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!

Example `a`a lava flow with well defined margins and channel with flowing lava. This type of flow can be modeled with existing deterministic models for viscous lava flowing on an inclined plane [e.g., Hulme, 1974; Baloga,1987; Baloga et al., 1998, 2001; Harris and Rowland, 2001; Baloga and Glaze, 2008; Glaze et al., 2009].

Example pahoehoe lava flows with complex morphology. Because random processes appear to dominate the emplacement, existing deterministic models are not appropriate. A new approach is required! Previous work by Baloga and Glaze [2003] suggested that pahoehoe emplacement can be thought of as a random walk.

Pahoehoe lavas are typically found on very low slopes (< 5˚), and generally are emplaced with very low effusion rates (< 10 m^3/s).

Pahoehoe emplacement is often dominated by random effects, such as small-scale topography, self induced topograhy, skin formation and strength, and small variations in discharge rate.

Can pahoehoe emplacement be "modeled", and if so, how?

What field observations/measurements are needed to constrain a model?

Key Obersvables

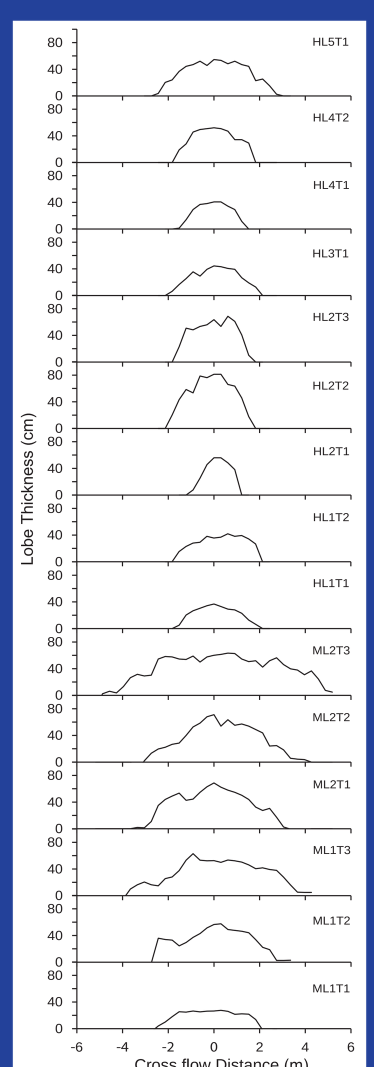
- Topographic profile shape
- Plan form variability
- Morphologic diagnostics
- Areal spreading rate
- Advance rate of the flow front
- Age distribution of the surface
- Flow directions on the surface

Key Factors Influencing Observables

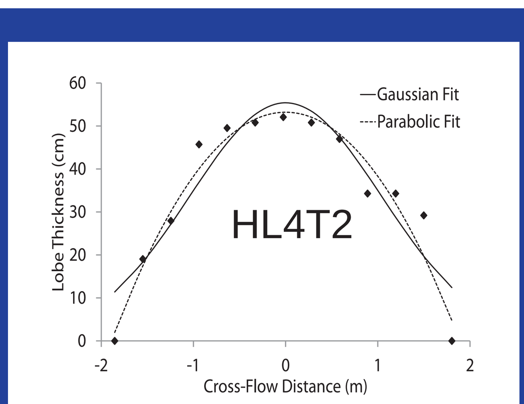
- Lava source boundary conditions
- Topographic barriers
- Overall pre-existing slope
- Micro-topography
- Periods of inflation
- Channels, tubes, and preferred pathways
- Volumetric flow rate
- Durations of supply
- Growth and mechanical strength of the crust

Field Data: Topography

The examples at right show topograhpic 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 Mauna Ulu eruption on Kiluaeua. The lobes tend to have a medial 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 HL4T2 topographic profile is shown below.



Simulation Approach

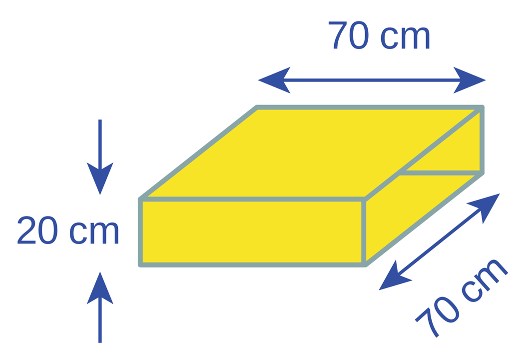
The approach is based on a three-dimensional random walk of lava parcels (see below for definition of a "parcel" and the basic assumptions). The model assumes volume conservation and random walks governed by stochastic rules. In this case, the word simulation implies that at least one parameter derives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

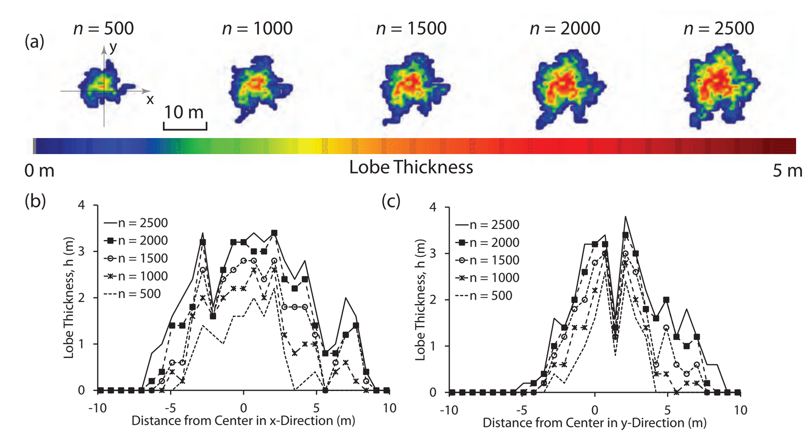
A Lava "Parcel"



Crown and Baloga (1999): Typical toe V = 0.09 m^3

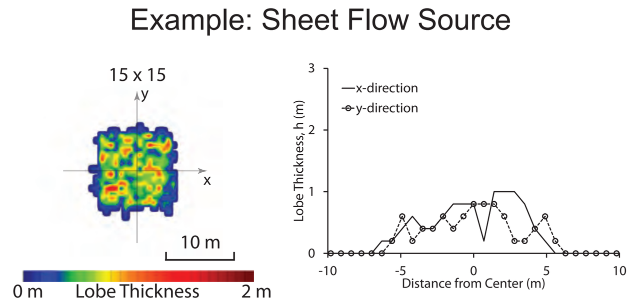
- Single parcel of volume, V, added at each time step, G
- For constant source of supply, volume flow rate, Q = V/G
- Parcel volume equivalent to a pahoehoe "toe"
- Parcel becomes a toe when affixed at the surface or margin of a lobe
- Parcels remain fluid and mobile in the lobe interior

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

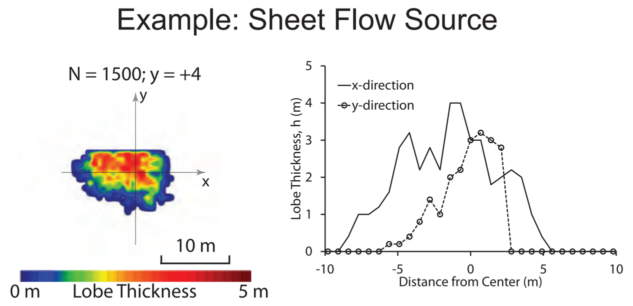
Example: Sheet Flow Source



Example shown here is for a sheet flow source that is 15 x 15 parcels in areal extent, and one parcel thick (20 cm). 500 additional parcels are then simulated.

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

Example: Sheet Flow Source

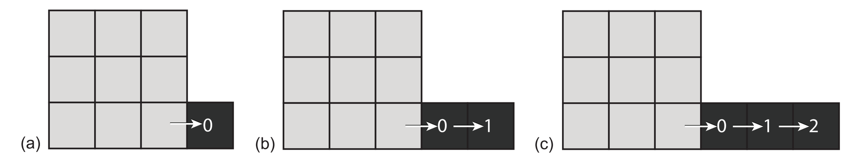


Example shown here is for a point source with a barrier to the north at y = 4 pixels. 1500 additional parcels are then simulated.

Relatively few collisions with the barrier (40), but influence seen in planform and in topographic profile.

Sequential Breakouts at the Margin

"Correlation" is a statisitcal 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 transfered at the margin, increasing the lobe area, we can automatically add 0, 1 or 2 extra parcels at that location (in the same direction).

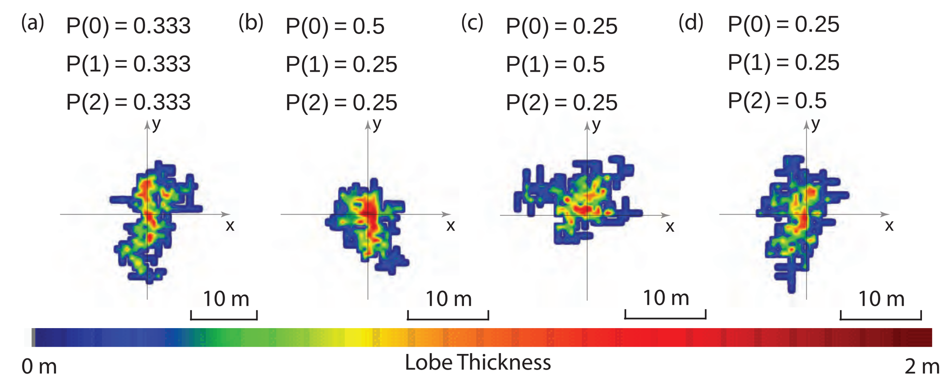


$P(0) = p_i$ $P(1) = p_j$ $P(2) = p_k$

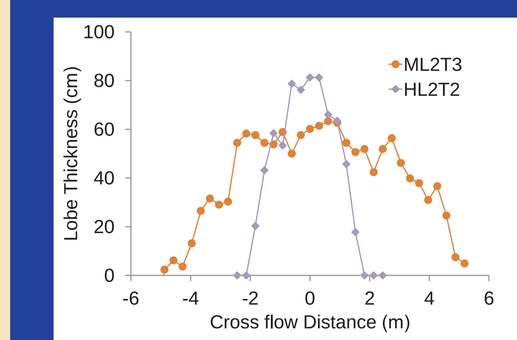
$p_i + p_j + p_k = 1$

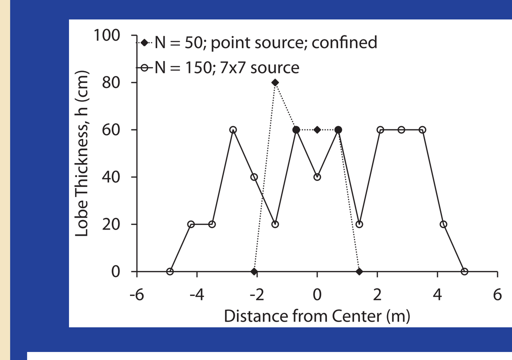
We can define a probability distribution for the likelihood of 0, 1, or 2 sequential steps after a breakout at the margin, where the sum of the individual probabilities must equal one.

Sequential Breakout Examples (500 parcels)

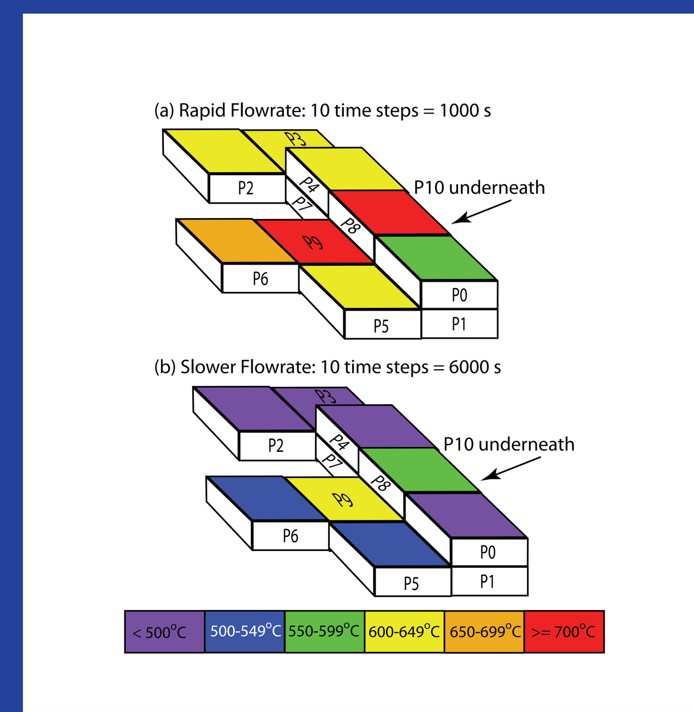


The examples shown here illustrate the effects of varying the probabilities for 0, 1 and 2 sequential breakouts. As the probability distribution is more hevaily weighted toward 2 sequential steps, the area increases and the overall thickness of the lobe decreases.





The example here compares two topographic profiles for lobes at Hualalai and Mauna Ulu. The top figure is field data and the lower figure is simulated. The simulated profiles are qualtitatively similar to the field data. Correlation weighted toward 2 sequential breakouts is used in both simulations.



One future application of the model is to track the movement of each parcel and to keep track of the "age" of each of the surface parcels. Models for cooling [e.g., Crisp and Baloga, 1990] can then be used to estimate the temperature distribution on the surface. This distribution changes as a function of flow rate.

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

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