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High-temperature, inter-mineral Mg stable isotope fractionation in mantle xenoliths

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The bulk Mg isotope composition of the silicate Earth is homogeneous and identical within analytical error to that of chondritic meteorites (Yang et al., 2009; Handler et al., 2009; Bourdon et al., 2010 Chakrabarti and Jacobsen, 2010; Schiller et al., 2010; Teng et al., 2010; Pogge van Strandmann et al., 2011). Systematic fractionations among minerals in mantle peridotites (Wiechert and Halliday, 2007; Handler et al., 2009; Yang et al., 2009; Young et al., 2009; Chakrabarti and Jacobsen, 2010) are resolvable, however, and are broadly consistent with theoretical predictions for high-temperature equilibrium Mg isotope fractionation using density functional perturbation theory (Schauble, 2011). The high-temperature equilibrium Mg isotope fractionations are predicted to correlate with co-ordination number (Schauble, 2011); the tetrahedral crystallographic sites (e.g., spinel) are expected to have higher ^{26}Mg/^{24}Mg than the coexisting octahedral silicate sites. Theoretically predicted spinel – silicate ^{26}Mg/^{24}Mg fractionations can thus be quite large, about 0.5 – 0.8‰ at 1000K (Schauble, 2011), and appear to be confirmed by recent data from two spinel peridotites (Young et al., 2009). Here we investigate the inter-mineral Mg isotope fractionation in five spinel peridotite and five garnet pyroxenite xenoliths from Salt Lake Crater, Hawaii. Mass balance calculations show that calculated whole rock δ^{26}Mg compositions of both the spinel peridotites and the garnet pyroxenites are within error of those of bulk silicate Earth, consistent with inter-mineral fractionations being due to equilibrium isotope fractionation. In the spinel peridotites, the δ^{26}Mg of olivine (ol), orthopyroxene (opx) and clinopyroxene (cpx) are indistinguishable within analytical error. In the three measured olivine-spinel pairs, the spinels (sp) have consistently higher δ^{26}Mg values than the olivines, by 0.21 - 0.28‰.The difference between spinel and olivine δ^{26}Mg values suggest an equilibration temperature of ca. 1700˚C, which is, however, considerably higher than the calculated opx-cpx mineral equilibration temperature of ca. 1100˚C. The δ^{26}Mg of garnet in the garnet pyroxenites is consistently lower by 0.38 - 0.45‰ than in the coexisting clinopyroxenes, consistent with theoretical predictions for high coordination number sites (Schauble, 2011). Hence, the coordination number of Mg exerts a first-order control on the δ^{26}Mg of the minerals at high temperature; the δ^{26}Mg values increase from garnet with a Mg coordination number of 8, to the octahedrally coordinated silicates (ol $\leq$ opx $\leq$ cpx) and the tetrahedrally coordinated spinels. However, a strong positive correlation of $\delta^{26}\mathrm{Mg}_{spinel}$ with the spinel Cr (Al) content or spinel Cr#, and of $\delta^{26}\mathrm{Mg}_{cpx}$ with spinel Cr#, shows that there is also a compositional control on the δ^{26}Mg values of individual minerals in mantle rocks. The latter may explain the discrepancy between calculated equilibration temperatures based on mineral equilibria (opx-cpx) and Mg isotope fractionation ($\delta^{26}\mathrm{Mg}_{ol-sp}$), and may hamper the use of spinel-silicate Mg isotope fractionation in magmatic rocks as a reliable geothermometer.

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