Volatile Records in Olivine-Hosted Melt Inclusions: What Can We Actually Learn From Them?

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Constraining the volatile contents and oxidation state of basaltic magmas is critical to understanding their generation and evolution. However, quantitatively assessing the pre-eruptive concentrations of H_2O, CO_2, and other volatiles in magmas is challenging because their solubilities decrease dramatically with decreasing pressure, resulting in near-total degassing of erupted lavas. Further, the $Fe^{3+}/\sum Fe$ ratio of a magma can be modified by crustal assimilation, magma mixing, or crystallization. Olivine-hosted melt inclusions have become an important source of information on magmatic volatiles and f_{O2} because they are largely protected from degassing or changes in f_{O2} experienced by the external magma. However, the major uncertainty involved with interpreting volatile and $Fe^{3+}/\sum Fe$ heterogeneities preserved in melt inclusions is the potential for post-entrapment modification by diffusive processes.

Here, we present a comprehensive set of volatile, hydrogen isotope, and $Fe^{3+}/\sum Fe$ data from recent dehydration experiments on olivine-hosted melt inclusions, which demonstrate that diffusive processes result in post-entrapment modification of not only H_2O, but also f_{O2}, CO_2, and to a lesser extent S. Moreover, these processes may occur on timescales of hours to days at magmatic temperatures. We develop an integrated open-source analytical model that accounts for post-entrapment changes to H_2O, CO_2, D/H ratios, and f_{O2} in a spherical melt inclusion located at the center of a spherical olivine. Isotropic diffusion of protons, deuterons, and metal vacancies is allowed through the olivine crystal, resulting in H_2O, D_2O, and f_{O2} equilibration. Changes in the internal pressure of the melt inclusion due to diffusive loss of H_2O and the resulting change in CO_2 are modeled assuming an isochoric inclusion and considering expansion of the host olivine during decompression. Our model successfully reproduces the experimental data, indicating that it robustly accounts for the mechanisms of diffusive re-equilibration. Although melt inclusions are susceptible to diffusive modification, they remain a valuable source of information on crustal magmatic processes if interpreted carefully. For example, although measured concentrations of H_2O & CO_2 in initially hydrous melt inclusions may only yield estimates of the last depth of equilibration within the crust, quantitative modeling of multiple proxies for H_2O-loss, such as D/H ratios and vapor bubbles, can place constraints on pre-eruptive H_2O & CO_2 concentrations, and therefore initial pressures of entrapment.