EMPLACEMENT DYNAMICS OF LAVA FLOWS ON ELYSIUM MONS, MARS

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1) Introduction: Lava flow morphology (length L, width W, thickness D) is measured to deduce the rheology and emplacement dynamics of flows [1-9] and hence, by implication, their composition. With the emergence of higher resolution imagery of Mars (CTX and HiRISE) and more information on rheological properties of martian lavas [10, 11], the lava flows NW of Elysium Mons (24.88°N, 213.24°W) studied by [12] have been reexamined.

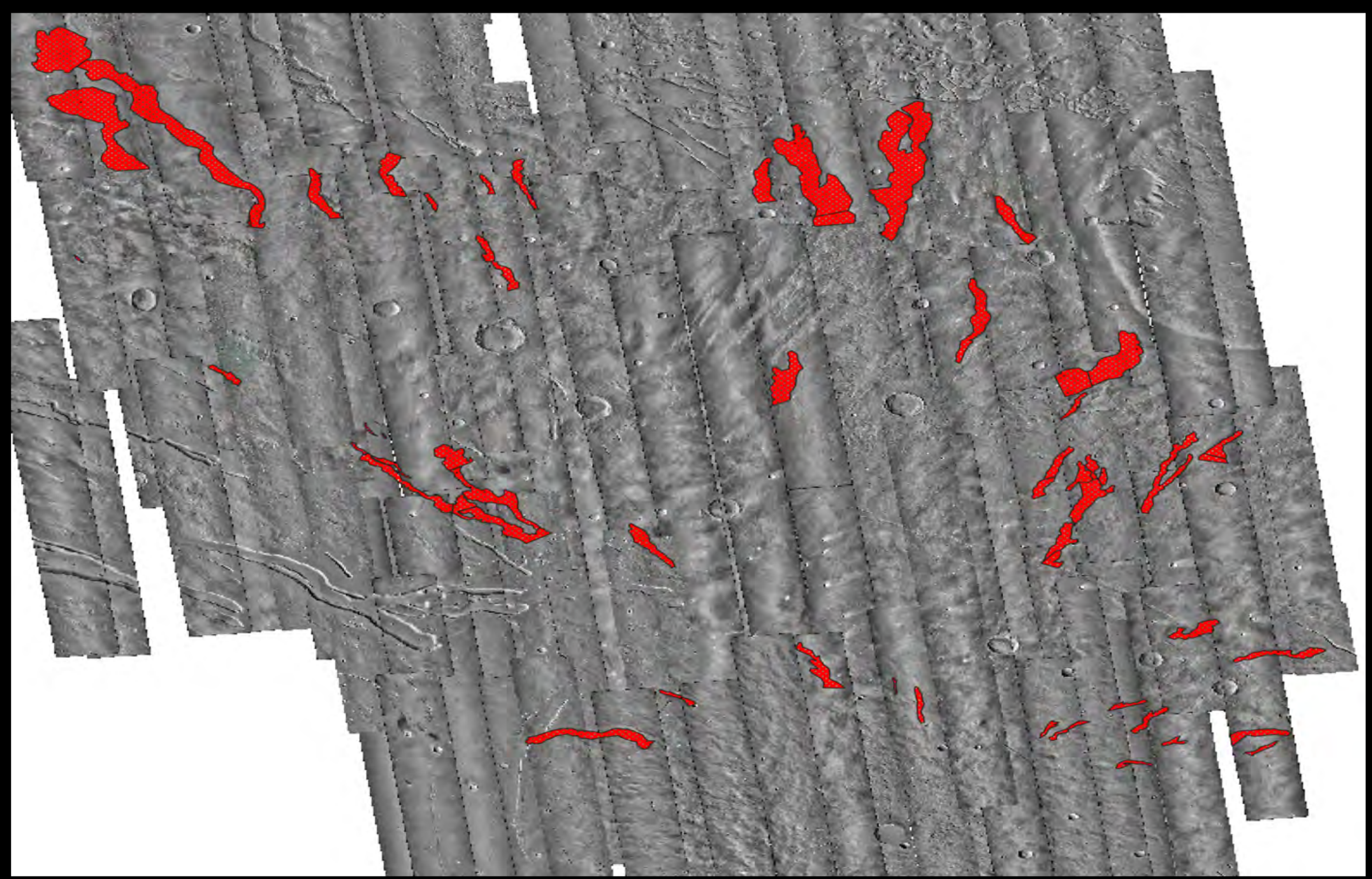

Fig. 1– the study area, 45 lava flows highlighted red. Images are CTX courtesy of NASA/JPL

2) Study Parameters: 45 lava flows on the north western flanks of Elysium Mons (Fig. 1) were studied for measurements of morphology using CTX images (~5 m/px) and GIS software. Altimetry data provided by Mars Orbiter Laser Altimetry (MOLA) were measured for 18 flows. Flow number 42 was too small to be measured by MOLA data was measured using DTM vertical terrain profiling tool. A comparison of these two data sets is shown in Fig. 2. The ~300 m point spacing of MOLA caused a large discrepancy between the data sets.

The morphology data for the 19 lava flows for which the thickness could be measured were used in calculations of their rheology parameters; this approach assumed Bingham fluid flow and that the flows were cooling-limited. Average morphology data can be seen in Table 1.

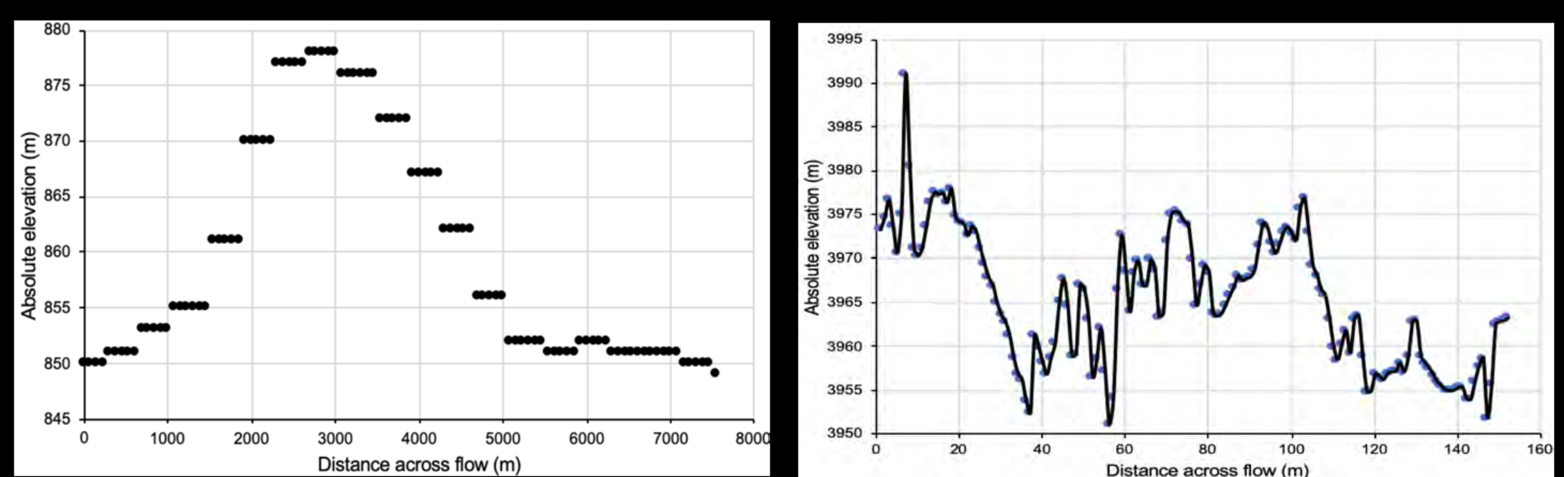

Fig. 2 – lava flow cross sections using MOLA altimetry data (left) and vertical terrain profiling from a DTM [13] (right)

3) Modelling Rheology: Methods

- *Yield strength*: Y = (ρ g D²) / W, from [8]

This equation assumes Bingham rheology and can be applied to laminar flows with a core and a cooling outer boundary layer. The boundary layer grows over time and can be viewed as controlling the average rheology. The average yield strength of the 19 flows measured was 3481 Pa – Table 2.

- *Viscosity:* η = (ρ g D⁴ sin α) / (56.25 κ L)

This equation has been used in calculations assuming cooling limited laminar flow conditions (Table 4). κ is thermal diffusivity (~7 x 10⁻⁷ m²/s).

- *Volume flux*: F = (18.75 κ L W) / D, from [14]

Also known as effusion rate, this parameter has been calculated for cooling-limited (T2) and laminar (T4) assumptions.

- *Flow speed*:

U = (ρ g D² sin α) / (3 η) for laminar flow (T4)
U = [(8 g D sin α) / λ]^1/2 for turbulent flow (T3)

4) Modelling Rheology: Results

Table 1: average morphology measurements

L (km)	W (km)	D (m)	α (rad.)
58	5.5	42	0.02

Table 2:average rheological and flow properties calculated with a cooling-limited assumption

Y (Pa)	F (m^3/s)	U (mm/s)	η (Pa s)
3481	139	0.74	7.7×10^8

Table 3: average rheological and flow properties calculated with turbulent flow assumption

F (m^3/s)	U (m/s)	η (Pa s)
8.3×10^6	26	< 6025

Table 4: average rheological and flow properties calculated with laminar flow assumption

F (m^3/s)	U (m/s)	Re
7.3×10^4	0.14	1.04

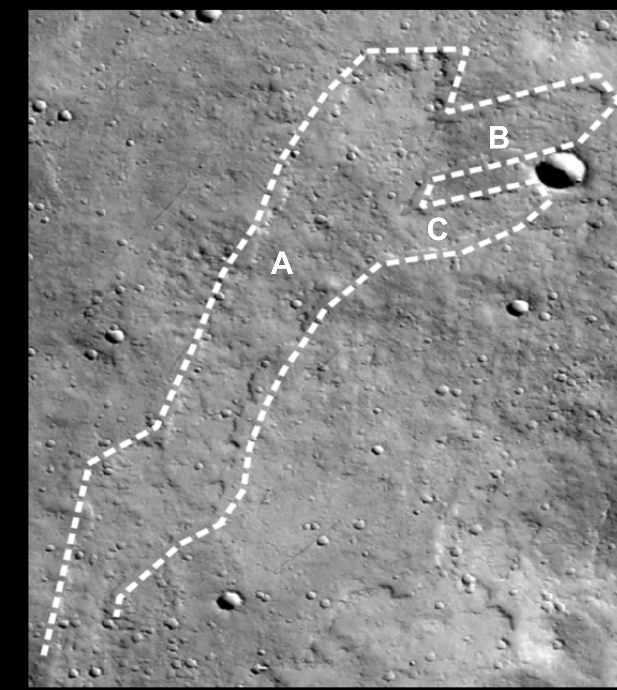

Fig. 4 – sideways segmented flow

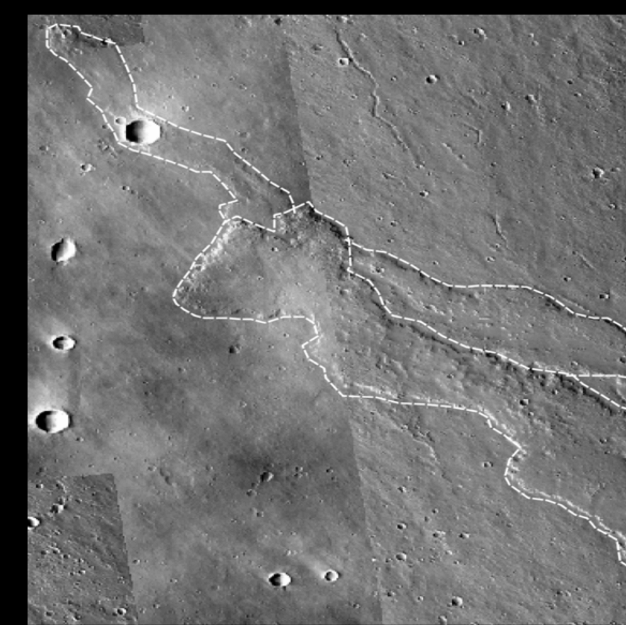

Fig. 5 – cross cutting flows

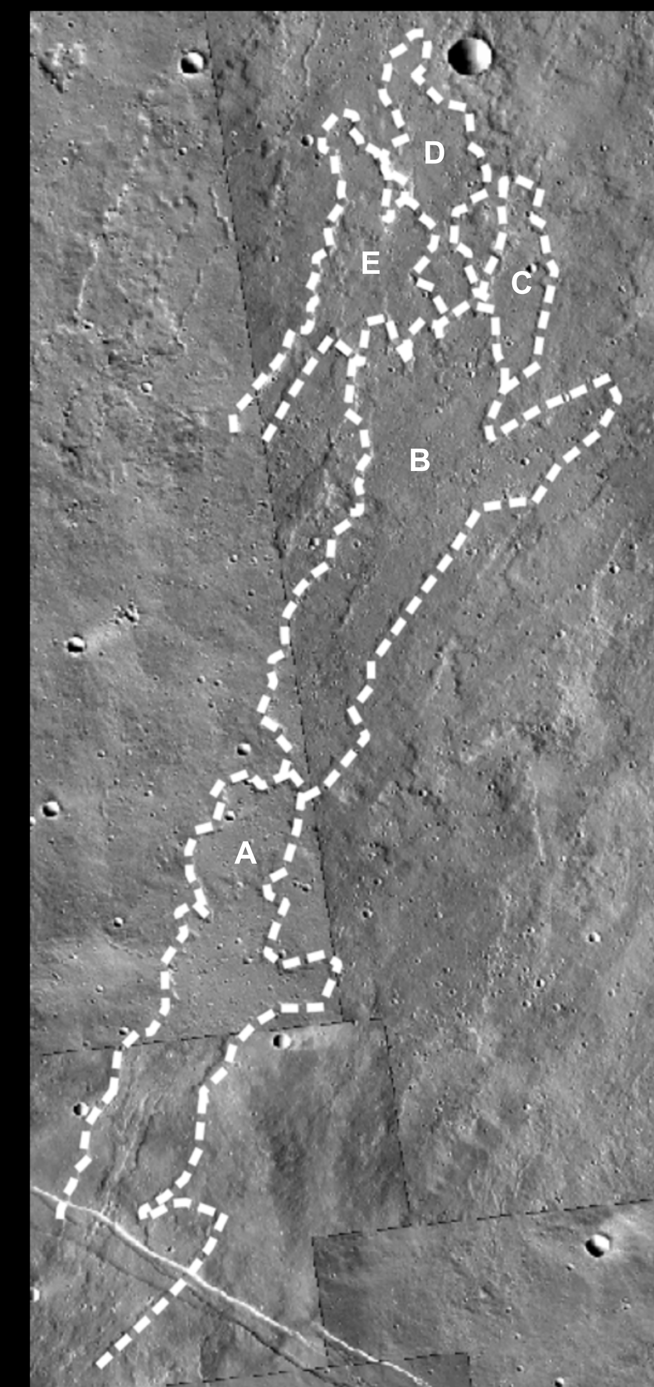

Fig. 6 – segmented flow with the emergence from the distal end of lobe

5) Modelling Rheology: Discussion

The very high viscosities and very low advance speeds, ~1 mm/s (Table 2), obtained by assuming flows were cooling-limited strongly suggest that these flows were in fact volume limited, meaning that potentially these estimates define the minimum effusion rate and thus maximum eruption duration.
The speeds and fluxes calculated assuming turbulent flow (T3) require viscosities < ~6000 Pa s. Volume fluxes of this order are greater than the largest for the longest flows on the Moon [14, 15] and are very hard to understand in terms of eruptions from shallow magma reservoirs such as those present in Martian shield volcanoes like Elysium Mons. The results suggest a volume-limited laminar flow regime for most flows.

6) Visual Flow Features: Channels were shown to have formed in at least 5 flows; Fig. 3 shows one of these. MOLA measurements suggest some are deeply channelized; this can arise from thermal erosion at the base of the flow on shallow slopes [16].
Segmented flows have been documented on the flanks of Elysium Mons previously [8, 12] but usually via emergence from the distal end of the previous lobe (Fig. 6). This study also found evidence of flow lobes emerging from the sides of previous lobes (Fig. 4).
Fig. 5 shows a later flow over-riding an earlier one, possibly suggestive of local high-speed turbulent flow.

Fig. 3 – channelized lava flow

7) Yield Strength and Crystallinity: The yield strength of a lava should be a function of its crystallinity, but there is great scatter among the models for this functional relationship [13], such that a yield strength of 3480 Pa could imply crystallinities > 55 vol. %. For the lowest-viscosity rock measured by [11], a 5% partial mantle melt, these crystallinities correspond to viscosities up to 10² Pa s if the crystals are considered equant and up to 10⁵ Pa s if crystals are prolate; for other Martian compositions (more silicic or more alkaline) >55vol.% crystallinity implies much higher viscosities (>10⁶ Pa s).

8) Conclusions

- Modelling is suggestive of a laminar and volume-limited flow regime for most of the Elysium flows.
- It is possible that thermal erosion occurred at the bases of the most deeply channelized flows.
- Currently there is great uncertainty in how crystallinity controls yield strength in mafic lavas, making it difficult to obtain consistent rheologies within calculations.
- In some places new lava lobes emerge from the sides of earlier lobes, suggestive of the earlier lobes having been emplaced in cooling-limited conditions.
- Segmentation via emergence at the distal end of the previous lobe suggests cooling-limited emplacement of the earlier lobe followed by its inflation.
- Later flows over-riding earlier ones suggests high speed and possibly turbulent flow in some cases.

References: [1] Baloga S.M. and Glaze L.S. (2008) *JGR*, *113* E05003, 15 pp. [2] Baloga S.M. et al. (2003) *JGR*, *108*, 1-10. [3] Basilevskaya E.A. et al. (2006). *Solar System Res.*, *40*, 375-383. [4] Garry W.B. et al. (2007) *JGR*, *112*, E08007, 21 pp. [5] Glaze L.S. and Baloga S.M. (2006). *JGR*, *111*, E09006, 10 pp. [6] Glaze L. S. et al. (2009) *JGR - Planets*, *114*, E07001, 15 pp. [7] Hiesinger H. et al. (2007) *JGR*, *112*, E05011, 24 pp. [8] Pasckert J.H. et al. (2012). *Icarus*, *219*, 443-457. [9] Vaucher, J. et al. (2009) *Icarus*, *200*, 39-51. [10] Chevrel M. O. et al. (2013) *EPSL*, *384*, 109-120. [11] Chevrel M. O. et al. (2014) *GCA*, *124*, 348-365. [12] Mouginis-Mark, P and Yoshioka, M.T (1997) JGR. 103, E8. pp 19,389-19,400. [13] UHM (2018) https://www.higp.hawaii.edu/prpdc/CTX_DEMs/Volcanoes/Elysium_Flanks/Elysium_Flanks.html. [14] Wilson L. and Head J.W. (2017) *Icarus*, *283*, 146-175. [15] Wilson L. and Head J.W. (2018) *GRL*, *45*, 5852-5859. [16] Hurwitz *et al.*, (2010) *Icarus*. 210, pp. 626 – 634.