Experimental evaluation of a new H$_2$O-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 ($D_{Ni}^{Ol/liq}$) 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 $D_{Mg}^{Ol/liq}$. 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 H$_2$O in the melt on $D_{Mg}^{Ol/liq}$ and $D_{Ni}^{Ol/liq}$ 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 $D_{Mg}^{Ol/liq}$ and $D_{Ni}^{Ol/liq}$ 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% H$_2$O 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 H$_2$O ($\leq$4.3 wt%) in the quenched melts of the run products, all experimental temperatures are recovered with an average ($\pm 1\sigma$) deviation of +7 °C. The combined results show that $D_{Ni}^{Ol/liq}$ has a negligible dependence on dissolved water in the melt ($\leq$4.3 wt% H$_2$O), which is in marked contrast to the strong dependence of $D_{Mg}^{Ol/liq}$ on water in the melt. An understanding of why $D_{Ni}^{Ol/liq}$ is insensitive to dissolved water, unlike $D_{Mg}^{Ol/liq}$, is obtained from spectroscopic evidence in the literature, which shows that Ni^{2+} (transition metal) and Mg^{2+} (alkaline earth metal) have distinctly different average coordination numbers (predominantly fourfold and sixfold, respectively) in silicate melts and that fourfold-coordinated Ni^{2+} is unaffected by the presence of dissolved water in the melt. This difference in coordination number explains why $D_{Ni}^{Ol/liq}$ and $D_{Mg}^{Ol/liq}$ 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 H$_2$O 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 H$_2$O contents. This study demonstrates that a thermometer based on $D_{Ni}^{Ol/liq}$ 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