Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.26475

Water solubility of olivine under redox-controlled deep upper mantle conditions: effects of pressure, temperature and coexisting fluids and implications

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Water as hydroxyl in olivine plays a crucial role in determining the water budget and many physicochemical properties of the upper mantle. However, the water solubility of olivine, which defines its maximum water content under given conditions, in the deep upper mantle remains poorly constrained. We have measured the water solubility by conducting annealing experiments at Fe-FeO buffered reduced conditions and 10–13 GPa and 1100–1450 °C, using a gem-quality natural olivine crystal with representative chemistry and different fluid materials (peridotite powder for buffering silica activity). Equilibrium water incorporation in the annealed olivine samples was examined by H diffusion kinetics, water profile analyses and time-series experiments. Infrared spectra of annealed olivine exhibit hydroxyl bands primarily at high frequency (3650–3450 cm^{-1}), though low frequency (3450–3100 cm^{-1}) bands are also present. This is different from the observed presence of both intense high and low frequency bands in olivine annealed at 1–7 GPa under otherwise similar conditions, suggesting the role of pressure in affecting the water incorporation. Given other conditions, the water solubility increases nonlinearly with both pressure and temperature. We show that the water solubility in runs coexisting with CH_4-H_2O is lower than that coexisting with H_2O. We model the storage capacity of water in olivine in the realistic upper mantle, and the highest value is only ~800 ± 80 ppm wt. H_2O that is observed at ~410 km depth. The actual water content of olivine in the upper mantle should be mostly, if not exclusively, lower than this value. The inferred bulk storage capacity of water in peridotite in the upper mantle increases with increasing depth in an inverse S-shape, with a maximum of 600 ± 100 ppm wt. H_2O at ~410 km depth and a minimum of 350 ± 50 ppm wt. H_2O at 190–230 km depth. The results allow novel constraints to be placed on the water storage in the upper mantle, as well as on the relevant hydrous melting in particular at the bottom of the upper mantle and at its mid-depths.