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A re-evaluation of the Al-in-Olivine geothermometer

YISHEN ZHANG[1], OLIVIER NAMUR[1], BERNARD CHARLIER[2], WEIRAN LI[3], OLIVER SHORTTLE[3], ESTEBAN GAZEL[4], ELEANOR JENNINGS[5], PETER THY[6] AND TIMOTHY GROVE[7]

[1]KU Leuven
[2]University of Liège
[3]University of Cambridge
[4]Cornell University
[5]Birkbeck, University of London
[6]University of California, Davis
[7]Massachusetts Institute of Technology

Presenting Author: yishen.zhang@kuleuven.be

Thermal and chemical exchanges between Earth's mantle and the lithosphere, e.g. mantle convection or upwelling plumes, are thought to generate voluminous magmas in large igneous provinces (LIPs). The Al-in-olivine geothermometer, which is based on Al partitioning between coexisting olivine and spinel, is a robust tool to constrain mantle source temperature [1, 2]. The geothermometer does not require any estimation of melt compositions and benefits from the slow diffusion rate of Al_2O_3 in olivine, thus minimizing the effect of re-equilibration at low temperature. The Al-in-olivine geothermometer has thus been widely used to investigate the temperature of terrestrial and extraplanetary rocks.

In this study, we re-evaluate and extend the calibration by performing 46 new experiments with an extended range of melt compositions and reanalyzed 21 published experiments with high precision measurements. The final calibration set (training dataset: 92; test dataset: 24) spans a wide range of temperature (1174-1606 °C), pressure (0-1.35GPa), oxygen fugacity (fO_2) (QFM-2.5 to QFM+7, where QFM = quartz-fayalite-magnetite buffer), and H_2O content (0-7.4 wt%). We regressed two thermometers from two algorithms, one follows a thermodynamic formalism, the other empirical one follows the formalism of Coogan et al. (2014). The results show that besides the Al partitioning in olivine and spinel, the spinel compositions have a significant effect on the empirical equation but not on thermodynamic formalized equation, which indicates an underestimation of the interplay between fO_2, and melt compositions in the empirical equation. Water has an insignificant effect on the thermometers, while a weak correlation with pressure is observed but it is not significant for the application on the current natural database. Applications to natural rocks of LIPs suggest that previous studies generally overestimated the crystallization temperature by ~ 40-60 °C. More refractory harzburgite components may exist in the mantle of intra-plate LIPs to compensate the lower potential temperatures.

References

[1] Wan et al. (2008). Am. Mineral. 93, 1142-1147.
[2] Coogan et al. (2014) Chem. Geol. 368, 1-10.