DEVELOPMENT AND APPLICATION OF RHEOLOGICAL LAWS FOR THE EMPLACEMENT OF LOW VISCOSITY LAVA FLOWS. AN INTEGRATION OF EXPERIMENTAL, FIELD AND REMOTE-SENSING METHODS

STEPHAN KOLZENBURG
Dipartimento di Scienze della Terra, Università degli Studi di Torino, Via Valperga Caluso, 35, 10125 Torino

Lava flows are the most common volcanic features on Earth and cover the majority of the surfaces of other terrestrial planets. Low viscosity lavas have been recognized as significant volcanic hazards and are the cause of considerable economic damage worldwide. Transport properties of natural silicate melts at super-liquidus temperatures are reasonably well understood. However, migration and transport of silicate melts in the Earth's crust and at its surface generally occur at sub-liquidus temperatures and in settings where the melts undergo crystallization under varying cooling-, shear- and/or pressure-conditions. These changing environmental conditions drastically influence the thermorheological evolution of silicate melts/magmas. The evolving rheological properties of the magma/lava govern its transport efficiency and its emplacement/eruption style. Predicting the evolving flow dynamics of lavas and magmas is, to date, hindered by an incomplete understanding of the rheological evolution of silicate melts during crystallization at emplacement conditions. Advancing our ability to accurately predict the flow behaviour of lava flows and, therewith, the areas potentially affected by them, requires a more in-depth understanding of lava rheology.

This doctoral study represents a multi-pronged approach to advancing our understanding of lava flow rheology through systematic experimentation on natural melts, development of new methods for these rheological measurements and correlation of the experimental data with field observations.

A case study was performed on the 2016-15 eruption at Holuhraun that occurred within the tectonic fissure swarm between the Bárðarbunga-Veiðivötn and the Askja volcanic systems (Kolzenburg *et al.*, 2017). The study combines field, and remote sensing data to constrain the lava's flow-path, its velocity and deformation rate and its thermal evolution during emplacement. These data were combined with measurements of the pure liquid viscosity and the sub-liquidus rheological evolution of the lava during crystallization. Sub-liquidus experiments were performed at a range of constant cooling- and shear-rates, to mimic the thermal conditions reconstructed from field data. The data show that the effective viscosity of the lava drastically increases at a sub liquidus temperature, so-called "rheological cut-off temperature; Tcutoff". This departure to high viscosity is a result of the onset of crystallization and is found to be primarily controlled by the cooling rate experienced by the melt, with shear-rate having a secondary effect.

The data from the case study indicate that both cooling- and shear-rate affect the rheologic cut-off temperature of the melt. This observation requires a more detailed study of the parameters influencing the crystallization driven rheologic departure of natural melts at constant cooling conditions. To do this, a new experimental setup was developed for *in situ* thermal characterization of cooling/crystallising lavas during viscosity measurement to provide a broader spectrum of data for the interpretation of the crystallization process (Kolzenburg *et al.*, 2016b). This device was used to recover *in situ*, real-time, observations of the combined rheological and thermal evolution of natural, re-melted lava samples during the transient disequilibrium conditions characteristic of lava flows and shallow crustal magma migration and storage systems in nature. The data show that the effect of increasing crystal content on the viscosity of the suspension dominates any effect of latent heat or viscous heating under constant cooling conditions, resulting in the rheological death of a lava flow. This data can be employed to more accurately constrain the results of physical property based models of lava flow emplacement.

Through the newly developed experimental infrastructure and method, the effect of shear-rate on the crystallization kinetics and, therewith, the rheological evolution of natural melts can be studied in detail. The results presented here are the first systematic investigation of this kind at conditions pertinent to lava flow emplacement and transport in shallow magmatic systems. The data show that the crystallization kinetics of the melt (*i.e.*, the phase dynamics, -shapes, and-abundances) and the coupled rheologic cut-off strongly depend on the applied deformation rate. They further demonstrate that most currently available experimental data on the crystallization of natural silicate melts are insufficient to accurately describe the phase dynamics and the evolution of the transport properties of crystallizing melts under natural conditions.

The rheologic data acquired during the experimental phases of this doctoral are applicable to predict lava flow paths through the use of computational lava flow models. This, however, requires accurate and up to date topographic information for simulation. Such topographic data can also be used for correlation of rheologic data and lava flow geometry. Acquisition of topographic data commonly requires expensive equipment and expert users. In order to generate such critical input data, rapidly and in an affordable manner, a workflow was developed to create, scale, georeference, and integrate digital elevation models (DEMs), created using open-source structure-from-motion (SfM) multiview stereo (MVS) software into existing DEMs (Kolzenburg *et al.*, 2016a). This represents a new approach for rapid low-cost construction and updating of existing DEMs at high temporal and spatial resolutions and for areas of up to several thousand square meters. This method uses existing DEMs as a georeferencing tool and can therefore be used in limited access and potentially hazardous areas as it no longer relies exclusively on control targets on the ground.

REFERENCES

Kolzenburg, S., Favalli, M., Fornaciai, A., Isola, I., Harris, A.J.L., Nannipieri, L., Giordano, D. (2016a): Rapid Updating and Improvement of Airborne LIDAR DEMs Through Ground-Based SfM 3-D Modeling of Volcanic Features. *IEEE T Geosci. Remote*, **PP(99)**, 1-13.

Kolzenburg, S., Giordano, D., Cimarelli, C., Dingwell, D.B. (2016b): In Situ thermal characterization of cooling/crystallizing lavas during rheology measurements and implications for lava flow emplacement. *Geochim. Cosmochim. Ac.*, **195**, 244-258.

Kolzenburg, S., Giordano, D., Thordarson, T., Höskuldsson, A., Dingwell, D.B. (2017): The rheological evolution of the 2014/2015 eruption at Holuhraun, central Iceland. *B. Volcanol.,* **79**, 45. doi:10.1007/s00445-017-1128-6.