EPSC Abstracts,
Vol. 4, EPSC2009-577, 2009
European Planetary Science Congress,

Rheologies and ages of lava flows on Elysium Mons, Mars

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Introduction: Previous studies have shown that in principle, the geometric dimensions of lava flows reflect rheologic properties such as yield strength, effusion rates and viscosity [1-8]. In this study we expand on earlier studies of rheologic properties of lava flows on Arsia Mons, Pavonis Mons, and Ascraeus Mons, by determining the rheology of lava flows on Elysium Mons [1,2,3]. A major goal of this study is the comparison of these two volcanic regions. We also derived new crater statistics for Elysium Mons lava flows to identify possible changes in the rheological properties with time. In addition, we investigated possible changes in rheological properties with the distance from the caldera of Elysium Mons.

Data: Images obtained by the High Resolution Stereo Camera (HRSC) on board ESA's Mars Express spacecraft, in combination with Mars Reconnaissance Orbiter Context Imager (CTX) images and Mars Orbiter Laser Altimeter (MOLA) data, were used to identify, map, and measure the dimensions and slopes of lava flows to constrain their rheologic properties. We utilized several HRSC orbits with spatial resolutions of about 12.5-25 m/pixel and CTX images with 5-6 m/pixel spatial resolutions to derive the lengths, widths and crater statistics of the studied lava flows. The heights and slopes of the lava flows were measured in individual MOLA profiles.

Methods: To investigate the rheological properties of the lava flows, we make the following assumptions: (1) flow dimensions are related to the rheological properties of the flow, (2) rheological properties can be estimated from flow dimensions measured in remotely sensed data, (3) lava flows behave as Bingham fluids, (4) lava flows in a laminar fashion, (5) no inflation of lava flows has occurred, (6) the densities of Martian volcanic rocks are on average 2,500 kg m^{-3}, (7) the Graetz number is 300, and (8) the thermal diffusivity is on the order of ~10^{-4}-10^{-8} m^2s^{-1} with an assumed value of 3 x 10^{-7} m^2s^{-1}. Moore et al. [5] and others [e.g., 6] related the yield strength, τ (Pa), of lava flows to the flow dimensions by the following equations:

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

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

where ρ is the density (kg m^{-3}), g is the gravitational acceleration (m s^{-2}), α is the slope angle (degree), h is the flow height (m), and w is the flow width (m).

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

$$Q = G_z\ \kappa\ x\ w/h \quad (3)$$

where G_z is the dimensionless Graetz number, κ 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 η (Pa^{-s}) were calculated using the relationship given for example by [7,8]:

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

Jeffrey's equation relates the viscosity of a flow to its effusion rate and its dimensions [e.g., 3,7]:

$$\eta = (\rho\ g\ h^3\ w\ \sin\alpha)/nQ \quad (5)$$

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

To derive the ages of the lava flows, we performed crater size-frequency measurements [9,10]. We paid particular attention to avoid including a large number of secondary craters in our counts. At CTX resolution, this proved to be difficult because of the large number of small craters on the relatively small count areas of the lava flows. In particular, in some cases, separating small secondary from primary craters was difficult because of the generally rough appearance of the

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flow surfaces and possible subsequent modification of the craters.

Results: We mapped 35 lava flows on and around Elysium Mons (Fig. 1) with distances from the caldera between 53 and 640 km. We calculated the rheological properties of 32 of these flows. Three of the flows were too small in width to yield reliable heights from the MOLA profiles. All morphometric parameters were measured several times along each flow and were averaged for calculation of the rheologic properties.

The lengths of the Elysium flows vary between 9.9 and 118 km, with widths on the order of 428 m to 13.679 km. The MOLA profiles of the investigated flows have heights of 5 to 34 m and slopes of 0.06-6.9°. Using the results of our morphometric measurements of each individual lava flow, we estimated the yield strengths, effusion rates, and viscosities of the studied lava flows. We found that the yield strengths of the Elysium Mons lava flows range from ~1.1 x 10^2 Pa to ~2.7 x 10^4 Pa, with an average of ~3.1 x 10^3 Pa . These values are in good agreement with estimates for terrestrial basaltic lava flows. The effusion rates are on average ~663 $m^3 s^{-1}$, ranging from ~99 to 4452 $m^3 s^{-1}$. The viscosities show an average of about 4.1 x 10^6 $Pa^{-}s$ with a range of 2.0 x 10^4 $Pa^{-}s$ to 3.7 x 10^7 $Pa^{-}s$. On the basis of our effusion rates and the flow lengths, we calculated the eruption durations of the flows to be between 4 and 153 days, with an average of ~49 days.

Compared to the Tharsis Montes volcanoes, our results for Elysium Mons are generally similar. While yield strengths are in the range of the Tharsis Montes, effusion rates and viscosities are slightly higher but on the same order of magnitude (Table 1).

	τ (Pa)	Q ($m^3 s^{-1}$)	η (Pa^{-s})	T (days)
Ascraeus	2.1 x 10^4	185	4.1 x 10^6	26
Pavonis	3.4 x 10^3	242	1.6 x 10^6	22
Arsia	2.2 x 10^3	567	2.5 x 10^6	30
Elysium	3.1 x 10^3	663	4.1 x 10^6	49

Table 1 *Comparison of average rheologies of lava flows on the Tharsis Montes and Elysium Mons. Data for the Tharsis flows are from [2,3].*

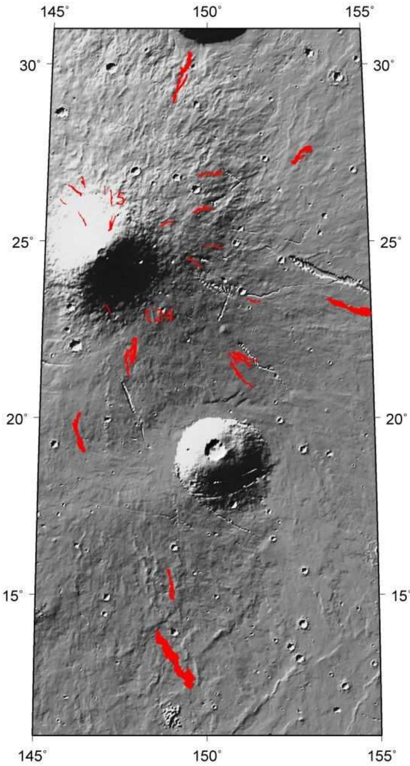

Fig. 1: *Investigated lava flows in the Elysium Mons region.*

So far, we determined the ages of 20 lava flows on Elysium Mons. The derived ages show a wide variation from about 532 Ma to 1.97 Ga (Figure 2, 3). On the basis of our preliminary study, we do not see increasing ages of the flows with increasing distances from the caldera (see Fig. 1-3). We have also not observed a link between the ages and rheological properties of the flows.

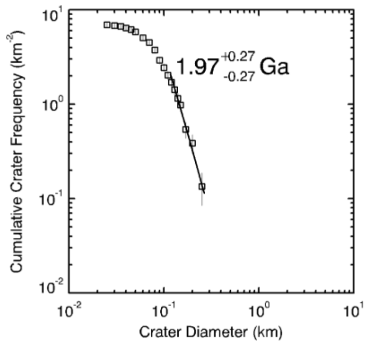

Fig. 2: *Maximum age of all measured lava flows on Elysium Mons (lava flow 24).*

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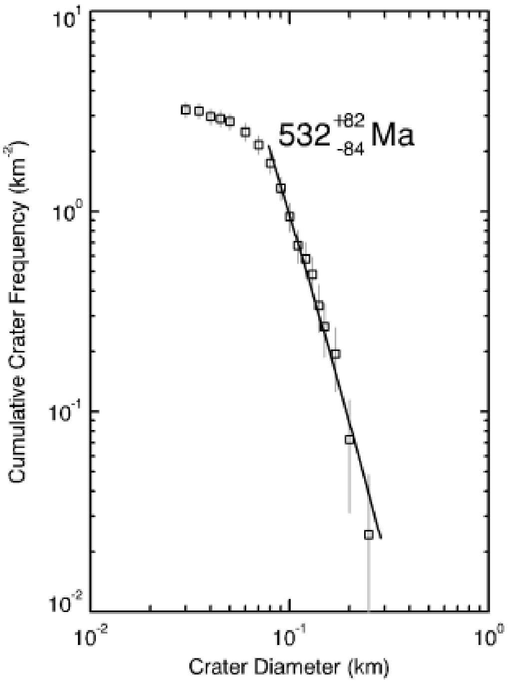

Fig. 3: *Minimum age of all measured flows on Elysium Mons (lava flow 5).*

Conclusions: On the basis of our studies we conclude that the rheological properties of lava flows in the Elysium Mons region are generally very similar to those of the Tharsis Montes [2,3]. In terms of rheologic properties, there are no significant differences between the studied lava flows in the eastern and the western hemisphere. We also do not see systematic changes of the rheological properties of flows with their distances from the caldera on Elysium Mons. We determined new surface model ages of 20 individual lava flows on Elysium Mons. So far, we have not found any relationship between ages and rheological properties of the investigated flows on Elysium Mons, or the ages and distances from the Elysium Mons caldera.

References:

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