NEW MODEL TO CALCULATE LAVA VISCOSITY DURING DISEQUILIBRIUM CRYSTALLIZATION FOR A WIDE RANGE IN COOLING AND STRAIN RATES.

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Introduction: The viscosity (η) of silicate melts is a fundamental physical property controlling mass transfer in magmatic systems. Viscosity can span many orders of magnitude, strongly depending on temperature and composition. Cooling below the liquidus temperature promotes crystallization. The viscosity of crystallizing lava rapidly increases from that of ketchup (~60 Pa s) to smooth/creamy peanut butter (~200 Pa s), lard (~1500 Pa s), and window putty (~100,000 Pa s) within a narrow temperature interval of about 30 to 50 degrees [1–4]. The crystallization kinetics (i.e., crystal nucleation delay and growth rate) strongly depend on the degree of undercooling and cooling rate.

The increase in bulk viscosity during cooling below the liquidus, due to crystallization, has previously been described as "quasi-exponential" [5]. A mathematical description of the viscosity change has not been formulated so far. We found a feasible solution with which we can fit the viscosity paths for a single lava composition (Fig. 1).

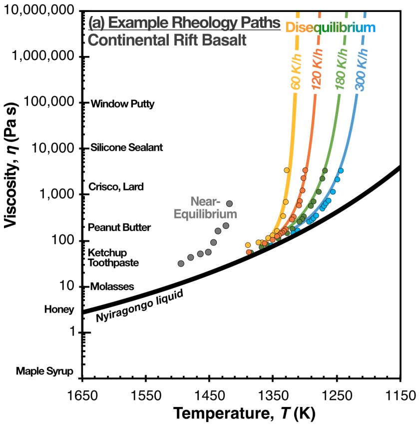

Figure 1: *Variations in lava viscosity increase during cooling and crystallization demonstrated for continental rift basalt during near-equilibrium [6] and disequilibrium [7] cooling.*

Model Description: We were successful in fitting a three-parameter Steinhart-Hart equation for each individual experiment in the form of:

$$\eta = 1/(A+B(\ln T)+C(\ln T)^3) \qquad \text{Eq.1}$$

where A, B, and C are empirically derived parameters, and T is the absolute temperature. Our approach is to relate constants A, B, and C in Eq. 1 as a function of the cooling and strain rate. Figure 2 shows the results of our proof-of-concept model using rheology data for Continental Rift Basalt (CRB) cooling at rates between 60 to 300 K per hour (and constant strain rate) [7]. After fitting each rheology path, parameters A, B, and C can be related to the cooling rate via three individual fit equations (Figure 2a). Substituting these equations into Eq. 1 allows us to calculate the viscosity of crystal-bearing lava at any desired temperature and cooling rate within the range of the experimental data (Figure 2b). Our approach reproduces the viscosity data within a 5% relative error, for cooling rates from 60 to 180 K per hour.

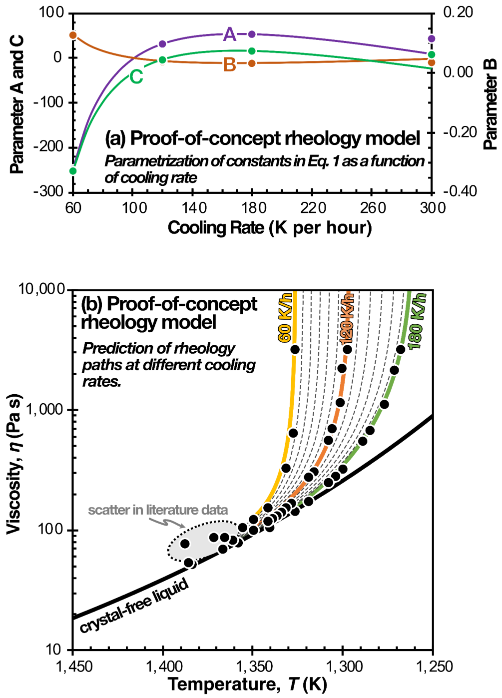

Figure 2: Proof-of-concept rheology model using available literature data for CRB. (a) Eq. 1 parameters as a function of cooling rate then (b) translated into a rheology model allowing the interpolation of rheology paths (dashed lines) between the training data set (dots).

Conclusion and Future Work: We were able to find a mathematical solution describing the "quasi-exponential" increase in lava viscosity during disequilibrium crystallization, enabling viscosity calculations for a wide range of cooling rates.

Our goal is to expand the model to also reflect viscosity changes as a function of strain rate. Suitable data sets are incomplete. Viscosity measurements of Martian analog basalts at different cooling and strain rates by our team are forthcoming. We will apply and test this model on these data.

Acknowledgments: We thank NASA's Solar System Workings program office for funding our research through grant 80NSSC19K1010 to AS.

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