Geophysical Research Abstracts
Vol. 14, EGU2012-2471-1, 2012
EGU General Assembly 2012

Transient rheology of crystallizing andesitic magmas

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The viscosity of magma strongly influences its rheological behaviour, which is a key determinant of magma transport processes and volcanic eruptions. Understanding the factors controlling the viscosity of magma is important to our assessment of hazards posed by active volcanoes. In nature, magmas span a very wide range in viscosity (10^{-1} to 10^{14} Pa s), depending on chemical composition (including volatile content), temperature, and importantly, crystal fraction, which further induces a complex strain rate dependence (i.e. non-Newtonian rheology).

Here, we present results of transient viscosities of a crystallizing andesitic melt (57 wt.% SiO_2) from Tungurahua volcano (Ecuador). We followed the experimental method developed by Vona et al. (2011) for the concentric cylinder apparatus, but optimized its implementation by leaving the spindle in situ before quenching the experimental products, to preserve the complete developed texture of the sample. The viscosity is investigated under superliquidus (1400 ˚C) and sub-liquidus temperatures (1162 and 1167 ˚C). For each temperature increment, thermal equilibrium is achieved over a period of days while the spindle constantly stirs the magma. Simultaneous monitoring of the torque is used to calculate the apparent viscosity of the transient suspension. To get a better understanding of the nucleation and crystal growth processes that are involved at sub-liquidus conditions, further time-step experiments were carried out, where the samples were quenched at various equilibration stages. The mineralogical assemblage, as well as the crystal fraction, distribution and preferential alignment were then quantitatively analyzed.

At temperatures below the liquidus, the suspension shows a progressive, but irregular increase of the relative shear viscosity. First, the viscosity slightly increases, possibly due to the crystallization of small, equant oxides and the formation of plagioclase nuclei. After some time (1.5-2.5 days), crystallization of large, tabular plagioclase begins, inducing a significantly stronger increase in apparent viscosity until thermo-chemical equilibration is achieved. After continued stirring the apparent viscosity slightly decreases, likely due to increasing crystal alignment. The analysis of pre-equilibrium quenched samples indicates that crystals nucleate and grow preferentially in proximity to both the spindle and the crucible wall. Furthermore, decreasing the stirring rate (aka strain rate) results in an increase in the apparent viscosity, which evidences the non-Newtonian characteristics of the magmatic suspension. In conclusion, these experiments indicate that natural andesitic magmas undergo significant rheological changes at the onset of crystallization. The observed thermo-chemical variations elucidate a transient viscosity, which deserves consideration into all problems of magma transport.

Reference:

Vona, A., Romano, C., Dingwell, D.B., Giordano, D. 2011. The rheology of crystal-bearing basaltic magmas from Stromboli and Etna. Geochim. Cosmochim. Acta, 75, 3214-3236.