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Vapor-bubble growth in olivine-hosted melt inclusions

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Abstract

Melt inclusions record the depth of magmatic processes, magma degassing paths, and volatile budgets of magmas. Extracting this information is a major challenge. It requires determining melt volatile contents at the time of entrapment when working with melt inclusions that have suffered post-entrapment modifications. Several processes decrease internal melt inclusion pressure, resulting in nucleation and growth of a vapor bubble and, time permitting, diffusion of volatiles (especially CO_2) into the vapor bubble. Previous studies have shown how this process may lead to most of the CO_2 in the bulk melt inclusion being lost to the bubble. Without reconstruction, most of the melt inclusion data in the literature vastly underestimate the CO_2 concentrations of magmas by measuring the glass phase only. Methods exist that attempt to reconstruct the entrapped CO_2 contents, but they can be difficult to apply and do not always yield consistent results. Here, we explore bubble growth, evaluate CO_2 reconstruction approaches, and develop improved experimental and computational approaches. Piston-cylinder experiments were conducted on olivine-hosted melt inclusions from Seguam (Alaska, U.S.A.) and Fuego (Guatemala) volcanoes at the following conditions: 500–800 MPa, 1140–1200 °C for Seguam and 1110–1140 °C for Fuego, 4–8 wt% H_2O in the KBr brine filling the experimental capsules, and run durations of 10–120 min. Heated melt inclusions form well-defined S-CO_2 trends consistent with degassing models. CO_2 contents are enriched by a factor of ~2.5, on average, relative to those of the glasses in unheated melt inclusions, whereas S contents of heated and unheated melt inclusion glasses overlap, indicating that insignificant amounts of S partition into the vapor bubble. For naturally quenched melt inclusions, relatively low closure temperatures for CO_2 diffusion enables some CO_2 to enter vapor bubbles during quench, whereas higher closure temperatures for S diffusion limits its loss to vapor bubbles. We evaluate the timescales of post-entrapment processes and use the results to develop a new computational model to restore entrapped CO_2 contents: melt inclusion modification corrections (MIMiC). Heated melt inclusion data are used as a benchmark to evaluate the results from MIMiC and other published methods of CO_2 reconstruction. The methods perform variably well. Key advantages to our experimental technique are accurate measurements of CO_2 contents and efficient rehomogenization of large quantities of melt inclusions. Our new computational model produces more accurate results than other computational methods, has similar accuracy to the Raman method of CO_2 reconstruction in cases where Raman can be applied (i.e., no C-bearing phases in the bubble), and can be applied to the vast body of published melt inclusion data. To obtain the most robust data on bubble-bearing melt inclusions, we recommend taking both experimental- and MIMiC-based approaches.

Keywords: Melt inclusion, olivine, volatile, magma, CO_2, depth, diffusion, volcano