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Iron isotope fractionation and the oxygen fugacity of the mantle

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The oxygen fugacity of the mantle exerts a fundamental influence on mantle melting, volatile speciation and the development of the Earth's atmosphere. However, its evolution through time remains poorly understood. Changes in mantle oxidation state should be reflected in the $\text{Fe}^{3+}/\text{Fe}^{2+}$ of mantle minerals, hence in stable iron isotope fractionation. We have investigated the relationships between Fe isotope fractionation and oxygen fugacity with a combined MC-ICPMS Fe isotope and Mössbauer spectroscopy ($\text{Fe}^{3+}/\Sigma\text{Fe}$) study of spinels from mantle xenoliths and massif samples originating from different tectonic settings (1, 2). Significant (1.7‰) and systematic variations exist in the iron isotope compositions ($\delta^{57}\text{Fe}/^{54}\text{Fe}$) of mantle spinels, and in corresponding bulk-rock samples (0.9‰). Spinel $\delta^{57}\text{Fe}/^{54}\text{Fe}$ values correlate negatively with relative oxygen fugacity, $\text{Fe}^{3+}/\Sigma\text{Fe}$ and $\text{Cr}^{\#}$, implying that Fe isotope fractionation is closely related to changes in the oxidation state of the upper mantle. Hence iron isotopes in mantle spinels may provide a powerful new proxy of changes in mantle oxidation state, melting and volatile recycling.

References

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Hotspot and mid-ocean ridge basalt genesis from melting of a non-layered heterogeneous mantle

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Many geochemical differences between ocean island basalts (OIBs) and mid-ocean ridge basalts (MORBs) are readily explained by a chemically layered mantle; however, a dilemma arises from geophysical evidence for whole mantle convection, which is predicted to efficiently stir the mantle and prevent any long-lasting, global chemical layering. Indeed, mantle heterogeneities over a range of length scales are likely to influence the compositional variability among and between MORBs and OIBs. Few studies, however, have quantitatively simulated melting of small-scale heterogeneities and quantified its importance on OIB and MORB genesis. We present models of melting in which mantle heterogeneities are present as small veins in both mantle plumes and in ambient mantle. Three different components are considered. Enriched mantle (EM) is highly concentrated in the most incompatible trace elements, has isotopic characteristics reflecting long-term enrichment, and begins melting deepest. Pyroxenite (PX) is relatively depleted in the most incompatible trace elements, has Pb isotope compositions reflecting a high U/Pb ratio, and begins melting at intermediate depths. Depleted mantle (DM), the most abundant component, is depleted in the most incompatible elements, has corresponding isotope signatures, and begins melting shallowest.

Models predict the deeper melting, EM and PX components to be preferentially extracted at intraplate settings where thick lithosphere limits melting to large depths and low extents. In contrast, DM is more heavily sampled at mid-ocean ridges where thinner lithosphere allows for more extensive melting. Besides differences in extent of melting, differences in mantle flow also influence magma composition. Plume-driven upwelling is most rapid at depth, decreases to the base of the lithosphere, and therefore enhances the extraction of EM and PX. In contrast, seafloor spreading at mid-ocean ridges allows for more uniform upwelling with depth and more even sampling of all mantle components. Models predict general systematics consistent with observations: incompatible trace-element and Sr, Nd, and Pb isotope ratios with large variability, extending to more enriched compositions at hotspots, and a smaller range of variability, with more DM-like compositions at mid-ocean ridges. Models can also explain the apparent mixing arrays defined by OIB and MORB isotope compositions. Some solutions imply a chemically layered mantle, but others predict major geochemical systematics of MORB and OIB to arise from a well-stirred, heterogeneous mantle without large-scale chemical layering.