SIMILARITIES IN EMPLACEMENT STYLES BETWEEN CRUSTED LAVA FLOWS AND IGNEOUS INTRUSIONS: IMPLICATIONS FOR PLANETARY LAVA FLOW FORMATION. Steven W. Anderson[1], Suzanne E. Smrekar[2], Ellen R. Stofan[3], Michael S. Ramsey[4], Jeffrey M. Byrnes[5], [1]University of Northern Colorado, CO 80639, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [3]Proxemy Research, 29528 Farcroft Lane, Laytonsville, MD 20882, [4]Department of Geology and Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260, [5]Boone Pickens School of Geology, Oklahoma State University, Stillwater, OK 74078

Introduction: Understanding the processes that occur in lava flow interiors is a key factor in evaluating emplacement models for terrestrial and planetary lavas. However, little is known about the interior structure of an active lava flow. For example, is the liquid material sandwiched between upper and lower insulating crusts in a basaltic flow ubiquitous in terms of viscosity, yield strength, density, and temperature, or do gradients exist that can give rise to fluid instabilities? If fluid instabilities exist, what affect will they have on the interior flow structure and preferred paths of movement that lava will move through in as it travels between its upper and lower insulating crusts? Are lava tubes the only structural expression of flow localization in flow interiors, or is the formation of viscous fingers [1-5] a viable mechanism for creating flow paths in active flows? What affect does the interior structure have on the ability of lava to travel great distances, as required in the formation of large igneous provinces on the terrestrial planets? How does the interior structure of an active flow influence the development of key surface morphologies, such as tumuli, pressure ridges, and compressional ridges that are now within the imaging resolution of several planetary missions.

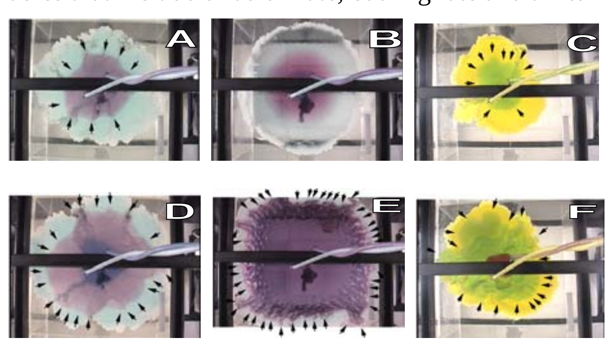
To better understand the interior structure of an active lava flow, we consider the similarities that crusted, active lava flows share with igneous intrusions, and have designed a set of analog flow experiments, field studies of active basaltic flows, and evaluations of theoretical models to provide insights regarding the processes occurring in lava flow interiors.

Previous work – Lava Flow Interiors: Analyses of vesicles in cross-sectional exposures of older flows also provide a glimpse into processes occurring during [6,7], but do not clearly show the temporal and spatial evolution of the flow interior during eruption. Other information used to infer interior structure is found in the location of inflation features such as tumuli, which have been linked to pressurization from underlying tube systems [8,9], although some investigators find no evidence for tubes beneath some of these feature [10].

Several investigators have made efforts to study the interior of active flows. Sutton et al. [11] used VLF geophysical imaging techniques to determine flow rate in active lava tubes, and Roggenthen et al. [12] generated images of an active lava tube with ground penetrating radar. However, both of these techniques require walking directly over the active area, and are only suitable for flows that have well-established (and cool) surface crusts. Realmuto et al. [13] used airborne infrared spectroscopy to determine the temperature distribution across an active Hawaiian flow field, although variations within individual flow lobes were not evident with the ~10m/pixel resolution. Thus, these techniques are not practical for studying the fine-scale interior evolution of fresh flows.

The size, shape, and extent of interior pathways in lava flows is critical to understanding the kinetics of lava movement beneath cooled crusts, and therefore provides constraints for modeling. For instance, Sakimoto and Zuber [14] and Anderson et al. [1] both showed how the size and shape of interior pathways had a profound affect on the distance that lava could travel, potentially limiting the advance of long lava flows. Keszthelyi [15], and Keszthelyi and Self [16] have also shown that the thermal budgets for terrestrial and planetary flows are also a function of the size and shape of the tube or pathway.

Analog Flow Experiments: We examined the formation and evolution of preferred pathways in flow interiors by sequentially extruding different colors of polyethylene glycol wax (PEG) from a point source into a cold sucrose solution [5]. The setup was videotaped from the top and side to show time-lapse views of the developing surface morphology, and from the bottom to capture the interaction of the different PEG colors in the flow interior. We conducted 18 experiments that showed the development of interior flow pathways as a function of emplacement variables that include effusion rate, cooling rate and time.

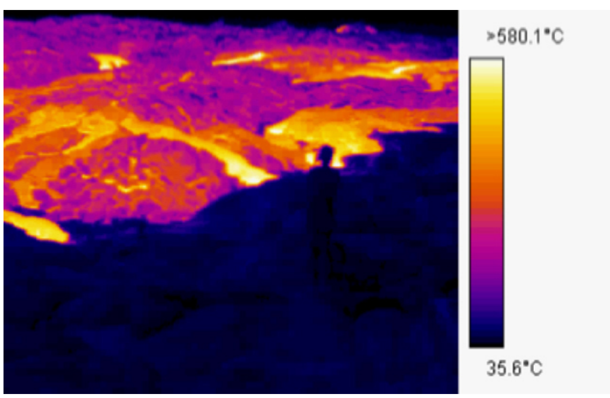


Above: Three image pairs from experiments in [5]. Arrows denote the location of viscous fingers. Top image of each pair is from early in the experimental run, whereas the bottom image is from late.

High effusion rate combined with slow cooling produced extrusions with little or no surface crust, and flow interiors that displayed a breakdown of radial flow into smaller broad fronts as the experiment proceeded. Where crusts formed near the margins of some of these flows late in the run, narrower pathways formed beneath the solidified surface. Lower effusion rates and more rapid cooling produced completely crusted flows with a highly complex interior pathway network.

Flow surface morphology was affected by interior pathway development. Broad interior pathways capable of applying stress over large areas resulted in widespread flow surface disruption and the formation of rifts and levees, whereas narrow finger-like pathways capable of applying stress over much smaller areas resulted in many local surface disruptions such as pillows. Pillows typi-cally consisted of fluid that had been residing in the inte-rior for some time, rather than the freshest, hottest liquid to emanate from the point source. We suggest that the development of Saffman-Taylor fluid instabilities in lava flow interiors leads to viscous fingering and the forma-tion of preferred pathways. Fractal analysis suggests that these instabilities affect the tortuosity of both the exterior flow margins and the interior flow pathways. We find many similarities between these analog flows and lava flows, and suggest that viscous fingering is an important mechanism in the emplacement of some lavas.

Field Studies: Determining the nature of fluid structure in an active lava flow is difficult because direct observation is not possible. To better infer the thermal structure of material just below the cooler crust of an active basalt flow, we used a FLIR ThermaScan camera to image actively inflating basaltic flows on hummocky topography in October of 2005. The FLIR has a temperature range of –40^{o}C to 1500^{o}C, and a precision of 0.5^{o}C, and can therefore image small temperature variations on a flow.



Above: FLIR image of an actively inflating pahohoe flow at Kilauea volcano, Hawaii showing the thermal variation on the flow surface.

Because pahoehoe flows grow as successive toes emanate from the flow front in complex spatial and temporal patterns, the age and temperature of the flow surface and the underlying preferred-pathways are suspected to be equally complex. However, preferred interior flow pathways should bring a continual supply of fresh lava and associated heat through the flow, and should keep flow surfaces above much hotter than those that have less movement of fresh material beneath. Although we are in the initial stages of analyzing our data, we believe that these FLIR images will shed light on whether we see individual flow pathways become more distinct with time, or whether the influx of material break down septa between flow paths.

Modeling: Anderson et al. [1] proposed that viscous fingering may be an important process in the emplacement of some basalt flows, and that it may ultimately affect flow surface morphology. Saffman and Taylor [17] described the mathematical formulation for the stability of such fingers. This phenomenon was thus given the name Saffman-Taylor instabilities, and is applicable to a variety of geologic flow problems. Recently, viscous fingering was proven valuable in describing fissure eruptions [2-5], and has been linked to the emplacement of sills [18]. Specifically, cooling results in an increase in lava viscosity, such that subsequent magma that enters the fissure or intrusion is of lower viscosity. Under certain conditions that are a function of the flow rate, viscous fingers of the newer, hotter, less viscous magma will develop within the older, cooler, more viscous material. At a large scale (>10m), fingers may express themselves as localized areas of increased flow along high flow-rate fissure eruptions [2-5]. At the smallest scale (<1m), toes emanating from the front of pahoehoe flows may represent a small-scale expression of fingers. Modeling suggests that the thicker sections of an inflated flow should allow for larger fingers, possibly on the order of meters in width, possibly linked with the typical meter-scale surface features (tumuli, hummocks) on some inflated lava flows. The sizes of these fingers can then be used to determine whether crusted lava flow emplacement represents a likely emplacement scenario for long planetary flows.

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