AMORPHOUS MATERIALS: PROPERTIES, STRUCTURE, AND DURABILITY†

Compositional dependent compressibility of dissolved water in silicate glasses

WIM J. MALFAIT,1,* CARMEN SANCHEZ-VALLE,1,* PAOLA ARDIA,1,2 ETIENNE MÉDARD,3,4,5 AND PHILIPPE LERCH6

1Institute for Geochemistry and Petrology, ETH Zurich, CH-8092 Zurich, Switzerland
2Department of Geology and Geophysics, University of Minnesota, Minneapolis 55455, U.S.A.
3Laboratoire Magmas et Volcans, Clermont Université, Université Blaise Pascal, BP 10448, F-63000 Clermont-Ferrand, France
4CNRS, UMR 6524, LMV, F-63038 Clermont-Ferrand, France
5IRD, R 163, LMV, F-63038 Clermont-Ferrand, France
6Swiss Light Source, Paul Scherrer Institute, CH-5232 Villigen-PSI, Switzerland

ABSTRACT

The sound velocities and elastic properties of a series of hydrous rhyolite, andesite, and basalt glasses have been determined by Brillouin scattering spectroscopy at ambient conditions to elucidate the effect of glass composition on the compressibility of dissolved water. Both the adiabatic bulk (Ks) and shear modulus (µ) of the dry glasses decrease with increasing silica content (Ks_andesite > Ks_basalt > Ks_rhyolite and µ_andesite > µ_basalt > µ_rhyolite). For each composition, the shear modulus systematically decreases with increasing water content. Although the addition of up to 14 mol% water decreases the Ks of andesite and basalt glasses by up to 6%, there is no discernable effect of water on the Ks of the rhyolite glasses. The partial molar Ks of dissolved water (Ks_rhyolite) in rhyolite, andesite, and basalt glasses are 37 ± 5, 19 ± 7, and 40 ± 3 GPa, corresponding to partial molar isothermal compressibilities (βv) of 0.029 ± 0.005, 0.042 ± 0.004, and 0.026 ± 0.002 GPa⁻¹, respectively. These results indicate that the compressibility of dissolved water strongly depends on the bulk composition of the glass; hence, the partial molar volume of water cannot be independent of the bulk composition at elevated pressure. If the compressibility of dissolved water also depends on composition in the analog melts at high temperature and pressure, these observations will have important consequences for magmatic processes such as magma mixing/unmixing and fractional crystallization.

Key Words: Hydrous silicate melts, silicate glasses, sound velocities, compressibility, partial molar volume of water, Brillouin scattering

INTRODUCTION

The density of hydrous magmas is a key parameter affecting the outcome and timescales of many magmatic processes, e.g., the crystal settling velocities in a magma chamber and the emplacement depth of intrusions. Direct density measurements on hydrous liquids at magmatic temperature and pressure conditions are, however, experimentally challenging. Nevertheless, some measurements have been made for hydrous compositions at simultaneous high temperature and pressure with various methods, including a customized internally heated pressure vessel (Burnham and Davis 1971), the sink-float method (Agee 2008; Matsukage et al. 2005; Sakamaki et al. 2006), X-ray radiography (Sakamaki et al. 2009) and Brillouin scattering spectroscopy in a diamond-anvil cell (Tkachev et al. 2005). In the last decade, additional constraints on the volumetric and structural properties of volatile-bearing melts at high pressure-temperature conditions have been provided by ab initio calculations (Mookherjee et al. 2008). However, most of the available data correspond either to mafic and ultramafic melts at temperatures and pressures relevant to the mantle transition zone, or to more acidic compositions in a narrow low pressure-temperature range. Consequently, no experimental density data are available for hydrous melts with compositions and pressure-temperature conditions relevant for mid-oceanic ridges, subduction zones, and mid- to lower-crustal settings.

Despite the fundamental dynamic and thermodynamic differences between the liquid and glassy state (Webb 1992), the physical properties of hydrous silicate glasses at ambient pressure and temperature conditions can provide insights into the properties of the analog melts. For instance, although there are noticeable differences between the thermal expansion of glasses and melts (Dingwell and Webb 1990; Webb 1992; Webb et al. 1992), the thermal expansion of hydrous silicate glasses up to the glass transition temperature (Tg) has been used to constrain the partial molar volume of water in silicate melts (Ochs and Lange 1999). Apart from non-ideal effects for Al2O3 (Ai and Lange 1987), the thermal expansion of hydrous melts can yield useful information on the incompressibility of dissolved water in the glass (Burnham and Davis 1971; Agee 2008; Courtial and Dingwell 1999; Kress and Carmichael 1991), most of the experimentally derived density and compressibility data of anhydrous glasses and melts can be reproduced well by an ideal mixing model with respect to volume (Bottinga and Weil 1970; Nelson and Carmichael 1979; Rivers and Carmichael 1987). In this model, the molar volume V is given by V =...