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SPECIAL COLLECTION: OLIVINE

A comparison of olivine-melt thermometers based on D_{Mg} and D_{Ni}: The effects of melt composition, temperature, and pressure with applications to MORBs and hydrous arc basalts

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Abstract

A new olivine-melt thermometer based on the partitioning of Ni ($D_{Ni}^{Ol/liq}$), with a form similar to the Beattie (1993) $D_{Mg}^{Ol/liq}$ thermometer, is presented in this study. It is calibrated on a data set of 123 olivine-melt equilibrium experiments from 16 studies in the literature that pass the following five filters: (1) 1 bar only, (2) analyzed totals between 99.0–101.0 wt% for olivine and 98.5–101.0 wt% for quenched glasses, (3) olivine is the only silicate phase in equilibrium with the melt, (4) the NiO concentration is ≥0.1 wt% in olivine and ≥0.01 wt% in quenched glass, and (5) no metallic phase is present other than the capsule. The final data set spans a wide range of temperatures (1170–1650 °C), liquid compositions (37–66 wt% SiO_2; 4–40 wt% MgO; 107–11 087 ppm Ni), and olivine compositions ($Fo_{36\text{-}100}$; 0.10–15.7 wt% NiO). The Ni-thermometer recovers the 123 experimental temperatures within ±29 °C (1σ), with an average residual of 0 °C. A re-fitted version of the Mg-thermometer of Beattie (1993), calibrated on the same 123 experiments as for the Ni-thermometer, results in an average residual of 1 ± 26 °C (1σ). When both thermometers are applied to the same 123 experiments, the average ΔT ($T_{Mg} - T_{Ni}$) is 1 ± 29 °C (1σ), which confirms that the Mg- and Ni-thermometers perform equally well over a wide range of anhydrous melt composition and temperature at 1 bar. The pressure dependence of the Ni-thermometer under crustal conditions (≤1 GPa) is shown to be negligible through comparison with experimental results from Matzen et al. (2013), whereas the pressure dependence of the Mg-thermometer is up to 52 °C at ≤1 GPa (Herzberg and O'Hara 2002). Therefore, neglecting the effect of pressure when applying both thermometers to basalts that crystallized olivine at crustal depths (≤1 GPa) is expected to lead to negative ΔT ($T_{Mg} - T_{Ni}$) values (≤ –52 °C). Application of the two thermometers to nine mid-ocean ridge basalts results in an average ΔT of –3°, consistent with shallow crystallization of olivine under nearly anhydrous conditions. In contrast, application of the two thermometers to 18 subduction-zone basalts leads to an average ΔT of +112°; this large positive ΔT value cannot be explained by the effect of pressure, temperature or anhydrous melt composition. It is well documented in the literature that $D_{Mg}^{Ol/liq}$ is affected by dissolved water in the melt and that Mg-thermometers overestimate the temperature of hydrous basalts if an H_2O correction is not applied (e.g., Putirka et al. 2007). Therefore, the reason why hydrous arc basalts have higher ΔT ($T_{Mg} - T_{Ni}$) values than MORBs may be because $D_{Ni}^{Ol/liq}$ is less sensitivite to water in the melt, which is supported by new Ni-partitioning results on three olivine-melt equilibrium experiments on a basaltic andesite with up to 5 wt% H_2O. More hydrous experiments are needed to confirm that the Ni-thermometer can be applied to hydrous melts without a correction for H_2O in the melt.

Keywords: Ni partitioning, thermometry, olivine, subduction zone magma, H_2O