Experimental determination of hydrogen partitioning between melts and nominally anhydrous minerals: Consequences for melting and H storage capacity in the upper mantle

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The small amounts of H dissolved in nominally anhydrous mantle minerals (NAMMs) have significant influence on the melting behavior of the mantle. Unfortunately, direct experiments determining the effect of H in NAMMs on the peridotite solidus temperature are intractable and thermodynamic calculations are impeded by a lack of available calibration data. However, mineral/melt partition coefficients can be used to model the effect of H on the peridotite solidus using a cryoscopic approximation. Recent determinations of H partitioning between NAMMs and silicate melt by newly developed low blank SIMS techniques (Koga et al., 2003; Aubaud et al., 2004) yield a bulk $D_{\text{peridotite/melt}}$ of 0.009, consistent with estimates based on analogies to LREE in oceanic basalts (e.g., Michael, 1988). Tests of the cryoscopic approximation in simple systems (forsterite-H$_2$O, enstatite-H$_2$O, diopside-H$_2$O) reproduce melting behavior for modest amounts of H$_2$O (<10 wt.%) in the liquid. Applied to peridotite, this approach indicates that 50–200 ppm H$_2$O causes melting beneath ridges 5–20 km deeper than intersection with the dry peridotite solidus. Beneath plumes, where the H$_2$O content may be 500–1000 ppm, the predicted increase is 60–100 km.

The H storage capacity is the maximum H that can be stored in solid peridotite at a given $T$ and $P$ without stabilization of a hydrous fluid or melt. Solubility measurements of individual NAMMs provide some evidence of peridotite storage capacities, but a critical additional constraint is equilibrium partitioning of H between coexisting peridotitic minerals. Experiments indicate values of $D_{\text{pyrox/melt}}$ of $\sim$10±1 (n=6) at modest pressure (1–2 GPa). Combined with solubility measurements of H in olivine (Kohlstedt et al. 1996; increased by 3 X: Bell et al., 2003, Koga et al., 2003), this suggests that the storage capacity of H$_2$O in the upper mantle is at least 0.4 wt.% at 410 km. This challenges the view that the storage capacity of the upper mantle is small and that hydrous material advected from the transition zone will likely melt.