THE VISCOSITY OF PLANETARY THOLEIITIC MELTS: A CONFIGURATIONAL ENTROPY MODEL. A. Sehlke[1,2] and A. G. Whittington[1], [1]Geological Sciences, University of Missouri, Columbia MO, 65211, USA (asehlke@mail.missouri.edu), [2]NASA Ames Research Center, Moffett Field CA 94035, USA

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 during geological processes, strongly depending on temperature and composition. Several models are available that describe this dependency for terrestrial melts quite well. Terrestrial basaltic lavas however are distinctly different in composition compared to planetary lavas, which are dominantly alkali-poor, iron-rich and/or highly magnesian.

Results: We measured the viscosity of 20 anhydrous tholeiitic melts, of which 15 represent known or estimated surface compositions of Mars, Mercury, the Moon, Io and Vesta, by concentric cylinder and parallel plate viscometry. The planetary basalts span a viscosity range of 2 orders of magnitude at liquidus temperatures and 4 orders of magnitude near the glass transition, and can be more or less viscous than terrestrial lavas (Fig. 1).

We find that current models under- and overestimate superliquidus viscosities up to 2 orders of magnitude for these compositions, and deviate even more strongly from measured viscosities toward the glass transition (Fig. 2ab) [1,2].

We used the Adam-Gibbs theory (A-G) to relate viscosity (η) to absolute temperature (T) and the configurational entropy of the system at that temperature (S^{conf}), which is in the form of $log\ \eta = A_e + B_e/TS^{conf}$ [3]. Heat capacities (C_P) for glasses and liquids of our investigated compositions were calculated via available literature models [4,5]. We show that the A-G theory is applicable to model the viscosity of individual complex tholeiitic melts containing 10 or more major oxides as well or better than the commonly used empirical equations. We successfully modeled the global viscosity data set using a constant A_e of -3.12 log units and 12 adjustable sub-parameters, which capture the compositional and temperature dependence on melt viscosity. Seven sub-parameters account for the compositional dependence of B_e and 5 for S^{conf}.

Discussion: Our model returns the 494 measured viscosity data points with a root-mean squared standard deviation (rmsd) of 0.15 log units across 13 orders of measured melt viscosity (Fig. 2c). The model performed well in predicting the viscosity of planetary melts not used in calibration (Fig. 3). Although the new model predicts the viscosities of anhydrous planetary melts better than any previous model, we empha-

size three caveats. These are (i) that liquid C_P is modeled, not measured, (ii) that T_g is modeled, not measured, and (iii) the parameters b_1 to b_7 and s_1 to s_5 are not simply the result of mixing compositional components, but also involve complex interactions that were selected for by trial and error.

Furthermore, the model does not account for volatiles (H_2O, CO_2, SO_2, F) in silicate melts, which makes it strictly applicable only to anhydrous and volatile-free compositions. Despite the fact that previous lunar viscosity data collected under reducing conditions are reproduced well with our model, future work could also incorporate variable oxidation states in such a viscosity model.
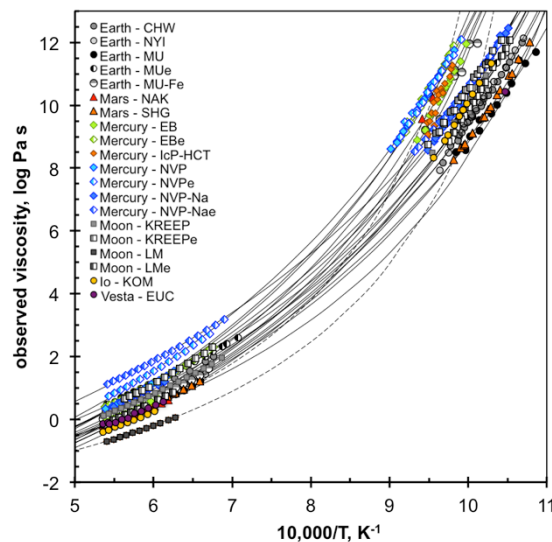

Fig. 1: 494 individual liquid viscosity data points plotted in an Arrhenian diagram, collected by (high temperature) concentric cylinder and (low temperature) parallel plate viscometry. At high temperatures, collected viscosity data points span a viscosity range of two orders of magnitude, whereas at low temperatures, the viscosity range is about 4 orders of magnitude. Viscosity data belonging to the same composition are fitted with a Vogel-Fulcher-Tammann (VFT) equation.

References: [1] Shaw H. (1972) *Am. J. Sci. 272,* 870–893. [2] Giordano D. et al. (2008) *Earth Planet Sci. Lett. 271(1–4),*123–134. [3] Richet P. (1984) *Geochim. Cosmochim. Ac. 48,* 471-483. [4] Richet P. (1987) *Chem. Geol.* 62, 111-124. [5] Stebbins J. F et al. (1984) *Contrib. Mineral Petrol. 86,* 131-148.
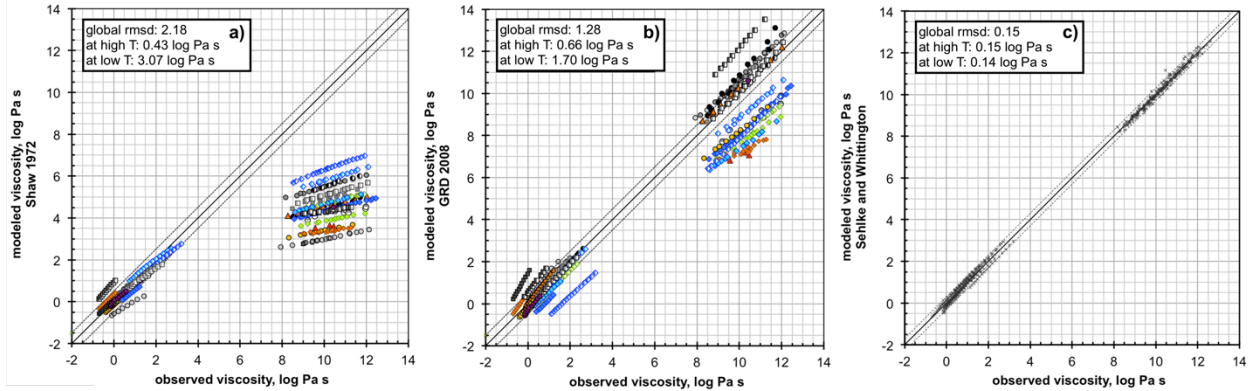
Fig. 2: a) Experimentally studied viscosity against viscosity predictions by the model of Shaw (1972). Viscosities at high temperatures are mostly within 0.5 log Pa s uncertainty. However, trajectories for individual compositions are curvy, causing super-liquidus viscosities to span about 1 log units in uncertainty. The curvy trajectory causes all compositions to be stromgly underestimated towards low temperatures. b) Experimentally studied viscosity against viscosity predictions by the model of Giordano, Russel and Dingwell (2008). Low viscosity data are mostly within the 0.45 rmsd of the GRD model (except NVP-Na and NVP-Nae, LM and LMe), whereas the mismatch between observed and modeled viscosities towards the glass transition temperature becomes much larger. c) Observed versus predicted viscosity values after modeling in a global set using the Adam-Gibbs theory (this study). Almost all viscosity data are returned within a 2σ uncertainty of 0.30 log Pa s at high and low temperatures. Colored symbols in b and c represent symbals in Figure 1.
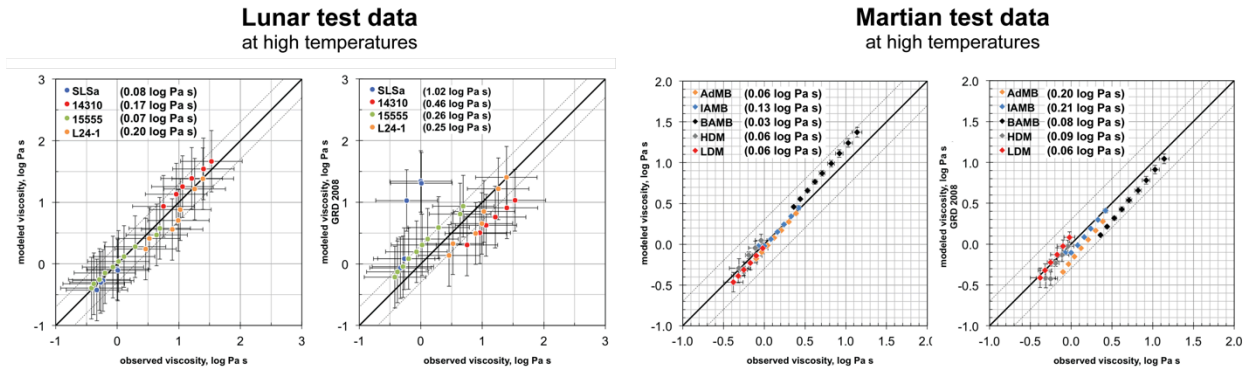

Fig. 3: Predictions of Lunar (left) and Martian (right) viscosity data not used in the calibration for this model. Viscosity calculations of this model (left panel) are compared against the Giordano et al. (2008) model (right panel). Root-mean-standard deviations (rmsd's) are given in parentheses.