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Post-eruptive diffusive fractionation of lithium isotopes: Implications for mantle and volcanic processes

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Lithium (Li) isotopes are useful for investigating melt and fluid migration in the mantle and for identifying recycled crustal components in magmatic sources. Several published studies of mantle xenoliths and of mafic phenocrysts separated from lavas record large Li isotope fractionations that exceed those expected for mantle-derived rocks and also note correlations between host-rock type and Li isotope variability. These observations suggest syn- or post-eruptive isotopic disturbance. To test this hypothesis explicitly, and to explore its implications for mantle geochemistry and volcano dynamics, we compared the Li geochemistry of olivines from different eruptive styles of two volcanic centers in the Basin and Range Province of the Southwest United States.

Samples consist of peridotite xenoliths from the surge deposits, scoria, and lava at Peridot Mesa (San Carlos Volcanic Field, Arizona) and scoria and lava from Lathrop Wells volcano (Southwestern Nevada Volcanic Field, Nevada). Polished sections of lapilli and lava fragments were prepared and olivine crystals were analyzed using secondary ion mass spectrometry (SIMS) to determine the Li isotope ratios and Li concentrations. Electron probe microanalyses were used to determine major element compositions and the raw Li isotope ratios were corrected for olivine matrix effects.

Results show that trends of Li isotope ratios and Li concentrations vary significantly within crystals from effusive deposits. Crystal rims display higher Li concentrations and lower δ^7Li values than cores, indicating diffusion of ^{6}Li into crystals from surrounding fluids in glass or grain boundaries. The variations observed in the effusively erupted samples are absent in the explosively erupted samples from both field locations. Olivine phenocrysts in the Lathrop Wells explosive samples show average δ^7Li values of -1.7 ‰ and average Li concentrations of 4 ppm. In the effusive samples, edges of olivine crystals show δ^7Li deviations down to -20.7 ‰ and Li concentrations increase up to 16 ppm in some cases, whereas centers of crystals remain close to the average values reported above. Olivines in the San Carlos explosive samples show average δ^7Li values of 8.2 ‰ and average Li concentrations of 1 ppm. Isotopically lighter olivine rims occur in the effusive samples. These light rims exist in several crystals within a single xenolith, including those bordering the lava and also those several millimeters inward from the lava margin. In some cases, δ^7Li values at lava margins may decrease to -35.0 ‰ and Li concentrations may increase to 49 ppm.

Lengths of Li diffusion into crystal rims allow an estimate of minimum time periods over which lava flows reached closure temperatures and effectively locked in the measured isotopic and compositional values. These distances average 380 and 260 μm for the San Carlos and Lathrop Wells samples, respectively. Using experimentally determined diffusion coefficients for Li in olivine, minimum time periods are on the order of 10 to 25 years for both volcanic centers, depending upon the assumed temperature of the magma at eruption.

These results show that Li isotope ratios and concentrations in olivine vary with the style of eruptive mechanism, and may also depend on characteristics of grain boundaries and neighboring phases at the time of eruption. It appears that samples best suited to preserving mantle and magmatic isotopic information are those from explosive volcanic eruptions, where samples are rapidly quenched and preserve the original values. In combination with diffusion data, Li isotope variations place quantitative constraints on the minimum timescales of post-eruptive processes.