THE CHARACTER OF LAVA FLOW MARGINS

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The planimetric shape of a planetary lava flow is often the only quantitative feature that is available from remote sensing data for developing inferences regarding the flow emplacement conditions. A recent study [1] has shown that certain terrestrial lava flows feature margins with a distinct and discernable fractal character, depending on whether the flow was emplaced in the a'a or pahoehoe state. In contrast, for some lava flows, the character and length of the margins are completely imposed by the pre-existing topography and terrain, regardless of fluid dynamic and rheologic considerations.

The character and length of a flow margin are two diagnostics of the flow dynamics that operated during emplacement. Analysis of these features of planetary flows may lead to new inferences regarding eruption conditions or the independent corroboration of existing quantitative conjectures. It is now well-known [2,3] that physical phenomena represented by a dependent variable $\phi$ satisfying Laplace's equation $\nabla^2\phi = 0$ are subject to instabilities resulting in a distinct fractal signature. The fluid dynamic pressure in a lava flow during the final, creep-flow stage of emplacement satisfies a Laplacian. On this basis alone, one might conjecture that the fine-scale lobate structures and characteristics of flow margins are geologic analogs of dendritic branching patterns or viscous fingers.

A significant recent advance in the fundamental understanding of pattern formation has been the realization [4] that nonlinear diffusion equations can also produce a fractal signature.

We have developed a governing equation for the three-dimensional surface of a lava flow during emplacement that is based on an analytic solution of the Navier-Stokes equations for momentum transfer and the conservation of volume. Different scalings of this equation show that it embraces elementary transport properties [5] and both types equations (nonlinear Laplacians and diffusion equations) with fractal signatures at the margins. These different emplacement regimes are delineated by two dimensionless parameters,

\[ p = \frac{L h \cot \alpha}{3 w^2}, \quad q = \frac{g \sin \alpha h^3 w}{\nu Q}, \]

where $L$, $h$, and $w$ are the characteristic flow dimensions, $\alpha$ is the pre-existing slope, $g$ is gravity, $\nu$ represents the viscosity, and $Q$ is the characteristic eruption rate. The parameter $p$ represents the ratio of the pressure-gradient influence to direct gravity-driven kinematic transport. The parameter $q$ is an absolute measure

of the role of the gravity-driven force on the flow. These two key parameters have diagnostic virtue in that sufficiently accurate estimates are available for many terrestrial flows. The table below shows the general nature of the flow margins expected for different combinatorial regimes of these parameters.

Table: Character of Lava Flow Margin

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<thead>
<tr>
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<th>p &lt;&lt; 1</th>
<th>p = 1</th>
<th>p &gt;&gt; 1</th>
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<tbody>
<tr>
<td>q &lt;&lt; 1</td>
<td>Externally Controlled</td>
<td>Externally Controlled</td>
<td>Fractal Tendency</td>
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<tr>
<td>q = 1</td>
<td>Externally Controlled</td>
<td>Fractal Tendency</td>
<td>Fractal Tendency for $L = w$</td>
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In the table, the term "Externally Controlled" indicates that the nature of the margins is dictated by factors not related directly to the fluid dynamics, e.g., pre-existing topographic constraints. The regimes with fractal tendencies highlights the variety of morphological consequences resulting from strong nonlinearities in the emplacement processes.

Preliminary studies [6] support the results in the table. The margins of certain pahoehoe flows on flat slopes (<5°) exhibit a fractal character, while a'a flows on steep slopes (>20°) do not. Further studies are underway to validate the governing nonlinear equation by comparison of theoretical prediction and field measurements and to extend the underlying physics to include more complex rheologic properties for lava flows of different compositions.

REFERENCES