Rheology of lava flows on Mercury: an experimental study. A. Sehlke and A. Whittington, Geological Sciences, University of Missouri - Columbia, Columbia, MO, USA.

Introduction: The morphology of lava flows is controlled by the physical properties of the lava and its effusion rates, as well as environmental influences such as surface medium, slope and ambient temperature and pressure conditions. The important physical properties of lavas include viscosity (η), yield strength (σ_y), thermal diffusivity ($\varkappa$) and heat capacity (C_p), all of which strongly depend on temperature (T), composition (X), crystal fraction (ϕ_c) and vesicularity (ϕ_b). The crystal fraction (ϕ_c) typically increases as temperature decreases, and therefore is temperature dependent itself and influences the residual liquid composition (X). The rheological behavior of multi-phase lava flows is expressed as different flow morphologies, for example basalt flows transition from smooth pahoehoe to blocky 'a'a at higher viscosities and strain rates. We have previously quantified the rheological conditions of this transition for Hawaiian basalts [1], but lavas on Mercury are very different in composition and expected crystallization history. Here we determine experimentally the temperature and rheological conditions of the pahoehoe-'a'a transition for two likely Mercury lava compositions.

Methods: Concentric cylinder viscometry under atmospheric conditions has been conducted in order to investigate the rheological response of crystal-liquid lava suspensions at different equilibrium temperatures for two likely Mercury lava compositions. The first is an enstatite basalt, derived from an experimental partial melt of the Indarch (EH4) meteorite composition [2], and assumed to be representative of primitive basalts on Mercury. The second is a representative Northern Volcanic Plains (NVP) composition based on new data provided by NASA's MESSENGER mission [3-5].

Results: We present new experimental data on two-phase rheology for the enstatite basalt and NVP composition and compare the evolution of both during cooling and crystallization. For the enstatite basalt composition, calculations in MELTS [6] predict a liquidus temperature of 1403 ºC. We first detect solid phases around 1302 ºC, where Mg-rich forsterite and prismatic-dipyramidal enstatite are observed. As crystallization progresses, we observe a depletion in MgO and slight enrichment in Al_2O_3 and CaO contents of the residual melt, leading to an increase in melt polymerization expressed as NBO/T (the ratio of non-bridging oxygens to tetrahedrally-coordinated cations) from 0.93 to 0.73 during the first 30 ºC of undercooling of the liquid.

Apparent viscosities (η_{app}) of the two-phase suspensions change from Newtonian to pseudo-plastic at temperatures below 1286 ºC, where the crystal fraction is 0.11 and mean crystal length-width aspect ratio of 2.38. The stress-strain rate dependency becomes stronger at lower temperatures and higher crystal fractions. By 1250 ˚C the two-phase suspension has become a Herschel-Bulkley fluid with an extrapolated apparent yield strength (τ_0) around 200 Pa, and a measured apparent viscosity of 1913 Pa s at a strain rate of 0.1 s^{-1}, dropping to 882 Pa s at a strain rate of 1 s^{-1}. Rheological measurements of the two-phase suspension at temperatures below 1250 ºC become very difficult due to crystals forming a network that increases the viscosity dramatically (> 10^5 Pa s).

The NVP composition is a much more polymerized melt with an NBO/T of 0.61 and calculations in MELTS [6] predict a very high liquidus temperature of 1557 ºC. The first phase to crystallize is predicted to be Mg-rich spinel making up only 2 vol% until the appereance of enstatite at 1406 ºC.

By analogy with the rheological conditions of the pahoehoe-'a'a transition for Hawaiian basalts [1], we can relate the data for Mercury to lava flow surface morphology as shown in Figure 1, where the onset of the transition threshold zone (TTZ) for the enstatite basalt composition is around 1270˚C. This is about 80 ºC higher than for Kilauea basalt. These data may allow emplacement temperatures and/or rates to be determined from remote sensing observations of the surface morphology of different volcanic fields on Mercury.

References: [1] Sehlke A. et al. (2013) Concentric cylinder viscometry at subliquidus conditions for Mauna Ulu Lavas, Kilauea Volcano, Hawaii, Abstract V51D-2697 presented at 2013 Fall Meeting, AGU, San Francisco, Calif., 9-13 Dec. [2] McCoy T. J et al. (1999) *Meteoritics and Planet. Sci., 34,* 735–746. [3] Weider S. Z. et al. (2012) *JGR, 117,* E00L05. [4] Nittler L. R. et al. (2011) *Science, 333*, 1847–1850. [5] Stockstill-Cahill K. R. et al. (2012) *JGR, 117,* E00L15. [6] Ghiorso M. S. and Sack R. O. (1995) *Contributions to Mineralogy and Petrology*, *119*, 197-212. [7] Robert B. et al. *Bull. Volc.*, in review.

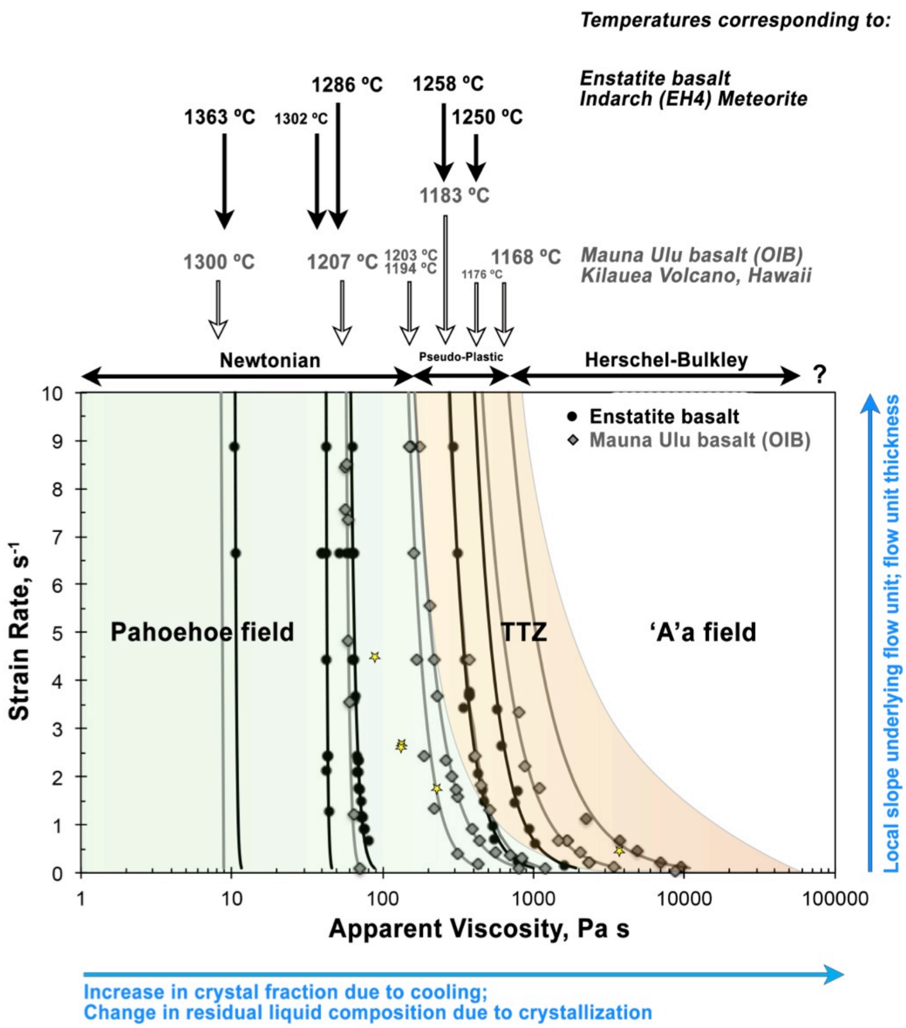

Figure 1: Change of measured apparaent viscosities with different strain rates for Mauna Ulu lava (grey diamonds) and enstatite basalt (EH4) composition (black circles). Star symbols represent textural analysis of lava flow morphologies from the Muliwai a Pele lava channel at Mauna Ulu (Kilauea) [7]. Lines represent an isothermal power-law fit of the experimental collected data points for each composition. The transition threshold zone (TTZ) is colored in yellow, representing a change of lava flow morphology from pahoehoe (green field) to 'a'a (white field). The onset of the TTZ for the enstatite basalt is 80 ºC elevated compared to the terrestrial composition.