

The viscosity of F + H₂O-bearing peralkaline and peraluminous rhyolitic melts

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Introduction

The viscosity of magmas controls the rates of many petrogenetic processes responsible for the compositional complexity of igneous rocks. Examples of processes controlled by viscosity include: the rates of melt removal from magmatic source regions, the rates of crystal settling in magma chambers, and the possibility and speed of magmatic convection. Previous studies have measured the viscosities of water-bearing rhyolitic melts (Shaw, 1963; Burnham, 1964) and F ± H₂O-bearing melts in the Na₂O–Al₂O₃–SiO₂ system (Dingwell, 1987). This research expands upon these earlier studies to measure the viscosities of high-silica melts containing 1.5 wt% F and 6 wt% H₂O. As will be demonstrated, some of these melts have very low viscosities, on the order of 1 × 10³ Pa-s at magmatic temperatures, which may have important petrogenetic consequences.

Experimental techniques

Fluorine-bearing glass powders, water, and Pt spheres (150 to 320 μm in radius) with either Pt or SiC powder to mark their starting positions were loaded into Pt capsules which were welded closed without volatile loss. Capsules were stored in a 110°C drying oven for a minimum of 2 h to homogenize water along glass grain boundaries and then inserted into 1.91-cm NaCl-Pyrex-Crushable Al₂O₃ assemblies for experiments in a piston-cylinder apparatus at 1.0 GPa and temperatures between 800°C and 1000°C. Experimental durations were a few minutes. After quenching, sample capsules were mounted in epoxy and sectioned to find the Pt spheres. The distance the spheres travelled relative to the marker horizon of Pt or SiC powder was measured. A minimum of two experiments were performed at each temperature and the time versus distance travelled for the spheres was used to calculate viscosities from the Stokes equation with the Faxen correction (Shaw 1963). Estimated uncertainties in viscosity determinations are ±15%.

Results and Discussion

Viscosities measured for the peralkaline and peraluminous melts (Fig. 1) appear Arrhenian over the temperature range investigated and can be described by the following equations:

$$\text{Peralkaline} + 1.5 \text{ wt\% F} + 6 \text{ wt\% H}_2\text{O}: \eta = 2.99 \pm 0.23 \times 10^{-6} \exp(180.9 \pm 1.0/RT)$$

$$\text{Peraluminous} + 1.5 \text{ wt\% F} + 6 \text{ wt\% H}_2\text{O}: \eta = 2.60 \pm 0.25 \times 10^{-8} \exp(242.8 \pm 1.0/RT),$$

where the viscosity is in Pa-s, the activation energy is in kJ/mol, R is the gas constant, and T is the temperature in Kelvins. Uncertainties are 1 standard error based upon estimated errors in viscosity measurements.

Measured viscosities are plotted in Fig. 1 and compared to viscosities of hydrous metaluminous (Shaw, 1963) and peraluminous (Burnham, 1964) rhyolitic melts, and to the viscosity of albite melt + 11.7 wt% F + 5.58 wt% H₂O (Dingwell, 1987). Viscosities of the peraluminous melt + 1.5 wt% F + 6 wt% H₂O are similar to those of the albite + F + H₂O melt and the F-free, hydrous, peraluminous melt, despite the lower total volatile concentration of the peraluminous melt of this study. Viscosities of the peralkaline melt + 1.5 wt% F + 6 wt% H₂O are an order of magnitude below the viscosity of the F-free, peraluminous melt with 8.8 wt% water and 1.5 orders of magnitude below the metaluminous melt with 6 wt% water at 800°C.

Viscosities of the hydrous and fluorine-bearing melts have been calculated by the techniques of Shaw (1972) with the assumption that the effect of 1.5 wt% F + 6 wt% H₂O on melt viscosity is identical to the effect of 7.5 wt% H₂O. Agreement between calculated and measured viscosities is good, almost always within a factor of 2. However, calculated viscosities for the peraluminous melt + 1.5 wt% F + 6 wt% H₂O are below the measured viscosities whereas calculated viscosities for the peralkaline melt + 1.5 wt% F

+ 6 wt% H₂O are always above measured viscosities. The systematic underprediction of viscosities for the peraluminous melt + 1.5 wt% F + 6 wt% H₂O suggests that fluorine is less effective than water on the viscosity reduction of peraluminous melts; whereas the overprediction of peralkaline melt + 1.5 wt% F + 6 wt% H₂O viscosities is consistent with fluorine being more effective than water in the reduction of viscosities for peralkaline melts. Nevertheless, differences between the effects of water and fluorine on peraluminous and peralkaline rhyolitic melt viscosities are small.

Viscosities in the peralkaline melt + 1.5 wt% F + 6 wt% H₂O also can be calculated from diffusivities measured in similar composition melts combined with the Eyring equation; in this case calculated viscosities are below those measured, but by less than a factor of two. The close similarity between measured viscosities and those predicted by the Eyring equation from interdiffusion measurements supports the premise that viscous transport and Si-Al interdiffusion are controlled by the same mechanism, probably the

formation of highly coordinated (Si,Al)-O₅₋₆ complexes.

Because of the low activation energy for viscous transport in the hydrous and fluoridated peralkaline melt the differences between the viscosity of this melt and the others will be magnified at lower temperatures. Any processes which are rate limited by viscous transport will have significantly greater rates in the peralkaline melt + 1.5 wt% F + 6 wt% H₂O than in the other melts.

References

- Burnham, C.W. (1964) *Geol. Soc. Am. Special Paper*, 76, 26.
 Dingwell, D.B. (1987) Melt viscosities in the system NaAlSi₃O₈-H₂O-F₂O₋₁. In *Magmatic Processes: Physicochemical Principles*, *Geochem. Soc. Spec. Pub. No. 1* (Mysen, B.O., ed.) Geochemical Society, University Park, 423-31.
 Shaw, H.R. (1963) *J. Geophys. Res.*, 68, 6337-6343.
 Shaw, H.R. (1972) *Amer. J. Sci.*, 272, 870-93.

