Thermo-rheological feedbacks in silicic lavas and ignimbrites

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The rheology of lava is highly dependent on temperature, both directly (via non-Arrhenian temperature dependence of melt viscosity) and indirectly (via increasing crystal content). Rheology feeds back to temperature, because rapidly sheared melts can undergo viscous heating (heat production = viscosity $\times$ [strain rate]^2), and rapid disequilibrium crystallization can cause heating due to latent heat release (ΔH_{xt}). The heat budget of partially crystalline lava offsets these gains with conductive losses controlled by thermal diffusivity (D) and conductivity ($k = D\rho C_{\mathrm{P}}$, where ρ is density and C_{P} is heat capacity).

We measured the apparent viscosity of several crystalline dacitic lavas from Santiaguito, Guatemala. At conditions appropriate to lava flows (shear stress ~0.1 to 0.4 MPa, strain rate ~10^{-8} to $10^{-5}s^{-1}$), apparent viscosity is best modeled as a power-law with no yield strength. Viscosity of the flow core, at ~850 ℃, is estimated $\sim 5\times10^{10}$ Pa.s. There is no evidence for significant crystallization during flow emplacement at Santiaguito, but viscous heating may be significant ongoing heat source within these flows ~ 100Wm^{-3} if most shearing is restricted to a ~1m wide zone), enabling highly viscous lava to travel long distances (~4 km in ~2 yrs for Santiaguito).

Extremely high-grade, lava-like welded ignimbrites are produced by many large explosive (super-)eruptions. The lava-like and rheomorphic Grey's Landing ignimbrite, Idaho, provides abundant field evidence supporting the upward migration of a transient, 1-2 m thick, sub-horizontal ductile shear zone at the interface between the pyroclastic density current and deposit, through which all of the deposit passed. Using rheological experiments and thermo-mechanical modeling, we demonstrate that syn-depositional welding and ductile flow is achievable within a very restricted field of likely time-temperature-strain space where rapid high-strain deformation (≤1000%) is favored by higher emplacement temperatures (≥850 ℃). The field of ductile deformation is broadened significantly by accounting for strain-heating, which permits a sustained temperature increase up to 250 ℃ within the shear zone, and helps to explain the enormous extents of lava-like lithofacies and intense rheomorphism recorded in extremely high-grade ignimbrites. Recognition of short-lived but very powerful (≥1MWm^{-3}) strain-heating within rheomorphic ignimbrites suggests that large pyroclastic flows may travel over a hot substrate.

We conclude that strain heating, an inevitable result of magma transport that feeds back to rheology and transport, should be taken into account in thermal modeling of volcanic processes at both high and low strain rates, and both pre- and post-eruption.