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The effect of mineral paragenesis on Al diffusion in olivine

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Al is the most abundant trivalent impurity of olivine and is particularly important because its concentration in olivine is temperature dependant, and it therefore has potential as a geothermometer (Wan, et al. 2008). Furthermore recent studies show that the incorporation of water into the olivine lattice is affected by the presents of trivalent cations such as Al3+ (Berry, et al. 2007; Hauri, et al. 2006). The Al distribution in olivines from volcanic rocks is often zoned and mantle olivines may also show an inhomogeneous distribution of Al, whereas the majority of other trace elements homogenized by diffusion (Mallmann, et al. 2009; McKibbin, et al.). However, there are no quantitative experimental data for Al diffusion in olivine, probably because the combination of low concentration rate and low diffusion rate make measurement difficult. We investigated the effect of silica activity on the diffusion rate of Al in forsterite at varying temperatures using solid-state buffer assemblages. Our study aimed to quantify the effect of major cation activities on the diffusion and concentration of Al in forsterite and also provide insights into the mechanism of Al substitution into the olivine lattice.

The activities of SiO_2, MgO and $Al2O_3$ were buffered in each experiment by four different mineral associations: forsterite + periclase + spinel (fo+per+sp); forsterite + spinel + sapphirine (fo+sp+spr); forsterite + sapphirine + cordierite (fo+spr+cor); forsterite + cordierite + enstatite (fo+cor+en). Iron oxide in proportion of FeO/(FeO+MgO) = 0.1 was added to mixtures for San Carlos olivine experiments. Diffusion experiments were performed at the one-atmosphere vertical tube furnaces modified to control the fO_2 by CO-CO_2 gas mixing or in a box furnace in air for 10 – 28 days at temperatures from 1100 to 1500oC and $logfO_2$ -0.7 and -5.7. The experiment with the San Carlos olivine was performed at 1300oC and at $logfO_2$ = -5.7. In order to obtain equilibrium concentrations of the point defects we performed some experiments with pre-annealing. Diffusion profiles were measured by LA-ICP-MS in a traverse mode. The Al content of forsterite decreases with temperature dependence, increasing the potential of Al in olivine as a geothermometer. We obtain the activation energy of 379 kJ/mol for the high $aSiO_2$ experiments, which is close within error of the value of 364 kJ/mol for the low $aSiO_2$ experiments implying a common diffusion mechanism. The pre-exponential factor, however, increases by 5 orders of magnitude from low $aSiO_2$ (fo+per+sp buffer) to high $aSiO_2$ (fo+cor+en buffer). The much higher diffusivity at high $aSiO_2$ indicates that Al diffusion occurs through octahedral cation site vacancies.