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Rheology of Three-Phase Magmas

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We present novel experimental results on the rheological properties of three-phase magmas (composed of solid crystals, gas bubbles and melt in different relative proportions), which are directly relevant for processes operating in sub-volcanic reservoirs and during ascent in volcanic conduits. This study mainly aims to constrain the dependence of rheology of three-phase magmas (ranging from dilute suspensions to crystal mushes) on the viscosity of the suspending silicate melt, on the relative contents of crystals and bubbles and on the interactions occurring between the three phases during deformation. Hydrous haplogranitic magmas containing variable amounts of crystals (between 24 and 65 vol%; 68 μm in mean diameter), and fixed bubble volume (9-12 vol% CO2-rich bubbles) were deformed in simple shear with a HT-HP Paterson-type rock deformation apparatus (Paterson and Olgaard, 2000). Strain rates ranging between 5•10-5 s-1 and 4•10-3 s-1 were applied at temperatures between 823 and 1023 K and constant pressure of 200 MPa.

The results suggest that three-phase suspensions are characterized by strain rate-dependent rheology (non-Newtonian behavior). Two kinds of non-Newtonian behaviors were observed: shear thinning (decrease of viscosity with increasing strain rate) and shear thickening (increase of viscosity with increasing strain rate). The first effect dominantly occurs in crystal-rich magmas (55-65 vol% crystals) because of crystal size reduction and shear localization. The second effect prevails in dilute suspensions (24 vol% crystals) due to outgassing promoted by bubble coalescence. At intermediate crystallinity (44 vol%) both effects occur.

2D (SEM images) and 3D (synchrotron X-ray microtomography) microstructures clearly display the partitioning of strain and relative strain rate. Hence, we conclude that magma rheology is strongly controlled by local physical instabilities and localizations in strain.

BIBLIOGRAPHY

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