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# GEOMORPHOLOGIC MAP OF THE FISSURE 3 LAVA CHANNEL OF THE 1783-1784 LAKI ERUPTION, ICELAND

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## INTRODUCTION

Over the course of eight months, the Grímsvötn volcanic complex in the East Volcanic Zone fed the 1783-1784 Laki eruption in South Iceland (Thordarson and Self, 1993). The source of the Laki eruption were ten en echelon fissures that formed a linear row of cones and craters, called Lakagígar*,* which trends 045° and decreases in age to the northeast (Thordarson and Self, 1993). Two cones formed by Fissure 3 fed the Eastern and Western branches which converged at the Confluence and became the Main Branch (Fig. 1). The West Branch is 0.6 km long and the East Branch is 1.5 km long (Fig. 1). From the Confluence, the Main Branch continues roughly 2.5 km and then opens into Chaos Pond which is 0.25 – 0.45 km wide and 1.0 – 1.1 km long (Fig. 1).

Our study focused on mapping the Fissure 3 lava channel. Because the erupted material from Fissure 3 has generally equivalent basaltic composition, we focused on mapping volcanic facies, material types (e.g., tephra, spatter, lava) and landforms. Our mapping efforts help to spatially constrain these morphologic characteristics in order to inform future research on the formative history, derived geologic setting, and flow dynamics within the lava channel. For example, by examining remnant features and discretely mapping islands, hummocks, polygonal channel floors, and facies within Chaos Pond, we set a general morphologic context that provides evidence for the lava ponding sequence of events.

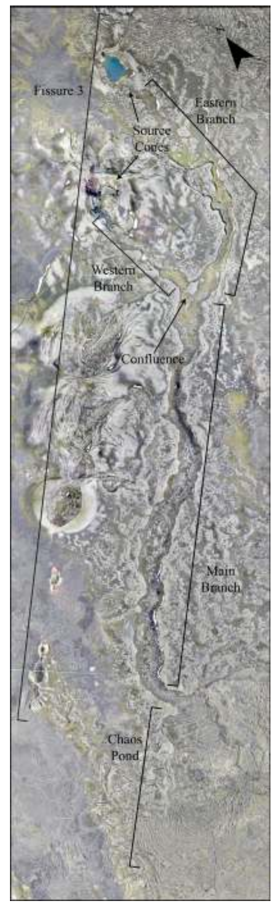


*Figure 1. Orthoimages (3.0 – 3.9 cm/pix) of the Fissure 3 lava channel. Key areas referenced in this map are bracketed and general locations are indicated with an arrow. The orthoimages were rotated 37° west of north; true north is indicated by the arrow in the upper right-hand corner. The cones formed by Fissure 3 along Lakagígar were identified by Thordarson and Self (1993); all other labels were developed by the field-team for this project.*

## BASE MAP AND DATA

Traditional field-mapping methods involve the physical traverse of the study area coupled with the drafting of map components (i.e., morphological contacts and units) on paper. However, the development of drone technology paired with photographic data provides a powerful tool in non-traditional settings. Lakagígar and the lava channel are within the Vatnajökull National Park in Iceland, which is characteristically covered by delicate layers of moss that are protected by Icelandic National Park standards and procedures. Eschewing traditional field-mapping methods, we remained respectful of the Icelandic requirement of preserving the moss while continuing our research in and around the lava channel by acquiring drone data.

Led by Christopher Hamilton and Stephen Scheidt of the University of Arizona, we used a Trimble UX5 HP fixed-wing drone to collect aerial data of the lava channel. The drone is integrated with a Trimble Global Navigation Satellite System (GNSS) to pair spatial information with aerial photography captured by a custom Sony a7R camera affixed to the drone. After collection of raw data in the field, image and differential global position system (DGPS) data were processed using Trimble Business Center software, specialized for small Unmanned Aerial Systems (sUAS), to produce an orthoimage and digital terrain model (DTM).

The orthoimage data have a resolution range of 3.0 – 3.9 cm/pix, whereas the DTM has a 15 cm/pix spatial resolution. A DTM-derived, synthetic hillshade map was used as the basemap because it does not rely on color variance to convey data like the DTM and orthoimages. The orthoimages and DTM served as supplemental data sets and were valuable to our mapping efforts. We could effectively connect our field observations to the remotely sensed data, essentially providing virtual outcrops of the lava deposits to further analyze back in the lab. When forming facies descriptions, we paired the broad observations from the orthoimages with our local field observations.

## METHODOLOGY

We assembled the geomorphologic map of the Fissure 3 lava channel using methods developed by planetary geologic mappers who exclusively use remotely-sensed data (e.g. Greeley and Batson, 1990; Tanaka et al, 2014). Below we describe the methodology for the digital drafting parameters used for (1) defining the types of line features, (2) distinguishing the types and relevance of facies contacts, and (3) delineating facies groups and determining their names and symbols.

### Digital Drafting Parameters

We used Esri® (version 10.3, 1982-2015, Redlands, CA) ArcGIS® and ArcMap™ software packages to map on the data sets. Using digital streaming capability, we digitized lines and polygons in ArcGIS® to maintain legibility and consistency at the mapping scale. We set the vertex spacing of the linework to place points every 0.75 map units (75 cm) and kept the display consistent at 1:400 when drafting linework. These two specifications provide significantly detailed linework that is accurate at the 1:400 digitizing scale.

We digitally drafted linework using a WACOM Cintiq 21UX interactive pen display to map linework into an ArcGIS® digital geodatabase. This database uses the International Terrestrial Reference Frame (ITNF) datum, the Island Net 2004 (ISN2004) coordinate system, and a Lambert Conformal Conic projection. We populated this geodatabase with attribute domains for contacts and linear features based on the Federal Geographic Data Committee Digital Cartographic Standard for Geologic Map Symbolization (Federal Geographic Data Committee, 2006). The completed geodatabase retains attribute information for each vector feature within the mapping boundary.

We drafted linework by cross-examining the primary base map with the supplemental orthoimages to refine hillshade-based contact locations and establish unit descriptions. Contacts were iteratively cleaned to remove topological errors, and the cleaned linework was used to build geomorphological units as polygons. Though the final map that was drafted with these parameters will be released as a digital product, the geomorphologic map presented herein (Fig. 2) is too small to show the detail mapped digitally and was adjusted accordingly. Therefore, we exported the contacts and linear features into a new geodatabase and generalized the linework from the initial digitization. Linework was simplified and facies units were merged at a scale of 1:5,000 in order to present clear and accurate representation of the morphologies at 1:20,000. We rebuilt polygons after this simplification to show an accurate representation of the facies at this print scale of 1:20,000. Mapped features are limited to line feature lengths > 22 m and facies areas > 117 $m^2$ (Fig. 2). These restrictions mark a 1 mm lower limit for both lines and polygons in Figure 2; features smaller than this were removed for clarity. The statistics reported below apply to the generalized geodatabase used for the print map (Fig. 2).

### Line Feature Types

We identified two morphologic line features and one park service line feature. We aimed to map the morphologic features consistently but this was not wholly feasible or practical due to feature size, feature density, or obfuscation due to moss coverage. We mapped *axial clefts, arcuate ridges,* and *park trails* within the map area. We mapped 14 *axial clefts* that range from 22.5 m to 237 m in length, and 19 *arcuate ridges* that range from 83.1 m to 362.4 m. We removed *park trails* from the print map to maintain map clarity.

### Facies Contact Types

We attributed contacts based on both our interpretation of the contact's existence and the degree of certainty in its location and expression. *Certain* contacts (solid) delineate known boundaries that have precise locations between facies. *Approximate* contacts (dashed) delineate expected boundaries between facies but our certainty in the contact location is less precise. Approximate contacts were used when morphologic facies were subtle or gradational (or had complex boundaries), were moss-covered, or were ambiguous due to secondary processes. Both certain and approximate contacts separate discrete facies that differ in morphologic and/or topographic expression.

### Facies Groups, Names, and Symbols

We identify the units within our map area based on characteristic geomorphologic features and superpositional relationships for each facies. We mapped 182 facies polygons that range from 0.12 $km^2$ to 791.9 $km^2$ in area. To aid geomorphologic descriptions and stratigraphic correlations, we have grouped the facies into three temporal categories: Pre-Laki eruption, Laki eruption, and Post-Laki eruption (Tab. 1). Due to the density of facies contained within the Laki eruption group, we split this category into Tephra Facies and Lava Facies (Tab. 1). Excluding the Pre- and Post-Laki eruption facies, which are *Kipuka (K)* and *Sedimentary Infill (Si)* respectively, we label facies first based on their Tephra or Lava category, then by the geomorphologic area they occur, and finally by the key geomorphologic feature they contain (Tab. 1).

## DESCRIPTION OF FACIES

The focus of this project is the Fissure 3 lava channel. As such, facies that are older or younger

| | | |
|---|---|---|
| PRE-LAKI ERUPTION FACIES | | |
| | *Kipuka* | **K** |
| LAKI ERUPTION FACIES | | |
| Tephra Facies Group | | |
| Cone Tephra Facies | *Mantling Tephra* | **Tm** |
| | *Outer-Cone Building Tephra* | **$Tc_o$** |
| | *Inner-Cone Building Tephra* | **$Tc_i$** |
| | *Cone Floor Tephra* | **$Tc_f$** |
| Lava Facies Group | | |
| Channel Floor Facies | *Early-Stage Fissure 3 Valley Infill* | **$Lf_3$** |
| | *Fissures 4-5 Lava Flows* | **$Lf_{4-5}$** |
| | *Channel Overbank Lava Flows* | **Lco** |
| | *Channel Wall Lava* | **Lcw** |
| | *Undifferentiated Channel Floor* | **$Lcf_u$** |
| | *Polygonal Channel Floor* | **$Lcf_p$** |
| | *Hummocked Terrain* | **Lh** |
| | *Islands* | **Li** |
| Disrupted Facies | *Disrupted-Slab Terrain* | **$Ld_s$** |
| | *Disrupted-Rubble Terrain* | **$Ld_r$** |
| | *Arcuate Terrain* | **La** |
| POST-LAKI ERUPTION FACIES | | |
| | *Sedimentary Infill* | **Si** |

*Table 1. Organization of mapped facies names, labels, and grouping. Facies names are in italics and facies labels are bolded. Grey vertical lines indicate which facies names correlate with which subgroup titles.*

than the 1783-1784 Laki eruption and facies that are not sourced from Fissure 3 are combined into undifferentiated units. The descriptions of the following facies were initiated by the collection of field-observations and bolstered by observations made through digital mapping. For facies names, labels, and grouping refer to Table 1.

### Pre-Laki Eruption Facies

The Pre-Laki Eruption facies mapped are *Kipuka*

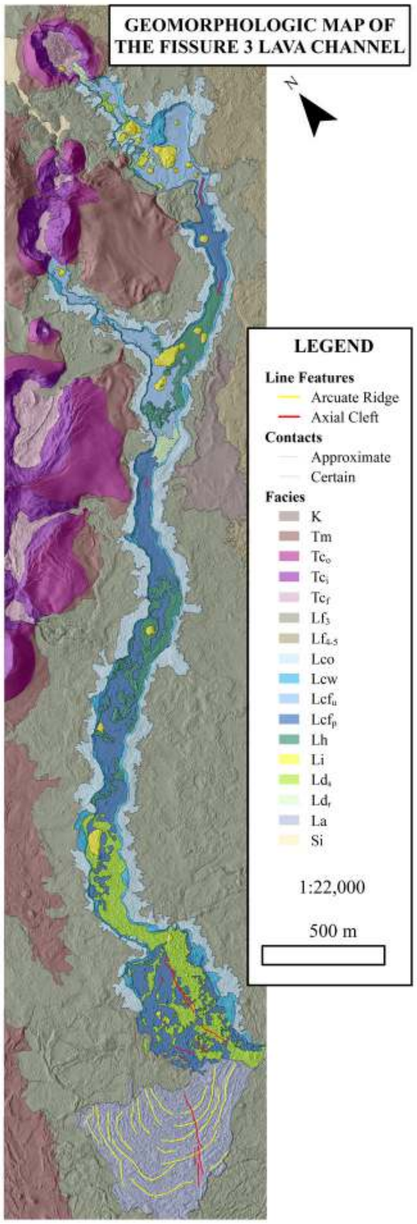


*Figure 2. Geomorphologic map of the Fissure 3 lava channel. This map is printed at 1:20,000 and mapped features overlay the synthetic hillshade (15 cm/pix) with 50% transparency. The data frame is rotated 37° west of north; true north is indicated by the arrow in the upper right-hand corner. Map features and corresponding symbology are indicated in the legend; for full facies names refer to Table 1.*

(K). *Kipukas* are isolated exposures of the terrain existing before the Laki Eruption occurred. They are pervasively covered by a top-soil and varying amounts of moss. *Kipukas* typically have certain contact with *Fissures 4-5 Lava Flows* ($Lf_{4-5}$) and *Channel Overbank Lava Flows* (Lco).

## Laki Eruption Tephra Facies

The Laki Eruption tephra facies correspond to either mantling facies or cone facies. The *Mantling Tephra* (Tm) facies occurs along the western edge of the map area and is concentrated along Lakagígar. *Mantling Tephra* (Tm) is composed of tephra and spatter and is loosely consolidated. This tephra (Tm) grades with the Cone Tephra facies and *Sedimentary Infill* (Si).

The Cone Tephra facies are the *Outer-Cone Building Tephra* ($Tc_o$), *Inner-Cone Building Tephra* ($Tc_i$), and *Cone Floor Tephra* ($Tc_f$), and all occur along the cones of Lakagígar. The outer cone tephra ($Tc_o$) is a tephra mantled surface, the inner cone tephra ($Tc_i$) is composed of layers of tephra and spatter that vary in thickness, and the cone floor ($Tc_f$) is a mix of tephra, spatter, and lava, and commonly has ridges in its center or along floor margins. The boundary between the outer cone ($Tc_o$) and inner cone ($Tc_i$) is the cone rim. The boundary between the inner cone ($Tc_i$) and cone floor ($Tc_f$) is more ambiguous but tends to follow a continuous topographic inflection point. Each mapped cone has a breach point where lava has flowed from the cone floor ($Tc_f$) and into the valley; the contact between the cone floor ($Tc_f$) and the exiting lava flow lies where the floor has transitioned to predominately undifferentiated lava.

## Laki Eruption Lava Facies

The Laki Eruption facies not related to the Fissure 3 lava channel are *Early-Stage Fissure 3 Valley Infill* ($Lf_3$) and *Fissures 4-5 Lava Flows* ($Lf_{4-5}$). Early Fissure 3 lavas ($Lf_3$) occur on the western side between Lakagígar and the Lava Channel group facies, and Fissures 4-5 lavas ($Lf_{4-5}$) occur in the northeast along the map boundary. Early Fissure 3 lavas ($Lf_3$) are predominately varying types of lava flows with infrequent occurrences of tephra and spatter; Fissures 4-5 ($Lf_{4-5}$) a sheet-like lava flow with pervasive pressure ridges and lobe-like flow margins. Both Early Fissure 3 ($Lf_3$) and Fissure 4-5 ($Lf_{4-5}$) lavas have distinct contact margins, with Early Fissure 3 lavas ($Lf_3$) extruding from Lakagígar cones and being encroached by *Channel Overbank Lava Flows* (Lco) and with Fissures 4-5 lavas ($Lf_{4-5}$) embaying the *Kipukas* (K) and all other Laki Eruption Lava facies in this map area.

The Lava Channel facies group has *Channel Overbank Lava Flows* (Lco) bordering a majority of the outside margins of the channel, *Channel Wall Lava* (Lcw) marking the edges of the lava channel, and Channel Floor facies group in the interior of the lava channel. The overbank flows (Lco) are lobe-like lava flows that have dendritic margins and pahoehoe toes. The channel wall (Lcw) has layered lava flows that are commonly interbedded with spatter and infrequent interbedded with tephra layers. Infrequent locations of the channel wall (Lcw) are covered by a vertical sheet of lava that is commonly fractured and frequently has spackle and lava drips. Rubble margins of cobbles and boulders are commonly adjacent to the channel wall (Lcw) and are included in this facies. The outer boundaries of the overbank flows (Lco) are distinct and the inner boundaries in contact with the channel wall (Lcw) are marked at the edge of the upper-most layer of the channel wall (Lcw). The contact at the base of the channel wall (Lcw) within the channel varies depending on which Channel floor facies it is in contact with.

There are six types of Channel Floor facies mapped in the lava channel: *Undifferentiated Channel Floor* ($Lcf_u$), *Polygonal Channel Floor* ($Lcf_p$), *Hummocked Terrain* (Lh), *Islands* (Li), *Disrupted-Slab Terrain* ($Ld_s$), and *Disrupted-Rubble Terrain* ($Ld_r$). *Undifferentiated Channel Floors* ($Lcf_u$) are concentrated in the northern part of the Eastern Branch of the channel but, there are isolated occurrences of undifferentiated channel floors ($Lcf_u$) to the south. This floor is smooth and pervasively planar with no distinctive morphologic characteristics. Undifferentiated channel floor ($Lcf_u$) contacts are certain with channel walls (Lcw) and other Channel Floor group facies, but it grades with polygonal channel floors ($Lcf_p$) with those contacts mapped approximately along the edge of the first whole polygon.

Polygonal channel floors ($Lcf_p$) are located wall-to-wall in the southern portion of the Eastern Branch and south of the Confluence, and then is pocketed around Disrupted group facies in the southern portion of the Main Branch. It is characterized by interlocked polygonal shapes on a smooth channel floor. Where polygonal channel floors ($Lcf_p$) are mapped across the width of the channel they form a dome-like cross section with the outer 5-10 m margins of the polygonal floor ($Lcf_p$) dipping towards the channel wall (Lcw). Commonly when the polygonal channel floor ($Lcf_p$) is in contact with *Islands* (Li) or hummocks (Lh), margins <5 m also dip towards these features. This dip is rare when polygonal floors ($Lcf_p$) are in contact with Disrupted group facies. More notably, there is a distinct lack of this dip within Chaos Pond where the polygonal channel floor ($Lcf_p$) actually has a slight upward slope to meet the channel wall (Lcw), the disrupted-rubble terrain ($Ld_r$), and the arcuate terrain (La). The contacts of polygonal channel floors ($Lcf_p$) are frequently certain throughout the map, with infrequent approximate contacts along channel walls (Lcw) and Disrupted group facies.

Hummocks (Lh) and *Islands* (Li) are similar to each other as they both create topographic highs within the lava channel, but there are two distinct differences between the two. (1) Hummocks (Lh) can occur as either isolated hummocks or as a continuous hummocky terrain but *Islands* (Li) only occur as isolated promontories, and (2) hummocks (Lh) are defined as being capped by lava slabs similar to those characterizing disrupted-slab terrain ($Ld_s$) whereas *Islands* (Li) are not capped by lava slabs. Both hummocks (Lh) and *Islands* (Li) occur throughout the lava channel and both contain one of three identified core types: primary cone tephra, rootless cone tephra, or levees. Primary cone tephra are pieces of cone tephra rafted down the channel from one of the lava source cones. Rootless cone tephra are either in situ or rafted occurrences of secondary lava fragmentation. Levee cores are portions of the channel wall (Lcw) that have broken off and rafted into the lava channel while the channel processes were still active. Both hummocks (Lh) and *Islands* (Li) have pervasive certain contacts, but there are infrequent approximate contacts between hummocks (Lh) and channel walls (Lcw).

The two Disrupted group facies occur throughout the lava channel. The primary distinction between the two are whether the disrupted material are predominately slabs ($Ld_s$) or rubble ($Ld_r$). The pieces of disrupted slabs (Lds) range from slightly tilted to overturned. The pieces of disrupted rubble ($Ld_r$) range from cobble to boulder size. The contacts for both disrupted-slab terrain ($Ld_s$) and disrupted-rubble terrain ($Ld_r$) vary depending of the facies they are adjacent to.

The final Lava facies is *Arcuate Terrain Lava* (La) and is located at the end of the lava channel within the southern portion of Chaos Pond. It is characterized by long, arcuate pressure ridges that are uniform in direction and south-facing convexity. There is a grade between the arcuate terrains (La) and disrupted-slab terrains ($Ld_s$), with disrupted-slab terrains ($Ld_s$) lacking the mappable uniformity and size of the arcuate ridges found within the arcuate terrain (La). Arcuate ridges are also mapped exclusively within the arcuate terrain (La). The contact surrounding the arcuate terrain (La) is certain with isolated ridges projecting out of the pond in infrequent areas.

### Post-Laki Eruption Facies

Post-Laki eruption, there has been no volcanic activity in this area leaving sedimentary processes as the current geologic activity. A small channel has been cut into the *Mantling Tephra* (Tm) and Early Fissure 3 lavas ($Lf_3$) between the two northern-most cones and has created a sedimentary plain in the northwest corner of the map area which is mapped as *Sedimentary Infill* (Si). This infill (Si) is composed of sand, gravels, and re-mobilized tephra. Contacts with the *Sedimentary Infill* (Si) are approximate due to the subtle sedimentary processes eroding surrounding units and depositing the infill.

## DISCUSSION

From our mapping results, there are three observations that improve our preliminary understanding of the lava ponding events. First, we analyzed where the polygonal floor ($Lcf_p$) does not dip down along channel wall (Lcw) margins and interpret the presence of a slight upward slope as support for pond draining in these locations. Next, if the channel ponded and then drained the distinction between the lava slab capped hummocks (Lh) and the uncapped *Islands* (Li) suggests we can track where the pond high-stand might have been at various stages of ponding. Finally, if there was pond drainage, the arcuate terrain is an indicator for direction and flow dynamics of the lava drain based on the convexity of the arcuate ridges and the physics behind their formation if they are in fact pressure ridges.

More work should be done in this area to further investigate both the lava ponding history as well as improving the facies map produced for use in future scientific investigations. Ground-truthing of promontories as either hummocks or *Islands* within the channel should be conducted, along with identifying what the cores of those hummocks and *Islands* are. Additionally, contacts along overbank flows and their adjacent facies should be traversed to ensure proper mapping of the last occurrence of lava overflow. The descriptions of the facies herein could also benefit from more detailed field-observations coupled with the identification of type localities. The additional collection of this data would serve to combine traditional field-mapping methods with those for mapping of remotely-sensed data, resulting in an advanced map product.

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