

LAVA FLOWS IN THE THARSIS REGION OF MARS: ESTIMATES OF FLOW SPEEDS AND VOLUME FLUXES

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ABSTRACT

The goal of this study was to characterize the eruptive behavior of Olympus Mons, Mars, by estimating flow speeds and volume fluxes for lava flows produced from various vents on the volcano. During my fellowship, I have made width, depth and ground slope measurements of 65 lava tubes and 271 channels from 56 MOC images and 65 THEMIS images of Olympus Mons. The data show that channels are more numerous than tubes, but this may be due to the fact that tubes cannot be detected until they collapse and are therefore likely under represented due to sampling biases. We observe that tubes are prevalent near the summit while channels are dominantly seen on the middle and lower flanks as well as on the basal scarp. Channels are found on a variety of slopes from 0 to 29°, while tubes are found on slopes less than 10°. This is consistent with the terrestrial experience that tube roofs form less readily on steep slopes.

INTRODUCTION



Figure 1: Lava tube, photo by Scott Rowland

In order to determine and understand the eruptive behavior of Olympus Mons, theory and photogeology must be utilized. Theory refers to applying present knowledge of Earth's volcanic eruptions, especially the current eruption of Kilauea, to images received by Martian satellites so that hypotheses about volcanism on Mars can be made. Many features that are seen on Olympus Mons are also seen on volcanoes on Earth, and thus photogeology refers to interpreting the geology of Mars by comparing Martian images with terrestrial features. With the application of these two approaches, the collective scientific knowledge of

geologic processes that occurred, or are occurring, on other planets will be enriched and the evolution and history of bodies in our solar system will become clearer.

Specifically, this research was aimed at estimating flow velocities and volume fluxes for lava on Olympus Mons (based on both known and assumed input parameters) and to characterize lava emplacement styles. Lava morphologies that I looked for are lava tubes, shown in Figure 1 and Figure 3, and lava channels, shown in Figure 2 and Figure 3. In the process of doing this, I examined the data for correlations and trends among variables such as velocity, flux, emplacement, location on the volcano, and topographic slope.

METHODOLOGY

The methodology used for this research involves four main steps. First, I identified pristine lava tubes and channels from the data received by the Thermal Emission Imaging System (THEMIS) on Mars Odyssey and the high-resolution Mars Orbiter

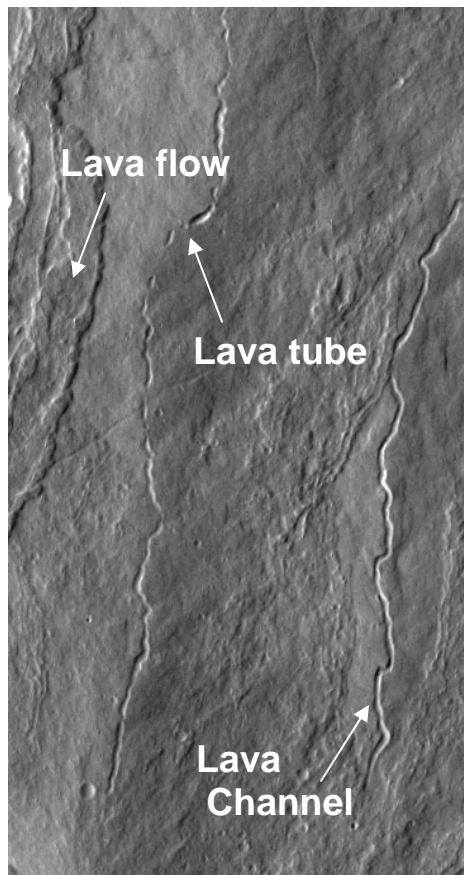


Figure 3: Martian lava flow morphologies in THEMIS image V11326014

Camera (MOC) aboard Mars Global Surveyor as demonstrated in Figure 3. It is important that

these lava tubes and channels are pristine and crisp so that shadow measurements and width measurements may be as accurate and precise as possible. The resolution of the MOC images that were used was three meters per pixel while the resolution of the THEMIS images that were used were either 18 or 36 meters per pixel.

Second, I processed and reprojected these images using the UNIX program ISIS in order to successfully compare them with Mars Orbital Laser Altimeter (MOLA) digital elevation data. The ISIS commands thm2isis, thmvismc, levgeoplane and cub2envi were used for THEMIS images and moclevall was used for MOC images. Detailed information on these commands is available from <http://isis.astrogeology.usgs.gov/documents/Isis2Tutorials/index.html>. As a final processing step I exported the images in a format compatible with ENVI, the software used to make the measurements.

Third, I measured widths and depths of channels and tubes from the reprojected images and I also measured the ground slopes from a slope map that was produced based on the MOLA 1/128° DEM. Widths were measured

by averaging the distance of two lines placed orthogonal to the channel walls. One line was between the top edges, representing the largest possible width of the tube or channel and one line was placed on the gray area at the bottom of the tube or channel, representing the smallest possible width. Depth measurements were made by measuring the length of dark areas inside the lava tubes and channels and dividing by the tangent of the incidence angle in radians. These dark areas were assumed to be shadows, but were compared to the darkest areas of the image they originated from to make sure that what was measured actually was a shadow. Ground slopes were taken by comparing the MOC and THEMIS images to the MOLA slope map, and the slope of corresponding area on the MOLA slope map between the two images gave the slope of the ground surface underlying the lava.



Figure 2: Lava channel, photo from Scott Rowland

Finally, lava flow velocities and total volume fluxes, based on assumed values of viscosity and density, were calculated. The Jeffreys equation for laminar flow (Jeffreys, 1925), which is $u = \frac{g \sin \theta \rho h^2}{3\eta}$, was used for velocity and the subsequent resultant velocity was multiplied by the cross-sectional area of the tube or channel to get the volume flux. When calculating the velocity, g is the gravitational acceleration of Mars – which is 3.73 m/s^2 , θ is the ground slope that was measured from the MOLA slope map, ρ is the assumed lava density of 2000 kg/m^3 , h is the flow thickness (which is calculated as 75% of depth for channels and as a function of $(-0.08) \cdot \text{ground slope} + 1$ for tubes) and η is the assumed flow viscosity of 3000 Pas . It is important to note that estimates for lava flow velocities and lava volume fluxes incorporate a couple of assumed input parameters. The flow density and dynamic viscosity are assumed for this research project because there are no samples to inspect or methods to determine them from Earth. The values chosen reflect mean numbers for terrestrial basalts.

RESULTS

The data collected reflect 336 lava tubes and channels from 121 MOC and THEMIS images. Of these lava tubes and channels, 81% were lava channels and 19% were lava tubes, as seen in Figure 4. However this does not necessarily imply that lava channels are more abundant than tubes on the Martian surface. Instead, it may reflect a sampling bias since lava tubes cannot be detected until the roof collapses in enough areas to trace the tube. There is a correlation between the emplacement of tubes and channels with the ground slope on which they occur. A ground slope of 10° appears to be the cutoff for tube formation. At or above a ground slope of 10° , only channels are observed.

Figure 4: Percent LTC of 336 Measured

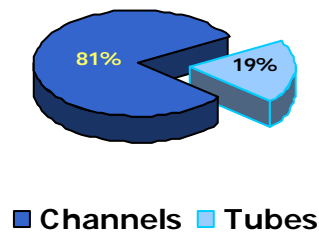


Figure 5: Numerical results from MOC and THEMIS.

<u>MOC Data:</u>		<u>THEMIS Data:</u>	
Width = 7.4 – 390 m (Mean = 70.1 m)	Depth = .2 – 47.1 m (Mean = 8.2 m)	Width = 24.3 – 323.9 m (Mean = 118.0 m)	Depth = 1.4 – 42.8 m (Mean = 9.5 m)
$u = \sim 0 - 56.2 \text{ m/s}$ (Mean = 4.6 m/s)	$Q = \sim 0 - 128,200 \text{ m}^3/\text{s}$ (Mean = 4,916.1 m^3/s)	$u = \sim 0 - 34.9 \text{ m/s}$ (Mean = 4.1 m/s)	$Q = 4.3 - 83,600 \text{ m}^3/\text{s}$ (Mean = 6,532.5 m^3/s)
<u>Totals:</u>			
Width = 7.4 – 389.5 m (Mean = 94.1 m)	Depth = 0.2 – 47.1 m (Mean = 8.8 m)	$u = \sim 0 - 56.2 \text{ m/s}$ (Mean = 4.4 m/s)	$Q = \sim 0 - 128,200 \text{ m}^3/\text{s}$ (Mean = 5,724.3 m^3/s)

Diverse data showed a wide range of results in terms of width, depth and slope measurements along with flow velocity and volume flux calculations. However, the ranges for MOC derived measurements and the ranges for THEMIS measurements correlated almost exactly. In short, both data sets support the same ranges of lava tube and channel widths, depths, slopes, velocities and fluxes as shown in Figure 5. The means however, differ for each data set. This is most likely due to the image resolution and how much area is covered in the image. MOC images gave means that were lower than THEMIS (Figure 5).

The calculated velocities and flux rates show overlap with terrestrial values for basaltic volcanoes. However, the upper ends of the Martian ranges are much higher than what is recorded on Earth. This could be for two reasons: Martian gravity and the size of Olympus Mons. Gravity on Mars is roughly one third of gravity on Earth, and this would allow magma to reach the surface of Olympus Mons easily and readily. Also, dikes that feed the flank eruptions could occur more numerous and have greater widths (Wilson and Head, 1994) than terrestrial volcanoes, thus providing more magma to the surface and enlarging the effusion rate. Since Olympus Mons is the largest volcano in the solar system, it would most likely have an extensive magma chamber that would have the capacity to erupt large amounts of lava (Zuber and Mouginis-Mark, 1992)

RESULTS: ERROR ANALYSIS

I believe my width and slope measurements are fairly accurate. Probably, the largest source of error is in the depth measurements because of the slight ambiguity of where a shadow ends in a picture. There is possibility for both over- and under- estimation depending on the contrast setting during each measurement. In addition, overestimation can occur when surges in flux overflow the channel of transportation and build up levies higher than the original channel. Alternatively, fast velocities on steeper slopes could promote lava downcutting into the volcano, again making the channel deeper than it was upon formation. Also, it is possible that some dark areas, such as in fissures or cracks, were misidentified as shadows of lava tubes and channels and thus lead to erroneous depths. Finally, an error may lie in using the wrong velocity equation for a few lava tubes and channels with high Reynolds numbers. For Reynolds numbers over 2300, a velocity equation for turbulent flow should be used, not laminar flow.

CONCLUSION

Martian volcanism appears to resemble basaltic volcanism on Earth. Lava with low viscosities appears to have built up Olympus Mons, which is the largest volcano in the solar system. Slopes are relatively shallow due to this low viscosity and thus Olympus Mons is a shield volcano. The mean widths, depths, effusion rates, and flow velocities seem consistent with those observed on Earth, even though the upper ends of the ranges are much higher than anything recorded in terrestrially. There is a negative correlation between emplacement style of lava tubes and a positive correlation of channels with both ground slope and velocity: as slope and velocity increase, tube occurrences decrease and channels increase in number. There is a sampling bias because tubes cannot be detected until there is a structural failure of the roof, however we were able to document enough of them to make good estimates of flow velocities and fluxes through them. I adopted strict criteria for using pristine and crisp lava tubes and channels, however, the data set could be expanded later to include features not as well preserved.

FUTURE WORK

This project could be enhanced by adding data from other Tharsis Volcanoes (Arsia Mons, Pavonis Mons, and Ascraeus Mons) on Mars, but the data for Olympus Mons is well covered from the MOC and THEMIS images of this project. With enough data from all four volcanoes, it would be possible to compare and contrast effusion rates and volume fluxes to get a broad picture of volcanic activity from the Tharsis area of Mars.

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