

Experimental evaluation of a new H₂O-independent thermometer based on olivine-melt Ni partitioning at crustal pressure

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ABSTRACT

An olivine-melt thermometer based on the partitioning of Ni ($D_{\text{Ni}}^{\text{Ol/liq}}$) was hypothesized by Pu et al. (2017) to have a negligible dependence on dissolved water in the melt (and pressure variations from 0–1 GPa), in marked contrast to thermometers based on $D_{\text{Mg}}^{\text{Ol/liq}}$. In this study, 15 olivine-melt equilibrium experiments were conducted on a basaltic glass starting material (9.6 wt% MgO; 353 ppm Ni) to test this hypothesis by comparing the effect of dissolved H₂O in the melt on $D_{\text{Mg}}^{\text{Ol/liq}}$ and $D_{\text{Ni}}^{\text{Ol/liq}}$ on the same set of experiments. Results are presented for six anhydrous experiments at 1 bar, two anhydrous experiments at 0.5 GPa, and seven hydrous experiments at 0.5 GPa. Analyzed olivine and glass compositions in the quenched run products were used to calculate $D_{\text{Mg}}^{\text{Ol/liq}}$ and $D_{\text{Ni}}^{\text{Ol/liq}}$ values for each experiment, which in turn permit temperature to be calculated with the Mg- and Ni-thermometers calibrated in Pu et al. (2017) on anhydrous, 1-bar experiments from the literature. The Ni-thermometer recovers the temperatures of all 15 experiments from this study with an average deviation of -3 °C, including those with up to 4.3 wt% H₂O dissolved in the melt. In contrast, the Mg-thermometer recovers the anhydrous, 1-bar experimental temperatures within $+14$ °C on average, but overestimates the hydrous experimental temperatures by $+49$ to $+127$ °C, with an average of $+83$ °C. When the Mg-thermometer of Putirka et al. (2007) is applied, which includes a correction for analyzed H₂O (≤ 4.3 wt%) in the quenched melts of the run products, all experimental temperatures are recovered with an average ($\pm 1\sigma$) deviation of $+7$ °C. The combined results show that $D_{\text{Ni}}^{\text{Ol/liq}}$ has a negligible dependence on dissolved water in the melt (≤ 4.3 wt% H₂O), which is in marked contrast to the strong dependence of $D_{\text{Mg}}^{\text{Ol/liq}}$ on water in the melt. An understanding of why $D_{\text{Ni}}^{\text{Ol/liq}}$ is insensitive to dissolved water, unlike $D_{\text{Mg}}^{\text{Ol/liq}}$, is obtained from spectroscopic evidence in the literature, which shows that Ni²⁺ (transition metal) and Mg²⁺ (alkaline earth metal) have distinctly different average coordination numbers (predominantly fourfold and sixfold, respectively) in silicate melts and that fourfold-coordinated Ni²⁺ is unaffected by the presence of dissolved water in the melt. This difference in coordination number explains why $D_{\text{Ni}}^{\text{Ol/liq}}$ and $D_{\text{Mg}}^{\text{Ol/liq}}$ each have a different dependence on pressure, anhydrous melt composition, and melt water content. Application of the Ni-thermometer of Pu et al. (2017) to five natural samples from the Mexican arc, for which H₂O contents (3.6–6.7 wt%) in olivine-hosted melt inclusions are reported in the literature, leads to temperatures that match those obtained from the Putirka et al. (2007) Mg-thermometer that corrects for analyzed H₂O contents. This study demonstrates that a thermometer based on $D_{\text{Ni}}^{\text{Ol/liq}}$ can be applied to hydrous basalts at crustal depths without the need to correct for dissolved water content or pressure.

Keywords: Nickel, olivine-melt thermometry, subduction zone processes, phase equilibrium experiments