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

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KECK GEOLOGY CONSORTIUM
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Keck Geology Consortium: Projects 2014-2015
Short Contributions—Experimental Basalt Lava Flows Project

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COMPARISON OF ICELANDIC ROOTLESS CONES WITH EXPERIMENTAL LAVA FEATURES

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INTRODUCTION

Lava-water interaction is an important topic in volcanology. Phreatic eruptions (those involving water or steam) are often more explosive than those not involving water, and they can be very dangerous to humans living nearby (Lockwood and Hazlett 2010, 190). Northeastern Iceland is an ideal area in which to study landforms, such as rootless cones, created by phreatic processes. Rootless cones represent specific points in a lava flow where water flashed to steam and created a miniature explosive eruption without an underlying conduit to magma, resulting in a shallow cone.

Understanding how phreatic explosive centers are controlled by water abundance and how these centers interact with each other during rootless cone formation may help to predict and prepare for larger scale phreatic eruptions. This project focuses on analyzing the spatial distribution of rootless cones on a lava flow in Northeastern Iceland and understanding how the distribution of rootless cones may relate to water budgets.

Another aspect of this study was undertaken at the Syracuse University Lava Project, where flow features analogous to Icelandic rootless cones could be created under controlled conditions (Karson and Wysocki, 2012). This allowed small-scale replication of rootless cone distribution patterns and interactions, illuminating how they are controlled by the water budget.

GEOLOGIC SETTING OF FIELD WORK

Iceland sits astride the Mid Atlantic Ridge, which bifurcates underneath the country, and it is also located above a mantle plume. Iceland is thus one of the most volcanically active places in the world, with 205 recorded eruptions between 870 CE and 2005 and more since then, averaging about one eruption every five to six years (Thordarson and Larsen, 2007). These eruptions span all styles of volcanism, with many types of volcanic products in evidence.

The Northern Volcanic Zone, a recently active Icelandic volcanic area, is where this study's field sites are located. Field sites are near Lake Mývatn, which is particularly notable for its large rootless cinder cones (Fig. 1). The volcanic history of the Mývatn area through postglacial time can be divided into three main eruptive cycles, according to Thorarinsson (1979). These are the Lúdent Cycle before 6,000 years ago; the Hverfjall Cycle, about 2,500 years before present; and the Viti Cycle from the 1700s through today (Thorarinsson, 1979).

Figure 1. Left: map of northeastern Iceland with mapping sites marked. Right: two views of Lake Mývatn cones, people for scale in lower photograph (Iceland: Mývatn, 1999).

About 200 years after the Lúdent Cycle, Ketildyngja, a shield volcano, erupted, producing the older Laxárhraun flow (Thorarinsson, 1979). This flow proceeded up the Laxá River valley until it almost reached Skjálfandi Bay, damming the river and forming Lake Mývatn in the process. During the Hverfjall Cycle, the Threngslaborgir-Lúdentsborgir eruption (about 2,000 years before present) created another flow, the Younger Laxárhraun, which followed the Laxá valley, this time reaching Skjálfandi Bay (Thorarinsson, 1979). The Younger Laxárhraun is dotted with various types of rootless cones.

The field sites for this project were on the Younger Laxárhraun in the Aðaldalur Valley south of Húsavík. Rootless cones here occur in clusters and they represent a wide variety of morphologies, with some large cones consisting mainly of cinders while smaller cones tend to be mainly spatter.

FIELD WORK AND METHODS

Field mapping involved two clusters of rootless cones. Site One contains mostly large, widely spaced cones on a tens of meters scale, whereas Site Two has mainly small, closely clustered cones on a meter scale (Fig. 2). Site Two contains two distinct clusters of cones, with a 160 meter gap between the clusters. Each site includes a variety of rootless cone morphological types (hollow; with craters; or fully filled in) represented within a relatively small area. Site One is swampier than Site Two, located only a few hundred meters from the Laxá River and containing many small ponds on the perimeter of the field. Site Two is not noticeably marshy, with dry grass and small trees common but without nearby bodies of water.

At Site One, reconnaissance mapping was undertaken unassisted. The mapping procedure involved determining a reference point on a given rootless cone, taking a back bearing to that cone from the mark point of the previous cone, and pacing the distance from mark to mark. Pacing is inherently prone to error, even though Site One is a relatively flat field, so paces were counted three times between each set of cones and an average was taken.

At Site Two, where the cones are more numerous and clustered close to each other, two people worked to

Figure 2. Iceland Site One (left; notebook for scale) and Site Two (person for scale) characteristic appearances.

create a map. This work was completed similarly to that at Site One, except that distances between cones were measured using a tape measure instead of by pacing. At both sites, average width and the average height of each cone were measured.

EXPERIMENTAL WORK AND METHODS

The Syracuse University Lava project melts gravel made up of 1.1 Ga tholeiitic Keweenawan basalt from the Mid-Continent Rift, as well as pieces of previous experiments, in a gas-fired tilt furnace. The resulting lava is poured onto a customizable sand pit. Experiments are filmed with an overhead camera, an infrared camera, and a front-facing camera.

The two experimental flows related to this project studied the effects of wet sand on lava morphology. Both flows proceeded with a medium pour rate onto sand raked to form a 10° slope. The first flow, at about 1200° C, poured out of the furnace onto a steel halfpipe and dropped eight inches onto the sand. For this experiment, three cinder blocks were positioned parallel to each other about two inches apart with their long edges perpendicular to the slope direction. Downslope from the last cinder block was a 12” by 6” by 2” metal pan of water. The holes of the uppermost cinder block were filled with an 8:1 sand to water mixture; the next cinder block contained 6:1 sand to water; and the last block, just above the pan of water, contained 4:1 mixture. Along the short sides of the cinder blocks an iron barrier was installed to channel the flow directly down the slope. This flow produced large, thick bubbles of lava (Fig. 3).

The setup for the second flow was much simpler. The lava, this time at about 1100° C, poured directly down the halfpipe and onto the sand. Thirty centimeters below the lava's first contact with sand was a stripe of nearly saturated wet sand forty centimeters wide. There was no constraint on lava movement for this experiment, which produced many thin glassy bubbles (Fig.3).

Figure 3. Syracuse Lava Project Flow One (left) and Flow Two (right).

WILLIAMS ANALYSES

Petrography

At Williams, the SEM and optical microscopes were used to analyze the porphyritic Icelandic basalt, which is the same at both sites. Zoned poikilitic plagioclase phenocrysts lie in an ophitic to intergranular groundmass of plagioclase (~An_{60}), clinopyroxene, minor olivine, and ilmenite (Fig. 4).

Crystallites of plagioclase and olivine were found in the otherwise glassy Syracuse University lava samples (Fig. 4). There were small crystals of quartz scattered through the sections.

Statistical Analyses

In Trimble SketchUp, geolocated maps of the Icelandic sites were created. Site Two's map used field measurements, which characterized 40 cones. Site One involved a field-measurement-based SketchUp map imported into Google Earth and supplemented with Google Earth imagery, tracing out the map footprints of a total of 80 rootless cones in the area. Using just Google Earth imagery, a map of part of the shore of Lake Mývatn containing 177 large rootless cones easily visible in Google Earth was also created.

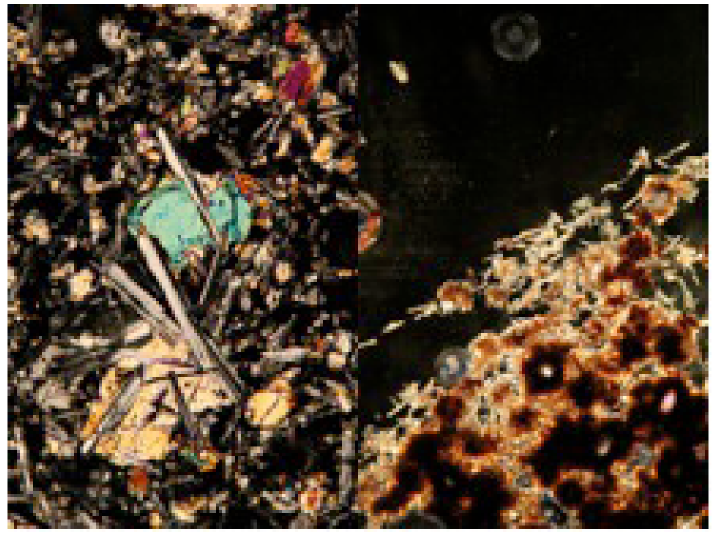

Figure 4. Left: Iceland basalt fabric (100x magnification). Right: Syracuse crystallites (40x magnification). Both viewed through crossed polars of a petrographic microscope.

Each map was transferred into ArcMap using the WGS84 datum, and the centroid of each cone's ground footprint was calculated by adding latitude and longitude fields to the attribute tables; an XY Event Layer was then created. The text files of centroid coordinates were imported into Geological Image Analysis Software (GIAS) to run spatial analyses for each site, including Mývatn, and for some subsets of the sites (Fig. 5).

For the two Syracuse flows, overhead camera footage was used to take screenshots once five or more bubbles appeared. Screenshots were taken at five-second intervals until the flows solidified enough that bubble positions were unchanging. For Flow One, this required 10 observations; for Flow Two, there were 33. Polygons were drawn on each screenshot to mark the footprints of bubbles at each time interval. After removing the lava flow background image in Powerpoint, a collection of polygons on a blank slide were left over for each observation. In SketchUp, the slides were scaled up until they were 100 meters across on the short side. They were geolocated to the equator at 17° West in order both to minimize distortion and to match the UTM zone of the Icelandic sites. After this, the process was identical to that used on the Icelandic areas.

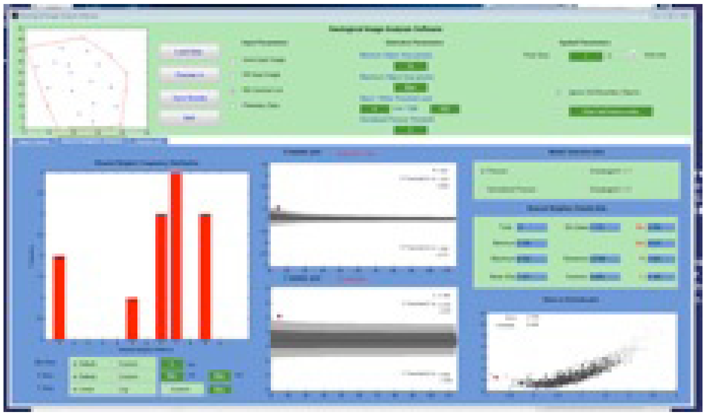

Figure 5. Typical interface and results for GIAS.

RESULTS

Terminology

Hamilton et al., in their two papers from 2010, use the terms “clustered,” “random,” and “repelled” when describing spatial distributions of rootless cones. This paper will use the terms “clustered,” “random,” and “uniform.” In both cases, rootless cone centroids are used to determine cone spatial distributions. Clustered distributions occur when the cone centroids are concentrated in groups often enough to reject the idea of a statistically random distribution. Random distributions are returned when there is no statistical pattern in the spatial distribution data. Uniform distributions mean that rootless cones are evenly distributed across the site, approximately equidistant from each other.

Iceland Sites

Iceland Site One contains large, widely spaced rootless cones in a swampy area. Analyzing 80 cones mapped at the site yielded an overall random spatial distribution. Dividing the cones into three subsections (west, central, and east) produced a random distribution for each subset of the site.

Iceland Site Two, consisting of small, closely clustered cones in a dryer area, has only 40 mapped cones, as the cone footprints are too small to appear in Google Earth. Overall, the site exhibited a clustered distribution. Dividing Site Two into northern, middle, and southern sections resulted in randomly distributed cones in the north and uniformly distributed cones in the other two subsets.

The Mývatn area contains large rootless cinder cones on the shore of the lake. Using Google Earth imagery, 177 cones were mapped, displaying a clustered spatial distribution overall. Dividing Mývatn into separate clusters indicated a northeastern section with a random spatial distribution, a southeastern section that was also random, and a western section exhibiting a clustered spatial distribution.

Syracuse Flows

The first Syracuse flow created large but relatively scarce lava bubbles. Of the ten measurement points, only six worked with the statistics program, since there were so few bubbles. Of these six, three observations indicated a random spatial distribution of bubbles, while three indicated a uniform spatial distribution.

The second Syracuse flow resulted in relatively abundant bubbles, and it provided 33 measurement points. Of the 33 observations, 27 indicated randomly distributed glassy bubbles and six showed a uniform spatial distribution of bubbles.

DISCUSSION

Statistical Analyses

Iceland Site Two and Syracuse Flow One both showed uniform cone distributions for at least half of the measurements taken. Hamilton et al. hypothesized that rootless cones in a water-limited environment would compete for water resources and therefore repel each other during formation (2010b). Site Two and experimental Flow One had the least abundant water in this study, and their results aligned closely with each other. Not only do the results of spatial analysis match for these two examples, but they are also the two instances with proportionally the most uniform distributions. These examples support the hypothesis of Hamilton et al.

Iceland Site One and Syracuse Flow Two each had relatively abundant water supplies. The results for these areas are almost exclusively random distributions. This indicates that rootless cones in areas that are not water-limited will have very little interaction with other cones during formation. In other words, there will be little to no competition for water between cones, so the cone distribution will be random instead of uniform.

Mývatn is a special case, as the rootless cones are on the lakeshore. Clearly there is no shortage of water, and it is known that the lake formed before this flow occurred, so there was abundant water during the formation of the rootless cones at Mývatn. The Mývatn results indicate absolutely no competition for water resources, with random or clustered distributions for all subsets of the area. The clustered subset in particular indicates that there were no water shortages, as cones would not form close together if water were a limiting factor on their development.

CONCLUSIONS

Based on this study and the previous work of Hamilton et al. in 2010b, it appears that rootless cones in water-limited areas, such as Iceland Site Two, compete for water resources during their formation. This results in spatially uniform cone distributions. For cones in wetter areas, such as Iceland Site One and Mývatn, the spatial distribution is random or even clustered, indicating no competition for water resources. The Syracuse University Lava Project sems to be able to replicate this relationship between water abundance and rootless cone (or bubble) distribution on a small scale, although more experiments are needed to confirm this relationship.

FUTURE WORK

Rootless cone distribution is an important topic when considering the dynamics of phreatic eruptions, and much work remains to be done. Relating the volume of material in, and dimensions of, rootless cones to their distributions and to surrounding water resources would be valuable for gaining a better understanding of the mechanisms at work during phreatic landform formation. Uniform distributions of rootless cones appear to occur in water-limited areas, and this relationship could be useful for confirming the presence of rootless cones on other planets, particularly Mars. The usefulness of the Syracuse Lava Project in creating small-scale analogues to real environments is clear, but more applications should be tested.

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