Geophysical Research Abstracts
Vol. 18, EGU2016-15195, 2016
EGU General Assembly 2016

The non-isothermal rheology of low viscosity magmas.

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Accurate prediction of the run-out distance of lava flows, as well as the understanding of magma migration in shallow dyke systems is hampered by an incomplete understanding of the transient, sub-liquidus rheology of crystallizing melts. This sets significant limits to physical property based modelling of lava flow (especially flow width, length and advancement rate) and magma migration behaviour and the resulting accuracy of volcanic hazard assessment The importance of the dynamic rheology of a lava / magma on its emplacement style becomes especially apparent in towards later stages of flow and dyke emplacement, where the melt builds increasing resistance to flow, entering rheologic regimes that determine the halting of lava flows and sealing of dykes. Thermal gradients between the interior of a melt body and the contact with air or the substratum govern these rheologic transitions that give origin to flow directing or impeding features like levees, tubes and chilled margins.
Besides the critical importance of non-isothermal and sub-liquidus processes for the understanding of natural systems, accurate rheologic data at these conditions are scarce and studies capturing the transient rheological evolution of lavas at conditions encountered during emplacement virtually absent.
We describe the rheologic evolution of a series of natural, re-melted lava samples during transient and non-equilibrium crystallization conditions characteristic of lava flows and shallow magmatic systems in nature. The sample suite spans from foidites to basalts; the dominant compositions producing low viscosity lava flows. Our data show that all melts undergo one or more change zones in effective viscosity when subjected to sub liquidus temperatures. The apparent viscosity of the liquid-crystal suspension increases drastically from the theoretical temperature-viscosity relationship of a pure liquid once cooled below the liquidus temperature.
We find that:

1) Both cooling rate and shear rate have significant and independent effects on the crystallization kinetics and, therewith the rheology of natural silicate melts.

2) Dynamic cooling produces different crystallization kinetics / sequences and therewith phase-dynamics than equilibrium or near-equilibrium conditions.

The data presented here constitute the first step towards the development of a new strategy and a related database for investigation of sub-liquidus, non-isothermal magma rheology. We also highlight, that any data to be employed in accurate, physical property based modelling of lava flow emplacement and shallow magma migration needs to be assessed with respect to its ability to represent natural, non-isothermal and shear regimes.