MORPHOMETRIC AND RHEOLOGICAL PROPERTIES OF RIDGED LAVA FLOWS IN DAEDALIA PLANUM, MARS.

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Introduction: Lava flow surfaces display textures and structures, such as compressional ridges [1-7], that allow us to infer the rheological properties of eruptive material. Models for compressional ridge formation on lava flows have been developed and previously applied to terrestrial basaltic and silicic lava flows, as well as to flows on Mars, including a ridged flow to the west of Arsia Mons [1-3]. Here we use detailed measurements of morphometry (including ridge wavelength, amplitude and flow thickness) from high-resolution topographic data of Mars to estimate the viscosity and yield strength of ridged lava flows in the Daedalia Planum lava flow field south of Arsia Mons (Figure 1).

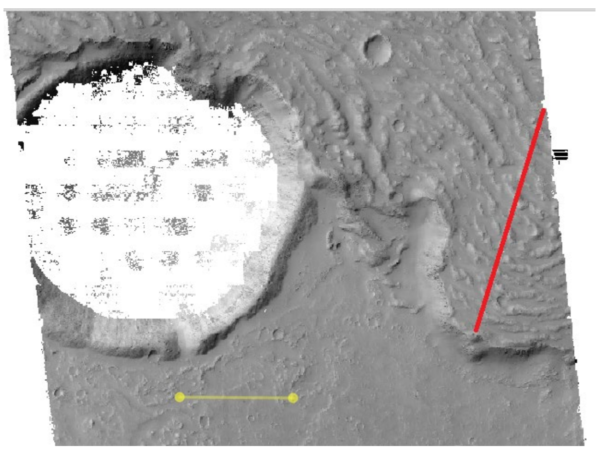

Figure 1: HiRISE image of Daedalia Planum ridged lava flow with profile line (red) and 1 km scale bar (yellow).

Study Site: Daedalia Planum Lava Flow Field: The southwest rift apron of Arsia Mons includes vast lava flow fields that extend through Daedalia Planum to the southern margin of the Tharsis Volcanic Province. Recent geologic mapping studies have considered various aspects of the volcanic geomorphology and eruptive history of Arsia Mons and southern Tharsis [8-10]. Mapping studies and related analyses of crater statistics show evidence for several episodes of geologically recent volcanism, including widespread emplacement of broad flow units in the Middle Amazonian (~900 Ma) followed and partially covered by intermingled smooth and rough elongate flow types in the Middle to Late Amazonian (~250-300 Ma) [9,11]. Within Daedalia Planum broad flow units occur in large lobate to sheet-like forms that commonly have ridged surfaces. The ridged Daedalia Planum flow analyzed in this study (~35°S, 137°W) is part of a complex of ridged sheet flows that embay cratered terrain at the southern extent of Tharsis [10].

Datasets: Our investigation utilized CTX images (~5 m/pixel) and a HiRISE DTM for analysis of flow morphology and measurements of ridge morphometry. The HiRISE DTM has 1 m post spacing and was constructed using the Ames Stereo Pipeline [12] from HiRISE images ESP_024587_1465 and ESP_024877_1465.

Methodology: Ridge Measurements - Daedalia Planum, Mars: Elevation profiles oriented perpendicular to the predominant trend of the flow ridges were created using QGIS software (Figure 2), allowing us to measure ridge spacing, amplitude, flow thickness, and surface slope. Measurements were made in an ~6500 m-across area with regular ridge spacing and similar ridge morphology.

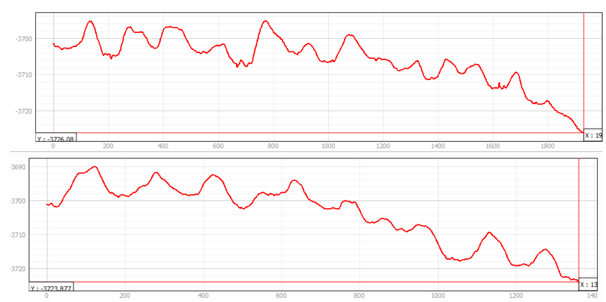

Figure 2: Elevation profile (elevation in meters vs distance in meters) of line from Figure 1 (top), a another profile north of the crater in Figure 1 (bottom).

Five different profiles oriented roughly perpendicular to the long axis of the ridges were generated in areas where the folds are clear and well-defined. The topographic data were then detrended to remove the flow surface slope prior to ridge amplitude and spacing measurement (Table 1).

Table 1: Morphometry of Flows in Daedalia Planum

Morphometric Feature	*Measurement*
Average Ridge Spacing	141.16 m
Average Amplitude	5.740 m
Average Flow Thickness	95.36 m
Average Surface Slope	0.703°
Average Flow Width	6500 m

Flow thickness was measured along the flow margin in five locations corresponding to the profile locations. For each profile, we determined amplitude by measuring the elevation difference between the peaks of ridges and the surface in the adjacent troughs. Ridge spacing was measured by the peak to peak distances between ridges that were clearly defined in the profiles. The measurement of flow width was more problematic as the ridges occurred in a zone within a larger sheet flow; the width of the ridged area was used as an approximation for flow width. We therefore used the widths of clearly defined zones of ridges as a proxy for flow width in our modeling. A maximum width of 8000 m, a minimum of 5000 m, and an average width of 6500 m were used in the calculations. Measurements for all five profiles were compiled to determine minimum, maximum, and averages that were used in equations *a-d*.

Comparison of Ridge Measurements to Terrestrial Flows and Other Martian Flows: The measurements documented here are comparable to those made by Warner and Gregg [1] for other Arsia Mons flows (Table 2). They are similar in scale to folds measured on terrestrial silicic flows reported by Byrnes et al. [7].

Table 2: Comparison of Fold Geometries

	Sabancaya [1]	*Arsia Mons [1]*	*Daedalia Planum*
Avg flow thickness	113±56 m	65±20 m	95 m
Avg fold amplitude	5 m	27± 11 m	6 m
Avg fold spacing	67 m	100±34 m	141 m
Avg slope	3.9° ±1.0°	0.30° ±0.11°	0.7°

Model Results: We used our morphometric measurements from these ridged flows in Daedalia Planum to constrain models for the rheology of the lava as in Warner and Gregg [1]. Yield strength and viscosity values were calculated using the following equations.

(a) Y=(ρ*g*h)*sin(Θ)
(b) Y=(ρ*g(h^2))/ω
(c) Q=(Gz*k*x*ω)/h
(d) h= (Q*η/ρ*g)^1/4

where Y = yield strength, ρ = fluid density, g = gravity, h = flow thickness, ω = flow width, Gz = Graetz number, x = flow length, Q = flow rate, and η = viscosity.

These model results suggest that the measured flows had a rheology consistent with basalt (Table 3).

Table 3: Yield Strength and Viscosity Result

	Daedalia Planum
Avg Yield Strength	1.30×10^4 Pa
Max Yield Strength	2.75×10^4 Pa
Avg Viscosity	2.60×10^3 Pa s
Max Viscosity	4.30×10^3 Pa s

Average yield strength was determined by using the average values for density, thickness, width, and slope. The purpose of using two different yield strength equations (*a*, *b*) is to demonstrate how other factors can relate to yield strength. Average viscosity was determined in solving for effusion rate first using a thermal diffusivity value (k) of 3.0 x 10^-7 m^2s^{-1} and Graetz number (Gz) 300. An average effusion rate was determined as well as a maximum and minimum that were used in equation *d* to solve for viscosity.

Constraints on Martian Flow Rheology: These new estimates of viscosity and yield strength for Daedalia Planum derived from high-resolution imaging and topographic data compare closely with those calculated previously for Arsia Mons [1]. The maximum yield strength estimate from that study was 4.33 x 10^4 Pa with a minimum of 5.90 x 10^2 Pa. The maximum viscosity estimate from that study was 1.61 x 10^8 Pa*s and the minimum was 1.69 x 10^4 Pa*s.

Conclusion: These rheological estimates of flows on Daedalia Planum are consistent with values for terrestrial basalt flows. Future analyses of flow rheology will derive additional constraints on viscosity from flow folding models using constraints on ridge spacing and amplitude reported here [1-3].

References: [1] Warner, N. H., T. K. P. Gregg, 2003. *J. Geophys. Res, 108* (E10), 5112. [2] Fink, J.H. and Fletcher, R.C., 1978. *J. Volcanol. Geotherm. Res*., 4, 151-170. [3] Fink, J.H., 1980. Geology, 8, 250-254. [4] Fink, J.H., 1980. *Lunar Planet. Sci. Conf*., XI, 285-287. [5] Theilig E., and Greeley, R., 1986. *Proc. Lunar Planet. Sci. Conf.*, 17th, Part 1. [6] Schenk, P., 1992. *Lunar Planet. Sci. Conf.,* XXIII, 1217-1218. [7] Byrnes, J.M., et al., 1997. *Lunar Planet Sci. Conf*., XXVIII, 1250. [8] Garry, W.B, D.A. Williams, J.E. Bleacher, 2014. *Proc. Lunar Planet. Sci. Conf.* XLV, Abstract #2133. [9] Crown, D.A., and Ramsey, M.S., 2017. *J. Volc. Geotherm.* Res. 342, 13-28. [10] Crown, D.A., Berman, D.C., and Chuang, F.C., 2013. *Lunar Planet. Sci. Conf.,* XLIV, Abstract 2499. [11] Berman, D.C., and Crown, D.A., 2019. *Lunar Planet. Sci. Conf.,* L, Abstract 1418. [12] Beyer, R.A., O. Alexandrov, and S. McMichael, 2018. *Earth and Space Sci. 5*, 537-548.