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The effect of Fe on olivine H_2O storage capacity: Consequences for H_2O in the martian mantle

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Abstract

To investigate the influence of chemical composition on the behavior of H_2O in Fe-rich nominally anhydrous minerals, and to determine the difference between H_2O behavior in the martian and terrestrial mantles, we conducted high-pressure H_2O storage capacity experiments employing a wide range of olivine compositions. Experiments were conducted with bulk compositions in the system FeO-MgO-SiO_2-H_2O with Mg no. [Mg no. = 100 × molar Mg/(Mg+Fe)] ranging between 50 and 100 at 3 GPa in a piston-cylinder and at 6 GPa in a multi-anvil apparatus. Experiments at 3 GPa were conducted at 1200 °C, with f_{O_2} buffered by the coexistence of Fe and FeO, and at 1300–1500 °C in unbuffered assemblies. Experiments at 6 GPa were conducted at 1200 °C without buffers. Experiments at 1200 °C produced olivine+orthopyroxene+hydrous liquid (liq), and higher T experiments produced olivine+liq. Additionally, we synthesized a suite of 7 olivine standards (Mg no. = 90) for low blank secondary ion mass spectrometry (SIMS) analysis of H in multi-anvil experiments at 3–10 GPa and 1250 °C, resulting in large (200–400 μm) homogeneous crystals with 0.037 to 0.30 wt% H_2O. Polarized Fourier transform infrared (FTIR) measurements on randomly oriented grains from the synthesis experiments were used to determine principal axis spectra through least-squares regression, and H contents were calculated from the total absorbance in the OH stretching region. Using these olivines as calibrants for SIMS analyses, the H contents of olivines and pyroxenes from the variable Mg no. experiments were measured by counting ^{16}OH ions. Ignoring any matrix effects owing to variation in Mg no., H contents of olivine and pyroxene increase linearly with decreasing Mg no. At 6 GPa and 1200 °C, olivine H contents increase from 0.05 to 0.13 wt% H_2O (8360 to 23 900 H/10^6 Si) as olivine Mg no. decreases from 100 to 68, and at 3 GPa and 1200 °C olivine H contents increase from 0.017 to 0.054 wt% (278 to 10 000 H/10^6 Si) as Mg no. decreases from 100 to 55. The partition coefficient for H between pyroxene and olivine, $D_H^{opx/ol}$, decreases from 1.05 at 3 GPa and 1200 °C to 0.61 at 6 GPa and 1200 °C. The storage capacity of Fe-rich olivines with compositions expected in the martian mantle is ~1.5 times greater than those in the terrestrial mantle, suggesting that the geochemical behavior of H_2O in the mantles of the two planets are quite similar. If 50% of the K_2O on Mars remains in its mantle (Taylor et al. 2006), then a similar or greater proportion of the H_2O is also in the mantle. Given accretionary models of the total martian H_2O budget (Lunine et al. 2003), this suggests concentrations of 100–500 ppm H_2O in the martian mantle and 0.1–1.9 wt% H_2O in primary martian basalts.

Keywords: Olivine, H_2O storage capacity, Mars, infrared spectroscopy, ion microprobe