SPECIAL COLLECTION: GLASSES, MELTS, AND FLUIDS, AS TOOLS FOR UNDERSTANDING VOLCANIC PROCESSES AND HAZARDS

Experiments and models on H₂O retrograde solubility in volcanic systems†

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ABSTRACT

We present a suite of 36 high-temperature (900–1100 °C) experiments performed on 10 × 10 mm unjacketed cores of rhyolitic obsidian from Hrafntinnuhyrggur, Krafla, Iceland, under atmospheric pressure. The obsidian is bubble- and crystal-free with an H₂O content of 0.11(4) wt%. The obsidian cores were heated above the glass transition temperature (T_g), held for 0.25–24 h, then quenched. During each experiment the volume of the samples increased as H₂O vapor-filled bubbles nucleated and expanded. Uniquely, the bubbles did not nucleate on the surface of the core, nor escape, conserving mass during all experiments. Within each isothermal experimental suite, the cores increased in volume with time until they reached a maximum, after which continued heating caused no change in volume (measured by He-pycnometry). We interpret these T-t conditions as representing thermochemical equilibrium between the melt and exsolved vapor. These experiments are modeled to recover the 1-atm, temperature-dependent solubility of water in the rhyolite melt. Our results define the magnitude of retrograde solubility (~7.1 × 10⁻³ wt% H₂O per 100 °C) and provide estimates of the enthalpy and entropy of the H₂O exsolution reaction [ΔH° = 17.8 kJ/mol, ΔS° = 107 J/(K·mol)]. We conclude by modeling the implications of retrograde solubility for the glass transition temperatures (T_g) of cooling volcanic systems at pressures relevant to volcanic conduits and the Earth’s surface. All volcanic systems cool; the effects of retrograde solubility are to allow melts to rehydrate by H₂O dissolution as they cool isobarically, thereby depressing T_g and expanding the melt window. Ultimately, the melt is quenched at higher H₂O contents and lower temperatures where the isobaric retrograde solubility curve “catches” the evolving T_g.

Keywords: Rhyolite, hydrous, H₂O-solubility, volcanic, experiment, modeling, glass transition, retrograde

INTRODUCTION

All magmas contain dissolved volatiles that strongly affect the thermodynamic and physical properties of the melt and dramatically influence magmatic and volcanic processes (Hess and Dingwell 1996; Navon et al. 1998; Mysen and Acton 1999; Sparks et al. 1999; Zhang 1999; Gardner et al. 2000; Di Matteo et al. 2004; Zhang et al. 2007; Giordano et al. 2008). Exsolution of a fluid phase, where the dissolved volatile reaches supersaturation, affects the bulk properties of magmas, drives many volcanic eruptions, and controls the duration, magnitude, rate, and style of eruption (e.g., effusive vs. explosive) (Webster and Botcharnikov 2011; Watkins et al. 2012). Water (H₂O) is the most prevalent, and usually the dominant, volatile species in volcanic systems making the low-pressure solubility limits of H₂O in silicic melts particularly relevant to many eruptive and post-eruptive volcanic processes (Sparks et al. 1999; Castro et al. 2005; Robert et al. 2008; Kennedy et al. 2010).

There are a plethora of H₂O solubility studies on melts at pressures >50 MPa (Burnham and Jahns 1962; Silver et al. 1990; Holtz et al. 1995, 2000; Dixon et al. 1995; Carroll and Blank 1997; Dingwell et al. 1997; Moore et al. 1998; Yamashita 1999; Newman and Lowenstern 2002; Papale et al. 2006; Zhang et al. 2007). There are, however, surprisingly few lower pressure (i.e., ≤5 MPa) studies of H₂O solubility in silicate melts (Friedman et al. 1963; McMillan et al. 1986; Silver et al. 1990; Liu et al. 2005). This lack of data has been pointed out by numerous authors, including Zhang (1999), Liu et al. (2005), Robert et al. (2008), and Kennedy et al. (2010), yet the data gap persists. A compilation of all 1-atm, H₂O solubility data are presented in Appendix A† and comprises 28 values deriving from three experimental studies.

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