

SPECIAL COLLECTION: OLIVINE

Diffusion of phosphorus in olivine and molten basalt[†]

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ABSTRACT

The diffusivity of phosphorus in San Carlos olivine (SCO) was measured at near-atmospheric pressure and 650–850 °C by in-diffusion of P from a surface powder source consisting of pre-reacted SCO and AlPO₄. The experiments were conducted in evacuated silica-glass ampoules at oxygen fugacities fixed by solid-state buffers, generally Ni-NiO but also including two experiments buffered at wüstite-magnetite. Phosphorus uptake profiles were characterized by Rutherford backscattering spectroscopy (RBS) and nuclear reaction analysis (NRA). The temperature dependence of P diffusion in SCO conforms to the expected Arrhenius relation $D = D_0 \exp(-E_a/RT)$, where the constants are as follows: $\log(D_0, \text{m}^2/\text{s}) = -10.06 \pm 0.80$ and $E_a = 229 \pm 16 \text{ kJ/mol}$. These values characterize P as a relatively slow diffuser in olivine—slower by about an order of magnitude than Cr and Ca at basalt near-liquidus temperatures—but substantially faster than Si.

With a view toward modeling P uptake during rapid growth of natural olivines, P diffusion was also characterized in dry MORB basalt melt over the temperature range 1250–1500 °C at 1 GPa, using traditional diffusion couples contained in graphite. Phosphorus diffusion profiles in the quenched and depressurized samples were quantified by laser-ablation ICP/MS. Phosphorus diffusion in basaltic melt is similar to that of Si, with $\log(D_0, \text{m}^2/\text{s}) = -6.30 \pm 0.7$ and $E_a = 147 \pm 22 \text{ kJ/mol}$.

The new data for P diffusion in olivine and basalt melt can be used to explore the acquisition of fine-scale zoning in natural olivine phenocrysts through kinetic models, as well as the survival of P zoning in olivine with time spent at elevated temperature. Models of growth entrapment of a P-enriched near-surface layer in the olivine lattice indicate that crystal growth at plausible sustained rates is indeed likely to result in regions of anomalously high P content in the resulting crystal. Phosphorus concentrations above the equilibrium partitioning value can also result from development of a diffusive boundary layer in the melt against a rapidly growing crystal, but this mechanism is ineffective at typical sustained olivine growth rates, requiring dendrite-forming growth speeds. Preservation of P zoning on the scale of a few micrometers apparently requires cooling within a few months of formation of the zoning.

Keywords: Diffusion, phosphorus, olivine, basaltic melt, growth kinetics, basalt thermal history