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Probing Melt Transport Processes with Heavy Stable Isotopes

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Novel heavy stable isotope systems, such as Fe and Mg, can be useful tracers of mantle lithology (e.g., peridotite vs pyroxenite). However, equilibrium models of mantle melting, coupled with expected source variability, fail to capture the full extent of stable isotope variation in natural basalts, with models giving ~0.1‰ fractionation in δ^{57}Fe and ~0.2‰ in δ^{26}Mg but natural MORB and OIB showing anomalously high and low fractionations of up to 0.4‰ and -0.65‰ respectively [1]. This suggests either multi-stage and/or or disequilibrium processes during basalt genesis, e.g., diffusive stable isotope exchange [2]. Recent studies have proposed that Fe-Mg interdiffusion and associated kinetic isotope fractionation may account for some of the Fe-Mg isotope heterogeneity observed in oceanic basalts, exemplified by their covariation in δFe-δMg space [3]. However, a major challenge is that the length scales, magnitudes, contexts, and ultimate causes of these isotopic effects remain poorly constrained. Here, we investigate how heavy stable isotope fractionation in basalts may be induced by melt transport processes. Channelisation in the solid mantle may act as a vehicle for these kinetic diffusional effects to occur as Fe-rich melts forming deep in the mantle are juxtaposed with Fe-poor residues higher in the mantle column. Such disequilibrium will cause isotopically light Fe to diffuse from melt to solid, replaced by isotopically light Mg isotopes, leaving a melt enriched in heavy iron isotopes while simultaneously displaying light Mg isotopic compositions. In this contribution we attempt to quantify this process and account for the varying time- and length-scales of melt transport in the mantle. Our models suggest that variation upwards of 0.1‰ for both Fe and Mg isotopes can be created by diffusional processes during melt extraction. Additionally, the 'triple-isotope' method was employed to further constrain these processes [3]. We show that heavy stable isotopes provide powerful new insights into melt transport processes, and we expand on the understanding of both equilibrium and disequilibrium isotope processes.

[1] Soderman *et al*. (2024) *EPSL* **638** 118749

[2] Watkins and Antonelli. (2021) *Elements* **17(6)** 383-388

[3] Liu *et al*. (2024) EPSL **642** 118868