Crystal/melt partitioning of water and other volatiles during the near-solidus melting of mantle peridotite: Comparisons with non-volatile incompatible elements and implications for the generation of intraplate magmatism

JOHN ADAM1,*, MICHAEL TURNER1, ERIK H. HAUERI2, AND SIMON TURNER1

1Department of Earth and Planetary Sciences, Macquarie University, New South Wales 2109, Australia
2Carnegie Institution of Washington, 5424 Broad Branch Road, Washington, D.C. 20005, U.S.A.

ABSTRACT

Concentrations of H2O, F, Cl, C, P, and S have been measured by secondary ion mass spectrometry (SIMS) in experimentally produced peridotite phases (including clinopyroxene, orthopyroxene, olivine, garnet, amphibole, and mica) and coexisting basanitic glasses. Because only two experiments produced glasses on quenching (with the melt phase in others reverting to felt-like crystallite masses) H2O concentrations in melts were also separately determined from mass-balance relationships and by assuming constant H2O/La in melts and starting materials. The resulting values were used to calculate mineral/melt partition coefficients ($D_{\text{H}_2\text{O}}$) for H2O (where $D_{\text{H}_2\text{O}}$ = (mass fraction of H2O in crystal)/(mass fraction of H2O in melt)) for conditions of 1025–1190 °C and 1.0–3.5 GPa. These gave 0.0064–0.0164 for clinopyroxene, 0.0046–0.0142 for orthopyroxene, 0.0015–0.0016 for olivine, and 0.0016–0.0022 for garnet. Although less information was obtained for the other volatiles, F was found to be significantly more compatible than H2O during peridotite melting, whereas Cl is significantly less compatible. S also has small but appreciable solubilities in amphiboles and micas, but not in pyroxenes or olivine. The solubility of C in silicate minerals appears to be negligible, although C was present in coexisting melts (~0.5 wt% as CO2) and as residual graphite during experiments. The $D$ values for H2O in clinopyroxene and orthopyroxene are positively correlated with $^{44}$Al but negatively correlated with the H2O concentrations of melts (when considered as wt%). These relationships are consistent with the broad trends of previously published partitioning data. Although some of the concentration dependence can be related to cross-correlation between $^{44}$Al in pyroxenes and H2O concentrations in melts (via the latter’s control of liquidus temperatures) this relationship is too inconsistent to be a complete explanation. A concentration dependence for $D_{\text{H}_2\text{O}}$ can also be independently predicted from speciation models for H2O in silicate melts. Thus it is likely that $D_{\text{H}_2\text{O}}$ is influenced by both $^{44}$Al and the absolute concentration of H2O in melts. $D_{\text{H}_2\text{O}}/D_{\text{Ce}}$ for clinopyroxene is inversely correlated with M2 site radii. Because the latter decrease with increasing pressure and temperature, relatively hot and/or deeply derived melts should be enriched in Ce relative to H2O when compared to melts from cooler and shallower mantle sources. Conversely, melts from H2O-rich settings (e.g., subduction zones) should have higher H2O/Ce than their source rocks. When combined with previously obtained partitioning data for non-volatile elements (from the same experiments), our data are consistent with the enrichment of intraplate basalt sources in both volatile and non-volatile incompatible elements by small-degree melts derived from local mid-ocean ridge basalt sources. In this way, volatiles can be seen to play an active role (via their promotion of partial-melting and metasomatic processes) in the auto-regulation of incompatible element concentrations in the depleted upper mantle.

Keywords: Experiments, partitioning, basanite melts, peridotite minerals, H2O, water, halides, carbon, sulfur, volatiles, incompatible elements, intraplate magmatism

INTRODUCTION

The capacity of nominally volatile-free minerals (e.g., pyroxenes, olivine, and garnet) to store volatiles (e.g., H2O and halogens) within the mantle (e.g., Wilkins and Sabine 1973; Aines and Rossman 1984; Bell and Rossman 1992; Kohn 1996; Hervig and Bell 2005) has significant implications for the Earth’s deep vola-