Aluminium in olivine: substitution mechanisms and implications for thermometry

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The Al-in-olivine thermometer [1] has rapidly found popularity [2,3] because of the ease with which it can be applied to basaltic rocks. At present it is calibrated for spinel-saturated conditions [1,2]; an extension to spinel-free rocks would be benefical.

A rigorous evaluation of the thermodynamics of this thermometer require the systematics of Al substitution to be well understood. For example, Al can substitute into forsterite (Mg_2SiO_4) as the following components:

(1) $MgAlAlO_4$ (substitution onto the T- and M-sites)
(2) $MgRAlO_4$ (substitution onto the T-site, with R = Cr^{3+}, Fe^{3+} etc.)
(3) $Al_{4/3}\square_{2/3}SiO_4$ or $MgAl_{2/3}\square_{1/3}SiO_4$ (vacancy-mediated substitution onto one or both M-sites)

New systematic experimental forsterite/melt partitioning data for Al and Cr^{3+} at 1400 °C provide insights into the charge compensation mechanisms for these cations, the extent of short-range order in these defects, and the relative importance of the different substitution mechanisms. In contrast to [4] we observe D_{Al} to vary by a factor of 2 in Cr-free systems, implying that mechanism 1 dominates; D_{Al} is substantially enhanced by the availability of Cr^{3+}. Mechanism 3 is important because it permits fast diffusion of Al, in contrast to the low mobility of Al on the T-site [5].

The results of this study reiterate the complexity of trivalent cation substitution into olivine [4], which should be unsurprising given the diversity of substitution mechanisms for H^+ in forsterite [6].

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