THE SPATIAL DISTRIBUTION OF LAVA FLOW SURFACE FEATURES ON EARTH AND MARS

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Introduction: Lava flow surface morphology results from processes that occur during emplacement. Features such as tumuli and lava rises are indicators of flow inflation [1]. Tumuli in particular have been identified as possible indicators of lava tube location [2-5], indicating that their distribution on the surface of a lava flow is a function of the internal pathways of lava present during flow emplacement. However, the distribution of tumuli on lava flows has not been examined in a statistically thorough manner, nor have these features been positively identified on other terrestrial planets.

In order to more rigorously examine the spatial distribution of tumuli, we examined 3 different flows: two on Earth that display numerous lava rises and tumuli, and another south of Elysium Mons with features morphologically similar to tumuli (Figures 1 and 2). The terrestrial flows include a discrete lobe of the 1969-1974 Mauna Ulu flow at Kilauea, Hawaii. The lobe is located in the distal portion of the flow below Holei Pali, and is characterized by hummocky pahoehoe flows emplaced from tubes [6]. This flow allows complete mapping of surface morphologies because of its well-defined boundaries, well-constrained emplacement parameters, and known flow thicknesses. In addition, tube locations for this flow were mapped by Holcomb [7] during flow emplacement. We also examine the distribution of tumuli on the distal portion of the hummocky Thrainsskjoldur flow field from maps provided in Rossi and Gudmundsson [8].

MOC image 20-01192 (centered at 1.86°N, 186.11°W) depicts a portion of a lava flow to the southwest of Orcus Patera that may display primary flow surface features. Based on Viking data, the flow extends for over 60 km; we have mapped a 3 x 4.5 km section of the flow imaged at 5.8 m/pixel. The flow is relatively dark with an irregular surface, little apparent mantling, and few impact craters. It appears to superpose a bright unit to the southeast. The surface of the flow has many positive relief features that are at the same scale (<10 – 50 m) as terrestrial inflation features (tumuli, lava rises). The flow is characterized by raised elliptical to circular mounds, some with axial cracks [1,5]. One potential avenue of determining whether they are tumuli is to look at the spatial distribution to see if any patterns similar to those of tumuli-dominated terrestrial flows can be identified.

Since tumuli form by the injection of lava beneath a crust, the distribution of tumuli on a flow should represent the distribution of thermally preferred pathways beneath the flow surface. That distribution of thermally preferred pathways may be a function of the evolution of a basaltic lava flow. As a longer-lived flow evolves, initially broad thermally preferred pathways would evolve to narrower, more well defined tube-like pathways [9-10]. The final flow morphology clearly preserves the growth of the flow over time, with inflation features indicating pathways that were not necessarily contemporaneously active. Here, we test using statistical analysis whether this final flow morphology produces distinct distributions that can be used to readily determine the distribution of thermally preferred pathways beneath the surface of the crust.

Method: To statistically analyze the distribution of inflated features on the flow lobe at Mauna Ulu, we documented the height, planform shape, location, and major fractures using a Trimble ProXR real-time differential GPS, logging positions every 1 second. We mapped the perimeters of every inflated feature with well-defined margins that had 1 or more meters of relief. The data were corrected with differential information acquired from the Kopoho, Hawaii base station, with the average horizontal precisions for each tumulus/lava rise ranging from 0.29-0.44 m, and average vertical precisions ranging from 0.44-1.07 m.

Tumuli distributions from the Thrainsskjoldur flow field were determined from maps provided by Rossi and Gudmundsson [8]. On MOC image 20-01192, we mapped every positive relief feature on the flow surface of at least 3 pixels; relief was determined by shading. In total, 88 features were mapped on the Mauna Ulu flow, over 400 on the Thrainsskjoldur flow, and over 800 on the flow SW of Orcus Patera.

Poisson Distributions: Based on visual inspection in the field, it appeared that tumuli within the Mauna Ulu unit clustered near the lateral margin of the flow unit, and we suspected that statistical analysis would show a non-random distribution. In order to test for randomness of the spatial distribution of the tumuli, we compared the their locations to the Poisson distribution; the limiting form of the binomial used to describe random events in time or space that are relatively rare [11]. The Poisson probability distribution for k discrete events (tumuli) occurring within some spatial area a is

$$p(k) = \frac{(\lambda a)^k e^{-\lambda a}}{k!}$$

If the spatial distribution of surface features within the study area is significantly different from the Poisson, then there may be some systematic behavior controlling their occurrence. Alternatively, if the spatial distribution is indistinguishable from the Poisson, we must conclude that the inflation features occur randomly.

Table 1 shows the results of this analysis when we use 74 equal area grids. In this case, we have 86 features and 1.16 features/grid. The result is a test statistic *U* = 0.364. Not only is this *U* significantly less than the critical value. Based on the analyses above, we must conclude that the tumuli are randomly distributed in space.

Table 1.

λ = 1.16 features/grid cell; *U* = 0.364

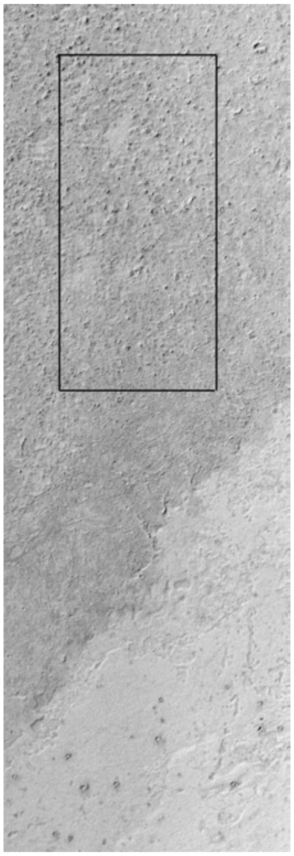
k	p(k)	p(k) * 74	Actual # of Cells
0	0.3128	23	25
1	0.3635	27	25
2	0.2112	16	15
>= 3	0.1124	8	9

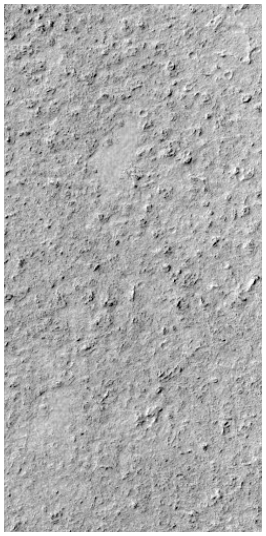
For MOC 20-01192, we considered only the flow interior (754 features within 532 grid cells, and *U* = 1.14). Thus, we conclude that these features are distributed randomly and consistent with the Poisson.

Discussion: Are the positive relief features on the Mars flow tumuli and/or lava rises? Their distribution, morphology and size are consistent with terrestrial inflation features. Although we cannot rule out that they have been produced by differential erosion of the flow surface w e do not favor this interpretation because the morphology of this flow is different that another, more clearly eroded flow in the region, there are few craters on the flow surface and they are not highly eroded, and the flow has a well-defined boundary.

Tumuli must form above pathways capable of producing overpressures sufficient for inflation. On some lava flows, linearly aligned tumuli clearly tap well-defined tubes [5]. However, the random distribution of inflated in this study shows that the location of inflated features cannot always be used to infer major tube locations. We suggest this random distribution of tumuli and lava rises on hummocky flow lobes result from formation above transient thermally-preferred pathways and tubes that change position over the growth period of the lobe.

The growth of hummocky pahoehoe lobes is linked to a network of anastamosing thermally preferred pathways that migrate beneath a cooled crust [9,10,12]. Since inflation is essentially an intrusive process, Anderson et al. [10,12] suggested that these pathways behave as “pods”, or “viscous fingers” [13-14], of injecting lava that are analogous to the 3-5 m wide "fingers" of magma found along the margins of laccoliths that penetrate the host rock [15]. We suggest that viscous fingering results from fluid instabilities [10,13,16,17]) in the inflating flow, and that these instabilities propagate during emplacement. Therefore, inflation occurs in “pulses” [10,12] where discrete sections of the flow lobe in the vicinity of the advancing instability inflate as other portions of the active lobe stagnate. Tumuli formation is tied to the spatial and temporal migration of these pathways, and the random spatial distribution of tumuli on hummocky lava flows marks the locations of transient pathways, rather than those that have fixed positions with time.





Left and Above: MOC 20-01192 with enlargement on right showing suspected tumuli field.

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