alkaline magma by feldspar empowers the application of Ca as a versatile tracer of crustal evolution, allowing further tests on other common magma types and tectonic environments across various planetary objects.

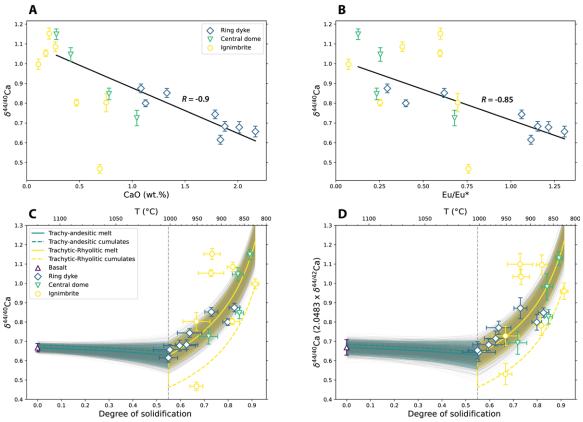

Figure 1. Ca isotope evolution of the Øyangen Caldera.

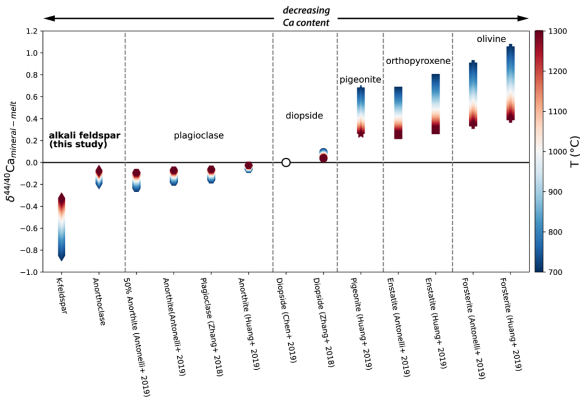

Figure 2. Mineral ^{44}Ca/^{40}Ca isotope fractionation factors determined in this study and compiled from the literature (expressed as $\delta^{44/40}Ca_{mineral\text{-}melt}$)