The solubility of H$_2$O in phonolitic melts

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ABSTRACT

We have calibrated the IR spectroscopic technique for measurement of H$_2$O dissolved in phonolitic glasses as hydroxyl and H$_2$O molecules using manometric and weight-loss methods. The resulting molar absorptivity coefficients are 1.25 (for absorbance due to OH at 4500 cm$^{-1}$) and 1.10 (for absorbance due to molecular H$_2$O at 5200 cm$^{-1}$). These values are similar to those previously determined for hydrous jadeitic glasses. We have applied our calibration to a new set of solubility experiments in which H$_2$O and a natural phonolitic glass were equilibrated at near-liquidus temperatures (85–973 °C) and pressures of 191–1500 bars for periods of 38–272 h. We used a regular solution model to develop an equation of state for the solubility of H$_2$O in phonolitic melts. Our experimental results demonstrate that H$_2$O solubility is appreciably higher in phonolitic melts compared with basaltic and rhyolitic melts at the same pressures and near-liquidus temperatures; e.g., the solubility of H$_2$O at 1000 bars is 4.9 wt% in phonolitic melt (850 °C), 4 wt% in rhyolitic (850 °C), and 3.2 wt% in basaltic (1200 °C) melts. The calculated partial molar volume of dissolved H$_2$O in phonolitic melt (8.5 ± 2.5 cm$^3$/mol) falls between that determined by similar methods for rhyolitic and basaltic melts, but we note that the significance of this number is unknown because speciation changes during quenching are not sufficiently well characterized.

INTRODUCTION

Exsolution of dissolved H$_2$O during magma decompression provides a major driving force for subaerial explosive volcanism. To construct quantitative models of magmatic systems and eruptive processes it is desirable to know the variation of H$_2$O solubility with changes in melt composition, pressure, and temperature. In general, experimental data document a strong pressure dependence of H$_2$O solubility (e.g., from ~0.1 wt% at 1 bar, to ~1 wt% at 100 bars, to ~3–5 wt% at 1000 bars) and much smaller, negative temperature dependence, on the order of a few tenths of a weight percent over several hundreds of degrees at near-liquidus temperatures (Holtz et al. 1992). The effect of melt composition on H$_2$O solubility is less understood and not easily predicted with great accuracy. Burnham (1979, 1981) introduced an H$_2$O solubility model that accounts for changes in melt composition, and although his model works well for silicic melts there are considerable discrepancies between measured and predicted solubilities for other compositions (cf., Holloway and Blank 1994). Moore et al. (1995) proposed an empirical model for calculating the effects of melt composition, P, and T on H$_2$O solubility that appears to work well for calc-alkaline magma compositions but whose applicability to a wider range of compositions remains to be determined.

While H$_2$O solubilities in rhyolitic and basaltic melts are relatively well known at pressures up to several thousand bars (Hamilton et al. 1964; Silver et al. 1990; Blank et al. 1993; Dixon et al. 1995), high quality measurements of H$_2$O solubilities in diverse natural melt compositions are not abundant (Holloway and Blank 1994). Some data exist for H$_2$O dissolved in andesitic (Hamilton et al. 1964) and basanitic (Cocheo and Holloway 1993) compositions, and Moore et al. (1995) have recently presented 16 bulk H$_2$O solubility determinations in 7 natural melt compositions at pressures below 2 kbar. Among what might be broadly classified as rhyolitic melt compositions, systematic variations exist in H$_2$O solubility, and these variations are sensitive to changes in the proportions of Na and K (Holtz et al. 1994); there is generally a higher H$_2$O solubility in more Na-rich melts. There are also numerous solubility determinations for a wide variety of simple synthetic melt compositions (cf. McMillan 1994), but extrapolation from these results to natural melt compositions is not straightforward.

Recent studies of the alkaline volcanism of Teide volcano (Tenerife, Canary Islands) has spurred our interest in the behavior of H$_2$O in phonolitic melts. The absence of existing experimental data and uncertain accuracy of available H$_2$O solubility models prompted us to determine a new FTIR calibration for measurement of hydrous species in phonolitic glasses directly. These results have been used to determine H$_2$O solubility behavior in a relatively evolved phonolitic-melt composition, synthesized under H$_2$O-saturated conditions at near liquidus temperatures.