INTERFIELD ANALYSIS OF TUMULI ON MARTIAN INFLATED LAVA FLOWS. S. Sangha[1] (sangha@oxy.edu), S. Diniega[2], and S. E. Smrekar[2], [1]Occidental College, Los Angeles, CA, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: Inflated lava flows consist of a rigid upper crust that insulates and is lifted by a fluid interior. These flows are found on both Earth and Mars [1] and contain surface features that record information about the structure of the original fluid interior [2,3]. In particular, tumuli are small-scale positive topographic features formed by locally high magmatic pressures that develop within subsurface lava tubes [4-7]. As tumuli form over lava tubes in large-scale flows, their sizes, shapes, and location should record subsurface flow history. Specifically, measurable tumuli physical characteristics such as tumuli dimension, form, orientation, and flow density are likely dependent on location within a lava flow as they are directly related to the expansion of lava tube networks. Based on prior studies of terrestrial and Martian flows, we form hypotheses about how tumuli morphometrics will change in different parts of a flow, due to differences in the underlying flow pattern, especially as one approaches a flow margin. We then test these hypotheses by making inter-field comparisons and intra-field analysis of tumuli measurements.

Datasets: As we analyze small-scale features such as tumuli, we focus on HiRISE images which have sufficiently high-resolution (25 cm/pixel) and signal-to-noise for consistent identification and measurement of small-scale features. Additionally, we use detailed tumuli identification criteria [6]. To date, we have surveyed over 20 HiRISE images and have measured tumuli within 4 volcanic flows (Figure 1). This is the largest database of Martian tumuli (Table 1) and we seek to expand it globally, thus creating a valuable resource for a range of volcanic studies.

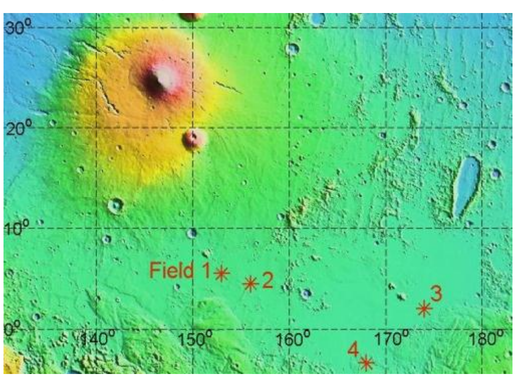


Figure 1. Topographic map of Elysium Planitia, Mars. The highlighted locations are of the studied tumuli fields (Table 1).

Our Study: We focus on large simple lava flows, where we expect lava tube growth to be dependent primarily on (1) the overall flow direction (yielding tubes parallel to the overall flow direction, as would be expected within a narrow flow or within a large flow's interior) and (2) transverse spreading of the flow (yielding distributary tubes oblique to the flow direction; e.g., as might be found near the margins) that can occur if the flow becomes unconstrained by topography or encounters lower slopes [3]. By studying tumuli metrics (such as size and orientation) within flows that contain discernible margins, we aim to identify tumuli morphometrics associated with specific flow regimes. This would help us infer the location of margins in other flows where margins are ambiguous, and to distinguish between large single flows and flows forming through more complicated emplacement patterns. *Towards this end, we investigate the following hypotheses*:

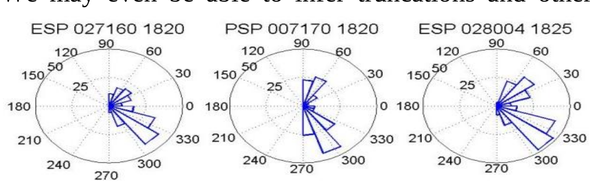
- *The range of tumuli sizes will be consistent across flows where lava flow conditions are comparable*. Since tumuli serve as proxy indicators of lava tubes, we expect them to be of similar size and shape between flows with comparable flow conditions. Observed similarities between tumuli width and length/width ratio distributions between flows within the same field support this hypothesis.
- *The mean/dominant tumuli orientation within an individual flow will align with the local flow direction*. Under stable eruption conditions, arterial tubes will form and grow [3]. At the margins, however, a flow can widen and distributary tubes may form and branch. Thus, in the interior of the flow, we expect the dominant flow (and thus tube and tumuli) direction to be parallel to the overall flow direction. For flows that appear to have widened through spreading, we expect a gradual decrease in this alignment as we move towards a margin as flow has also been directed in a transverse direction. Approaching the flow front, we expect a wider spread in tube (and thus tumuli) orientations as flow would have been towards both the front and side margins. Figure 2 shows an example where this appears to be the case.
- *A high density of small tumuli will be found towards the margin of a flow, while a low density of large tumuli will be found closer to a vent and within the flow interior***.** This, again, is based on the differences we expect between arterial tubes (in the flow

interior) and distributary tubes (near the flow margin). We have plotted tumuli size and density as a function of distance to the margin for images of a single field (the two western images shown in Figure 2) and found the expected relation between tumuli size and density as one approaches the margin in each image. We also investigated tumuli size as a function of distance to the flow front for a string of three images (Figure 2; images span a distance of ~44.2 km) to see if tumuli changed size as the flow extended to its full length. This has not yielded a definitive relationship. However, other literature suggests that changes in Martian flow morphology can occur over ~100s km [8]. Thus, we continue our investigations and aim to study images spanning larger fields.

Lava field	HiRISE image ID	Lat.	Lon.	Total inflation features	# tum.	Tum. width [m]	Tumuli length [m]	Length/ width ratios
1	PSP_006472_1855	5.7°N	152.8°E	76	60	8.2 ± 8.5 [2.7, 54.5]	13.2 ± 13.4 [3.6, 86.9]	1.7 ± 0.5 [1.0, 3.2]
	PSP_007685_1850	5.2°N	152.4°E	244	226	9.1 ± 3.0 [2.5, 23.7]	15.3 ± 5.6 [4.9, 40.7]	1.7 ± 0.6 [0.9, 3.9]
	ESP_012524_1855	5.6°N	153.1°E	992	913	8.0 ± 2.9 [3.0, 22.2]	12.9 ± 4.8 [3.9, 36.9]	1.7 ± 0.5 [0.6, 4.8]
2	PSP_004072_1845	4.5°N	156.0°E	107	27	17.2 ± 10.8 [6.3, 42.7]	25.6 ± 14.5 [10.1, 53.2]	1.5 ± 0.4 [1.1, 3.1]
3	PSP_007170_1820	2.2°N	174.1°E	182	175	14.3 ± 6.6 [4.5, 38.1]	24.4 ± 10.2 [6.3, 65.9]	1.8 ± 0.7 [1.0, 4.7]
	ESP_027160_1820	2.0°N	173.8°E	190	119	9.2 ± 3.8 [3.0, 31.8]	14.5 ± 5.2 [6.5, 35.4]	1.7 ± 0.5 [1.0, 3.0]
	ESP_028004_1825	2.4°N	174.3°E	222	140	6.9 ± 2.1 [3.1, 12.9]	9.0 ± 2.8 [3.9, 21.4]	1.5 ± 0.4 [1.0, 2.7]
4	PSP_002542_1765	3.3°S	167.9°E	647	416	13.1 ± 4.6 [4.3, 32.6]	19.8 ± 7.7 [6.3, 60.0]	1.5 ± 0.4 [0.8, 3.9]
	ESP_027002_1765	3.4°S	168.1°E	184	134	7.7 ± 3.8 [3.8, 24.2]	11.4 ± 4.8 [4.6, 28.1]	1.5 ± 0.4 [1.0, 3.3]

Table 1. Tumuli measurements on the 4 lava fields identified in Figure 1. Values given are mean ± standard deviation, [min, max].

Discussion: As we are interested in understanding general tumuli characteristics and evolution, we study tumuli from many fields to identify common properties and trends. Any deviations from common tumuli population properties within a field would suggest unique or localized flow characteristics or processes, as opposed to general lava flow processes. For example, anomalous tumuli sizes or distributions within a flow-lobe would allow us to infer a change in flow conditions or that the flow was disrupted/altered. We may even be able to infer truncations and other post-emplacement processes not clear through observation. Additionally, although we focus primarily on simple, coherent large flows (that we expect to form tubes/tumuli oriented primarily parallel to or ~perpendicular to the overall flow direction), we recognize that lava flow emplacement can be more complicated. We aim to also investigate other flows (such as long flows where tube structure and tumuli may be aligned with individual flow-lobes) and perhaps to differentiate between these emplacement patterns.



Future Work: We continue to add to our database of tumuli measurements as we seek to better test and refine our hypothesized correlations between tumuli morphometrics and location within the flow. This involves further inspection of HiRISE images as well as placing targets. All of this then leads into our larger goal, which is to determine whether or not the presence of tumuli mark an evolution in Martian volcanism. To-date, crater-date age estimates of inflated flows that we have identified as containing tumuli suggest that these flows are relatively young [9] (<30 Myr). If this is the case, then this yields further evidence that the eruption style on Mars evolved due to global changes in the planet's thermal and volatile content. Additionally, all of the fields where we have located tumuli are situated within Elysium Planitia. If we are unable to find inflated flows outside of the region, then this may imply a unique volcanic evolution within this region.

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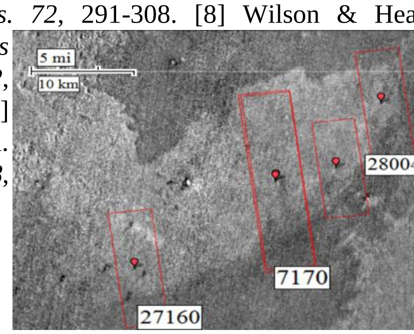

Figure 2. Rose diagrams of tumuli orientations measured within lava field 3. As shown, the lighter region in the THEMIS image is the flow. The overall direction of this flow appears to initially be towards the SE, and then towards the NE. We see a dominant trend in tumuli orientation towards the SE (i.e., the original flow direction and towards the flow margin) that persists, with a component towards the NE (i.e., towards the terminus) that increases moving towards the terminus.