Volcanic Facies and 15m Scale Roughness Throughout Athabasca Valles Lava System: A Multi-Stage Flow Development.

Russell C. Miller[1,2], Cyril Grima[1,3], Sean P.S. Gulick[1,2,3], Timothy Goudge[2,3], N.E. Putzig[4], M.R. Perry[4], A. T. Russell[4], B.A. Campbell[5], [1]Institute for Geophysics, University of Texas at Austin, [2]Department of Geological Sciences, University of Texas at Austin, [3]Center for Planetary Systems Habitability, University of Texas at Austin, [4]Planetary Science Institute, [5]Center for Earth and Planetary Studies, Smithsonian Institution

Introduction: Athabasca Valles is an extensive outflow channel located at the southern extent of Elysium Planitia that contains some of the youngest, smoothest, and best preserved surface textures and lava flow morphologies on Mars. The juxtaposition of fluvial, glaciovolcanic, and volcanic morphologies have drawn the attention of several studies with a broad spectrum of interpretations as to the nature of the outflow channel materials [1-4]. Previous methods study lava-flow shapes and rely on quantitative parameters such as fractal properties, flow length, width, thickness, volume, etc., to extract rheological properties, eruptive, and suggested emplacement processes. These studies provide important constraints for physical properties and selected features within the outflow such as volcanic rootless constructs (VRC's) [5] and platy-ridged textures [6]. However, the complexity of understanding the interconnected relationships responsible for the present terrain has yet to be fully illustrated. Hence, an integration of a diversity of datasets and knowledge of the outflow associated features is required to further the investigation into recent Martian outflows.

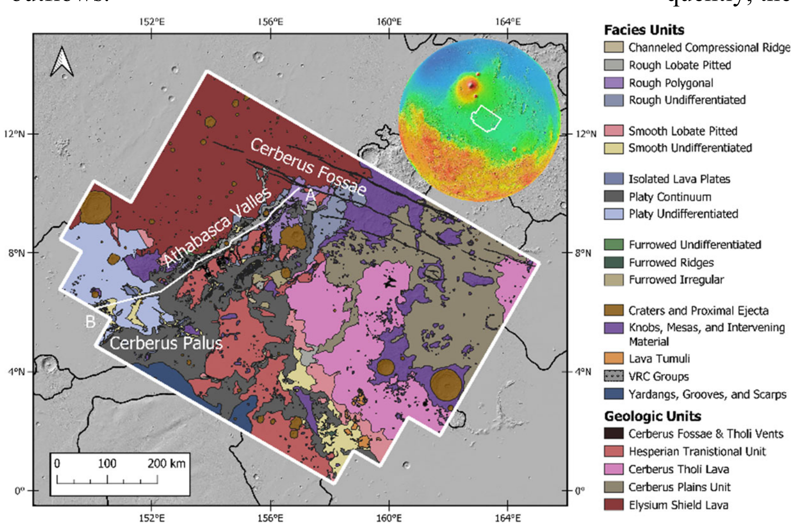

Figure 1 *Facies map on a MOLA hillshade mosaic (200 m/pixel). The study area covers 435,000 km² and includes 17 facies assessed at a digitizing scale of 1:25,000.*

To address these issues, we have constructed updated geological mapping to classify the Athabasca outflow terrains into unique facies using the Context Camera (CTX, ~ 6m/pixel) [7] and High-Resolution Imaging Science Experiment (HiRISE, ~1m/pixel) [8]. Additionally, we integrate these facies with Shallow Radar (SHARAD) [9] surface echo and roughness at 15m scale, processed through the Radar Statistical Reconnaissance (RSR) technique [10-12]. The combination of these data sets illustrates remnant surface and near-surface (<10m) snapshots of the final stages of the flow. Additionally, the RSR roughness measures, RMSh [m] and effective slope (S_{eff}) [°], provide sufficient resolution (15m) to characterize the morphologies and flow emplacement processes.

Athabasca Valles Facies: The identification of meter scale surficial morphologic changes throughout the Athabasca lava system (fig 1) provides an opportunity to explore spatial and temporal variations in flow formation processes. The main Athabasca channel compared to its southern branching channel contains morphological traits (i.e., terraces on exposed walls, teardrop shaped islands, and rootless cones), suggestive of repetitive stages of fluvial activity. However, there is a lack of fluvial associated features within the southern channel. We suggest that most fluvial outbursts flowed down the main channel until later development of southern distributary channels. Consequently, the morphology differs within the northern main channel, dominated by VRC groups [5], whereas the southern channel, represented by platy-ridged terrain [6], features coherent crust slabs rafted atop the molten interior. Downstream, these two channels converge and the lava ponds into Cerberus Palus where the morphology is dominated by interconnected 100s of km² lava slabs. Despite similar planform appearances along the flow, these features have unique roughness signatures that can be linked to their different emplacement styles [13].

Facies Roughness Analysis: The RMSh and Seff response is consistent with facies transitions and the influence from the constraining environment. There are three distinct trends in (Fig 2): (1) where the Athabasca facies are more sensitive to variations in the RMSh (2) the geologic units [14] are more sensitive to variations in the S_{eff} [°], and (3) it appears that there is a transition to higher RMSh for facies along the margins of the Athabasca flow and closer to the source, with the exception of the VRC groups. Quantitative measures of RMSh roughness for Athabasca lava features range from 1.09m to 1.76m.

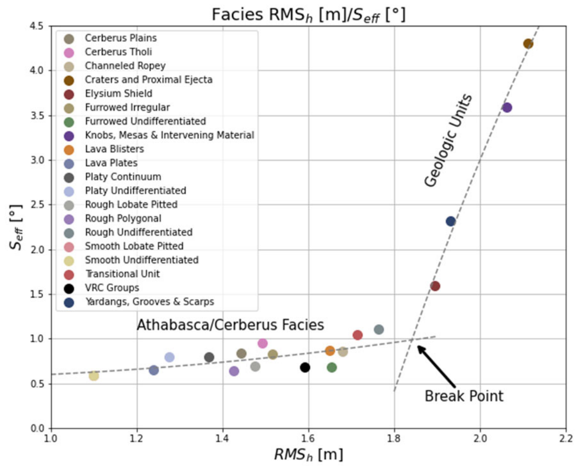

Figure 2 *Relation between RSR roughness measures RMSh [m] vs. Effective slope (S_{eff}) [°] for Athabasca Valles facies, Cerberus facies, and geologic units. Geologic units represent portions of units mapped by [14]. The colors of the scatter points represent the facies as they are mapped in Figure 1.*

We hypothesize that this breakpoint in roughness trends (Fig 2) is related to differences in the scale of surface features between Athabasca facies and surrounding geologic units [14]. Indeed, the geologic units have sizable features, likely resulting in the transfer in sensitivity. In addition to the surface echo, the near-surface properties (<10m) are a significant factor in the roughness distribution of the Athabasca facies.

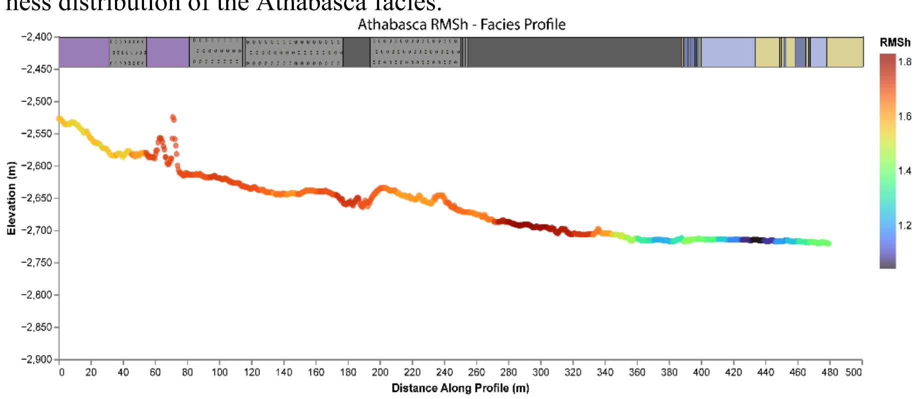

Figure 3 *Along-flow profile through Athabasca Valles originating at Cerberus Fossae and extending to Cerberus Palus Basin. The segmented horizontal represents the locations where Athabasca facies have been mapped. The color scale represents the root mean square height RMSh.*

Until recently, geologic units have largely been mapped with MOLA data analysis [15-16], resulting in kilometer-scale roughness maps used for global geologic unit mapping and characterization. We expand on the hypothesis that roughness reflects the morphologies and emplacement conditions [13] of the flow by extracting topographical elevation measured from Mars Orbiter Laser Altimeter (MOLA, ~400m/pixel) and analyze with roughness and facies patterns along the Athabasca flow path.

Results: There are 3 major distinguishable RMSh segments along the main flow path (Fig 3): (1) proximal to the channel head, exhibits inflated channel morphologies, (2) continuing downslope until the channel terminus, dominated by VRC's and platy-continuum, and (3) beyond the channel terminus a broad flat plain with platy-undifferentiated surfaces. Roughness patterns and facies localities suggest that the emplacement of Athabasca lava experienced a dynamic progression of eruptive stages as the flow fully developed.

It is geologically sensible to propose that the facies characterized by higher RMSh should have been emplaced during more intense eruption conditions [13], although local constraints and substrate irregularities could have a significant effect on surficial expressions. The RMSh-facies profile (Fig 3) has shown that an overall trend decreasing in RMSh exists. These initial results confirm the linkage between surficial morphologies and lava flow roughness, including the ability to constrain the spatial and temporal evolution of emplacement processes.

Conclusions: We find that that Athabasca facies are characterized by unique roughness patterns indicative of flow states and topographic influences on surface and near-surface morphology. Furthermore, lava flows emplaced in the northern and southern segments of our study area demonstrate that the Athabasca system underwent differentiated stages of a single eruption. Results from 3D roughness mapping at 15m scale with integration of SHARAD subsurface reflectors [17] will further test and constrain the spatial and temporal relationship between morphology and roughness, as well as provide additional insight into the formation processes involved in recent Martian outflow channels.

References: [1] D. Berman and W. Hartmann, *Icarus* 159, 1-17 (2002). [2] D. M. Burr, et al., *Icarus* 159, 53-73 (2002). [3] S. A. Fagents and T. Thordarson, *CPS*, 151-177 (2007). [4] W. L. Jaeger et al., *Icarus* 205, 230-243 (2010). [5] C. W. Hamilton et al., *JGR* 115, E09006 (2010). [6] L. Keszthelyi et al., *AGU and Geochem. Soc.*, 5, 11, Q11014 (2004). [7] M. C. Malin et al., *JGR* 112, E05S04 (2007). [8] A. S. McEwen et al., *JGR* 112, E05S02 (2007). [9] R. Sue et al., *Planet Sp. Sci.* 52, 157-166 (2004). [10] C. Grima et al., *Icarus* 220, 84-99 (2012). [11] C. Grima *Plant. Sp. Sci.* 103, 191-204 (2014). [12] C. Grima et al., *this conference* (2022). [13] C. Kilburn, *En. Vol.*, 291-305 (2000). [14] K. L. Tanaka et al., USGS, Map 2888 (2005). [15] M. A. Kreslavsky and J. W. Head III, *JGR* 105, E11 26,695-26,711 (2000). [16] G. A. Neumann et al., *GRL* 30, 11 1561 (2003). [17] A. Russell et al., this conference (2022).