PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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COMPARISON OF NATURAL AND EXPERIMENTAL BASALT AS AN INVESTIGATION OF PAHOEHOE-‘A’A TRANSITIONAL SURFACE TEXTURES

MARY BROMFIELD, Syracuse University
Research Advisor: Jeffrey Karson

INTRODUCTION

The most common types of macroscopic lava flow morphology are ropy pahoehoe and blocky ‘a’a. The details of these flows have been widely studied in terms of their viscosity, flow rates, chemical composition and other parameters in order to determine what causes these specific flow morphologies to form. On a finer scale, (few centimeters) their surface textures are also potentially important features in understanding flow behavior and properties. The transitional surface textures that occur when basalt changes from pahoehoe to ‘a’a have been briefly described in literature as being “less glossy than pahoehoe” having “rougher surfaces” and “lumpy relief” (Robert et al., 2014). According to Polacci et al., (1998), the lava characteristics that have proven useful for past researchers examining why the transition from pahoehoe to ‘a’a occurs, are changes in vesicularity, vesicle deformation, and crystallinity. Manga et al. (1998), on the other hand, claim that the rheology of bubble- bearing magmas is a function of the volume fraction of bubbles and the amount of deformation. Crystallinity can also play a key role in the kinematics of lava flows and subsequently their surface textures (Marsh, 1988).

It is uncertain however, what parameters control the formation of the finer surface textures. The study objective is to explain how surface textures form, and what aspects of a lava flow affect this process. Through the use of analog lava experiments with the SU Lava Project textures observed at Krafla volcano were re-created by simulating topography and flow conditions encountered at the Krafla flow on a smaller scale. Using the comparison of the two very different flow conditions that produced the same texture, vesicle/ crystal/ glass population, viscosity and flow kinetics were analyzed in order to understand the effect of these properties on the formation of transitional surface textures.

SAMPLE ORIGIN AND COLLECTION

Krafla Volcano Samples

Krafla Caldera, in Northeastern Iceland, erupted most recently during the Krafla fires (1975 to 1984), creating a landscape rich with spectacularly preserved basaltic lava flow textures and structures. Nicholson & Latin, (1992) conducted chemical analysis on the lava flows at Krafla and showed that the material has a typical composition of basalt, rich in silica and aluminum.

Surface textures on flows transitional between pahoehoe and ‘a’a were observed at three sites in the area. Typical surface textures of pahoehoe lava are smooth and lineated with ropy folds with parabolic hinge lines.

The folds generally have 2-3 cm of relief, but larger, thicker flows can have folds with nearly 10 cm amplitudes. The transitional surface texture originates as pahoehoe surface textures and grades into disjointed and fragmented pieces. These fragments are found on the outer edges of the flows in clusters or groupings. The fragments are rounded, cylindrical shapes that are pinched at each end like an eye. The shapes are then stretched in the direction of flow so that they are over-lapping one another, in a braid-like pattern. The transitional texture lacks the coherent organization and symmetry of the surface textures that occur on pahoehoe, and usually has ~1-2 cm of relief (Figure 1). This area of transitional braided textures covers small areas (less than 1 m^2) or large expanses (several meters across) along a flow. Beyond the transitional texture, the lava may or may not fully transition into ‘a’a, which has sharp, pointed surface textures on jagged, randomly sized blocks. The surface textures of ‘a’a are not consistently the same shape or size, but they are always sharp glass-like points and shards. At each field site, measurements of the dimensions of each flow (10’s of meters in length by <10 meters in width), as well as slopes of each section of the flow and scaled photographs were taken. Hand samples of the transitional texture as well as the pahoehoe and ‘a’a basalt surrounding it were collected and documented. This information is useful for reconstructing the topography for analog experiments and creating comparable samples.

The first field site is an outlet lava tube fed from an inflated lava lake up slope, the site includes several pahoehoe overflow sections from the lake that spill over the cliff and transition to ‘a’a. At this site, the transitional texture occurs on the outer skin of the lava tube, above the point where the lava spills over the cliff.

The second field site is again an overflow from a lava pool, where two pahoehoe tongues flow over a steep slope with an inflated pyroduct between them. There are several episodes of spill-over along these two tongues as a result of the eruption, and the transitional texture occurs along the sides of the flow where build-up of the lava has created a thick layer. Again, the texture is up slope in the flow, above the point where the lava spills over the cliff.

The third field site is again a flow over a relatively flat surface that drops off of a cliff. Large piles of clinkery ‘a’a occur next to the smooth pahoehoe folds at this site, and indications of reheating within the ‘a’a and a subsequent breakout during the time of the eruption are present, evidenced by cross-cutting striations in the preserved basalt. The smooth flow over the flat surface at the edge of the cliff above the point of drop-off is where the transitional texture occurs at this site.

Initial observations at the field sites show several

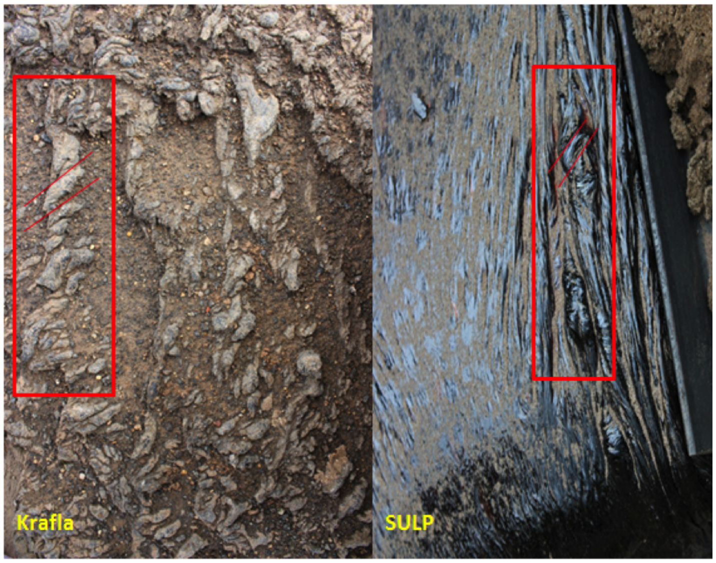

Figure 1. Transitional basaltic surface textures that were analyzed, seen as part of an open flow at Krafla volcano on left and experimentally made with a channelized flow at the Syracuse University Lava Project on the right.

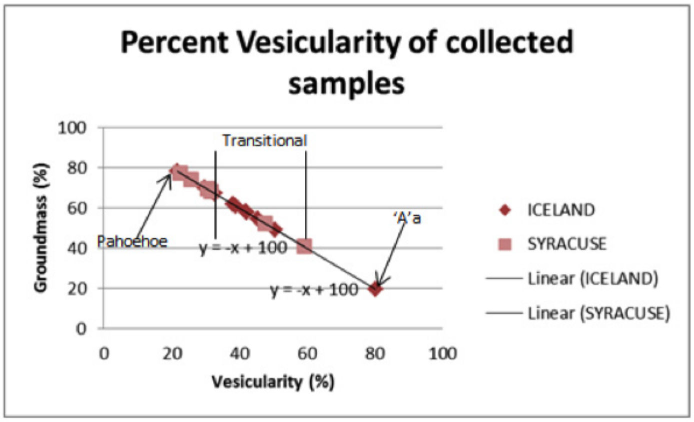

Figure 2. Scatter plot of the percentage of vesicularity vs. groundmass in each suite of samples, as shown, the majority of both samples fall between 20-40 % vesicles. All Syracuse samples included are of the transitional surface texture up to ~4cm below the surface and Iceland samples of pahoehoe, a’a, and transitional textures are displayed for comparison and were taken from the surface up to ~8cm below the surface.

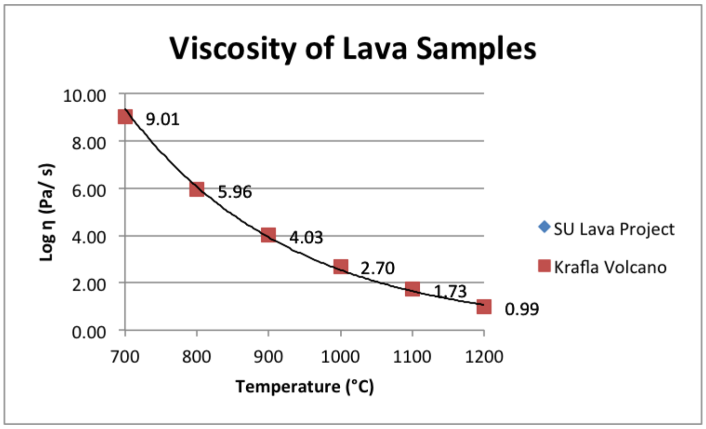

Figure 3. Plot of viscosity versus temperature of Syracuse University Lava Project material based on chemical analysis by Peterson, (1979) and Nicholson, et al., (1992) and generated by the Giordano, et al., (2008) viscosity model. Each set of data generated identical viscosity curves, and the transitional temperature range for Syracuse University is approximately at the 900 degree mark, the transitional temperature range for the Krafla samples is unknown.

similarities, including that this texture occurs on low-slope surfaces above the point of drop-off over a cliff and that, in all cases, they are seen in areas where both ropy pahoehoe and clinkery ‘a’a are also preserved surrounding it.

SYRACUSE UNIVERSITY LAVA PROJECT SAMPLES

Analog experiments were conducted with the goal of re-creating the braided-looking, overlapping transitional surface texture that occurs at Krafla. At the SU Lava Project, we utilized the facilities large furnace to melt down basalt originating from the Dresser Trap Rock Quarry in Polk Co., Wisconsin (Karson & Wysocki, 2013). With temperatures of molten lava reaching approximately 1300° C, the furnace which is mounted on a tilt axis is capable of pouring up to 450 kg of lava to simulate natural basalt flows.

With the dry sand pit underneath the furnace trough, we manipulated the experiment design to scale down the landscape that the lava has flowed over at Krafla and keep as many variables constant as possible. Keeping the slope at the beginning of the flow shallow

Figure 4. Sequence of development of transitional surface textures (yellow circle) in the recreated conditions of the SU Lava Project. Time elapsed from frame 1 to frame 6 is ~80 seconds, red/ orange lava is ~1,100°C, black lava is ~700-800°C.

Name	% Vesicle	% Crystal	% Glass
ICE1-1	42	56	2
ICE1-2	22	58	20
ICE1-3	46	33	21
ICE1-6	30	35	35
ICE2-1	42	18	40
ICE2-2	38	20	42
ICE2-5	51	14	35
ICE2-6	32	55	13
ICE3-1	80	2	18
ICE3-2	33	57	10
ICE3-3	39	58	3
SULP2-1	31	2	67
SULP2-2	26	5	69
SULP2-3	48	3	49
SULP2-4	59	5	36
SULP2-5	23	5	72
SULP2-6	32	5	63

Table 1. Percentage by area of vesicles, crystals and groundmass in the Krafla volcano samples and the SU Lava Project samples calculated by IMAGEJ64 for vesicularity and estimation methods for percent crystallinity. Those highlighted indicate transitional surface textures from each suite of samples. Samples ICE1-1, 2-1, 2-5, 3-1, 3-3 are pahoehoe, and samples ICE1-6, 2-2, 2-6, 3-2 are 'a'a.

(close to 2-5°), with a 90 degree drop and then a flat surface beneath the cliff, we were able to recreate the transitional surface texture that occurs at Krafla. The texture is observed at the same point on the flow transition as seen at Krafla, on the flat surface of channelized flow above the point where the cliff drops off. Like the flows at Krafla, measurements of the flow dimensions slope and scaled photographs are included in data collection. Video of the lava flow documents the flow progression and details of the movement of the material. Also, FLIR infrared imagery is utilized to determine temperatures of the flow surface at each point in the experiment, as well as to calculate cooling rates. The calculated flow rate from video is 0.0061 m/s.

With three trials of the experiment conducted, some with more than one flow on top of another, simulating the several layers of lava overflow from the lava lakes in the field (described previously at Krafla site 2). The sample of lava produced with the transitional texture was collected for further analysis.

Video shows that this texture forms on the low-angle surface above a drop-off or cliff. The lava begins to form a crust on the outer edges and channelize, forming high-angle ropes of lava to the direction of flow that get pulled along with the molten stream of lava that flows over the cliff. In some flows, a breakout or additional burst of molten material detaches chunks that get mixed into the molten material, and this tearing and then solidifying with cooling results in the surface texture. From purely a standpoint of motion, this could likely be the mechanism by which this texture forms, much like pulling a long rope of bread dough apart, the pahoehoe ropes become more viscous with cooling and pull apart making the disjointed cylindrical shapes that pinch off on either end. However, motion is not the only factor that determines flow behavior, so further investigation is necessary.

SAMPLE ANALYSES

Further analyses of the samples were done on a microscopic level. The samples from Krafla are highly vesicular, with well-developed crystals of plagioclase and pyroxene. The samples from the SU Lava Project experiments are similarly vesicular but with less than 5% crystal development, most of the groundmass is simply basaltic glass (Table 1). In the experiment, the thin sections are reduced to black and white binary images and analyzed with the ImageJ64 program and methods in order to determine percent area of vesicles (Figure 2). Similar methods have been used in several experiments to assess the nature of thin sections quantitatively (Ni et al., 2014: Higgins, et al. 2000).

Approximate percentages of crystal and glass in the material were determined by visual estimations (Table 1). The samples taken from the most analogous sections of the Krafla and SU suites could then be compared for similarities or differences in the amount of vesicles, crystals and glass to determine the importance of these factors in creating the transitional surface texture.

Viscosity is also an important factor used to understand flow behavior in terms of temperature and silica content. Chemical analyses by Peterson, (1979) and Nicholson et al., (1992) are utilized to produce a viscosity model (Giordano et al., 2008) (Figure 3). We use this curve to observe the temperature/ viscosity relationships because the compositions of the two materials are very similar.

DISCUSSION

Viscosity and Flow Kinematics

The viscosity of magmatic liquids has long been a means for scientists to assess lava behavior, and as Sehlke et al. (2014) point out, it can be a powerful tool in understanding the transition from pahoehoe to ‘a’a in basalt. Using viscosity modeling by Giordano et al. (2008), curves that show the projected liquid viscosity based on the chemical compositions of the Krafla and Syracuse lava samples were made. The compositions of the materials are similar enough to show that these two transitional surface textures, both natural and experimental, were created under similar viscosities (Figure 3). Within the temperature range of 700 to 1200 °C, the liquid viscosity of both materials is within 1 Pa/s of one another, implying that these materials will cool and have similar rheology and deformation patterns if all other factors remain the same. When the temperature of the materials decreases the flow viscosity increases and the braided surface texture begins to form.

The evidence shown by the video of lava flow development suggests that the reason this texture forms is also related to the direction and nature of flow movement. The flow rate of the experimental lava was approximately 0.0061 m/s and much like the pulling of dough, when the lava begins to cool and becomes more viscous, the pahoehoe ropes stretch apart and overlap as the flow continues, resulting in the braided-looking round, eye- shaped chunks of basalt (Figure 4).

Vesicle/Crystal/Glass Content

Robert et al. (2014) explain that in transitional surface textures, the bubbles or vesicles observed are flattened with irregular outlines but their size range is similar to that of pahoehoe vesicles. Cashman et al. (1999) state that in channel or breakout basalt flows the vesicularity is higher than that of open flows. They go on to explain that in pahoehoe samples one can expect spherical separate bubbles, but in contrast ‘a’a samples are irregularly shaped and highly interconnected. This proved to be true in our samples as well. For the SU Lava Project samples, several sections were taken from the transitional surface texture, and as expected, the majority of the vesicularity by area values fell between 35-45% (Table 1). This is the typical range of vesicle content of transitional basalt (Polacci et al., 1998).

It is also evident that many of the Syracuse transitional samples fall a bit higher (~10-20%) more than the range set forth by Polacci et al. (1998) and this is likely due to the channelized flow created by the experiment structure. The samples from the transitional material in Iceland are more vesicular than the Syracuse samples with the SU samples containing 26% vesicles by area and the Krafla samples containing 46% vesicles.

The main finding from these assessments however is that the average percent vesicularity of both the transitional surface textures at the Krafla and Syracuse flows are very similar, 36.5% and 34% respectively. The glass to crystal content of the material however is very different. There is a significant portion of the groundmass in the Krafla samples that is comprised of crystals however this is not the case with the Syracuse samples. In the Syracuse samples, the majority of the groundmass is basaltic glass.

This degree of crystallinity in the Krafla samples would greatly increase viscosity, even though these samples have as low as 20 % vesicularity in some cases. The Syracuse experimental samples that have 25-60 % vesicles and only 2-5% crystals may have had similar viscosity due to more rapid cooling rates and less material. This information could imply that there is a trade-off between vesicularity and crystallinity versus temperature of the flow that yields highly similar viscosity and flow behavior. In other words, when there is low crystallinity, greater vesicularity and lower temperature are needed to create this transitional surface texture. Conversely in more crystalline flows, less vesicles are needed to create the texture and slower cooling rates allow for more crystal growth, therefore the texture would form at a higher temperature.

CONCLUSIONS

Some conclusions can be made about the way surface textures form near the pahoehoe- ‘a’a transition. First, the basalt that erupted at Krafla and the basalt used at Syracuse University are of similar chemical compositions with nearly identical liquid viscosity-temperature relationships.

Next, because the vesicularity and crystallinity are important factors influencing the rheology of the lava, it is likely that they are also important in the development of the transitional surface texture. This texture can form when the values of these two factors are very different from one another. In other words, higher vesicularity and lower crystallinity of the SU Lava samples may result in the same transitional surface texture as highly crystalline (30% and above) samples at Krafla.

In future studies, analyzing samples with different crystallinities from one another could lead to a better assessment on the importance of crystallinity and vesicularity versus temperature and cooling rate, thereby establishing what percentage creates the same viscosity as certain temperature changes. Overall, this work contributes to a greater understanding of the characteristics of transitional surface textures near the pahoehoe- ‘a’a transition.

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