LAVA FLOWS ON ARSIA AND PAVONIS MONS, MARS: RHEOLOGY AND AGES. H. Hiesinger[1], N. Bartel[1], T. Boas[1], D. Reiss[1], J. H. Pasckert[1], and C. H. van der Bogert[1], [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster,Wilhelm-Klemm-Str. 10, 48149 Münster, hiesinger@uni-muenster.de.

Introduction: In previous studies, we reported on the rheologies of lava flows on Elysium, Ascreus, Pavonis, and Arsia Mons [*1-3*]. However, our previous work on Arsia and Pavonis Mons [*2*] was limited to only eight and five flows, respectively, and at that time no absolute model ages were available for investigating any potential correlation between the ages of the flows and their rheological properties [*3*]. Thus, compared to our previous study of Arsia and Pavonis flows [*2*], we not only expanded on the number of flows (13 additional new flows at Arsia; six new flows at Pavonis), but we also derived absolute model ages (AMAs) based on crater size-frequency distribution (CSFD) measurements. The current study does not reveal systematic changes of the rheology with time, a result that is supported by findings for the Elysium flows [*3*].

Method: All images were calibrated and map-projected with ISIS 3 [*4*] and imported into ArcGIS to measure the dimensions and slopes of the studied flows and to perform CSFD measurements. To derive the rheologic properties of flows on Arsia Mons, we applied the same methods as in our previous investigations [*1-3*]. The yield strength τ of lava flows (Pa) is linked to the flow dimensions by the following equations [e.g., *5*]

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

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

In these equations, 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 rate Q (m^3 s^{-1}) is given as

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

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., *6,7*].

Applying the equation of [*8,9*], we calculated the viscosities η (Pa-s)

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

Finally, Jeffrey's equation also allows for the calculation of the viscosity [e.g., *10-12*].

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

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

Within ArcGIS, we used CraterTools [*13*] to perform CSFD measurements using techniques described in [*14-17*]. The CSFDs were plotted and AMAs fit with CraterStats [*18*], using the chronology function (CF) of [*19*] and production function (PF) of [*20*].

Results: In [*2*], we reported an average yield strength for eight studied Arsia flows of ~2.2 x 10^3 Pa (ranging from ~2.7 x 10^2 to ~9.3 x 10^3 Pa), an average effusion rate of ~567 m^3s^{-1} (~76 to ~1455 m^3s^{-1}), and an average viscosity of ~2.5 x 10^6 Pa-s (~1.7 x 10^4 Pa-s to ~9.3 x 10^6 Pa-s). On the basis of the current study of 21 (13 additional) flows, we find similar rheological properties. The yield strengths of the studied 21 lava flows on Arsia Mons vary between ~2.54 x 10^2 Pa and ~9.63 x 10^3 Pa. The effusion rates are on average ~563 m^3s^{-1}. The calculated eruption durations range from three days to ~142 days with an average of ~32 days. The viscosities of the lava flows on Arsia Mons are on average ~2.54 x 10^6 Pa-s and vary between ~1.32 x 10^4 and ~2.88 x 10^7 Pa-s.

In [*2*], we also reported an average yield strength of five studied Pavonis flows of ~3.4 x 10^3 Pa (ranging from ~4.3 x 10^2 to ~1.3 x 10^4 Pa), an average effusion rate of ~242 m^3 s^{-1} (~168 to ~449 m^3 s^{-1}, and an average viscosity of ~1.6 x 10^6 Pa-s (~1.7 x 10^5 to ~5.7 x 10^6 Pa-s). The additional data from the current study revealed an average yield strength of the Pavonis flows of ~3.56 x 10^3 Pa, ranging from ~2.5 x 10^2 to ~8.6 x 10^3 Pa. The effusion rates range from ~ 60 m^3s^{-1} to ~309 m^3s^{-1}, with an average value of ~197 m^3s^{-1}. The investigated flows are characterized by an eruption duration in the range of ~3 to ~41 days, averaging about 15 days. The viscosities vary between ~2.8 x 10^4 Pa-s and ~7.6 x 10^6 Pa-s, with an average value of ~1.77 x 10^6 Pa-s.

The new CSFD measurements for the 21 Arsia flows yielded AMAs between ~36 and ~857 Ma. Unit A3 shows an underlying older age of ~2.50 Ga and evidence for a resurfacing event at ~857 Ma. These ages are similar to those presented by [*21-23*] for the caldera of Arsia Mons, i.e., ~100-200 Ma. In addition, [*23*] argued that their ages represent the latest stages of summit and flank eruptions and that earlier episodes stopped at about 500 Ma, 800 Ma, and 2 Ga ago. Errors of our CSFD measurements are relatively large due to the small sizes of the investigated flows and their rough morphologies that make it difficult to unambiguously identify craters and to accurately measure their diameters.

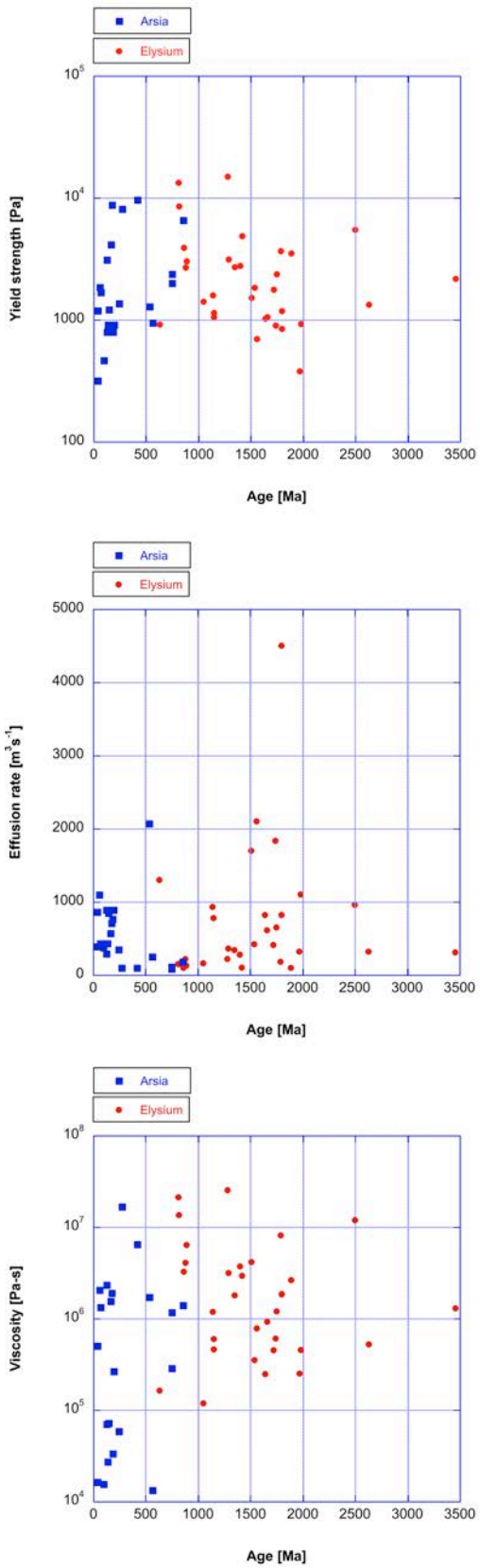

Figure 1: Rheologic properties and absolute model ages of flows on Elysium Mons [3] and Arsia Mons.

Comparison to Elysium flows: Previously, we performed the first study that correlated rheologic properties and AMAs of lava flows on Elysium Mons [*3*]. We reported that the yield strengths of 32 investigated Elysium flows are on the order of ~3.0 x 10^3 Pa, ranging from ~3.8 x 10^2 to ~1.5 x 10^4 Pa. The effusion rates of the flows range from ~99 to ~4450 m^3s^{-1}, averaging at ~747 m^3s^{-1}. The lava flows were emplaced in less than a week (very small flows) to up to half a year (~6-183 days). Viscosities were calculated to be on average ~4.1 x 10^2 Pa-s, with a range of ~1.2 x 10^5 to ~3.1 x 10^7 Pa-s. The AMAs of the Elysium flows range from ~632 to ~3460 Ma [*3*].

With the new results for the Arsia and Pavonis flows, we can now expand on the previous study. Figure 1 shows the yield strengths, effusion rates, and viscosities of lava flows on Arsia Mons and Elysium Mons plotted against their respective AMAs. Lava flows on both volcanoes do not show systematic correlations between the rheologic properties and model ages. Thus, the rheology of the studied flows did not change over several hundreds of million years. Preliminary results for Pavonis flows also do not show systematic changes of the rheology with time.

Future work: Preliminary results suggest that the AMAs of the flows on Pavonis Mons vary between ~79 Ma and ~834 Ma. At least three flows appear to show evidence for resurfacing. Once these ages are confirmed, we will update our investigation on the correlation between rheology and absolute model ages.

References: [1] Hiesinger et al. (2007) J. Geophys. Res. 112, 10.1029/2006JE002717. [2] Hiesinger et al. (2008) LPSC 39, 1277. [3] Pasckert et al. (2012) Icarus 219, 443-457. [4] Anderson et al. (2004) LPSC 35, #2039. [5] Moore et al. (1978) Proc. Lunar Planet. Sci. Conf. 9, 3351-3378. [6] Wilson and Head, (1983) Nature 302, 663-669. [7] Zimbelman (1985) Proc. Lunar Planet. Sci. Conf. 16, D157-D162. [8] Fink and Griffiths (1990) J. Fluid Mech. 221, 485-500. [9] Warner and Gregg (2003) J. Geophys. Res. 108, 10.1029/2002JE001969. [10] Nichols (1939) J. of Geology 47, 290-302. [11] Gregg and Fink (1996) J. Geophys. Res. 101, 16,891-16,900. [12] Gregg and Zimbelman (2000) Env. Effects on Volcanic Eruptions: From Deep Oceans to Deep Space, Kluwer, 243-251. [13] Kneissl et al. (2012) Planet. Space Sci. 59, 1243-1254. [14] Neukum et al. (2001) Space Sci. Rev. 96, 55-86. [15] Hiesinger et al. (2000) J. Geophys. Res. 105, 29239-29275. [16] Hartmann (1966) Icarus 5, 406-418. [17] Crater Analysis Working Group (1979) Icarus 37, 467-474. [18] Michael and Neukum, (2010) Earth Planet. Sci. Lett. 294, 223-229. [19] Hartmann and Neukum (2001). [20] Ivanov (2001) Space Sci. Rev. 96, 87-104. [21] Neukum et al. (2004) Nature 432, 971-979. [22] Robbins et al. (2011) Icarus 211, 1179-1203. [23] Werner (2009) Icarus 201, 44-68.