Highlights and Breakthroughs

Bubbles do matter!

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Abstract

Silicate melt inclusions (SMIs) are a very reliable tool for reconstructing the composition of magma (silicate melt + volatiles) and tracing its evolution from mantle depths to the Earth's surface. Although the scientific community already knew about the ability of shrinkage bubbles in SMIs to trap a significant fraction of CO_2, quantitative estimates were still lacking. In the article "Melt Inclusion CO_2 contents, pressures of olivine crystallization, and the problem of shrinkage bubbles" by Wallace et al (2015) included in the special collection "Glasses, melts, and fluids, as tools for understanding volcanic processes and hazards", the authors provide a numerical estimate of the amount of initial CO_2 dissolved in the melt that is lost to shrinkage bubbles and a computational method to estimate such an amount in absence of experimental studies and direct measurements by micro Raman spectroscopy.

Keywords melt inclusion; shrinkage bubble; carbon dioxide; volatile content

Silicate melt inclusions (SMIs) are small droplets of silicate melt (usually 1-100 μm) that are trapped in microcavities and imperfections of minerals during their growth in a magma body (Sorby, 1858). Upon trapping a melt enriched in volatile species', as a result of crystallization and thermal contraction, the pressure inside the melt inclusions decreases and leads to the formation of a shrinkage bubble (e.g. Roedder, 1979; Lowenstern, 1995, 2003; Métrich and Wallace, 2008); SMIs then start to behave as closed and isolated systems, evolving independently from their host crystal as the magma rises and erupts at the surface. For this reason, the study of SMIs represents a unique opportunity to reconstruct the chemical composition of the trapped magma, including its dissolved volatile content (e.g. H_2O, CO_2, Cl, S and F) which is of critical importance for determining the eruptive style and magma evolution of volcanic systems, since degassing is usually one of the major phenomena that occurs before and during an eruption.

In the last few years, several studies have focused on the role of shrinkage bubbles in controlling the volatile content of melt inclusions by taking into account mechanisms such as isochoric cooling, post-entrapment crystallization and rapid H^+ diffusion as promoters of volatile exsolution and bubble nucleation. If post-entrapment degassing occurs, CO_2 is trapped preferentially into the bubble as a vapor phase because its solubility in basaltic melts is much lower than that of H_2O. The determination of the pre-eruptive CO_2 content in melt inclusions with shrinkage bubbles then requires the adding of the mass of CO_2 in the bubble back into the inclusion.

In a recent issue of American Mineralogist, Wallace et al (2015)have developed an innovative experimental method to estimate the CO_2 content of bubbles. They have selected olivine-hosted SMIs from a scoria of Mauna Loa, both naturally quenched and reheated, and analyzed them by FTIR spectroscopy and electron microprobe. With the application of an appropriate correction for the H_2O and CO_2 contents determined for re-heated and naturally quenched SMIs, the authors have demonstrated that most of the CO_2 is lost to shrinkage bubbles that form after the entrapment. The comparison between the average CO_2 content of heated inclusions and unheated inclusions indicates that 40-90% of the initial CO_2 dissolved in the melt inclusions was lost to shrinkage bubbles, with an average loss of 75%.

Wallace and co-authors have also developed a computational method to estimate the amount of CO_2 in shrinkage bubbles in SMIs when there is a lack of experimental heating studies or direct measurements of CO_2 density by micro-Raman spectroscopy. Following the work of Riker (2005), the application of phase equilibrium calculations was coupled with volume and thermal expansion data for silicate melts allowing Wallace and co-authors to correlate the volume of the bubble with the difference between trapping and eruption temperatures. The results obtained by this computational method show that trapping pressures for heated melt inclusions are significantly higher than pressures calculated based only on the dissolved CO_2 in the naturally quenched inclusions, and agree very well with pre-eruptive bubble volume for SMIs calculated by Riker (2005) and the estimate of the fraction of initial CO_2 lost to the shrinkage bubbles based on heating experiments. They also created a closed-system degassing model to simulate the effect of post-entrapment decompression in a SMI; the mass and volume of CO_2 exsolved from the melt and the mole fractions of CO_2 and H_2O in the vapor phase were calculated by applying the Redlich-Kwong equation. To calculate the original concentration of CO_2 in the melt at the time of trapping, the authors added the estimated mass CO_2 back into each inclusion.

In their paper, Wallace and co-authors conclude that for tholeiitic magmas, such as those represented by SMI compositions from Mauna Loa picrites, the trapping pressure together with the difference between trapping and eruption temperature, and the initial content of H_2O and CO_2 in the melt, are all controlling the fraction of original CO_2 that can be lost to the shrinkage bubbles or any subsequently formed carbonate. The key implication of such findings is that we need to accurately quantify the CO_2 in shrinkage bubbles and add it back into the melt, in order to determine pressures of trapping and correctly track magma degassing behavior during ascent.

In conclusion, this paper provides numerical evidence that suggests an average of 75% of the CO_2 in a bubble-bearing SMI is contained in the bubble. If we do not account for this fraction of CO_2, we significantly underestimate the total amount of CO_2 in the SMIs, with the risk of potential errors in the determination of trapping pressure, and thus depths of magma storage and "false" magma degassing paths. Furthermore, this paper proves once again the reliability of melt inclusions in determining the pre-eruptive volatile content of magma and reconstructing its chemical composition during its evolution from formation in the mantle to its ascent and eruption at the surface.

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