SIMULATION OF INFLATED PAHOEHOE LAVA FLOWS. L. S. Glaze[1] and S. M. Baloga[2], [1]NASA Goddard Space Flight Center (Code 698, 8800 Greenbelt Road, Greenbelt, MD 20771, Lori.S.Glaze@nasa.gov), [2]Proxemy Research (20528 Farcroft Lane, Gaithersburg, MD 20882, steve@proxemy.com).

Introduction: Pahoehoe lavas are recognized as an important landform on Earth, Mars and Io [1,2]. Observations of such flows on Earth (e.g., Figure 1) indicate that the emplacement process is dominated by random effects. Existing models for lobate a`a lava flows (e.g., [3-6]) that assume viscous fluid flow on an inclined plane are not appropriate for dealing with the numerous random factors present in pahoehoe emplacement. We present a new model that incorporates a simulation approach to quantifying the influence of random and ambient factors on the evolving three-dimensional shape and morphology of pahoehoe lobes.

Figure 1. Typical pahoehoe flow field.

Simulation Approach: Complex pahoehoe flow fields such as the one shown in Figure 1, generally occur when volume flow rates of lava feeding the flow are very low (< 5 – 10 m^3/s, [7]), and frequently when underlying slopes are also extremely low (< 5 degrees). These flows typically advance through the emplacement of small "toes" that combine to form lobes (as in Figure 1), or coalesce to form broad sheet flows.

To simulate pahoehoe lava emplacement, we consider the movement of small parcels of lava with a volume equal to the size of a typical toe (70 x 70 x 20 cm^3) [8]. The model develops a set of probabilistic rules for determining the location and direction of movement for each parcel. For a constant volume flow rate feeding the lobe, a single parcel is added at each time step. However, unlike the classical random walk of Brownian motion [9], only one parcel is allowed to move at each time step. Thus many parcels may remain dormant, but fluid, for multiple time steps. The net effect of this approach is that parcels tend to accumulate preferentially within the lobe producing cross-sectional topographic profiles with a medial ridge, very similar to inflated pahoehoe lobes observed in the field [10].

Results: Because the model is based on a set of probabilistic rules, each simulation is unique and represents a single trial, or realization. Owing to randomness present at each time step, each simulation trial produces a different specific outcome, but the overall behavior for a defined set of underlying probability distributions is consistent from realization to realization.

Figure 2 shows an example realization for a purely random simulation of 500 parcels released from a point source at the x-y origin in Figure 2a. Figure 2a is a plan-form view where each point has been enlarged 10-times in the x-y plane and the surface has been smoothed for graphical interpretation. Figure 2b shows topographic profiles across the center of the simulated lobe in the x- and y-directions.

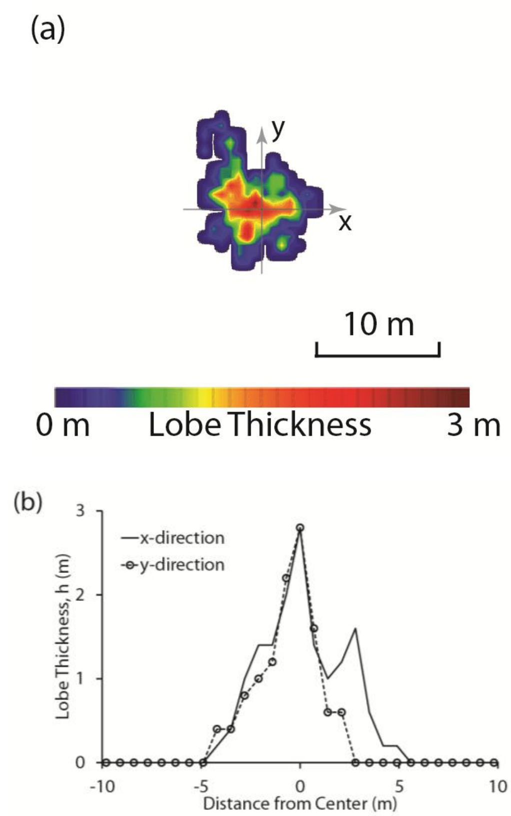

Figure 2. Purely random reference simulation case with 500 parcels released from a point source. (a) plan-view of lobe (enlarged and smoothed for graphical interpretation). (b) topographic profiles taken through the origin along the x- and y-axes.

This new approach to modeling pahoehoe emplacement is very encouraging. Even in the case where each step is purely random (no systematic effects), the plan-form view of individual realizations (e.g., Figure 2) indicate lobate variability similar to what is seen in the field. This basic approach provides a framework for examining a range of non-random effects on the final dimensions and morphology of a pahoehoe lobe. For example, topographic barriers may limit the growth of a lobe in a particular direction. The model accounts for such effects by requiring the flux of material across such a barrier to be zero. A parcel that encounters a barrier is reflected back to its original position, resulting in inflation at that location.

Another key systematic effect that has been explored is correlation at the lobe margin. Correlation means that a parcel has some memory of what happened during the last time step (unlike the purely random case where each step is completely independent). Correlation is used to simulate behavior along a lobe margin. When a new parcel breaks out from the lobe margin (increasing the area occupied by the lobe), the parcel has momentum that increases the probability that it will continue to move in that direction. The model has been used to explore the effects of varying the probabilities that a new toe will take 0, 1 or 2 additional sequential steps in time.

Figure 3 is an example realization for the case when the probabilities for 0, 1 and 2 extra steps are each 0.333 (note that probabilities for all possibilities must sum to one). For comparison with Figure 2, the simulation assumes 500 parcels released from a point source at the x-y origin. Comparing the plan forms in Figure 3 and Figure 2a, it can be seen that the inclusion of correlation for parcels at the lobe margins results in a lobe that covers more area and whose maximum thickness is reduced slightly compared to the purely random case.

Cross-flow topographic profiles from the simulations have been compared with analogous data collected for pahoehoe lobes on the 1973-74 Mauna Ulu lava flow and on a young, pre-historic lava flow from Hualalai, both in Hawaii. Comparisons indicate that the basic dimensions (width and thickness) of pahoehoe lobes can be approximated using the simulation model. The best fits are found when relatively strong correlation at the margin is included (more heavily weighted probability of two extra steps for every breakout parcel).

Conclusions: Existing models for lava flow emplacement based on deterministic physics models are inappropriate for application to pahoehoe lavas where random processes are dominant. A completely new simulation approach has been developed that provides a framework for exploring the effects of a range of processes such as source size and shape, microtopographic barriers, and correlation. The randomness of interior lava parcel transfers appears to be a heretofore unrecognized fundamental process in pahoehoe lobe inflation. Future activities include tracking the ages of parcels exposed at the surface and estimation of surface temperature distributions during emplacement. Future enhancements of the model will also include the incorporation of systematic effects such as underlying slope. Results to date indicate that a great deal of information about the emplacement of inflating pahoehoe lobes can be extracted by stochastic modeling of the random effects. Refinement of this approach is likely to have implications for the analysis of inflated pahoehoe lobes on the Earth, Mars, Io, and possibly the Moon.

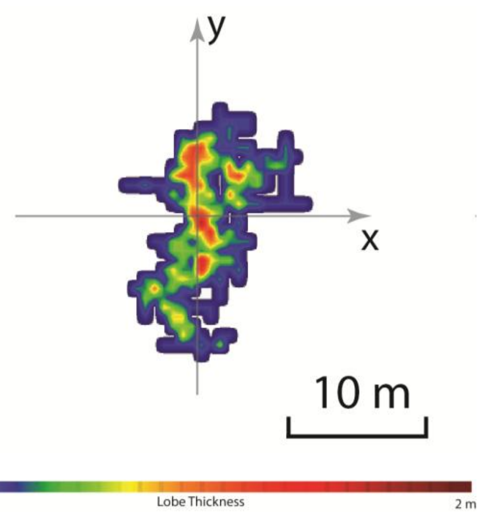

Figure 3. Example simulation realization with correlation, and equal probabilities (=0.333) of 0, 1 and 2 extra steps following a parcel breakout at the lobe margin.

References: [1] Self S. et al. (1998) *Ann. Rev. Earth Plan. Sci., 26,* 81-110. [2] Keszthelyi L. et al. (2006) *J. Geol. Soc., 163,* 253-264. [3] Baloga S.M. et al. (1998) *JGR, 103,* 5133-5142. [4] Baloga S.M. et al. (2001) *JGR, 106*, 13,395-13,405. [5] Baloga S.M. and Glaze L.S. (2008) *JGR, 113,* doi:10.1029/2007JE002954. [6] Glaze L.S. et al. (2009) *JGR, 114,* doi: 10.1029/2008je003278. [7] Rowland S. and Walker G.P.L. (1990) *Bul. Volcanol., 52,* 615-621. [8] Crown D.A. and Baloga S.M. (1999) *Bull. Volcanol., 61*, 288-305. [9] Chandreskhar S. (1943) *Rev. Mod. Phys., 15,* 1-87. [10] Hon K. et al. (1984) *Geol. Soc. Am. Bull., 106*, 351-370.