Simulation of inflated pahoehoe lava flows

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Existing models for describing lava flow emplacement cannot be applied to lava flows on Mars that appear to have inflated pahoehoe morphologies. A new modeling approach is needed.

Simulation Approach

The approach is based on a three-dimensional random walk of lava parcels (see below for definition of a “parcel” and the basic assumptions). The model assumes volume conservation and random walks governed by stochastic rules. In this case, the word simulation implies that at least one parameter derives its value by drawing a random number from a prescribed probability distribution.

In the most basic form of this model, two independent random numbers are drawn from the uniform probability distribution at each time step. The first random number determines the location of the next random walk, and the second random number determines the direction of next random walk step.

Each simulation represents a single trial or “realization” of the key observables. Due to randomness, each simulation produces a different set of outcomes depending on the nature of the underlying probability distributions.

This random walk differs significantly from the classical random walk where all walkers must move at each time-step. The approach used here is appropriate for inflating pahoehoe lavas, and has tremendous implications for interpreting possible pahoehoe flows on Mars.

Conclusions

- Pahoehoe emplacement is dominated by random effects.
- Conventional deterministic methods are not applicable to the dominant processes.
- New random walk simulation approach qualitatively reproduces pahoehoe lobe topography and plan form.
- Accommodates inflation and correlation observed in the field. This new approach has tremendous potential for future studies of pahoehoe emplacement.

References

Baloga, S., 1987, JGR 92 (B9), 9271–9279.
Chop, I. and Bagnara, Q., 1960, JGR 65, 20–44.

Sequential Breakouts at the Margin

“Correlation” is a statistical term that describes the influence of prior steps, i.e., a memory of what occurred previously. When correlation is present, the motion of lava parcels is no longer completely random. We can use correlation to describe sequential breakouts at the margin of a pahoehoe lobe. In essence, the sequential breakouts qualitatively describe the effects of momentum for the period until a sufficient crust has been established to stop advance. In practice, when a new parcel is transferred at the margin, increasing the lobe area, we can automatically add 0, 1 or 2 extra parcels at that location (in the same direction).

We can define a probability distribution for the likelihood of 0, 1 or 2 sequential steps after a breakout at the margin, where the sum of the individual probabilities must equal one.

Sequential Breakout Examples (550 parcels)

The examples shown here illustrate the effects of varying the probabilities for 0, 1 and 2 sequential breakouts. As the probability distribution is more heavily weighted towards 2 sequential steps, the area increases and the overall thickness of the lobe decreases.

Field Data: Topography

The examples at right show topographic profiles across several pahoehoe lobes in Hawaii. Those beginning with “H” are part of a historic flow from Hualalai, and those beginning with “M” are from the 1972 - 1974 Maua Ulu eruption on Kilauea. The lobes tend to have a metalic ridge with gently curving margins, resulting in topographic profiles that are concave down. Typical lobes are 2 - 10 m across, and 0.5 to 1 m high.

Typical lobe profiles can be described by either a Gaussian or parabolic shape. Statistical analysis shows that neither functional form can be precluded. An example of both fits to the HLAT2 topographic profile is shown below.

Example: Purely Random, Point Source

- Planform shape qualitatively similar to observed pahoehoe lobes
- Topographic profile qualitatively similar to observed pahoehoe lobes
- Incorporates inflation with dormant parcels

Example: Sheet Flow Source

- As source size increases, the planform variability and lobe thickness decreases.

Example shown here is for a sheet flow source that is 15 x 15 parcels in areal extent, and one parcel thick (20 cm). 1500 additional parcels are then simulated. Relatively few collisions with the barrier (40), but influence seen in planform and in topographic profile.

Example: Sheet Flow Source

- Planform shape qualitatively similar to observed pahoehoe lobes
- Topographic profile qualitatively similar to observed pahoehoe lobes
- Incorporates inflation with dormant parcels

Example shown here is for a point source with a barrier to the north at y = 4 pixels. 1500 additional parcels are then simulated. Relatively few collisions with the barrier (40), but influence seen in planform and in topographic profile.