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IMPLICATIONS OF PAHOEHOE CRUSTAL THICKNESS DISTRIBUTION THE FISSURE 3 LAVA CHANNEL IN LAKI, ICELAND

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INTRODUCTION

The 8 June, 1783- 7 February, 1784 Icelandic Laki eruption is well documented for its famous "Laki fog," that wreaked havoc across the Northern Hemisphere's atmosphere. However, due to era of the eruption, little is certain about the geomorphology underlying the flow field. From firsthand historical accounts, sequential and general geographical details have been collected on the event (Thordarson and Self, 1993; Thordarson and Self, 2003). While the general localities of the lava field are understood, missing knowledge of geologic features antecedent to the flow uphold uncertainties of the environmental controls on its formation dynamics and formation morphologies.

The goal of this study is to determine the formation morphology of a channel-like structure originating from fissure segment 3 of the Lakagígar eruption fissure. This will be done by determining the channelized flow's movement characteristics, it is possible to consider environmental effects on the flow dynamics and possible formation sequences. To do so, the study utilizes analysis of thickness measurements taken from a variety of pāhoehoe lava slab species dispersed throughout the primary channel and uses remote imagery synthesized on site with geographic information systems (GIS) to consider the implications of the measurements' spatial distribution. Furthermore, the cooling model of Hawaiian a`a lava developed by Hon et al. (1994), is used to draw further implications of the channel-structure's formation.

AREA OF STUDY

Lakagígar

The Laki eruption occurred outside the small, southern Icelandic town, Kirkjubæjarklaustur. Part of the Grímsvötn volcanic system, the 8-month long eruption effused out of vents in a fissure system that extends in a ~27km line, creating a row of >140 eruption sites on both sides of the hyaloclastite hill of Laki. These eruptive sites' vents are surrounded by scoria cones, spatter cones, and tuff cones. (Thordarson and Self 1993,2003; Thordarson et al., 1996; Guilbaud et al., 2005) The overall row of cones and vents is known as the Lakagígar, or alternatively the Skaftáreldagigar (Boer and Sanders, 2002). The Lakagígar can be divided into 10 fissure segments, each representing an eruptive episode occurring sequentially from west to east (Thordarson and Self, 1993; Guilbaud et al., 2005). In total, an estimated ~14.7km^3 of quartz-tholeiite basalt was effused from the eruption (Thordarson and Self, 1993; Guilbaud et al., 2005; Hamilton et al., 2010). The entirety of the flow is composed of 4 types of pāhoehoe: shelly pāhoehoe, spiny pāhoehoe, rubbly pāhoehoe, and slabby pāhoehoe (Guilbaud et al., 2005)

Fissure Segment 3 Channel-Structure

The study focuses in on a channel structure towards the southwestern part of the cone row located at 64.0°N, 18.3°W. It was fed from vents within the fissure 3 group (Guilbaud et al., 2005). Cone 1 and cone 2 (Fig. 1) both have smaller and thinner channels that then converge into a larger, main channel area. This main channel segment has a length of 3,300m and

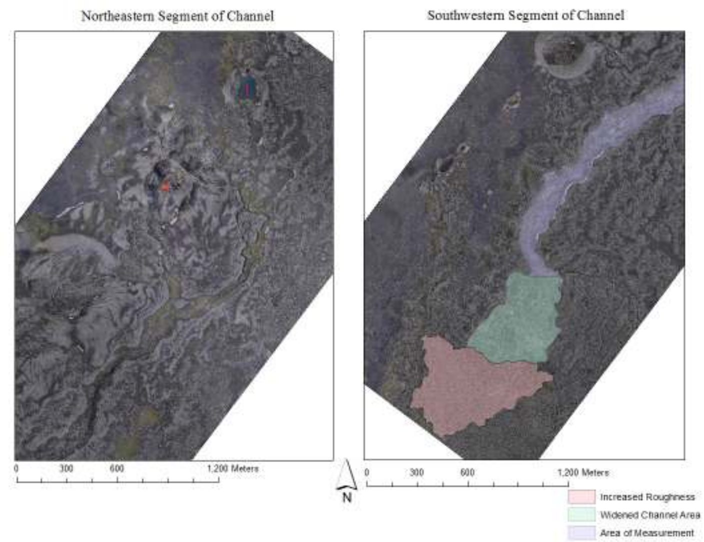

Figure 1. Maps depicting 2 large segments constituting the majority of the channel. Image on left represents the majority of the upper Northeastern channel and assigns values to the two vents with minor channels feeding into the main channel. Image on right represents the majority of the lower, Southwestern Segment of the Channel. Highlighted in red is the area of intense surface roughness, in green a significantly widened channel area, and in violet the area of measurement within the lower half.

an average width of 151.9m. The levee height within the area of field measurement averages at 6.16m (Fig. 1). The channel region south of the measurement region increases in width to a sudden 200m and continues to increase to a width of 500m (Fig. 1). Southward, the flow turns into a non-channelized area that has a high density of surface disruption for ~500m (Fig. 1).

Within the channel, the ground is segmented by areas of flat, undisrupted surface crust and areas of varying degrees of crustal disturbance including hummocks, tumuli, and large pieces of upturned slabby pāhoehoe. The northern half of the channel is markedly less disrupted than the southern half, which becomes progressively turbulent the further south it extends. Like the rest of the flow, the area is covered by a thick layer of gray and green moss, making the pāhoehoe textures of the top layer of undisturbed segments indistinguishable. Also noticeable are large lava boats dispersed throughout the channel, many of which parallel the height of the surrounding levees.

METHODS

Remote Sensing Imagery

Remote sensing imagery was taken on site with use of a Trimble UX5 unmanned automated vehicle (UAV). The UAV contained a Sony A7R camera which took imagery of the underlying ground. Hillshade, digital terrain model, and orthoimagery creation and processing was performed by Stephen Schiedt, Lunar Planetary Lab, University of Arizona.

Lava Slab Thickness Measurement

Pāhoehoe lava thickness measurements were taken within the channel ranging from 64.02478°N, 18.32277°W to 64.01152° N, 18.34483° W. The intent behind these measurements were their potential as a chronometer. When pahoehoe crust is disrupted, it creates pahoehoe slabs that are separated from the underlying molten lava. This stops their thickness growth and by utilizing an empirical cooling model created by Hon et al., (1994), we can know how long the crust was stagnant before disruption or large scale movement.

Tabular pieces of lava slabs that were exposed due to inflation, deflation, or were in contact with surrounding slabs were classified as "hummock" slabs (Fig. 2). Those that were upright due to the nature of slabby pāhoehoe were classified as "upturned" slabs (Fig. 2). Horizontal slabs in that appeared low to the ground, but with no supporting side hummock slabs were classified as "crust" slabs (Fig. 2).

Each slab was measured within a range of 10 meters from the center of an established waypoint where a GPS location was recorded. The number of measurements taken on each slab was dependent on its respective exposure and thickness variation. More thickness measurements were taken on slabs containing more variation in thickness to obtain an optimal representative average. Orientation from the central waypoint in addition to notable visual features were recorded as well for future coordinate correction. In total, 1435 thickness measurements were recorded from 82 hummock slabs, 27 crust slabs, and 118 upturned slabs. thickness width measurements were

Figure 2. Field images taken of the 3 variety of slab specie measured: upturned slabs (left) crustal slabs (bottom-right) and hummock slabs (top-right).

taken from an unknown number of misidentified slab types as note definitions were changed the third day in the field. Slab measurements came from 86 different waypoints within the channel.

Slab Population Analysis

The distance of each slab was measured along the channel centerline with the southwestern most point being set as distance 0m and measurements started ~500m. This centerline was created in ArcMap by creating 205 lines throughout the channel perpendicular to the flow, which were then averaged to a centroid and then converted into a polyline. Each measurement was broken up by distance intervals consisting of 250m.

In this study and within some previous (Guilbauld et al., 2005) observations within the field and datasets implies that there are multiple populations of slab thicknesses at a given location within the Laki channel. To determine the modality of these populations at each distance interval, a histogram was made of the frequency of each measurement within that respective interval. From these histograms, it was then considered whether the distribution within the interval was Gaussian or multimodal (Fig. 3). The

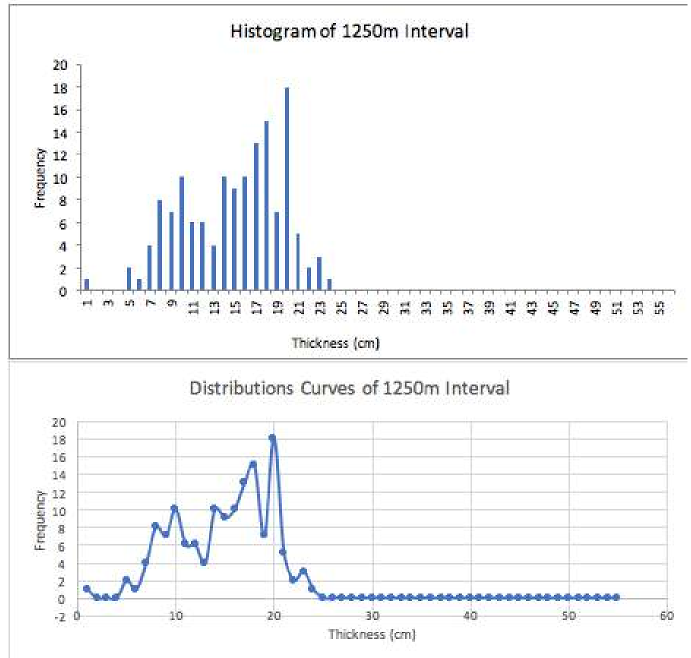

Figure 3. Example of a distance interval histogram from study. From the histogram and distribution curve graphs, it was determined that there were two modes within the population, one at thickness 10.30 cm -/+ 6.29 cm and the other at 18.06 cm -/+ 7.05cm. Slabs at this location interval were averaged based on which distribution they were more likely apart of.

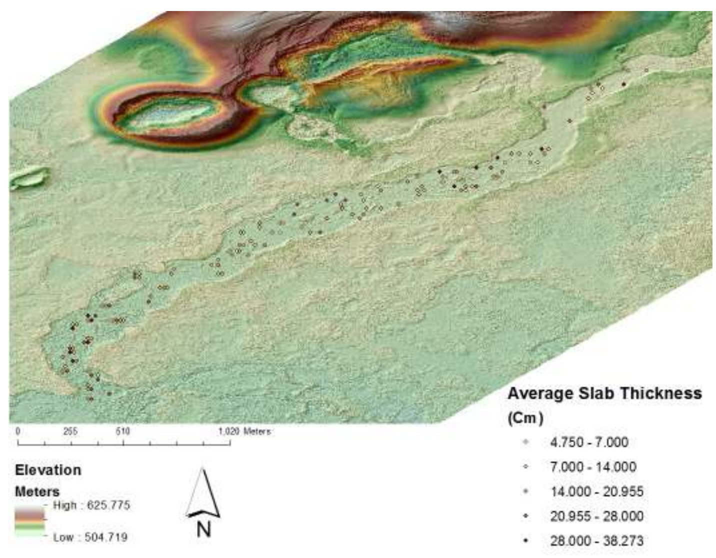

Figure 4. Map displaying each waypoint and their mean. Waypoints that contained slabs from multiple populations were spread apart based on field description of individual slab orientation. Base map is the digital terrain model

standard deviation for each recorded median was then calculated.

The arithmetic mean of each slab was then compiled. Using the determined medians and standard deviations

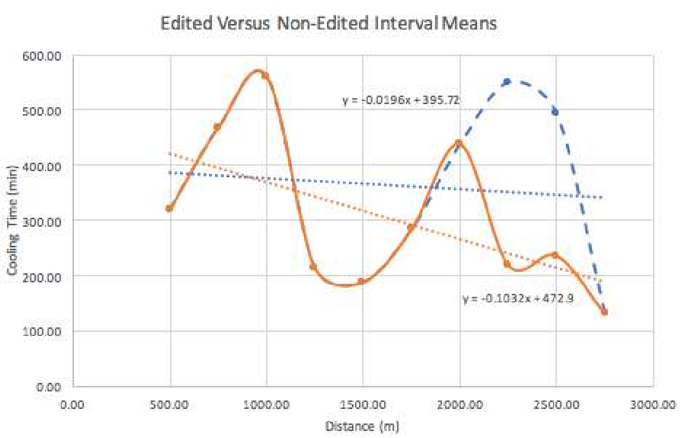

Figure 5. Graph showing the mean of each median by distance interval. Dotted line represents the unedited mean containing all measurements and the orange, filled line is the mean that excludes 2 slabs taken early on in the data set that were noted as anomalous. Linear lines are the overall mean over each interval.

at their respective interval, the mean of each slab at a given waypoint was then averaged if they adhered within the same median group (Fig. 4).

DISCUSSION AND RESULTS

Slab Thickness Distribution

From an overall mean of the collective median groups at each 250m distance interval, there is an overall trend in decreasing thickness as populations span increasing in distance away from point 0m. To more easily comprehend what this meant in terms of flow dynamics and sequence, the estimated lava cooling time of each mean was calculated from Hon et al. (1994):

$$t = 164.8 * C^2$$

Where C= thickness (cm) of a given piece of lava, and t=amount of time (hours) it takes to cool lava to a certain depth or thickness C of lava. Overall, the average cooling time that occurred within a slab sample decreased by a multiple of -.019 minutes (min) per meter. When measurements noted as anomalously formed within the field notes were removed this rate further, decreased to a multiple of -.103 min/meter (Fig. 5).

This result contrasts archetypical open channel flow crust. Typically, in channel flow, lava crust tends to thicken laterally towards the margins rather than longitudinally (Rossi, 1997). Longitudinal cooling implies that crust towards the southern end of the channel had a longer time to cool while lava accumulated increasingly further up flow toward the source. Thus, we speculate that a blockage occurred at the bottom of the channel, creating a fill event, impeding open flow.

Slabs of pāhoehoe are an indication of crustal surges caused by breakouts (Guilbauld et al., 2005; Lipman and Banks, 1987; Patrick and Orr 2012). Consistent patches of high slab presence of similar size throughout the channel may be an indication of channel-wide crustal movement. Furthermore, pāhoehoe closer to a breakout zone is often more likely to undergo slab formation (Lipman and Banks, 1987; Rossi, 1997; Patrick and Orr 2012). As the frequency of lava slabs increases while the channel progresses closer towards location 0m (Fig. 1), an area of high disturbance and characteristic of a breakout zone, it is further implied that large scale ponding occurred.

Maximum Slab Thickness

While marked in the field notes as an "anomalous feature," the thickest crust measurement measures at 44.735 cm -/+ 5.65 and is located at 64.024987°N, 18.321835°W. Using the Hon et al, (2009) cooling model, crust from this sample may have been stagnant for ~35.57 hours. From historical accounts, we know that the vent three eruption occurred for 8 days from 11-13 June, 1783 (Thordarson and Self, 2003). As the top layer of flow represents the last most episode, we can assume that if a blockage event occurred, it did not encapsulate the entirety of the flow. Because of this results and the case of lengthwise rather than horizontal flow thickening, we speculate that a channel structure was likely formed before channelized flow endured a blockage and deflation.

Multimodal Slab Population Distribution

Pāhoehoe flows containing slabs of numerous thicknesses is a product of multiple movement events. While multiple thicknesses populations can be attributed to general local movement in crusts, it is likely that if populations are uniform throughout the flow, that its crust moved harmoniously (Guilbauld et al, 2005). If the slab populations throughout the Laki channel share similar modalities, a suggestion can be drawn that multiple large-scale surge events occurred. This would imply that either multiple factors caused blockages in the flow head of the Laki flow or that the flow was repeatedly blocked by a renewing or locally common influencer, such as water.

CONCLUSION

Relationships drawn between multimodal thickness populations and the spatial distribution of pāhoehoe slabs show a general downflow thickness increase in the fissure 3 Laki channel. Observed downflow thickness increase combined with channel-long slab presence that exaggerates downflow brings upon the conclusion that largescale blockage occurred throughout the channel. Data suggests that blockage may have induced multiple ponding events that caused the top layer of flow to overprint an antecedent channel structure.

Further work will involve more rigorous statistical analysis of identifying multimodality. It is hoped to gain insight on whether modes reoccur between distance intervals to further examine the possibility of multiple ponding events. Additionally, the spatial relationship between the location of thicknesses and visible morphology such as levee slumps and lava boats is to be further investigated. Finally, the relationship between slab specie and thickness will be examined to make results more accurate and representative of the overall flow event.

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