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CHARACTERIZING DEVELOPMENT OF CHANNELIZED LAVA FLOWS AT KRAFLA VOLCANO, ICELAND

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INTRODUCTION

Lava channels are an especially hazardous component of volcanic eruptions because they allow lava to travel farther than it normally could outside the channel. The insulation from the channel walls, and oftentimes a roof, allows the lava to remain hotter for longer periods of time, keeping the viscosity low and allowing the lava to travel longer distances. In order to better understand their emplacement and to more effectively prepare for the damage they can cause, lava channels must be studied in greater detail.

In this study, I use the model of Riker et al. (2009), developed for Hawaiian lava channels, and that of Deardorff & Cashman (2012), as applied to Collier Cone in Oregon, to study lava channels of the 1984 eruption of Krafla volcano in northern Iceland. Riker et al. (2009) examine a 51 km long lava flow, 36 km of which is channelized, that formed during the 1859 flank vent eruption of the Mauna Loa Volcano in Hawaii. The authors use bulk composition, glass geothermometry, and microlite texture variations along the flow to assess flow dynamics. They also use historical chronicles to determine the viscosity, temperature, and other conditions associated with flow emplacement. Deardorff & Cashman (2012) use Light Detection and Ranging (LiDAR) technology to analyze digital terrain models (DTMs) of the Collier Cone in Oregon, along with geographic information systems (GIS) techniques to gather morphological data of the lava flow. These data are then applied to empirically derived equations from Kerr et al. (2006) which use slope, channel width, and other parameters to estimate effusion rates and emplacement times for a flow.

Three Krafla lava channels were chosen for analysis during my study (Figure 1). They range in length from 27 to 83 m, their widths span 1.5 to 4 m, and their average slopes vary from a shallow 2° to 15° (Table 1). The first flow formed from the collection of spatter from a nearby spatter ridge. As the lava collected and pooled, it came to a sharp break in slope at the edge of the ridge. The lava flowed down the side of the ridge, the steepest slope of the channel, at approximately 25°. This channel, based on its shallow depth and poorly

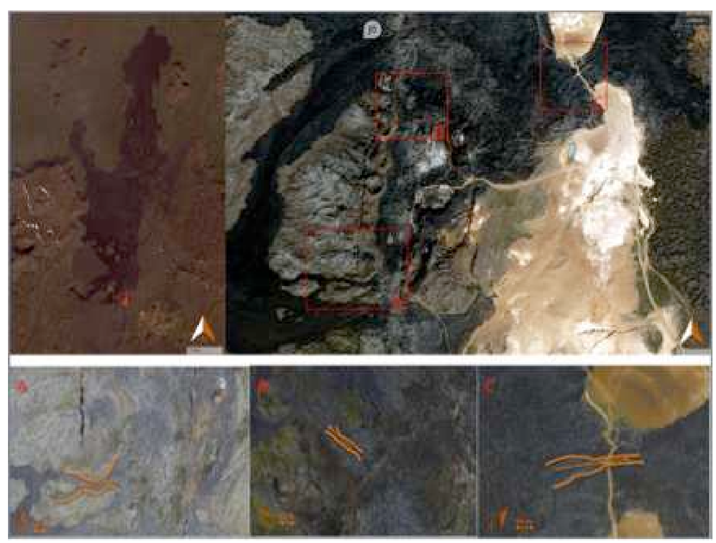


Figure 1. Created with the help of www.ja.is and aerial photos taken from a drone operated by Jeff Karson. The upper left image is a satellite view of the entire flow area of Krafla. The red box in this image is magnified in the image on the top right. This image displays the areas of the three channels of this study, outlined in red boxes. Box A correlates to the image on the bottom left, which is an aerial photo of the first channel of this study. The channel is outlined in a dashed orange line and the flow direction is indicated with an arrow pointing down the center of the channels. The same is true for the other channels, B and C.

	Flow 1	Flow 2	Flow 3
Source	Spatter ridge	Lava lake	A`a outbreak
Average slope	15°	8.5°	2°
Channel length	83 m	27 m	64 m
Channel width	1.5 m	2 m	4 m
Levee height	0.5 m	1 m	0.2 m

Table 1. Summary of morphological data collected at Krafla Volcano.

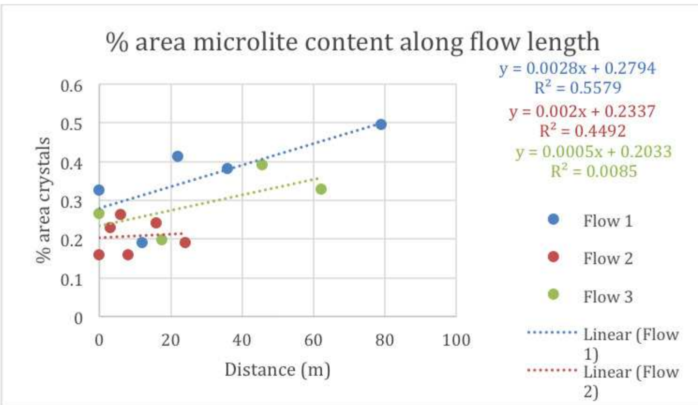


Figure 2. Percent microlite area along the length of each flow. Positive slopes of each trend line of each flow show a weak positive correlation between microlite content and distance along the flow. Increasing microlite contents along the length of the flow adds to the increasing viscosity of the flow, which leads to its eventual halt.

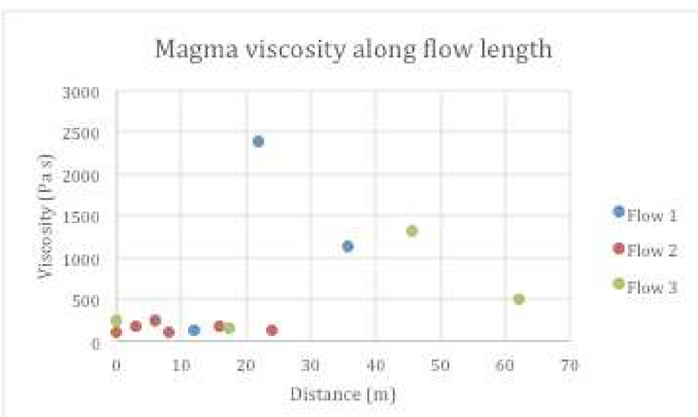
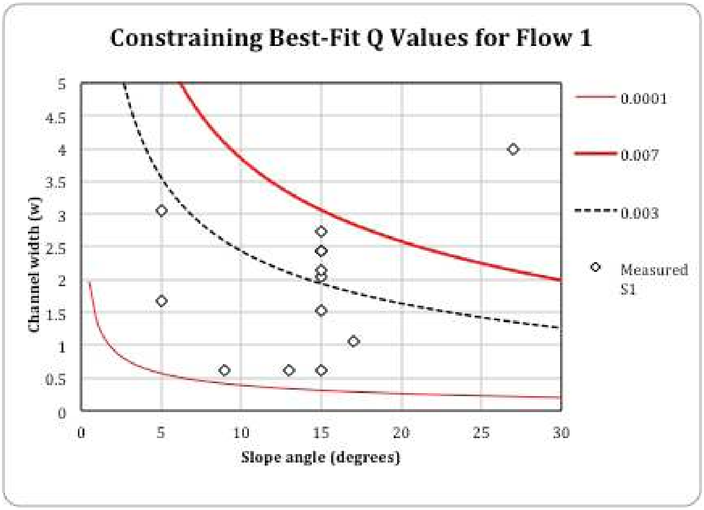


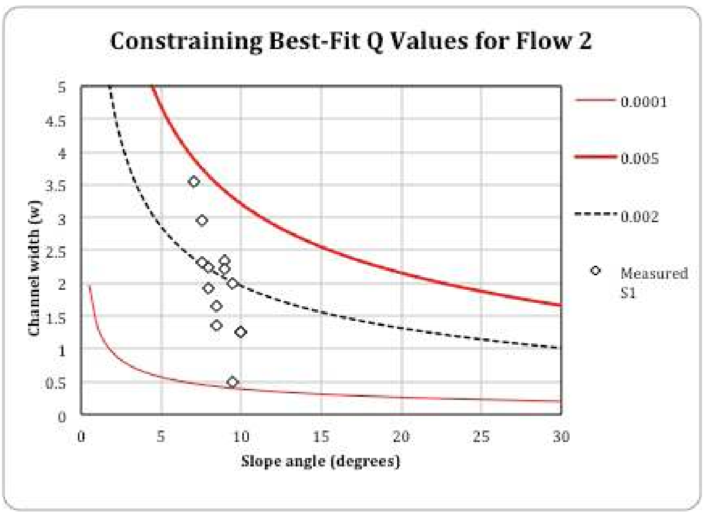
Figure 3. Magma viscosity as a function of distance along the flow. One point along Flow one was omitted as its viscosity was orders of magnitude higher than the rest of the values. This point is assumed to be an area of the flow that had stopped flowing due to its intense crystallization.

developed levee walls, was likely the shortest lived of the three examined. The second flow has much more highly developed levee walls that range from 0.6-1.5 m in height. For much of the channel's length the levees have a rounded top. The floor of the channel has some areas of intact pahoehoe sheets, which could have at one point been the channel roof. Near the flow terminus, the levees break down and the flow becomes mostly a'a. The third flow formed during an outbreak from an a'a flow; it is the widest of the three, ranging from 3-5.5 m, and is the only channel for which the roof is mostly intact. There is only one small area of the channel where the roof has detached from the levee walls, 45 m down the flow. At this site, the levee walls are exposed, and a layered "bathtub ring" texture is observed, suggesting that the flow of lava in the channel was not consistent, that either increased flow rates or blockages of lava down-flow caused the height of the lava in the channel to fluctuate. The roof of this flow is quite thick, ranging from 15-35 cm. This flow has the shallowest slope of the three flows examined. Guided by the Riker et al. (2009) and Deardorff & Cashman (2012) models and methods my goals are to (1) assess the eruption conditions associated with emplacement of these three small flows and explore implications from Krafla, (2) compare results to independent observations/deductions of the Krafla flow dynamics, and (3) evaluate the usefulness of the quantitative methods, each developed for much longer flows, when studying basaltic events in a different location and operating at a very different scale.

METHODS

Fieldwork was completed at Krafla volcano in northern Iceland in accordance with the field methods of Riker et al. (2009). I collected samples of the channel floor and levee walls at regular intervals along each channel length, and also from each channel's source. Sampling from the floor allowed for the most representative sample of the lava that was running through the channel. When collecting samples, I avoided parts of the lava flow that had moss or other organic material on them, as well as bits of the flow that had been physically or chemically weathered. I collected fist-sized samples in order to be able to create thin sections and XRF beads. Morphological data were collected to be applied to the Deardorff





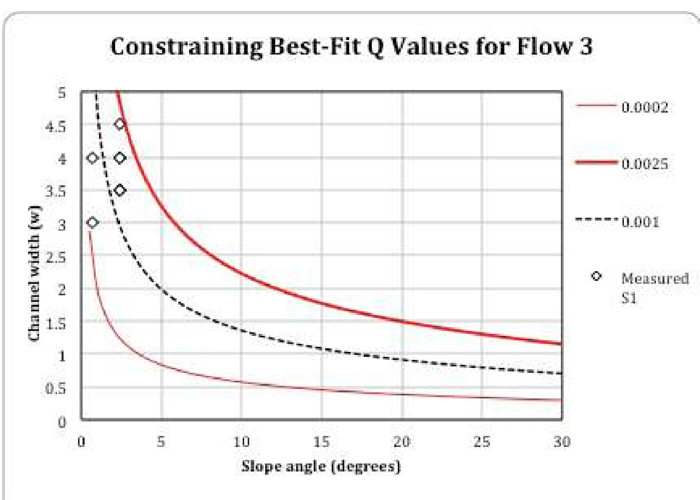


Figure 4. Q plots for each flow. Plots the upper and lower bounds for effusion rate (Q) of each flow as well as the best-fit effusion rate. These lines confine the points, which are measured channel widths vs the slope of the flow at that point. The effusion rates of these flows are quite low, most likely having to do with their short length and small widths

&Cashman (2012) model, which utilizes channel slope and width. Samples were analyzed for bulk geochemistry composition using the Pomona College Geology Panalytical Axios X-ray fluorescence (XRF) laboratory. These data were used to determine the density of the melt during the flow of the channels (e.g., Bottinga & Weill, 1970). Viscosity of the melt was determined using of the model of Giordano et al. (2007). These parameters were used in the equation employed by Deardorff & Cashman (2012) to determine the volumetric effusion rate of the flows. Finally, these results were compared to the results of the Riker et al. (2009) model to constrain the eruption conditions of the channelized flows during the 1984 eruption at Krafla Volcano.

RESULTS

Using the equation in Riker et al. (2009) developed by Montierth et al. (1995), the temperature of the lava as it was flowing through the channels at Krafla can be calculated based on the bulk chemistry:
T(°C) = 23.0 × (wt.% MgO) + 1012.
For MgO contents of ~6 wt%, these temperatures equate to ~1150 °C at each point evaluated along each flow. The corresponding melt viscosity of the three flows is 70.775 Pa s, and variations along each flow's length are not significant (+/- 4.895 Pa s).
Magma viscosities were determined by accounting for microlite crystal concentrations in each sample following Riker et al. (2009); the more distal the sample, generally, the higher the microlite content (Figure 2 and 3). Melt densities (3200.273 +/- 10.732 kg/m^3), like viscosity, show little variability as a function of position within any given flow.
Effusion rates for each flow were determined using the methods of Deardorff & Cashman (2012) (Figure 4). These methods include the equation developed by Kerr et al., (2006):

$$w_p = 2\left|\frac{(g\rho)^2 Q^7 \mu^4 \cos^4\theta}{\sigma_c^6 \kappa^3 \sin^7\theta}\right|^{\frac{1}{13}},$$

where w_p is the predicted channel width, g is the gravitational constant (9.8 m/s^2), ρ is density (3200 kg/m^3), Q is volumetric effusion rate (target of calculation), μ is viscosity (70 Pa s), θ is slope (field-derived), σ is crustal yield strength (2MPa), and κ is thermal diffusivity (10^{-6} m^2/s). Best-fit effusion rates for flows one, two, and three are 0.003, 0.002, and 0.001 m^2/s, respectively and are determined by calculating the root mean square error (RMSE) that compares the observed channel widths (w) to the predicted channel widths (w_p):

$$RMSE = \left\{\frac{1}{n}\sum_{i=1}^{n}\left(w - w_p\right)^2\right\}^{\frac{1}{2}}.$$

DISCUSSION

Harris et al. (2007) use Advanced Very High Resolution Radiometer (AVHRR) data collected during the 1984 eruption at Krafla volcano to obtain the temperature of the lava at the time of eruption, 1050 °C. When compared to the temperature determined through the use of the Riker et al. (2009) method the results of each are in good enough accordance to assume that the method used by Riker et al. (2009) can be applied to the 1984 eruption of Krafla volcano to determine eruption temperature. When using 1050 °C for calculations of viscosity and effusion rate, the best-fit Q only changes by 0.0025 m^3/s. Riker et al. (2009) found that high effusion rates and high eruption temperatures were the two most important eruption conditions that caused the extremely long flow of the 1859 eruption of Mauna Loa volcano. In the current study I found low effusion rates and average temperatures for its three short flows. A previous study done on one lava channel at Krafla volcano found effusion rates ranging from 0.0051-0.23 m^3/s (Browne, 2015). The best-fit effusion rates of this study are just below the bottom of this range, and again imply very low volumetric flow values, helping to explain why the channels reached only very short lengths before halting propagation.

One major difference between the Krafla channels and the channel studied by Riker et al., (2009) is the change in temperature along the lengths of the flows. The Icelandic flows do not vary in temperature along the length of the flow, while the Hawaiian flow does vary greatly. This could be explained by the exceptional difference in the length of the channels of each study. Although the methods of Riker et al. (2009) give a good value for the overall temperatures of the Krafla flows, the Riker et al. (2009) methods cannot be applied to find variation of temperature along the short flows of Krafla because the differences between the values are too small.

The Icelandic channels are not long enough to vary much along their length in more ways than just temperature. Their short length can also explain why there is not much variance in melt viscosity or density values along the length of the flow. There is variance, however, in the percent microlite area and hence magma viscosity down the length of each flow. Increasing microlite content further down the channel can account for the termination of flow of the lava. As microlite content increases and approaches its maximum packing fraction (50%; Marsh, 1981), viscosity increases as well, until the lava reaches a threshold when it contains too many microlites to be able to flow. This change in viscosity along the flow is consistent with the little change in temperature along the flows, suggesting the flow lengths were not temperature limited. Instead, the increase in microlite content had a more profound effect on the viscosity of each flow than the change in temperature, eventually causing the flow to come to a stop. This result shows that the Riker et al. (2009) methods for determining microlite content along the flow and its relation to viscosity can be applied to the short Krafla flows.

CONCLUSION

The combination of the various models used in this study (Deardorff & Cashman, 2012; Riker et al., 2009; Giordano et al., 2007; Bottinga & Weill, 1970) shows that many different methods can come together to develop the eruption history of the 1984 eruption of Krafla volcano. Despite the many differences between the eruption conditions of the 1859 eruption of Mauna Loa Volcano and the 1984 eruption of Krafla volcano, similar methods can be used on both flows to give meaningful results that are unique to each eruption. Further research on other flows from other eruptive environments should be done to determine whether or not these methods can be applied to even more basaltic eruptions.

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REFERENCES

Bottinga, Y. and Weill, D., 1970. Densities of liquid silicate systems calculated from partial molar volumes of oxide components: American Journal of Science, v. 269, p. 169-182.

Browne, N. C., 2015, Size of perched lava ponds as a product of volumetric flux: Keck Geology Annual Symposium, 28th, p. 1-6.

Deardorff, N. D. and Cashman, K. V., 2012, Emplacement conditions of the c. 1,600-year BP Collier Cone lava flow, Oregon: a LiDAR investigation: Bull Volcanol, v. 74, p. 2051-2066.

Giordano, D., Russell, J. K., Dingwell, D. B., 2007, Viscosity of magmatic liquids: A model: Earth and planetary science letters, v. 271, p. 123-134.

Harris, A. J. L., Vaughan, R. A., Rothery, D. A., 2007, Volcano detection and monitoring using AVHRR data: the Krafla eruption, 1984: International Journal of Remote Sensing, v. 16.

Kerr, R. C., Griffiths, R. W., Cashman, K. V., 2006, Formation of channelized lava flows on an unconfined slope: Journal of Geophysical Research, v. 111, B10206.

Marsh, B. D., 1981, On the crystallinity, probability of occurrence, and rheology of lava and magma: Contributions to Mineralogy and Petrology, v. 78, p. 85-98.

Riker, J. M., Cashman, K. V., Kauahikaua, J. P. & Montierth, C. M., 2009, The length of channelized lava flows: Insight from the 1859 eruption of Mauna Loa Volcano, Hawaii: Journal of Volcanology and Geothermal Research, v. 183, p. 139-156.