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Experimental investigation of basalt and peridotite oxybarometers: Implications for spinel thermodynamic models and Fe^{3+} compatibility during generation of upper mantle melts

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Abstract

Peridotites dredged from mid-ocean ridges and glassy mid-ocean ridge basalts (MORB) transmit information about the oxygen fugacity (f_{O_2}) of Earth's convecting upper mantle to the surface. Equilibrium assemblages of olivine+orthopyroxene+spinel in abyssal peridotites and $Fe^{3+}/\Sigma Fe$ ratios in MORB glasses measured by X-ray absorption near-edge structure (XANES) provide independent estimates of MORB source region f_{O_2}, with the former recording f_{O_2} approximately 0.8 log units lower than the latter relative to the quartz-fayalite-magnetite (QFM) buffer. To test cross-compatibility of these oxybarometers and examine the compositional effects of changing f_{O_2} on a peridotite plus melt system over a range of Earth-relevant f_{O_2}, we performed a series of experiments at 0.1 MPa and f_{O_2} controlled by CO-CO_2 gas mixes between QFM-1.87 and QFM+2.23 in a system containing basaltic andesite melt saturated in olivine, orthopyroxene, and spinel

Oxygen fugacities recorded by each method are in agreement with each other and with the f_{O_2} measured in the furnace. Measurements of f_{O_2} from the two oxybarometers agree to within 1σ in all experiments. These results demonstrate that the two methods are directly comparable and differences between f_{O_2} measured in abyssal peridotites and MORB result from geographic sampling bias, petrological processes that change f_{O_2} in these samples after separation of melts and residues, or abyssal peridotites may not be residues of MORB melting.

As f_{O_2} increases, spinel Fe^{3+} concentrations increase only at the expense of Cr from QFM-1.87 to QFM-0.11. Above QFM, Al is also diluted in spinel as the cation proportion of Fe^{3+} increases. None of the three spinel models tested, MELTS (Ghiorso and Sack 1995), SPINMELT (Ariskin and Nikolaev 1996), and MELT_CHROMITE (Poustovetov and Roeder 2001), describe these compositional effects, and we demonstrate that MELTS predicts residues that are too oxidized by >1 log unit to have equilibrated with the coexisting liquid phase. Spinels generated in this study can be used to improve future thermodynamic models needed to predict compositional changes in spinels caused by partial melting of peridotites in the mantle or by metamorphic reactions as peridotites cool in the lithosphere.

In our experimental series, where the ratio of Fe_2O_3/FeO in the melt varies while other melt compositional parameters remain nearly constant, experimental melt fraction remains constant, and Fe^{3+} becomes increasingly compatible in spinel as f_{O_2} increases. Instead of promoting melting, increasing the bulk $Fe^{3+}/\Sigma Fe$ ratio in peridotite drives reactions analogous to the fayalite-ferrosilite-magnetite reaction. This may partly explain the absence of correlation between Na_2O and Fe_2O_3 in fractionation-corrected MORB.

Keywords: Oxygen fugacity, XANES, spinel peridotite oxybarometry, electron microprobe, experimental petrology, MORB, abyssal peridotite, MELTS