ELEVATION-DEPENDENT FLOW RATES ON OLYMPUS MONS. A. A. Enevoldsen[1], S. E. H. Sakimoto[2], C. R. Cooley[1], [1]Whitman College, Walla Walla, WA 99362, enevolaa@whitman.edu, [2]Department of Civil Engineering and Geological Sciences, University of Notre Dame, 156 Fitzpatrick Hall, Notre Dame, IN 46556, sakimoto.1@nd.edu.

Introduction: Using current Mars Orbiter Laser Altimeter (MOLA) and Mars Odyssey's Thermal Emission and Imaging Spectrometer (THEMIS) data, we attempt to determine the volume flow rates of small lava flows (lengths of 1-15km) on Olympus Mons and quantify the difference between flow rates of low-elevation and high-elevation flows. With the new data provided by MOLA, THEMIS, the Mars Observer Camera (MOC), and the Mars Express High Resolution Stereo Camera (HRSC), as well as Sakimoto's 2001 flow-rate equations [1], we should be able to get more accurate flow rates with smaller error margins than did previous research based on lower-resolution Viking data and Hulme's 1975 flow-rate equations [2]. The lowest flow rate we have found so far is 4.0×10^1 m^3 s^{-1} and the highest is 5.8×10^3 m^3 s^{-1}.

Background: It has been shown that there is a link between the rheologic properties of a lava and the morphology of the solidified lava flow [2, 4]. In the absence of samples (of known origin) from Olympus Mons, this knowledge can be used to estimate the rheologic properties of the lava flows on Olympus Mons. The last time this was done was with Viking-era photographs and few data points [2]. Since then, new data have been used to examine lava flows in many other locations on Mars: Ascraeus Mons, Alba Patera, and even between the Tharsis Montes [4, 5, 6], but not Olympus Mons. The previously estimated volume flow rates for Olympus Mons (between 1×10^2 and 1×10^3 m^3 s^{-1}) are, according to Hulme [2], large compared to terrestrial volcanoes. With current THEMIS, MOC, MOLA, and HRSC data, we have a chance to re-estimate the flow rates and compare the new rates with other discoveries about Olympus Mons and Mars lavas over the past thirty years.

Method: Using the digital images provided from the THEMIS data, we measure the width in pixels of sheet flow channels, and calculate the depth of the channel from shadow measurements, using the sun angle and sun altitude data given with each THEMIS image. Unlike Bruno et al. [7], we assume that each flow channel is completely full and hence do not estimate depth of the lava flow. Then we reorient and overlay the THEMIS visible-band images on pictures from the MOLA data set. These pictures were taken using Roark and Frey's Gridview program [3], and allow us to calculate the overall slope of the flow, as well as to get detailed latitude, longitude, and elevation information for each flow. These data are then put into Sakimoto's equations [1] to find a final flow rate (Q) and peak velocity (u(0)) for each flow:

$$u(y)=\frac{16a^2\rho g\sin\theta}{\mu\pi^3}\sum_{i=1,3,5...}^{\infty}(-1)^{(i-1)/2} \bullet\left[1-\frac{1}{\cosh(i\pi b/2a)}\right]\left(\frac{\cos(i\pi y/2a)}{i^3}\right) \quad \textbf{(1)}$$

$$Q=\frac{4ba^3\rho g\sin\theta}{6\mu}\left[1-\frac{192a}{\pi^5 b}\sum_{i=1,3,5...}^{\infty}\frac{\tanh(i\pi b/2a)}{i^5}\right] \quad \textbf{(2)}$$

In these equations the variables are as follows:

Table 1: Notation from Sakimoto [1]

Symbol	Units	Definition
u(y)	m s^{-1}	Velocity down-flow
a	m	Flow half-width
b	m	Flow depth
θ	radians	Flow slope
y	m	Distance down-slope
ρ	kg m^{-3}	Flow density
μ	Pa s	Flow viscosity
Q	m^3 s^{-1}	Volume flow rate
g	m s^{-2}	Gravity: 3.72 ms^{-2}

Use of these equations assumes that the flow channel is a simple rectangular channel, with enough friction that the lava is not slipping downhill, but moving as a laminar (non-turbulent) flow. We further assume that the flow is well insulated: that there is not a large change in temperature over the width and length of the flow. Supported by the findings of Hulme [1], Zimbelman [4], and others, we assume that the lava on Olympus Mons is a silicic basalt similar to the lavas in Hawaii. The flow densities we use are from 1.2×10^2 to 1.5×10^2 kg m^{-3}, and the viscosities are between 1×10^3 and 1×10^5 Pa s; we assume that the material properties do not change over a small flow cross-section.

Data: We have gathered measurements of 51 flows so far, and have calculated a flow-rate and a velocity for each (see **Table 2** for a representative sample). Although the measurements taken from the MOLA data are extremely precise, due to the nature of pixel-counting, the width and depth measurements from the THEMIS pictures only have one or two significant digits.

There is error introduced into our data at two points in our process: first when we overlay the

THEMIS and MOLA pictures, and second when counting pixels to get widths and depths. Both of these are done by hand, and are subject to human error. We are confident, however, that our measurements are accurate enough to do preliminary data analysis.

Table 2: A Representative Data Sample of Individual Flows

Elevation	**Width**	**Depth**	**Slope**	**Q**	**u(0)**
m	km	km	deg	m^3s^{-1}	ms^{-1}
7070.23	0.06	0.01	7.2	156	0.42
7264.93	0.05	0.02	2.5	83.6	0.21
7376.2	0.06	0.02	1.2	64.3	0.13
7487.4	0.20	0.02	1.6	420	0.20
19356.7	0.11	0.02	3.5	985	0.74
19431.6	0.09	0.03	3.6	1070	0.88
19566.6	0.11	0.03	1.6	635	0.42
19530.5	0.12	0.03	3.3	1480	0.88

Conclusions: Currently the lowest flow rate we've found for a single flow is 4.0×10^1 m^3 s^{-1} and the highest is 5.8×10^3 m^3 s^{-1}. The average flow rate over all the flows measured is 2.0×10^3 m^3 s^{-1}, with an overall standard deviation of 7.3×10^3 m^3 s^{-1}, compared to Hulme's approximations that flow rates would fall anywhere between 1×10^2 and 1×10^3 m^3 s^{-1} [2]. These seem to be reasonable estimates for the type of lava we assume is making these flows and the general sizes of the flows. The velocities we find are between 2×10^{-1} and 2 m s^{-1}, with an average of 5×10^{-1} m s^{-1}, and a standard deviation of 4×10^{-1} m s^{-1}.

In this preliminary data we have noticed only a tenuous correlation between elevation and flow rate. Currently both the high- and low-elevation flows seem to peak around 3×10^2 m^3 s^{-1}, but the high-elevation flow rates are grouped slightly more tightly than the low-elevation flow rates (see **Fig. 1**). This could be due to a bias in the sample: there are currently more data points for low-elevation flows. We will continue this research, and determine the consistency of this trend, by adding more flows found in the THEMIS data, as well as the MOC and HRSC data.

Figure 1: Relationship Between High-Elevation Flows, Low-Elevation Flows and Flow Rate (corrected for dependence on slope)

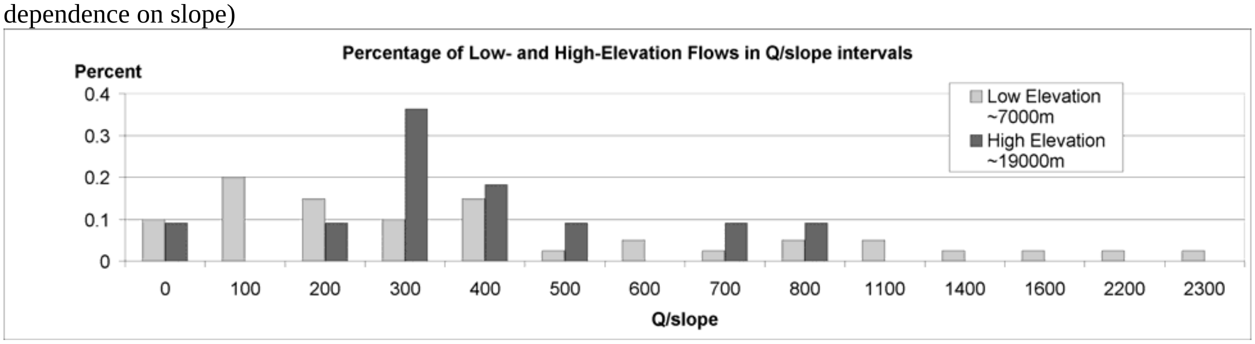
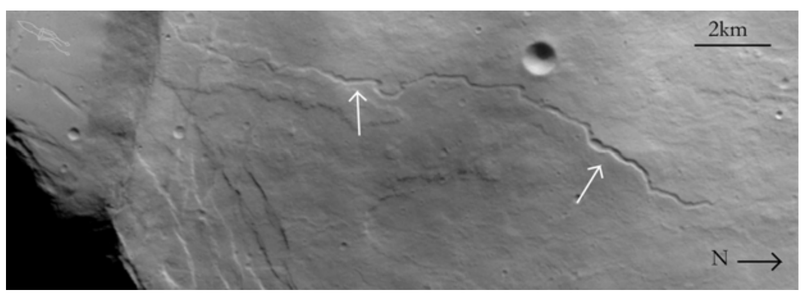


Figure 2. Detail from THEMIS image V04461003.png: a distinct flow channel near the caldera of Olympus Mons.

Center Latitude: 19°, Center West Longitude: 113°. Resolution: 18m/pixel.



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