# ARSIA, PAVONIS, AND ASCRAEUS MONS, MARS: RHEOLOGIC PROPERTIES OF YOUNG LAVA FLOWS.

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**Introduction:** We report on the rheologic properties of young lava flows on the large volcanoes Arsia Mons, Pavonis Mons, and Ascraeus Mons, which are located on the extensive Tharsis bulge [1,2]. We expand on our previous study of the rheologic properties of lava flows on Ascraeus Mons [3] in order to investigate possible similarities and differences among the late-stage lava flows of the Tharsis Montes. From previous studies it is known that in principle, the dimensions of flows reflect rheologic properties such as yield strength, effusion rates and viscosity [3-13].

**Data:** For our investigation we made use of high-resolution images obtained by the High Resolution Stereo Camera (HRSC) on board ESA's Mars Express spacecraft in combination with with Mars Orbiter Laser Altimeter (MOLA) data. In these data we measured the dimensions and slopes of the investigated young lava flows in order to constrain their rheologic properties. We utilized several HRSC orbits with spatial resolutions of about 10-20 m/pixel in order to measure the length and width of the studied lava flows. The heights of the lava flows were measured in individual MOLA profiles and gridded MOLA topography was used to measure the slope on which these flows occur. Compared to earlier studies, MOLA data and HRSC images that are favorably illuminated to recognize subtle morphologic details allowed us to identify and map a larger number of late-stage lava flows and to measure their dimensions, as well as to describe their morphological characteristics in greater detail.

**Method:** Like in our previous study, we modeled the investigated lava flows as a Bingham plastic controlled by two parameters, the yield strength and the plastic viscosity. As the method is described in detail in the literature [e.g., 3,4], we only provide a brief discussion. Moore et al. and others [e.g., 5] related the yield strength $\tau$ of lava flows (Pa) to the flow dimensions by the following equations

$$\tau = \rho\ g\ \sin\alpha\ h \qquad (1)$$

$$\tau = \rho\ g\ h^2/w \qquad (2)$$

$$\tau = \rho\ g\ \sin^2\alpha\ 2w_l \qquad (3)$$

$$\tau = \rho\ g\ \sin^2\alpha\ (w-w_c) \qquad (4)$$

where $\rho$ is the density (kg m$^{-3}$), g is the gravitational acceleration (m s$^{-2}$), $\alpha$ is the slope angle (degree), h is the flow height (m), w is the flow width (m), $w_l$ is the total levee width (m), and $w_c$ is defined as the width of a leveed channel (m).

The effusion rates Q (m$^3$ s$^{-1}$) can then be calculated as

$$Q = G_z\ \kappa\ x\ w/h \qquad (5)$$

where $G_z$ is the dimensionless Graetz number, $\kappa$ is the thermal diffusivity (m$^2$ s$^{-1}$), x is the flow length (m), and w and h are defined as above [e.g., 4,6].

The viscosities $\eta$ (Pa-s) were calculated using the relationship given for example by [7,8].

$$h = (Q\ \eta/\rho\ g)^{1/4} \qquad (6)$$

Jeffrey's equation relates the viscosity of a flow to its effusion rate and its dimensions [e.g., 9-11].

$$\eta = (\rho\ g\ h^3\ w\ \sin\alpha)/nQ \qquad (7)$$

In this equation n is a constant equal to 3 for broad flows and 4 for narrow flows.

**Results for Ascraeus Mons:** Our estimates of the yield strengths for flows on Ascraeus Mons range from ~2.0 x $10^2$ Pa to ~1.3 x $10^5$ Pa, with an average of ~2.1 x $10^4$ Pa. These values are in good agreement with estimates for terrestrial basaltic lava flows. The effusion rates are on average ~185 m$^3$ s$^{-1}$, ranging from ~23 m$^3$ s$^{-1}$ to ~404 m$^3$ s$^{-1}$. While these results are higher than earlier findings that indicate effusion rates of 18-60 m$^3$ s$^{-1}$, with an average of 35 m$^3$ s$^{-1}$, they are similar to terrestrial effusion rates of Kilauea and Mauna Loa and other Martian volcanoes [summarized in 3]. Viscosities were estimated to be on average ~4.1 x $10^6$ Pa-s, ranging from ~1.8 x $10^4$ Pa-s to ~4.2 x $10^7$ Pa-s. On the basis of our effusion rates and the flow dimensions, we calculated that the time necessary to emplace the flows is on average ~26 days.

**Results for Pavonis Mons:** The flows of Pavonis Mons are characterized by an average yield strength of ~3.4 x $10^3$ Pa, ranging from ~4.3 x $10^2$ to ~1.3 x $10^4$ Pa. The average effusion rate is ~242 m$^3$ s$^{-1}$, ranging from ~168 m$^3$ s$^{-1}$to ~449 m$^3$ s$^{-1}$. Viscosities are on average ~1.6 x $10^6$ Pa-s, ranging from ~1.7 x $10^5$ Pa-s to ~5.7 x $10^6$ Pa-s.

**Results for Arsia Mons:** For the flows on Arsia Mons we find that the average yield strength is ~2.2 x $10^3$ Pa, ranging from ~2.7 x $10^2$ to ~9.3 x $10^3$ Pa. The effusion rate varies from ~76 to ~1455 m$^3$ s$^{-1}$, with an average of ~567 m$^3$ s$^{-1}$. The average viscosity of the Arsia flows is ~2.5 x $10^6$ Pa-s, ranging from ~1.7 x $10^4$ Pa-s to ~9.3 x $10^6$ Pa-s.

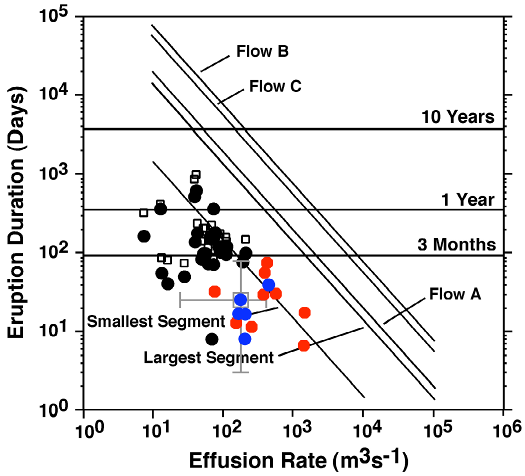

Fig. 1 Diagram of [12] showing the relationship between effusion rates and eruption durations for lava flows on Elysium Mons (black). Superposed are data for Arsia Mons (red dots), Pavonis Mons (blue dots), Ascraeus Mons (grey cross).

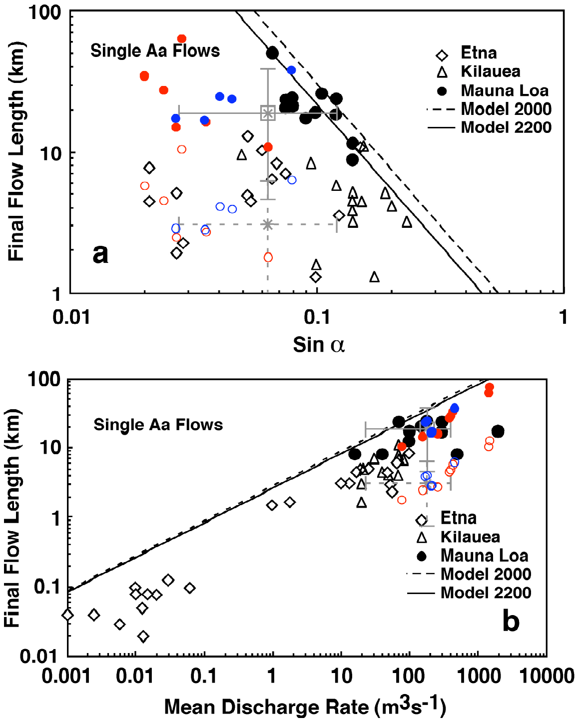

Fig. 2a Maximum flow lengths versus slopes of terrestrial lava flows and b: Maximum flow lengths versus discharge rate of terrestrial lava flows (black symbols) from Kilburn [15]. Superposed are results for Arsia Mons (red dots), Pavonis Mons (blue dots), and Ascraeus Mons (grey cross) Data corrected for Martian conditions are shown as open circles and dashed grey crosses.

**Conclusions:** On the basis of our study we conclude that our results for the yield strength, effusion rate, eruption duration, and viscosity are in good agreement with previously published results for Martian and terrestrial flows. Flows on Ascreaus, Pavonis, and Arsia Mons show very similar rheologic properties. The strength of our investigation is that we studied a larger number of flows than in previous studies [e.g., 5,6,8,12-14,16-20]. This provides a more complete foundation of our understanding of Martian lava rheologies. In a next step, we are planning to date the investigated flows with crater size-frequency measurements in order to study whether the rheology of the Tharsis Montes lava flows systematically varied with time.

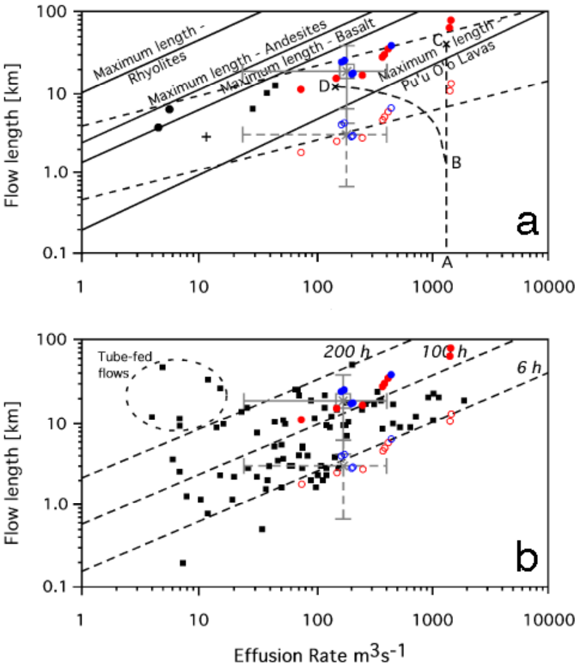

Fig. 3a: Maximum flow lengths of terrestrial rhyolits, andesites, and basalts from [19] compared to the studied Martian flows; b: Flow lengths and effusion rates of 84 Hawaiian lava flows (black squares) from [20] compared to our calculations for the studied Martian flows. Data corrected for Martian conditions are shown as open circles and dashed grey crosses. Color scheme as in Fig. 1.

**References:** [1] Scott and Tanaka, *I-1802-A,* 1986; [2] Neukum et al., *Nature, 432,* 2004; [3] Hiesinger, et al., *J. Geophys. Res., 112*, 2007; [4] Wilson and Head, *Nature, 302*, 1983; [5] Moore et al., *Proc. Lunar Planet. Sci. Conf., 9*, 1978; [6] Zimbelman, *Proc. Lunar Planet. Sci. Conf., 16*, 1985; [7] Fink and Griffiths, *J. Fluid Mech., 221*, 1990; [8] Warner and Gregg, *J. Geophys. Res., 108*, 2003; [9] Nichols, *J. of Geology, 47*, 1939; [10] Gregg and Fink, *J. Geophys. Res., 101,* 1996; [11] Gregg and Zimbelman, *Env. Effects on Volcanic Eruptions: From Deep Oceans to Deep Space*, Kluwer Academic/Plenum Publishers, New York, 2000; [12] Mouginis-Mark and Yoshioka, J. Geophys. Res., 103, 1998; [13] Glaze and Baloga, *J. Geophys. Res., 112*, 2007; [14] Glaze et al., *J. Geophys. Res., 111*, 2006; [15] Kilburn, in Encyclopedia of Volcanoes, Elsevier, 2000; [16] Keszthelyi, *J. Geophys. Res., 100*, 1995; [17] Sakimoto et al., *J. Geophys. Res., 102*, 1997; [18] Cattermole, *Proc. Lunar Planet. Sci. Conf., 17*, 1987; [19] Pinkerton and Wilson, Bull. Volcanol., 56, 1994 [20] Malin, Geology, 8, 1980.