Analyzing water contents in unexposed glass inclusions in quartz crystals

KENNETH S. BEFUS, JAMES E. GARDNER, AND ROBERT W. ZINKE

Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas 78712, U.S.A.

ABSTRACT

Fourier-transform infrared (FTIR) spectroscopy is commonly used to measure volatile contents dissolved in glass inclusions in minerals. The standard method is to doubly polish the crystal to fully expose the inclusion to allow infrared light to pass through the inclusion only. Glass inclusions are often a few tens of micrometers thick, which can limit the usefulness of FTIR because of how fragile samples become when thinned enough to doubly expose inclusions. Here, we test whether unexposed inclusions can be feasibly analyzed by measuring the dissolved volatile contents of a population of rehomogenized quartz-hosted glass inclusions at variable exposure levels. We analyzed 118 unexposed inclusions in 46 crystals. Of those, we analyzed the 74 inclusions in 38 crystals that survived being singly exposed. Of those, only 24 inclusions in 18 crystals remained to be analyzed when doubly exposed. Measuring the path length of light through the inclusion is critical to FTIR analyses. That length can be measured directly for doubly exposed inclusions. For those inclusions we find that water contents vary from 1.6 to 2.6 wt%, averaging 2.2 ± 0.3 wt%. Path length is difficult to measure, however, in singly exposed or unexposed inclusions. Indeed, we find that path length is variably underestimated when measured using a well-calibrated optical method. Despite that difficulty, the average water contents for the populations at each exposure level are statistically the same. But, on an inclusion-by-inclusion basis volatile contents at various exposure levels are highly discrepant because the typically underestimated thicknesses for non-doubly exposed inclusions result in anomalously high volatile contents. One way to measure path length in those inclusions is to reorient the host crystal to align the path length horizontally so it can be measured with the eyepiece reticle. Often, however, that technique proves impractical because small samples are difficult to handle. When path length cannot be measured directly, we find that using the average of the dimensions of the inclusion orthogonal to the path length can be used as a proxy for path length. That proxy allows volatile contents in unexposed inclusions to be analyzed accurately, which significantly reduces difficulties of sample preparation and can dramatically increase the number of potential target inclusions.

Keywords: Glass inclusion, FTIR, volatiles, water content, CO₂ content

INTRODUCTION

Water dissolved in silicate melts has profound impacts on their crystallization, rheology, and eruption (e.g., Ghiorso and Sack 1995; Hammer and Rutherford 2002; Giordano et al. 2008). Determining the amounts of water in silicate melts is thus paramount to both petrologists and volcanologists, but can be difficult because water can be lost during volcanic eruptions and magmatic crystallization. Dissolved water contents can be preserved in aliquots of melt trapped inside phenocrysts, which are quenched to glass during eruption. Many techniques have been developed to measure water contents in those glasses with one of the more accessible being Fourier-transform infrared (FTIR) spectroscopy, which measures the absorption of infrared light by water dissolved in glass (Ihinger et al. 1994; Devine et al. 1995; Lowenstern 1995). FTIR is especially valuable because it allows different species of dissolved water (hydroxyl and molecular H₂O) to be measured simultaneously.

Despite the importance and relative ease of FTIR measurements, the technique is hindered by sample preparation (Devine et al. 1995). Because infrared light is transmitted through the inclusion, it can be absorbed not only by the inclusion, but by everything else in its path. Crystals containing inclusions are thus usually doubly polished to expose the inclusion on both sides, so that light passes through only the inclusion. But, because inclusions are typically only ten to hundreds of micrometers in size, double exposure often results in very fragile samples that can easily disintegrate during polishing. Double exposure also often results in relatively thin samples whose thickness can be difficult to measure. Exposing small inclusions is thus difficult and painstaking (Lowenstern 1995; Nichols and Wysoczanski 2007). In fact, the error in thickness is often the largest uncertainty in an FTIR measurement.

One way to avoid losing precious samples during preparation and to decrease the error associated with thin samples would be to avoid doubly polishing the crystal and leaving the inclusion whole. To do that one would have to be certain that the crystal does not absorb infrared light, or if it does, the amount of absorbance needs to be taken into account (Bell et al. 1995; Rossman 2006; Koch-Müller and Rhede 2010). The thickness of the inclusion would also need to be measured accurately and precisely despite not being exposed, which would exclude most typical measuring techniques that use pin micrometers. Other studies