Tracing metasomatic and crystallization processes in the mantle through Fe isotopes

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Minerals from mantle-derived xenoliths and massif-type peridotites and eclogites have δ^{56}Fe values that vary from -0.5 to +0.7 ‰, a range that cannot be explained by equilibrium fractionation among major minerals such as olivine and pyroxene. Although non-zero olivine-pyroxene fractionations are measured in a number of samples, these are most common in minerals that have δ^{56}Fe values that deviate from the average of mafic igneous rocks, which have $\delta^{56}Fe \equiv 0.00 \pm 0.04$. This observation, as well as the fact that alkaline and tholeiitic mafic igneous rocks are isotopically homogeneous, argues that much of the Fe isotope variations in xenoliths and massif-type rocks reflects open system behavior of iron.

In contrast to the near-zero olivine-pyroxene fractionations that reflect equilibrium, clinopyroxene-garnet fractionations up to +0.7 ‰ may reflect equilibrium partitioning. Garnet fractionation in deep basaltic magmas therefore offers an alternative explanation for proposed Fe isotope - mantle fO_2 relations, which are largely constrained by garnet-bearing cumulates. Erupted mafic magmas rarely have garnet as a liquidus phase, and this is one explanation for the isotopic homogeneity of mafic lavas if there is significant equilibrium clinopyroxene-garnet fractionation.

Carbonate metasomatism is a process that may significantly shift the Fe isotope compositions of metasomatized mantle. δ^{56}Fe values for calcite and dolomite in carbonatites (10^2 to 10^4 ppm Fe) range from -1.0 to +0.6 ‰. At 800-450 ^{o}C there appears to be an equilibrium magnetite-calcite fractionation of +0.4 to +0.6 ‰. This fractionation may be reversed in samples where isotopic disequilibrium exists among silicate minerals. Combining magnetite-calcite fractionations with the near-zero olivine-pyroxene-magnetite fractionations in volcanic rocks predicts that olivine-calcite fractionations at mantle temperatures would be ~ +0.4 ‰. Metasomatism by low-δ^{56}Fe carbonate magmas, therefore, is a possible explanation for the anomalous Fe isotope compositions of olivine and pyroxene in some mantle-derived xenoliths.

Significant variations in the Fe isotope compositions of mantle rocks are most likely to be restricted to the lithosphere, reflecting both deep crystallization of mafic magmas, as well as metasomatic effects. We find no compelling evidence that the ambient convecting mantle has an Fe isotope composition that is different from the average of mafic igneous rocks.