LAVA TUBE FLOW: CONSTRAINTS ON MAXIMUM SUSTAINED ERUPTION RATES FOR MAJOR MARTIAN VOLCANIC EDIFICES. B. L. Woodcock[1] and S. E. H. Sakimoto[2], [1]Department of Geography and Geology, Western Kentucky University, 1 Big Red Way, Bowling Green, Kentucky, 42101 (woodcbl@wku.edu), [2]Department of Civil Engineering and Geological Sciences, 156 Fitzpatrick Hall, University of Notre Dame, Notre Dame, IN 46556 (ssakimot@nd.edu).

Introduction: Mars has more than half a dozen major volcanic constructs, including Olympus Mons, Alba Patera, Elysium Mons, Syrtis Major, Arsia Mons, Pavonis Mons, Ascreaus Mons, and Syria Planum shown in Fig. 1. These systems are well known for their massive sizes and aerial extents. It has long been known that martian volcanic constructs can produce very large flow features such as lava tubes and channels [e.g., 1,2]. Many of these features are poorly or partially visible in image data, but newly visible in high resolution topographic data from the Mars Orbiter Laser Altimeter (MOLA) on the Mars Global Surveyor spacecraft (e.g. [2, 4, 5, 6]). The topography for lava channels and tubes allows us to newly constrain models of flow rates and material properties from topographic characteristics. Comparing modeled flow rates for a range of martian edifices allows us to indirectly compare their magmatic source regions. Terrestrial volcanology studies link steady flow rates with lava tube formation, with unsteady rates more likely to form channels (e.g. [2]). Tube-fed flows tend to reach great lengths on Earth, and lava tube flow rates tend to reflect the most sustainable steady eruption rates for each system. We suggest that, for Mars, an abundance of lava tubes should indicate a steady supply system. In this study, we test the hypothesis that steady supply systems allow a larger final edifice size, and that while abundant channels may have larger local flow rates, final edifice size may be smaller. To test this we measure topographic characteristics for the largest lava tube and channel flows apparent in the MOLA topography for eight major martian volcanic edifices. Their locations are shown in Fig. 1 and include Syrtis Major, Elysium Mons, Olympus Mons, Alba Patera, Ascreaus Mons, Pavonis Mons, Arsia Mons and Syria Planum. We use a Newtonian sheet flow model [5] and a common set of assumed material properties (density, viscosity) to compare modeled maximum flow rates within and between volcanic systems.

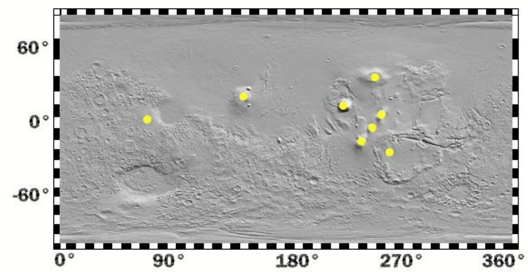

Fig. 1. Mars shaded relief map of MOLA topography showing study locations.

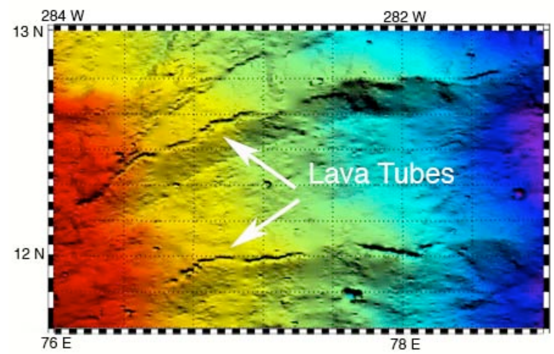

Fig. 2. 230 m/pixel gridded MOLA data for eastern Syrtis Major lava tubes.

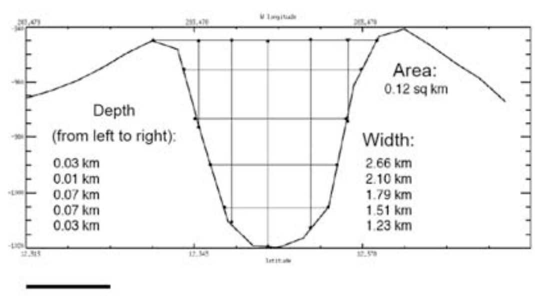

Fig. 3. MOLA topographic profile through the summit collapse pit of the southernmost lava tube in Fig. 2

Approach:

Lava Flow Measurements: The presence of lava tubes can be inferred from surface features such as chains of collapse pits along flow ridge summits, elongate tumuli, and rootless vents and flow deltas [4]. Where possible, we use MOLA data to find collapse pits in inferred lava tubes, and use the collapse pit dimensions as an approximation of former lava tube cross section dimensions. Fig. 2 shows MOLA topography for two large probable lava tubes in Syrtis Major. Fig. 3 shows a typical topographic profile through the collapse pit for the southernmost tube in Fig. 2. A similar approach is used for lava channels, except that the MOLA channel topography is likely to be a closer approximation of active channel dimensions. For system to system comparisons, we use the largest channels or tube collapses apparent in the topography to model representative maximum volume flow rates for each system. We assume, for comparison purposes, that currently preserved lava tubes and channels are a reflection of the last pulse of eruptive events, and that prior eruptive cycles and strata were substantially similar.

To model the volume flow rates we use Newtonian sheet and channel flow models, with the model selection determined by the dimensions of the lava tube collapse or lava channel [5]. For this study, aspect ratios (width/depth) are all greater than ~ 50, and thus our estimated error in approximating a channel or tube with a sheet is on the order of several percent of the volume flow rate, which is less than our estimated measurement error of approximately 10%. The sheet flow model [2] assumes a constant cross-section sheet with a no-slip base and zero shear stress on a planar top surface [2, 5]. The flow rate per unit width (Q/w) for a Newtonian sheet flow is expressed as

$$\frac{Q}{w} = \frac{b^3 \rho g \sin(\theta)}{3\mu}, \quad (1)$$

with the flow depth (b), flow width ($2a$) and local slope (θ) measured from the topography data, and the material properties of flow viscosity (μ) and density (ρ) assumed to be constant across the study regions and to be the same as typical terrestrial basaltic values (100 Pa s for viscosity and 2000 kg/m^3 for density). Table 1 shows the maximum model flow rates for each system.

Edifice Volume Measurements: In order to compare flow rates with eventual final edifice size, we measure total volumes for each edifice or volcanic system. The system boundaries for volume calculations are defined to be the mapped geologic unit boundaries for each system, and MOLA topography is used to calculate volumes from the defined map boundaries [7] and integrated elevation data. Table 1 shows the corresponding calculated system volumes for the maximum modeled flow rates described in the previous section.

Discussion and Conclusions: Fig. 4 shows the maximum modeled lava flow rates versus the calculated total system volume. We do find that, in general, those systems with the largest total volumes have the smaller maximum modeled flow rates. This is consistent with their observed greater abundance of lava tubes apparent in the topography data. Correspondingly, those systems with higher maximum modeled flow rates and a greater abundance of channeled lava flows instead of lava tube flows have relatively lower total calculated system volumes. So, while there is some scatter, there is an apparent inverse correlation between volcanic construct volumes and maximum-modeled sustainable eruption rates. Therefore, it seems reasonable to suggest that steady, but relatively lower, volcanic supply rates distributed through lava tubes over long periods of time are responsible for the largest volcanic constructs on Mars, while those with higher maximum flow rates and a relatively abundant number of channel flows have resulted in proportionately smaller final edifice volumes. Further work in quantitative mapping of relative lava tube and channel abundances for each edifice would allow additional testing of this proposed relationship.

Table 1. Volcanic system volume and maximum modeled volumetric lava flow rates.

Volcanic System	Volume of Volcanic System (km^3)	Volume Flow Rate (m^{3}s^{-1})
Alba Patera	1.12×10^7	1.21×10^6
Arsia Mons	7.25×10^6	7.20×10^7
Syrtis Major	5.66×10^6	1.87×10^8
Elysium Mons	6.31×10^6	1.81×10^6
Olympus Mons	5.58×10^6	5.83×10^7
Syria Planum	1.36×10^6	8.18×10^7
Pavonis Mons	1.50×10^6	2.80×10^7
Ascreaus Mons	3.73×10^6	2.49×10^8

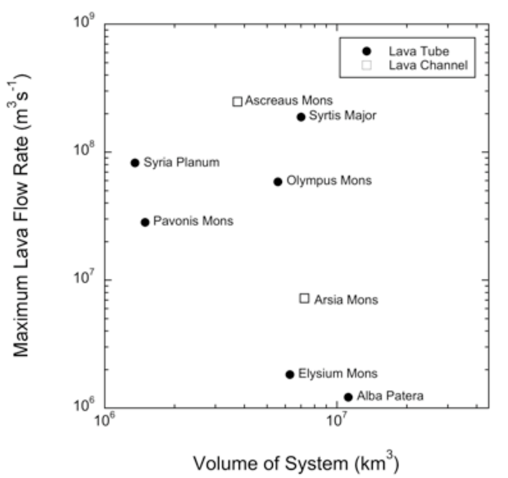

Fig. 4. Maximum modeled lava flow rates versus calculated total system volume.

References: [1] Hodges, C. A. et al. (1994)USGS Prof. Paper 1534, 2 [2] Sakimoto S. E. H. et al. (1997) JGR, 102, 6597-6613 [3] Spudis P. D., *(2000)*, 697-726. [4] Bleacher J. E. et al. (2005) *LPS XXXVI*, Abstract #1364. [5] Sakimoto S. E. H. et al. (2001) *JGR*, *106*, 8629-8644. [6] Riedel S.J. et al. (2001) *LPS XXXII*, Abstract #1954. [7] Greeley& Guest, USGS I-1802-B, 1987. [8] & Tanaka, USGS. I-1802-A,1986.