Constraints on deep, CO$_2$-rich degassing at arc volcanoes from solubility experiments on hydrous basaltic andesite of Pavlof Volcano, Alaska Peninsula, at 300 to 1200 MPa

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Abstract

The solubility of CO$_2$ in hydrous basaltic andesite was examined in $f_{O_2}$-controlled experiments at a temperature of 1125 °C and pressures between 310–1200 MPa. Concentrations of dissolved H$_2$O and CO$_2$ in experimental glasses were determined by ion microprobe calibrated on a subset of run glasses analyzed by high-temperature vacuum manometry. Assuming that the solubility of H$_2$O in mafic melt is relatively well known, estimates of $X_{C-O-H}^{fluid}$ and $P_{H_2O}^{fluid}$ in the saturating fluid were modeled, and by difference, values for $X_{CO_2}^{fluid}$ and $P_{CO_2}^{fluid}$ were obtained ($X_{CO_2} \sim 0.5–0.9$); $f_{CO_2}$ could be then calculated from the fluid composition, temperature, and pressure.

Dissolved H$_2$O over a range of 2.3–5.5 wt% had no unequivocal influence on the dissolution of CO$_2$ at the pressures and fluid compositions examined. For these H$_2$O concentrations, dissolved CO$_2$ increases with $f_{CO_2}$ following an empirical power-law relation: dissolved CO$_2$ (ppmv) = 14.9$^{\pm0.3}$[$f_{CO_2}$ (MPa)]$^{0.59\pm0.10}$. The highest-pressure results plot farthest from this equation but are within its 1 standard-error uncertainty envelope.

We compare our experimental data with three recent CO$_2$-H$_2$O solubility models: Papale et al. (2006); Iacono-Marziano et al. (2012); and Ghiorso and Gualda (2015). The Papale et al. (2006) and Iacono-Marziano et al. (2012) models give similar results, both over-predicting the solubility of CO$_2$ in a melt of the Pavlof basaltic andesite composition across the $f_{CO_2}$ range, whereas the Ghiorso and Gualda (2015) model under-predicts CO$_2$ solubility. All three solubility models would indicate a strong enhancement of CO$_2$ solubility with increasing dissolved H$_2$O not apparent in our results. We also examine our results in the context of previous high-pressure CO$_2$ solubility experiments on basaltic melts. Dissolved CO$_2$ correlates positively with mole fraction (Na+K+Ca)/Al across a compositional spectrum of trachybasalt-alkali basalt-tholeite-icelandite-basaltic andesite. Shortcomings of current solubility models for a widespread arc magma type indicate that our understanding of degassing in the deep crust and uppermost mantle remains semi-quantitative. Experimental studies systematically varying concentrations of melt components (Mg, Ca, Na, K, Al, Si) may be necessary to identify solubility reactions, quantify their equilibrium constants, and thereby build an accurate and generally applicable solubility model.

Keywords: Experimental petrology, magmatic CO$_2$, volcanic degassing, volatile solubility

Introduction

Many studies address the systematics of magmatic degassing in shallow crustal reservoirs and volcanic conduits, yet few are focused on degassing in the deep roots of volcanic systems. Understanding the behavior of C-O-H supercritical fluids in sub-arc magma at elevated pressures is important to a diverse suite of topics. Such knowledge is required to accurately assess volcanic volatile budgets and magma supply rates; model the linkage between basaltic underplating and remobilization of crystal mushes; interpret deep, long-period seismicity and tremor; and to characterize the thermodynamics of lower crustal melting.

Continued progress on these, and a host of other important research fronts, necessitate a more comprehensive and quantitative assessment of CO$_2$ solubility in hydrous mafic magmas at deep-to-mid-crustal conditions. Due to the complexity of high-temperature and high-pressure experiments using mafic melts, relevant data are limited to a handful of studies—Jakobsson (1997); Liu et al. (2006); Botcharnikov et al. (2005); Behrens et al. (2009); Shishkina et al. (2010); Vetere et al. (2011); Iacono-Marziano et al. (2012); Iacovino et al. (2013); Allison et al. (2019)—and the thermodynamic and empirical models used to predict C-O-H solubilities in magma at pressures above ~500 MPa (e.g., Papale et al. 2006; Iacono-Marziano 2012; Duan 2014; Ghiorso and Gualda 2015) have scant data to constrain them.

With the intent of building a stronger framework for understanding deep, CO$_2$-rich degassing of sub-arc magma, we conducted $f_{O_2}$-buffered solubility experiments at 1125 °C between...