



The effect of water on the viscosity of a synthetic calc-alkaline basaltic andesite

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ARTICLE INFO

Article history:

Accepted 2 October 2012

Available online 9 October 2012

Keywords:

Basaltic andesite

Viscosity

Water

Explosive volcanism

ABSTRACT

The viscosity of a series of 6 Fe-free, synthetic basaltic andesite liquids, containing up to 3.76 wt.% dissolved water, was measured in the range of the glass transition (10^8 – 10^{13} Pa s) by parallel-plate viscometry. Concentric-cylinder and falling-sphere viscometry provided high-temperature measurements (10 – 10^3 Pa s) on basaltic andesite liquids containing up to 2 wt.% dissolved water. The viscosity (η in Pa s) of Fe-free basaltic andesite can be described as a function of temperature (T in Kelvin) and water content (w in wt.%) by the expression $\log(\eta) = -4.81 + 6940.7/(T - \{491.9 - 272.5 \log[w + 0.49]\})$. This parameterization reproduces 55 viscosity data with a root-mean-square-deviation (RMSD) of 0.24 log units in viscosity. The results of this viscometry study suggest that basaltic andesite liquids should remain very fluid, even while undergoing equilibrium degassing, to pressures as low as 50 MPa (i.e., less than 2 km depth). Only a modest increase in viscosity of at most a factor of 100 would occur in the last 2 km of ascent. Furthermore, our results show that water affects the viscosity of a wide range of depolymerized melts to a similar degree. For example, the addition of 2 wt.% dissolved H₂O reduces the viscosity of andesite, basaltic andesite, basalt and their alkalic counterpart liquids by a factor of ~15–50.

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1. Introduction

Arc volcanism is synonymous with spectacular, destructive behavior (e.g., Mt. Pinatubo, Vesuvius, Krakatau), and explosive basaltic volcanism is now recognized as a significant threat that poses a hazard to millions of people in many countries (e.g., Roggensack et al., 1997; Coltelli et al., 1998). Arc magmas may contain significant amounts of dissolved volatiles, which in large part drive explosive volcanic activity. Water is the most abundant volatile (Carroll and Holloway, 1994; Behrens and Gaillard, 2006, and references therein), and water contents in arc magmas may exceed 6 wt.% (Sisson and Layne, 1993). There is ample research showing the dramatic effect of dissolved water in reducing the viscosity of rhyolitic magmas (Dingwell et al., 1996; Hess and Dingwell, 1996; Schulze et al., 1996), and violent degassing upon ascent makes rhyolitic volcanic eruptions very explosive. While basaltic volcanoes erupt less evolved, more primitive lavas, they may also display explosive behavior (Roggensack et al., 1997; Coltelli et al., 1998; Houghton et al., 2004; Burton et al., 2007), and their eruptive products are widely varied with respect to rheology; volcanic ash and bombs, tephra, aa and pahoehoe lava flows span the range from explosive to effusive (e.g., Ripepe et al., 2005; Giordano et al., 2007; Harris and Rowland, 2009; Giordano et al., 2010). Moreover, all these types of deposits may exhibit various degrees of crystallinity and vesicularity. Water

has a strong influence on magma transport and dynamics due to its effects on melt properties and phase relations. These effects coupled with the strong dependence of water solubility on pressure result in complex feedback relations during crystallization of magma in magma chambers, ascent in volcanic conduits, and eruption of volcanic products. The wide variety of magmatic and volcanic products at arc volcanoes is in part due to the effects of water on melt properties. A quantitative understanding of the physical and thermodynamic properties of basaltic magma and of the effects of H₂O on those properties is essential for modeling magma chamber and conduit processes that cannot be observed directly, and are most commonly interpreted from geochemical and textural signatures.

Calc-alkaline basalt and basaltic andesite eruptive products are volumetrically more important than their better-studied alkalic counterparts in arc settings, and are expected to be more viscous (Whittington et al., 2001) and hence potentially more explosive. Few calc-alkaline melts of andesite and basaltic andesite composition have been investigated for the effects of water on viscosity. Vetere et al. (2008) studied an Fe-bearing synthetic melt based on an andesite from Unzen volcano, Japan (V08; see Fig. 1), focusing on the effect of the oxidation state of iron on its viscosity at different dissolved water contents. Most of their measurements were obtained at high temperatures, using the falling-sphere method, and all measurements were obtained at pressures of 200 MPa or greater. Persikov (1991) measured the viscosity of a natural hydrous basaltic andesite lava from Klyuchevskoy volcano, Kamchatka, at superliquidus temperatures only (P91; Fig. 1). Other investigated mafic compositions are at higher alkali contents than typical arc

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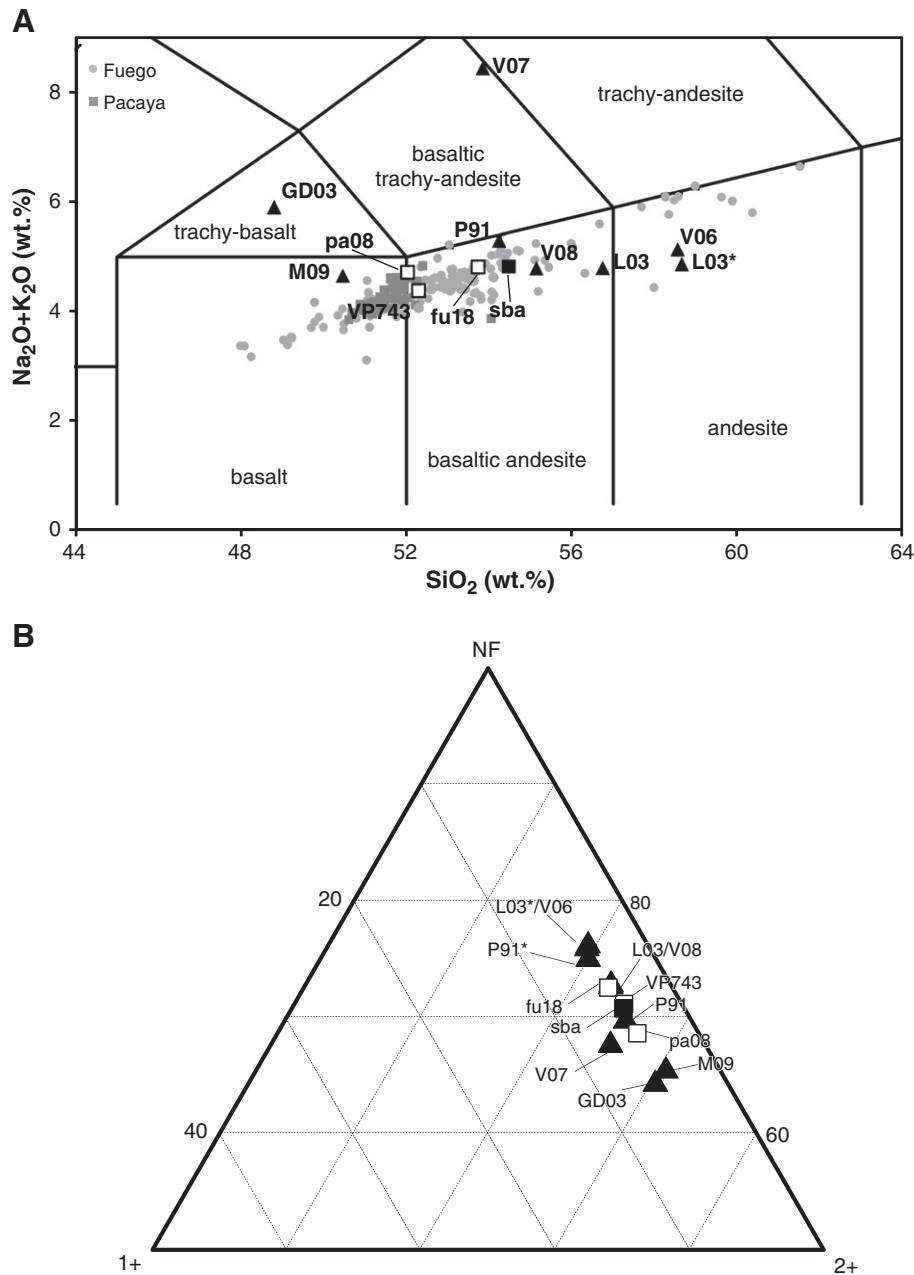


Fig. 1. A: Total alkali vs. silica diagram showing the compositions of eruptive products from the Guatemala arc volcanoes Pacaya and Fuego in grey. The natural composition serving as the base for the Fe-free synthetic basaltic andesite sba (black square) is labelled VP743 (open square). Two natural basaltic andesites for which we report preliminary viscosity data are also plotted: pa08 (Pacaya) and fu18 (Fuego). The black triangles are related compositions for which viscosity data on hydrous melts was obtained in previous studies. P91: (Persikov, 1991); L03 and L03*: (Liebske et al., 2003); GD03: (Giordano and Dingwell, 2003); V06: (Vetere et al., 2006); V07: (Vetere et al., 2007); V08: (Vetere et al., 2008); W09: (Whittington et al., 2009b); M09: (Misiti et al., 2009). **B:** Same melts as in **A** represented in terms of network-former (NF = SiO₂ + Al₂O₃ + TiO₂), alkali (1+ = Na₂O + K₂O), and alkaline earth oxides (2+ = MgO + CaO). P91 is calculated assuming all Fe as Fe_{total}; P91* is plotted using the published Fe oxidation ratio.

compositions (e.g., Giordano and Dingwell, 2003; Vetere et al., 2007; Misiti et al., 2009).

We present here the results of a comprehensive viscometry study over a wide range of temperatures and water contents (dry to 3.76 wt.% dissolved H₂O) on an Fe-free analogue to a calc-alkaline basaltic andesite from Pacaya volcano, Guatemala. This is the first part of a broader study on the rheology of magmas at Pacaya and Fuego. Pacaya volcano currently mostly produces lava flows, but occasionally erupts explosively producing ash columns and ejecting tephra and volcanic bombs. The latest of such explosive eruptions occurred in May 2010; the ash disrupted air traffic at the Guatemala City international airport, and tephra, ash and volcanic bombs damaged coffee plantations and buildings in nearby communities (Global Volcanism

Program, 2010). The active Guatemalan volcanoes provide an ideal laboratory to study the effects of water on the rheology of calc-alkaline arc magmas.

2. Experimental methods

The synthetic basaltic andesite composition (henceforth 'sba') is modeled after a natural lava composition from Pacaya volcano, compiled in the Central American Geochemistry database (sample VP743; Carr et al., 2007a,b; Bolge et al., 2009). To simplify the system and to avoid problems of crystallization and varying oxidation state during experiments, the synthetic samples are Fe-free. All the Fe, expressed as Fe_{total}, was replaced by MgO on a molar basis. Note

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