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The partitioning of H between olivine and melt at low pressures (10–200 MPa)

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Abstract

The concentration of H_2O_T (i.e., total H; assumed here to be the sum of hydroxyl and molecular water) in silicate minerals and melts exerts a primary control on the physicochemical properties of Earth's crust and mantle. The partitioning of H_2O_T between minerals and melts is a key parameter used to model the H_2O_T contents of magmatic source regions in terrestrial and planetary systems. In mafic systems, olivine is frequently the first crystallizing phase, which makes it a useful tracer of primitive melt composition. Previously, the partitioning of H_2O_T between olivine and melt was only experimentally constrained at H_2O-undersaturated conditions and pressures ≥500 MPa, which are broadly applicable to Earth's mid- to lower-crust and uppermost mantle. However, we have few constraints at upper crustal pressures, limiting our ability to model pre-eruptive H_2O_T contents of magmas, decompression rates, and ultimately volcanic hazards. Here we present the first experimental determination of the partitioning of H_2O_T between olivine and melt at pressures relevant to Earth's upper crust (10–200 MPa). Contrary to predictions based upon the extrapolation of experimental results from pressures ≥500 MPa, we find that the olivine-melt H_2O_T partition coefficient ($D_{H_2O_T}^{ol/melt}$ ranges from 0.0011 to 0.00033) decreases with increasing melt H_2O_T and increasing pressure from 10–200 MPa. One explanation for the observed relationship between $D_{H_2O_T}^{ol/melt}$ and melt H_2O_T concentration is that $D_{H_2O_T}^{ol/melt}$ is controlled by the speciation of H (e.g., hydroxyl and molecular water) in silicate melts. We calculate the concentration of hydroxyl (OH) dissolved in the melt, and assuming H is only incorporated into olivine as OH, calculate an olivine-melt OH partition coefficient ($D_{OH}^{Ol/melt}$). Our data indicate that $D_{OH}^{Ol/melt}$ is constant ($D_{OH}^{Ol/melt} = 0.0011 \pm 0.0002$; 1 St.dev.) and that the proportion of molecular water (H_2O_m) to OH in the melt controls the variation of $D_{H_2O_T}^{Ol/melt}$ with melt H_2O_T concentration for our experiments. We also compared San Carlos olivine seed crystals to olivine crystallized in the same experimental charges. Our data indicate that San Carlos olivine seed crystals have lower H_2O_T concentrations than olivine crystallized during the experiments, which may be explained by differences in their compositions and, therefore, extrinsic point defect populations. Our results demonstrate that at low pressures (≤200 MPa), the partitioning of H_2O_T between olivine and melt is primarily dependent upon the speciation of H in silicate melts. Similarly, in combination with prior experimental work on clinopyroxene and plagioclase, our results suggest that the speciation of H in silicate melts may be a primary control on the partitioning of H_2O_T between all nominally anhydrous minerals and melts, at least at H_2O_T contents up to ~5 wt%. We apply our results to prior estimates for magma decompression rates from the 1977 fire fountain eruption at Seguam volcano and find that, for the variable $D_{H_2O_T}^{Ol/melt}$ determined in our study, median magma decompression rates are slightly slower (a factor of ~2.5) but within the uncertainty of models using a constant $D_{H_2O_T}^{ol/melt} = 0.0009 \pm 0.0003$ (1 St.dev.) (Towbin et al. 2023). Therefore, prior estimates of magma decompression rates based upon H^+ diffusion in olivine may be slightly overestimated if the dependence of $D_{H_2O_T}^{ol/melt}$ on the speciation of H in the melt is unaccounted for.

Keywords: Olivine, partitioning, melt, crust, low pressure