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Mg diffusion in forsterite from 1250–1600 °C

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Abstract

^{26}Mg tracer diffusion coefficients were determined in single crystals of pure synthetic forsterite (Mg_2SiO_4). Isotopically enriched powder sources both acted as the ^{26}Mg source and buffered the activities of silica (a_{SiO_2}) at forsterite + protoenstatite ($Mg_2Si_2O_6$) (high a_{SiO_2}) and forsterite + periclase (MgO) (low a_{SiO_2}). Experiments were conducted at atmospheric pressure between 1250 and 1600 °C, and at oxygen fugacities (f_{O_2}s) between 10^{-12} bars (CO-CO_2 mix) and $10^{-0.7}$ bars (air). The resulting diffusion profiles were measured along the three principal crystallographic axes (*a*, *b*, and *c*; ||[100], ||[010], ||[001]) using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), with a quadrupole mass spectrometer. These measurements were corroborated by ion microprobe using the sensitive high resolution ion microprobe-reverse geometry (SHRIMP-RG) instrument.

Mg tracer diffusion is anisotropic, with $D_{[001]} > D_{[010]} > D_{[100]}$, the difference in diffusion coefficients varying by about one order of magnitude at a given temperature with crystallographic orientation. Diffusion is faster in protoenstatite-buffered than periclase-buffered conditions, again with around one order of magnitude difference in diffusivity between buffering conditions. There is no apparent effect of f_{O_2} on diffusion. A global fit to all data, including data from Chakraborty et al. (1994) and Morioka (1981) yields the relationship:

$$\log_{10} D = \log_{10} D_0 \left(m^2 s^{-1}\right) + 0.61(\pm 0.03) \log_{10} a_{\mathrm{SiO_2}} + \frac{-359(\pm 10)\mathrm{kJ/mol}}{2.303\mathrm{R}T}$$

where $\log_{10}D_0$ is –3.15 (±0.08), –3.61 (±0.02), and –4.01 (± 0.05) $m^2 s^{-1}$ for the [001], [010], and [100] directions, respectively (1 s.d.). The LA-ICP-MS technique reproduces diffusion coefficients determined by SHRIMP-RG, albeit with slightly different absolute values of isotope ratios. This shows that LA-ICP-MS, which is both accessible and rapid, is a robust analytical method for such tracer diffusion studies.

Keywords: Diffusion, olivine, forsterite, magnesium, experimental petrology