

QUANTIFICATION OF SURFACE ROUGHNESS OF LAVA FLOWS ON MARS. C. D. Rodriguez Sanchez-Vahamonde¹, C. D. Neish¹, L. L. Tornabene¹, ¹The University of Western Ontario, London, Ontario, Canada (crodr46@uwo.ca)

Introduction: Volcanic terrains on Mars are widely spread along its equatorial region. In radar images, these surfaces appear bright and have high CPR values, which are typically produced by extremely rough surfaces [1]. Martian lava flows share this property with many lava flows on Earth, including several blocky flows found in Iceland and Craters Of The Moon (COTM) National Monument and Preserve in Idaho [2]. Many Martian lava flows are observed to have a “platy-ridged” texture [3], similar to textures seen on lava flows formed by the Laki and Holuhraun eruptions in Iceland [3-5]. This morphology is thought to form by the emplacement of pahoehoe sheet flows, followed by a surge of lava that disrupts the subsequently solidified surface [4]. The emplacement conditions leading to the extreme roughness of Martian lavas remain uncertain. However, they can be constrained by comparing their surface roughness parameters to those of lava flows on Earth and other planetary bodies. Understanding lava flow emplacement on Mars will provide valuable information about the interior processes of Mars.

Surface roughness refers to the topographic expression of a surface over different horizontal scales (i.e., centimeters, meters, kilometers) [6]. To quantify surface roughness, we need topographic data to show differences in height along a surface. There are many planetary bodies on which the surface roughness can be quantified, however Mars is of particular interest because the roughness of its lava flows is quite distinctive (extremely rough) compared to the majority of the lava flows in the solar system [1]. Studies of Mars also benefit from abundant high resolution topographic data sets (~ 1 to 2-m per post), allowing for quantification of roughness at an unprecedented scale [7].

A variety of parameters are used quantify surface roughness of various geologic surfaces [6]. Two commonly reported roughness metrics are the Root Mean Square (RMS) slope and Hurst exponent (H) [6]. These parameters tell us how rough or smooth the surface is (RMS slope) and how it changes as the scale increases (H). Here, we report these parameters for High Resolution Imaging Science Experiment (HiRISE)[8] digital terrain models (DTMs) of a variety of lava flows on Mars to constrain their surface roughness and infer their emplacement processes.

Methodology: We used HiRISE DTMs of Martian lava flows to determine the RMS slope and Hurst exponent values of these surfaces. Here, the RMS slope refers to the average slope along a two-dimensional profile, which depends on the scale at which it is

measured [6]. The Hurst exponent describes how the roughness of the surface changes with scale, and its value ranges from zero to one [9]. Surfaces that become more smooth or more rough as the scale increases have an H value closer to zero. Conversely, surfaces that maintain their roughness or smoothness as the scale increases tend to have an H value closer to one [6,9].

The RMS slope can be extracted using the Allan variance (v^2) (Equation 1), which samples the topographic profile (z_i) at every step (Δx) and calculates the RMS slope as follows:

$$v^2(\Delta x) = \frac{1}{n} \sum_{i=1}^n [z(x_i) - z(x_i + \Delta x)]^2 \quad (1)$$

Here, n is the number of sample points, and $z(x_i)$ is the height of the surface at point x_i . From this equation, we get the RMS slope, S_{rms} .

$$S_{rms} = \frac{v(\Delta x)}{\Delta x} \quad (2)$$

The Hurst exponent, H , can be calculated from Equation 3. Typically, the Allan variance is plotted versus the step size in log-log space, and the Hurst exponent is inferred from the slope of the line.

$$v(\Delta x) = C_s \left(\frac{\Delta x}{\Delta x_0} \right)^H \quad (3)$$

Here, Δx_0 is the reference scale (we use 1 m), and C_s is the RMS slope at the reference scale.

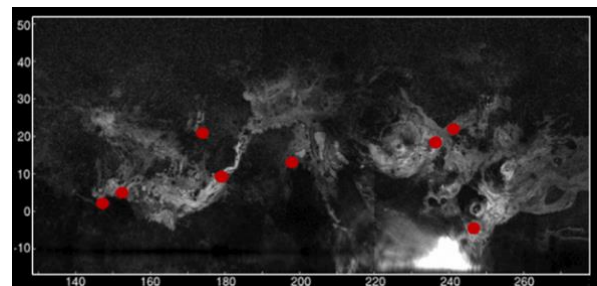


Fig. 1: Arecibo radar image of Mars from [1] showing the locations of the DTMs utilized in this work. Two of these locations are located south from the doppler equator.

Six of the DTMs utilized in this work were processed by the HiRISE team in SOCET SET, and posted for public use on the Planetary Data System [10]. We also processed four stereo-pairs of Martian lava flows using ISIS3 and the Ames Stereo Pipeline (ASP) to generate additional DTMs of the radar bright surfaces of Mars [7,11]. Fig. 1 shows the locations of all the DTMs processed and analyzed in this work thus far. These DTMs were used to extract the surface

roughness of different portions of Martian lava flows. Comparisons between SOCET SET derived and ASP derived DTMs show that the derived values are quite similar in both data sets, giving us confidence in their combined use.

Results: We extracted the RMS slope and Hurst exponent from 10 portions of lava flows that occur in Olympus Mons, Arsia Mons, Elysium Planitia, Daedalia Planum, Marte Vallis, and Phlegra Dorsa. We selected these regions because they are observed to be extremely rough in radar images [1], similar to blocky flows on Earth. Fig. 2 shows a flood lava on Daedalia Planum with its corresponding RMS slope and Hurst exponent, as well as the DTM of the analyzed region.

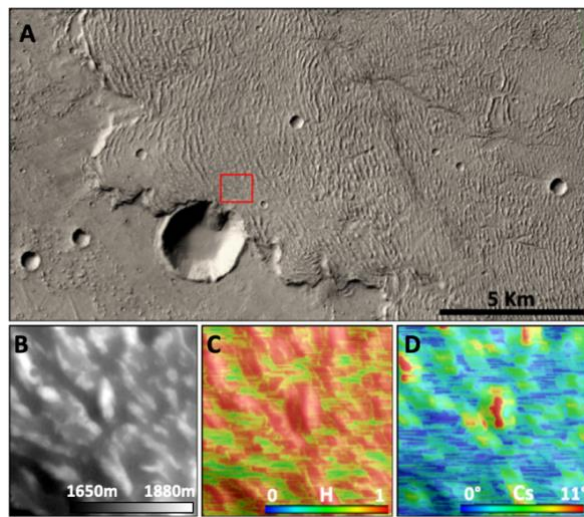


Fig. 2: MRO CTX image showing a flood lava near Daedalia Planum, Mars. Red box shows the portion of the surface used to calculate the Hurst Exponent and the RMS slope of the lava flow. (B). HiRISE DTM of the volcanic surface. (C) Hurst Exponent and (D) RMS slope calculated for this region.

The RMS slope and Hurst exponent values of all analyzed volcanic regions are plotted in Fig. 3 (red) with surface roughness values of lava flows on the Earth and Moon (black and grey) plotted for comparison [2].

Discussion: The surface roughness of Martian lava flows fall within the range of values observed for lava flows on the Earth and Moon. In general, Martian lava flows appear to be smoother than the roughest lava flows seen on Earth (e.g., at COTM), comparable to pahoehoe flows observed at Mauna Ulu or rubbly flows seen in Iceland, and rougher than Ina D on the Moon. However, their radar properties are more similar to rough blocky flows, which typically have larger RMS slopes [2]. The difference between their radar return and measured roughness properties could be the result of the differing emplacement styles, the differing

weathering processes occurring on the different worlds, and/or the resolution and method of acquisition and processing of the different data sets utilized. For example, Ina D might be rougher than inferred, but be covered in a layer of regolith which could result in a lower RMS slope and higher Hurst exponent. Similarly, Martian lava flows may be covered in a thick layer of dust and appear smoother than compared to dust-free surfaces on Earth. To investigate this issue, we plan to determine the dust cover index of all the studied locations on Mars, as well as analyze a variety of “smooth” lava flows for comparison to rough lava flows.

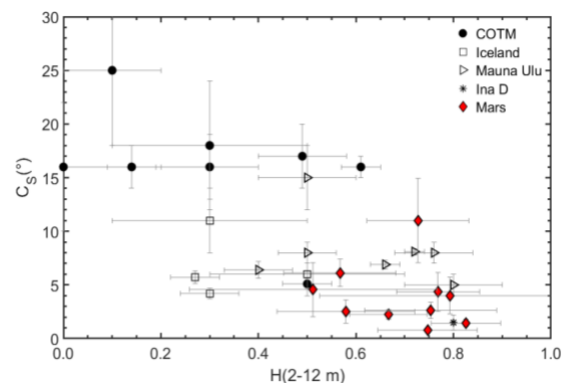


Fig. 3: RMS slope and Hurst Exponent parameters derived from this work (red) and Neish et al. 2017 (black and grey) for the Earth and Moon.

Conclusions: The surface roughness values observed for Martian lava flows are variable, ranging from RMS slopes of ~ 0.2 to 11° and $H \sim 0.5$ to 0.8 . These are most similar to smooth pahoehoes seen on Earth, and one rubbly pahoehoe from Iceland. However, the surface roughness parameters obtained from these Martian lava flows are smoother than expected, given their radar properties. The cause of the low RMS slope may be due to the different weathering and/or emplacement conditions on Mars. Extraction of surface roughness of additional Martian lava flows and correlations to the local dust index may help to better infer their emplacement conditions.

References: [1] Harmon J. K. et al. (2012) *Icarus*, 220(2), 990-1030. [1] Neish C. D. et al. (2017) *Icarus*, 281(C), 73-89. [3] Keszthelyi J. K. et al. (2000) *JGR*, 105(E), 15027-15050. [4] Keszthelyi J. K. et al. (2004) *GGR*, 5(11). [5] Keszthelyi J. K. et al. (2006) *JGS*, 163, 253-264. [6] Shepard M. K. et al. (2001) *JGR*, 106, 32777-32795. [7] Shean D. E. et al. (2016) *ISPRS*, 116, 101-117. [8] McEwen A. S. et al. (2007) *JGR*, 112, E05S02. [9] Turcotte D. L. (1997) *Cambridge Univ. Press*, 2 ed. [10] Kirk R. L. et al. (2003) *JGR*, 108 (E)12. [11] Anderson J. A. et al. (2013) *LPS XLIV*, Abstract #2318.