

Viscosity of hydrous rhyolitic melts inferred from kinetic experiments, and a new viscosity model

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ABSTRACT

Viscosity of hydrous silicate melts is a critical property for understanding magma transport, bubble growth, volcanic eruption, and magma fragmentation. We report new inferred viscosity for hydrous rhyolitic melt in the viscosity range of 10^9 to 10^{15} Pa·s based on the kinetics of hydrous species reactions in the melt upon cooling (i.e., based on the equivalence between the glass-transition temperature and the apparent equilibrium temperature), as well as data from bubble-growth experiments. By combining viscosity data of rhyolitic melts containing from 6 ppm to about 8.0 wt% total H₂O (both our own data and literature data), we propose the following relation for the dependence of viscosity on total H₂O content at a given temperature and pressure:

$$\frac{1}{\eta} = \frac{1}{\eta_1} + \left(\frac{1}{\eta_2} - \frac{1}{\eta_1}\right)x^n \approx \frac{1}{\eta_1} + \frac{1}{\eta_2}x^n$$

where η is viscosity and $1/\eta$ is fluidity, η_1 is the viscosity of the dry melt, x is the mole fraction of total dissolved H₂O, n and η_2 are two fitting parameters, and η_2 can be interpreted to be the viscosity of the hypothetical melt consisting of pure H₂O. The above simple equation appears to work well in modeling viscosity of hydrous rhyolitic melts. Using the above functional form and a weighted nonlinear regression, experimental data covering 570 to 1920 K and 0.0006 to 8.2 wt% total H₂O are used to obtain the following non-Arrhenian model for the viscosity of Mono Crater rhyolitic melts:

$$\log \eta = -\log \{ \exp(18.5611 - 49584/T) + \exp[1.47517 - (1795.5/T)^{1.9448}]x^{1 + (1812.2/T)^2} \}$$

where T is in K, and x is the mole fraction of total dissolved H₂O on a single oxygen basis. The 2σ uncertainty in the above 6-parameter formula is 0.36 in terms of $\log \eta$ (for experimental data with errors smaller than 1 log unit), much less than uncertainties in all previous models for hydrous rhyolitic melt. We hence recommend its use for predicting the viscosity of high-SiO₂ and calc-alkaline rhyolitic melts.

Our model shows that a minute H₂O content can still affect the melt viscosity significantly, especially at low temperatures (i.e., high viscosity). For example, at 973 K, the viscosity of rhyolitic melt increases by 1.2 orders of magnitude from a melt with 0.1 wt% total H₂O to a melt with less than 100 ppm total H₂O. Because a nominally “dry” melt may still contain some H₂O, such as several hundred ppm, it is critical for experimentalists to report its total H₂O content for viscosity measurements. Some inconsistency in literature viscosity data might be attributable to small variations in H₂O content in the samples.