The non-isothermal rheology of low viscosity magmas

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Abstract number: EGU2016-15195

Goal:

Understanding the rheologic evolution of crystallizing silicate melts under non-isothermal conditions, relevant to lava flow emplacement

Motivation:

- Crystallization induced rheologic changes play a key role in magma / lava flow and -migration.
- Non-isothermal experimentation to generate an understanding of natural, dynamic processes.
- The recovered data can be emploied for more accurate, physical property based lava flow emplacement modelling

Experimental Approach:

- Concentric cylinder rheometry on ~20 cm³ of natural samples.
- Constant cooling rates ranging from 0.5 to 5 degrees / minute.
- Deformation rates ranging from ~0.8 to ~3.1 sec^{-1}.
- Compositions spanning a wide range of natural lavas.
- The repeatability of these experiments was assessed to be within ~ 0.1 log units absolute viscosity

Results:

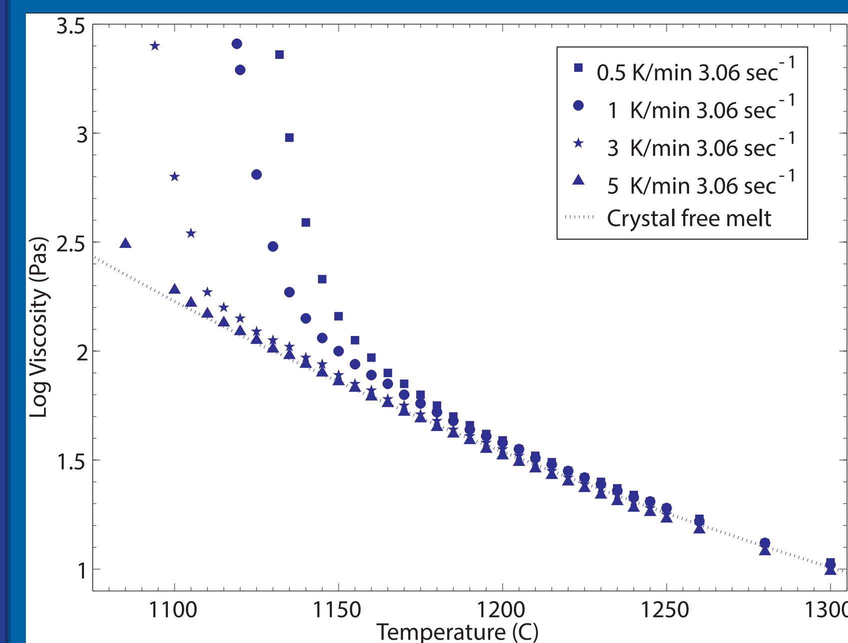
1) Both cooling-rate and shear-rate have significant and independent effects on the rheologic evolution of natural melts.
2) Both also influence the melts crystallization-kinetics and -sequences.

Outlook and Implications

- Further systematic characterization of the rheologic response of crystallizing magmas is being performed to build a database of the compositional, cooling-rate and shear-rate dependent rheologic evolution of natural low viscosity silicate melts.
- Such a database will help to accurately model the rheology of lava flows and of melts in the earths crust during emplacement.

Acknowledgments:
We want to thank Kai Uwe Hess, Danilo Di Genova and Corrado Cimarelli for interesting discussions on the topic; Markus Sieber and Guenter Hesberg for work shop assistance and Carmello Sibio as well as Hilger Lohringer for sample preparation.

Cooling-rate dependent rheology



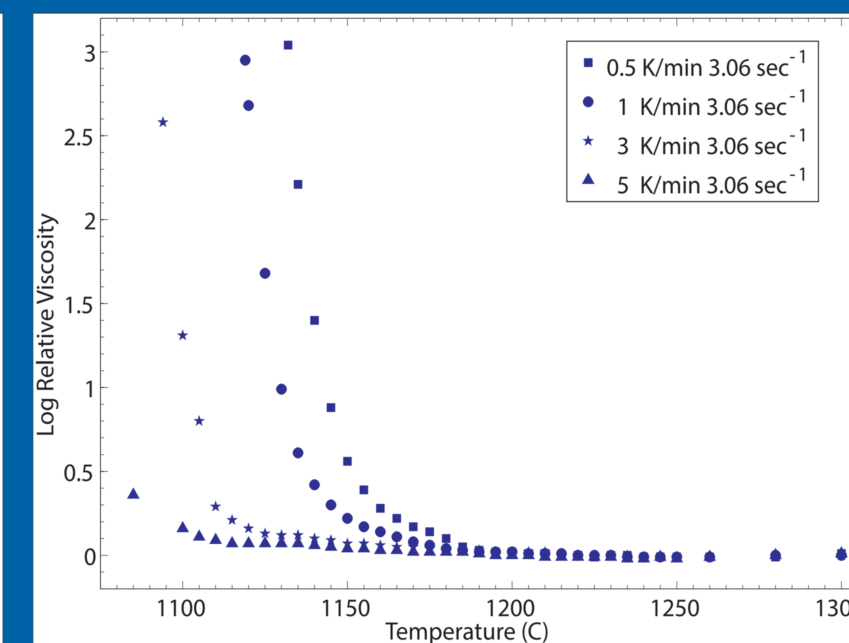


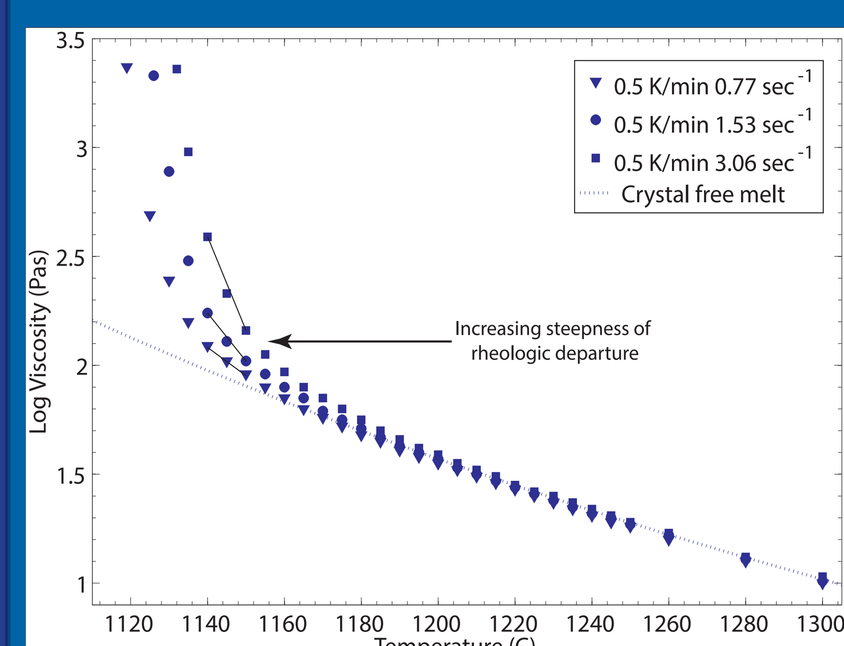
Figure 1: Apparent absolute lava viscosity

Rheologic evolution of a basaltic melt undergoing the same deformation rate but varying cooling rates.
Note that time (longer experimental times with slower cooling rates) is not considered in this plot.

Figure 2: Relative suspension viscosity

Relative viscosity of the crystal - liquid suspension with respect to the theoretical crystal free liquid.
Note the systematically increasing temperature of the departure from the pure liquid with decreasing cooling rate.

Shear-rate dependent rheology



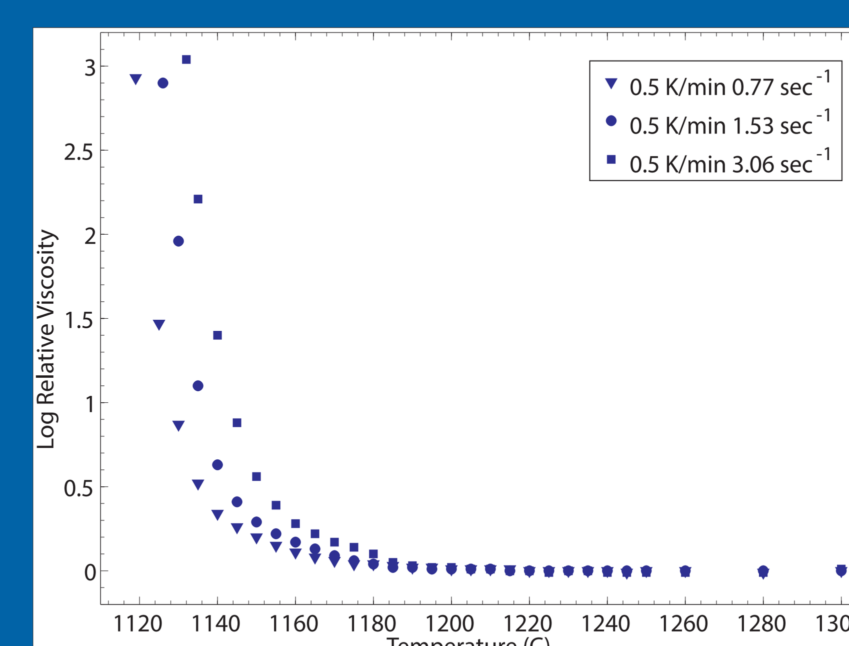


Figure 3: Apparent absolute lava viscosity

Rheologic evolution of a basaltic melt undergoing constant cooling- but varying shear rates.
The intensity (slope) of the rheologic departure is increasing with increasing shear rate over any given temperature interval

Figure 4: Relative suspension viscosity

Relative viscosity of the crystal- liquid suspension with respect to the theoretical crystal free liquid.
The earlier onset of the rheologic departure is likely a result of advection of "fresh" melt to the crystal surface facilitating crystal growth.

Composition dependent rheology

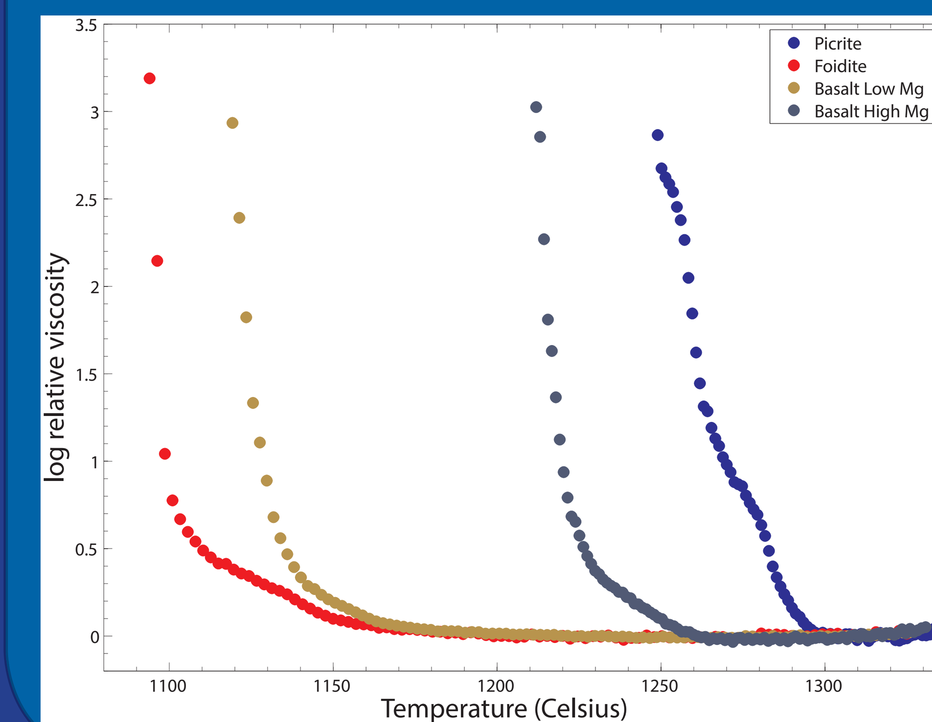
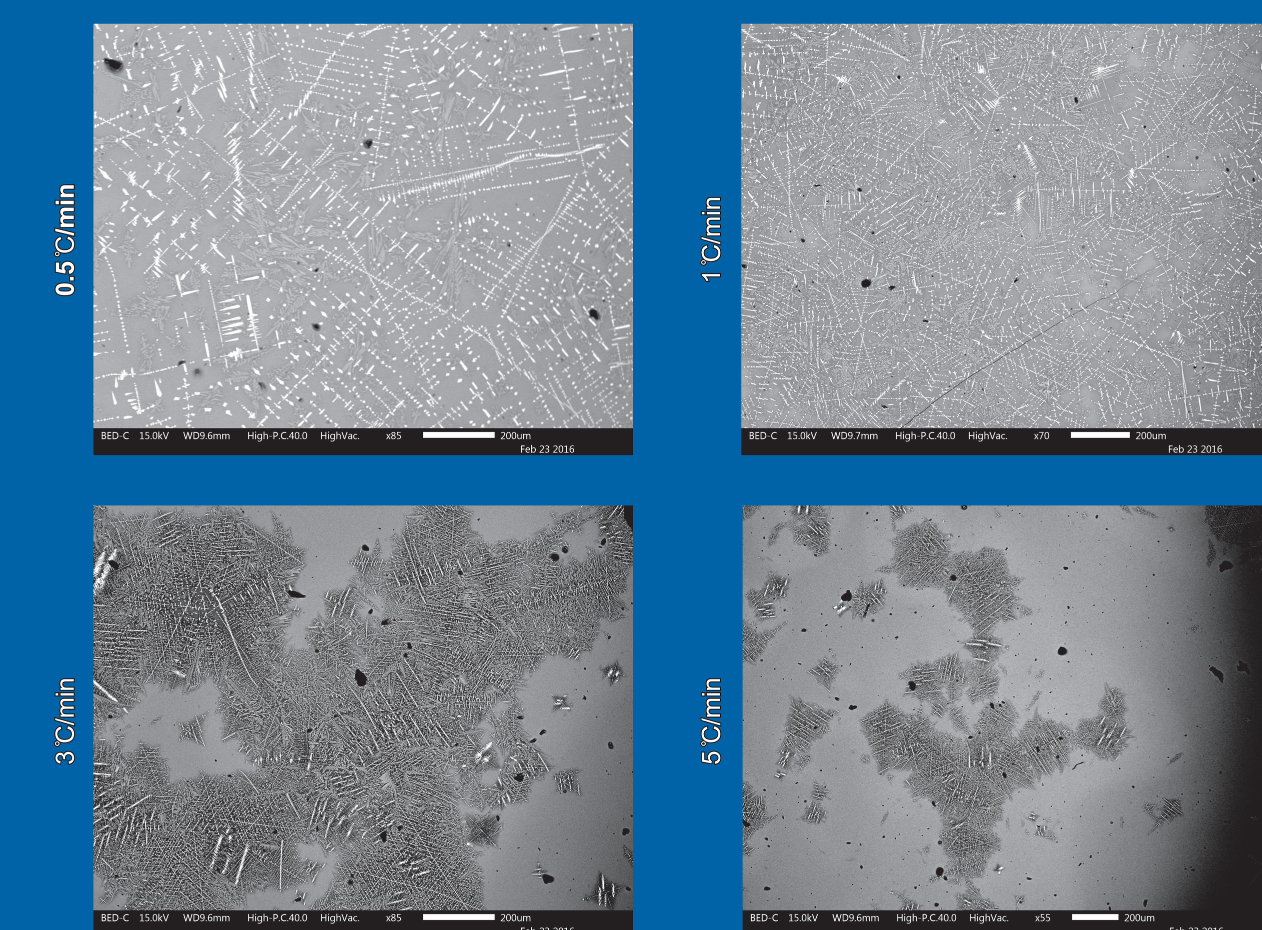


Figure 5: Composition and the rheologic departure

Evolution of the relative viscosity of a Picrite, Foidite, and two Basalts of varying MgO Content (7 vs. 12 wt%). Experiments were performed at identical cooling- (0.5 C/min) and shear-rates (0.77 sec^{-1}).

Note the drastically different temperatures at which the rheologic departure occurs.
This is related to both, the respective melt's liquidus temperature and the varying phase dynamics and crystallization kinetics within the melts.

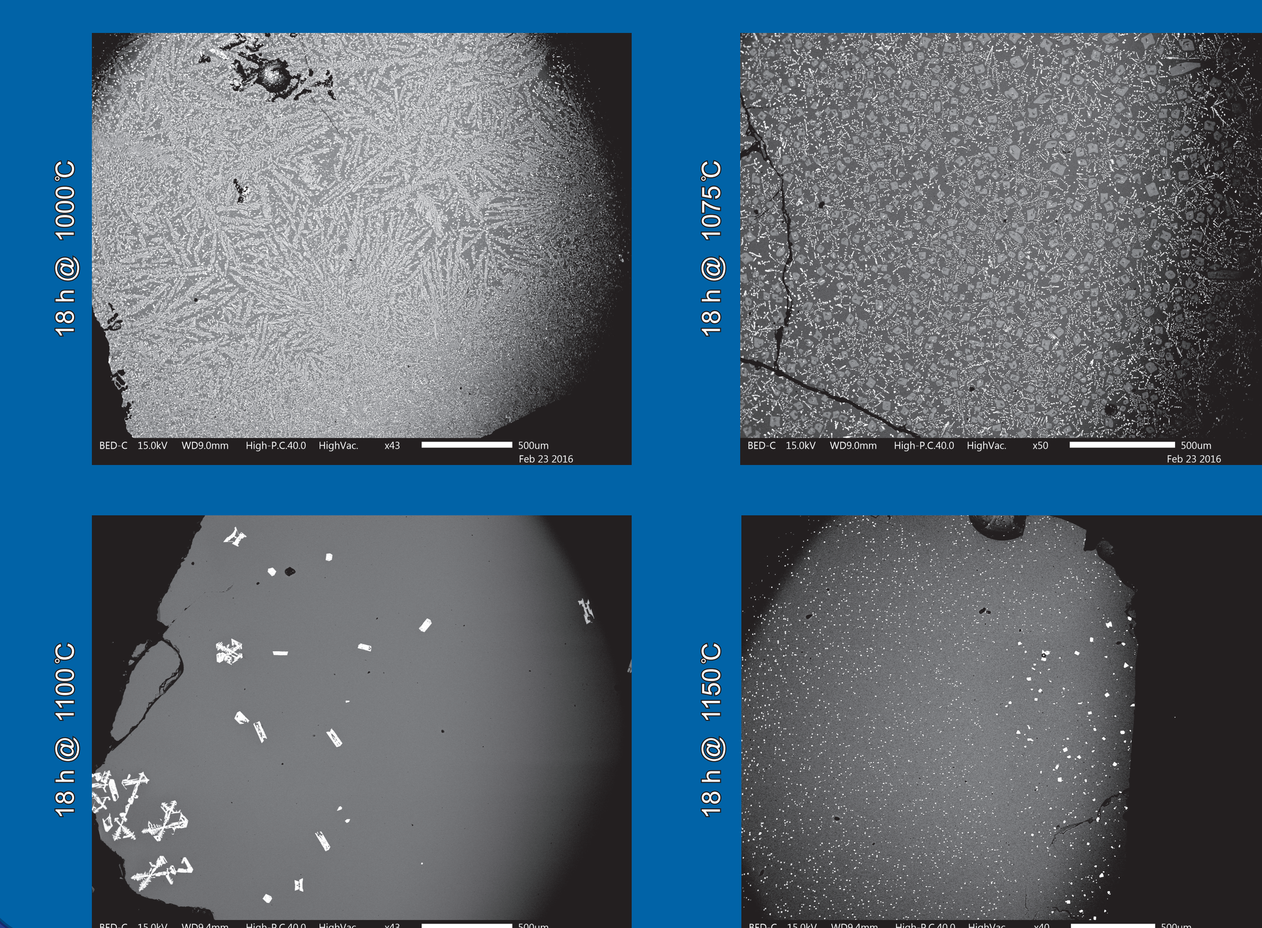
Textural evolution of a Basalt



Dynamic cooling:

- Produces dendritic growth forms, independent of cooling-rate
- Crystal size and abundance increases with decreasing cooling rate
- Crystallization occurrs as clusters rather than individual crystals. Therefore, assuming euhedral crystal shapes while modeling the transient rheology of lavas during emplacement may be flawed.

Note: These experiments were run under no shear conditions, cooling the sample at the respective rate from 1350 to 1080 degrees C!



Static undercooling:

- Produces subhedral growth forms
- Abundance and shape are dependent on the degree of undercooling
- Metal oxides crystallize first and then act as nucleation sites for other minerals

Note: These experiments were run under no shear conditions, cooling the sample from 1350 Celsius to the respective experimental temperature!