DYNAMICS OF EMPLACEMENT OF LAVA FLOWS ON ELYSIUM MONS, MARS. Emma Harris[1], Lionel Wilson[1] and Magdalena Oryaëlle Chevrel[2]. [1]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, U.K. (e.harris1@lancaster.ac.uk), [2]Laboratoire Magmas et Volcans, Université Clermont Auverge, 63178 Aubière, France.

Introduction: Many previous studies have measured the dimensions (length, width, thickness) of lava flows on Mars, on both the steep slopes of shield volcano flanks and in flatter plains areas (e.g., [1-9]), with the aim of deducing eruptions conditions and flow rheology and hence, by implication, composition. With the advent of more information on the rheological properties of liquids with the compositions of martian rocks [10-11], we have re-examined flows on the north flanks of Elysium Mons previous studied by [12].

Observations: Figure 1 shows the 18 flows measured in detail on a CTX image mosaic. For each flow the length, L, and the average values of width, W, thickness, D, and local substrate slope, α, were found using images and MOLA data (Columns 2-5 in Table 1).

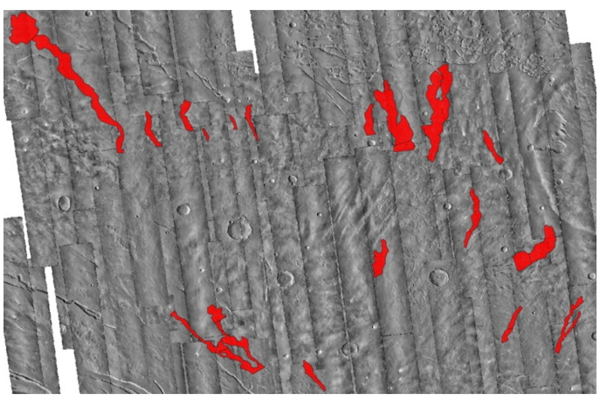

Figure 1. Measured flows on the northern flanks of Elysium Mons.

Analysis: We attempted to deduce the rheology and eruption conditions of the lavas.

Yield strength: The finite thickness and restricted lateral spreading of lava flows implies that at least the lava at the edges of a flow has a none-zero yield strength [13] and therefore a non-Newtonian rheology. Our first step is to find the yield strength of the lava in each flow. A model was developed by [13] based on the assumption that all of a lava flow has the same rheology, that of a Bingham plastic. Many later authors either explicitly or tacitly assumed that lava flows move in a laminar fashion, so that the core of the flow remains hot, losing heat only slowly by conduction through a thermal boundary layer consisting of the crust on top, the levees at the sides, and a basal layer. All parts of the boundary layer thicken in proportion to the square root of the time that has elapsed since a given batch of the lava left the vent. The flow therefore consists of two components, a shrinking core and a growing boundary layer, which in general have very different rheologies. However, provided the outer shell of the flow is regarded as defining an average or bulk rheology, the model of [13] may still be applicable. In that case, the yield strength Y can be found from

$$Y = (\rho\, g\, D^2)\, /\, W \qquad (1)$$

where g is the acceleration due to gravity, ρ is the bulk lava density (3000 kg m^{-3}), and D and W are the flow thickness and width, respectively. Calculated values of Y for the Elysium Mons flows analyzed are shown in Table 1, column 6; the average is 3480 Pa.

Viscosity based on crystallinity: It is expected that the yield strength of a lava should be a function of its crystallinity, but as Chevrel et al. [10, their Fig. 6] show, there is very great scatter among the various models in the literature for this functional relationship, such that a yield strength of 3480 Pa could imply crystallinities > 55 vol. %. Chevrel et al. [11] measured the viscosity of 5 melts with compositions corresponding to those of volcanic rocks on Mars, modelled the crystallinity, ϕ, as a function of temperature and deduced the effective viscosities as a function of temperature and crystallinity for the 5 compositions [11]. For the lowest-viscosity rock measured by [11], a 5% partial mantle melt, these crystallinities correspond to viscosities up to 10^2 Pa s if the crystals are considered equant and up to 10^5 Pa s if crystals are prolate; for other martian compositions (more silicic or more alkaline) >55vol.% crystallinity implies much higher viscosities (>10^6 Pa s).

Viscosity based on assuming cooling-limitation. The dense rock equivalent volume flux F producing a cooling-limited flow of length L is given by [14] as

$$F = (18.75\, \kappa\, L\, W)\, /\, D \qquad (2)$$

where κ is the thermal diffusivity, ~7×10^{-7} m^2 s^{-1}. This treatment tracks the penetration of waves of cooling into the flow from the top and base and tacitly assumes laminar flow. Since the flux is simply $F = U\, W\, D$ this means that the flow speed can be found from $U = (18.75\, \kappa\, L)\, /\, D^2$ and since the flow speed in laminar flow is related to the viscosity by $U = (\rho\, g\, D^2 \sin\alpha)\, /\, (3\, \eta)$, the viscosity is given by

$$\eta = (\rho\, g\, D^4 \sin\alpha)\, /\, (56.25\, \kappa\, L) \qquad (3)$$

The values of F, U and η are given in columns 7-9 in Table 1. The very high viscosities, 10^6 to 10^9 Pa s, and very low advance speeds, ~1 mm s^{-1}, strongly suggest that these flows were not cooling limited, and hence that the values of the volume flux, ~ 100 m^3 s^{-1} are severe under-estimates.

An alternative is to assume that the flows were turbulent, not laminar. In that case the speed is given $U = [(8\, g\, D \sin \alpha) / \lambda]^{1/2}$ where λ is a friction factor of order 0.03 [14]. The speeds implied by this assumption (column 10 in Table 1) are ~25 m s^{-1} and the volume fluxes (column 11) are ~10^7 m^3 s^{-1}; to ensure turbulence the viscosity of the lava would need to be <6000 Pa s . Volume fluxes of this order are greater than the largest inferred for the longest flows on the Moon [14, 15] and, while not impossible, are very hard to understand in terms of eruptions from shallow magma reservoirs such as those present in martian shield volcanoes like Elysium Mons.

Conclusions: Taken together, the above results suggest that the flows analyzed were emplaced in a laminar fashion, and were not cooling-limited but instead stopped advancing when the magma supply from the vent ended. If we assume that the lava viscosity was 10^5 Pa s, the average values of the advance speed, volume flux and Reynolds number would have been 1.4 m s^{-1}, 7 × 10^5 m^3 s^{-1} and ~10, respectively, with a typical flow emplacement time of 1.4 days. With an assumed viscosity of 10^6 Pa s, the corresponding values are 0.14 m s^{-1}, 7 × 10^4 m^3 s^{-1} and ~1, respectively and the typical emplacement time is 2 weeks.

Both of these viscosity scenarios are consistent with a yield strength of ~3500 but underline the difficulty of obtaining unique solutions for lava rheologies and eruption rates from morphological observations. A major problem is the current great uncertainty in how crystallinity controls yield strength in mafic lavas.

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Table 1. Columns 1-5 are morphological measurements on 18 lava flows on the north flanks of Elysium Mons. Column 6 is the lava yield strength deduced from eq. (1). Columns 7-9 give lava volume flow rate, mean flow speed and implied lava viscosity if the flow is cooling-limited. Columns 10-12 give mean flow speed, volume flux and maximum viscosity if the flow is assumed to be turbulent. Columns 13-15 give the mean flow speed, volume flux and Reynolds number if the flow is laminar and has a viscosity of 10^6 Pa s. See text for discussion.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flow	*L*	*W*	*D*	α	*Y*	*F*	*U*	η	*U*	*F*	max η	*U*	*F*	*Re*
No.	km	km	m	rad.	Pa	m^3/s	mm/s	Pa s	m/s	m^3/s	Pa s	m/s	m^3/s	
1	65	3.4	34	0.03	3057	86	0.75	1.7E+08	32	3.7E+06	5385	0.13	1.5E+04	0.52
4	41	4.6	39	0.02	3154	62	0.35	3.0E+08	27	4.8E+06	5235	0.10	1.9E+04	0.49
11	25	1.4	33	0.02	7391	14	0.31	2.3E+08	24	1.1E+06	3915	0.07	3.1E+03	0.28
15	39	4.7	27	0.01	1439	89	0.70	5.2E+07	19	2.4E+06	2566	0.04	4.6E+03	0.12
17	79	5.5	43	0.01	3129	132	0.56	1.8E+08	25	5.9E+06	5401	0.10	2.4E+04	0.53
18	110	5.3	30	0.01	1530	259	1.65	2.6E+07	20	3.1E+06	2904	0.04	6.7E+03	0.15
24	53	7.4	49	0.01	3005	105	0.29	4.4E+08	27	9.5E+06	6487	0.13	4.6E+04	0.76
25	65	4.8	52	0.02	5321	78	0.31	6.0E+08	31	7.7E+06	8082	0.19	4.7E+04	1.18
26	27	5.8	64	0.02	6607	32	0.08	3.3E+09	34	1.3E+07	10891	0.28	1.0E+05	2.13
27	39	5.9	49	0.02	3717	61	0.21	6.8E+08	28	8.1E+06	6844	0.14	4.2E+04	0.84
28	89	10.0	96	0.02	8455	124	0.13	5.0E+09	42	4.1E+07	20089	0.63	6.1E+05	7.26
29	76	13.0	74	0.02	4056	170	0.18	2.2E+09	38	3.5E+07	13976	0.39	3.7E+05	3.52
30	40	3.7	29	0.02	2161	66	0.62	1.1E+08	24	2.6E+06	3556	0.06	6.9E+03	0.23
33	16	2.0	31	0.02	4429	13	0.22	3.2E+08	25	1.5E+06	3793	0.07	4.3E+03	0.26
34	13	2.1	22	0.02	2054	17	0.36	9.3E+07	20	9.3E+05	2197	0.03	1.5E+03	0.09
35	34	6.3	34	0.02	1685	84	0.39	1.7E+08	23	4.8E+06	3832	0.07	1.4E+04	0.26
36	41	3.6	19	0.02	925	101	1.47	1.4E+07	17	1.2E+06	1617	0.02	1.4E+03	0.05
39	194	9.2	23	0.01	543	1010	4.74	3.8E+06	14	3.1E+06	1676	0.02	3.9E+03	0.05
averages		5.5	42	0.02	3481	139	0.74	7.7E+08	26	8.3E+06	6025	0.14	7.3E+04	1.04