Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
29th Annual Symposium Volume
23rd April, 2016
ISBN: 1528-7491

CONSTRAINING PROCESSES IN NATURAL & EXPERIMENTAL BASALTIC LAVA FLOWS

J.A. KARSON, Syracuse University
R.W. HAZLETT, Pomona College

INTRODUCTION

Basaltic lava flows constitute the most common and voluminous volcanic outpourings on Earth and the terrestrial planets (Basaltic Volcanism Project, 1981). Besides highly visible historic eruptions in Hawai'i, Iceland, Italy and Siberia, ancient basaltic lavas also dominate vast areas of the continents and almost the entire deep seafloor. Despite the widespread occurrence of basaltic lava flows, the significance of various flow morphologies remains a work in progress (e.g., Cashman and Sparks, 2013). Investigations of active lava flows (e.g., Kauahikaua 1998; 2003) provide important constraints on the dynamics of lava flows and the diverse features that form in different settings. Detailed investigations of young lavas and analog experiments provide additional information relevant to interpreting the wide range of flow morphologies found in ancient lava flows (Lockwood and Hazlett, 2010).

For obvious reasons, scientists seldom carefully investigate active lava flows at close range. In addition to the inherent hazards, volcanic activity tends to occur in inaccessible locations and with very limited predictability. For volcanologists studying lava flows, these unscheduled and uncontrolled "experiments" provide an important but limited observational database. Flow conditions cannot be duplicated making it difficult to assess the influence of even the most fundamental environmental parameters. Ideally, geologists would like to be able to know the details that influenced ancient lava flows as they were emplaced.

Based on Hawaiian lava flows, the terms "a'a" and "pahoehoe" have been widely used to describe jagged, blocky lava and smooth, lobate to sheet-like lava flows, respectively (e.g., Hon et al., 1994). Direct observations, numerical models and experiments using analog materials such as wax, syrup, etc., provided a framework for understanding the behavior of basaltic lava flows (Fink and Griffiths, 1992). However, natural lava flows are potentially influenced by a daunting array of parameters including composition (especially silica content), temperature, flow rate, slope, substrate, dissolved volatiles, vesicles, and crystals (Cashman et al., 1998; Hon et al., 1994; Thordarson and Höskuldsson, 2008; Thordarson and Self, 1998). Some of these parameters can be investigated with data from solidified, cooled flows, other factors are more elusive requiring different approaches.

In the past, attempts have been made to melt basaltic lava and create small flows under controlled conditions in order to better understand the influence of these parameters. In an early experiment (1805), James Hall used a blacksmith's forge to melt basalt to make small lava flows (Newcomb, 2009). Since that time, most lava experiments have used only very small amounts of lava (few ounces) to measure its various properties (Bottinga and Weill, 1972; Philpotts and Carroll, 1996). Analog experiments using various materials and numerical models also contribute to the understanding of the behavior of lava flows. However, it is not always clear how to apply the results from such tiny samples or analog materials to natural-scale lava flows.

In this project, students continued investigations begun in the 2014-15 Keck Geology Consortium lava flow on basaltic lava flows of the 1984 Krafla Fires eruption in north central Iceland. Detailed field investigations were the starting point for laboratory-based studies of compositional and textural relations, numerical models, morphologic analyses, and analog experiments with natural-scale lava flows in the context of the Syracuse University Lava Project (Karson and Wysocki, 2012; http://lavaproject.syr.edu).

ICELAND FIELDWORK

The North American/Eurasian plate boundary transects Iceland (Fig. 1) to provide direct access to divergent plate boundary processes analogous to those of mid-ocean ridge spreading centers (Einarsson, 2008; Sæmundsson, 1978, 1979). Nearly the entire island is covered by basaltic lava flows and hyaloclastites. Uplift and glaciation create steep vertical relief and remarkable 3-D perspectives on the internal structure of the lava pile that constitutes the upper crust. The Iceland Hot Spot, centered beneath the Vatnajökull Glacial Ice Cap, creates a hyperactive mid-ocean ridge magmatic system. Unlike mid-ocean ridges, volcanic eruptions from central volcanoes and discrete rift zones occur in an en echelon array of spreading segments (Sæmundsson, 1978, 1979; Thordarson and Höskuldsson, 2008). The Krafla Fires eruption of the 1970's and 1980's in northern Iceland (Sæmundsson, 1978) represents a discrete episode of spreading. Basaltic lava flows mostly erupted near the Krafla Caldera, erupted from fissures and small craters creating a spectacular array of volcanic features (Fig. 2). These lava flows provide a natural laboratory for our studies of distinctive features of basaltic lava flows (Fig. 3).

SYRACUSE UNIVERSITY LAVA EXPERIMENTS

With a unique mix of science, art, and education, the Syracuse University Lava Project (http://lavaproject.syr. edu) investigates the physical properties, aesthetics, and educational opportunities of making natural-scale basaltic lava flows in a controlled environment (Karson and Wysocki, 2012). This is done with a natural gas-fueled, tilt-furnace originally designed for pouring molten metals (Fig. 3). Its bathtub-size crucible is capable of pouring up to

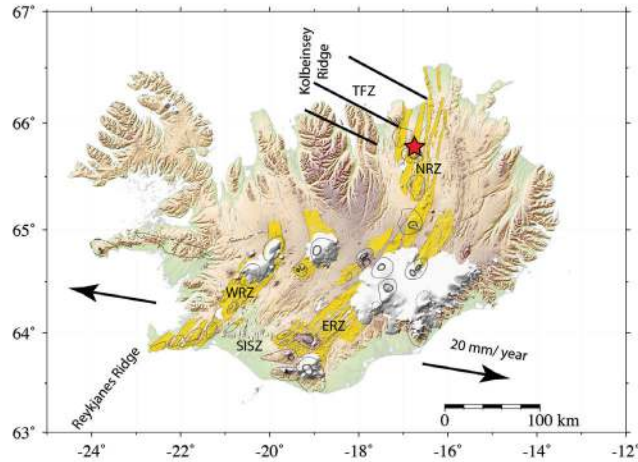

Figure 1. Tectonic map of Iceland showing the location of volcanic rift zones and central volcanoes. Krafla Caldera (star) in the Northern Rift Zone (NRZ). ERZ and WRZ- Eastern and Western Rift Zones, respectively. SISZ- South Iceland Seismic Zone; TFZ- Tjörnes Fracture Zone.

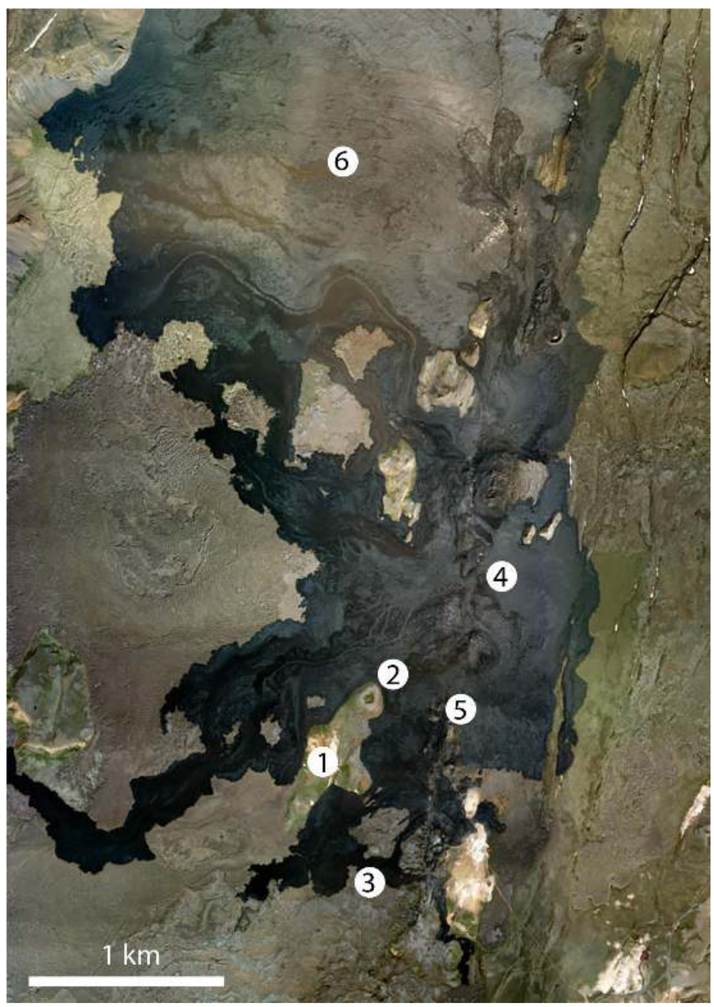

Figure 2. Basaltic lavas (black) from the 1984 Krafla Fires eruption on the N edge of the Krafla Caldera. Light areas are kipukas of older hyaloclastites. Numbers correspond to locations of student studies (see text).

Figure 3. Young basaltic lava flows just north of Krafla Caldera.

nearly 1000 lbs. of molten basalt (re-melted natural basalt) producing a wide range of flow morphologies and other features that closely mimic those found in nature and at a scale comparable to natural lava flow lobes. Different flow features are produced by varying the pouring (effusion) rate, slope, and temperature as well as the features of the pouring surface. After cooling, the lava flows are dissected to document textural details that may correlate with specific flow characteristics. To date, more than 100 lava flow experiments with more than 200 individual flows have been made. Varying the slope, flow rate, or temperature creates distinctly different flow morphologies (Karson and Wysocki, 2012; Edwards et al., 2013, Lev et al., 2012). By varying the experimental set-up, it was possible to produce lava flow features similar to those observed in the field.

Figure 4. Basaltic lava poured into water to make hyaloclastite from gas-fired tilt furnace operated by Professor Robert Wysocki and Keck students.

For all the experiments for the 2015 Keck Lava Project, the starting material was 1.1 Ga Keweenawan Basalt from the Dresser Trap Rock Quarry in Polk Co., Wisconsin (Leslie et al., 1994). Up to 800 lbs. of gravel-size lava was melted and poured in increments for small lava flow lobes. Lava from experiments was re-melted and poured in later experiments. Nearly all lava flows were over dry sand with slopes of 5-15° unless otherwise noted. The lava temperature as it began to move across the sand slope was typically 1150-1000°C. Pouring (effusion) rates were held more or less constant. Results were documented with both vertically downward and oblique digital video. Temperatures were measured with thermocouples and a FLIR (Forward-Looking Infrared) camera. After cooling in air, lava features were available to be dissected and sampled for more detailed investigations as necessary. Experiments ranged from flows over obstacles similar to those seen in the field, simple sheet-like flows for magnetic measurements, rapidly piled spatter and lava/water interactions to produce highly fragmented hyaloclastites.

LABORATORY ANALYSES

After the summer program, students continued their investigations with a wide range of laboratory analyses. These included quantitative determinations of compositions, textures, and magnetic properties. Other studies evaluated field data in the context of published numerical models or empirical studies of lava flow behavior.

KECK LAVA RESEARCH PROJECTS

1. Determining the Evolutionary History of a Hyaloclastite Ridge and the Composition of its Parent Magma, Leirhnjúkur, NE Iceland (Nelson Bandy, Carleton College) Leirhnjúkur Hill is near the eruptive center of young lavas just north of the Krafla Caldera. It is composed of a number of distinct volcanic facies related to lava/ice interactions and possibly epiclastic transport. Contrary to local tourist information indicating a rhyolitic composition, the hyaloclastites have a bulk basaltic andesite composition with basaltic clasts and low-temperature hydrothermal alteration. Hyaloclastite produced by pouring lava into water produced interesting fragmented textures.

2. Characterizing Development of Channelized Lava Flows at Krafla Volcano, Iceland (Esme Faneuff, Pitzer College) Numerous lava channels, meters wide and tens of meters in length, fed the young Krafla lava flow in a complex distributary system. Several different types of channels occur feeding and breaking-out from both pahoehoe and a'a flows. This study examined the details of three very different lava channels and analyzed them in terms of current models for the formation of these features.

3. Interaction of Basaltic Lava Flows with Patterned Ground: Field and Analog Studies (Ariel Hampton, Colgate University) Hummocky "patterned ground" is common in Iceland and other Arctic settings. At Krafla basaltic lava flowed over this lumpy terrain showing how small-scale (< 1 m) relief can deflect lava toes and possibly influence the larger scale flow morphology. Analog experiments at Syracuse University using smaller scale obstacles provided additional insights into these processes.

4. Clastogenesis as a Result of Reactivation of Agglutinated Spatter (Erin Hightower, Colorado College) This combined field and theoretical study considers the conditions necessary for remobilization of hot piles of lava spatter proximal to vents. Field examples were used to guide model parameters such as temperature, slope, and accumulation rate. Experimental spatter failed to show signs of significant remobilization, helping to demonstrate the limits of this process.

5. Using Anisotropy of Magnetic Susceptibility to Determine the Shearing History of a Channelized Pahoehoe Lava Flow (Trevor Maggart, Macalester College) Anisotropy of magnetic susceptibility (AMS) is widely used to study flow of rock materials in the ductile to viscous regimes (Canon-Tapia and Aubourg, 2004). In this study, AMS was measured in oriented samples from a lava flow at Krafla and compared to surface deformation features to evaluate different methods of analyzing flow kinematics. Samples from an experimental lava flow were also analyzed to better understand the potentially complex flow patterns.

6. Inflated Sheet Flows and the Origin of Bulbous Squeeze-ups (Grady Olson, Macalester College) Platey pahoehoe flows emanate from eruptive fissures north of the Krafla Caldera. Rifting and buckling of lava plates exposed vertical sections through the plates while still partially molten inside. Distinctive glassy bulbs of lava up to a few tens of centimeters across emerge from these exposed faces. This study investigated the origin of these strange and distinctive features in terms of their composition and texture relative to the parent lava plates.

REFERENCES

Bottinga, Y., and Weill, D. F., 1972, The viscosity of magmatic silicate liquids: a model for calculation: American Journal of Science, v. 272, p. 438-475.

Canon-Tapia, E., and Aubourg, C., 2004, Anisotropy of magnetic susceptibility of lava flows and dykes; a historical account in Martin-Hernandez, F., ed., Magnetic fabric; methods and applications, Volume Special Publication 238: Boulder, CO, Geological Society of America, p. 205-225.

Cashman, K., Pinkerton, H., and Stephenson, J., 1998, Introduction to special section: Long lava flows: Journal of Geophysical Research, v. 103, p. 27,281-27,290.

Cashman, K.V. and Sparks, R.S.J., 2013, How volcanoes work: A 25-year perspective, Geological Society of America Bulletin; v. 125; no. 5/6; p. 664–690; doi:10.1130/B30720.1.

Edwards, B. R., Karson, J. A., Wysocki, R. J., Lev, E., Binderman, I., and Kueppers, U., 2013, Insights on lava-ice/snow interactions from large-scale basaltic melt experiments: Geology, v. 41, p. 851-854.

Einarsson, P., 2008, Plate boundaries, rifts and transforms in Iceland: Jökull, v. 58, p. 35-58.

Fink, J. H., and Griffiths, R. W., 1992, A laboratory analog study of the surface morphology of lava flows extruded from point and line sources: Journal of Volcanology and Geothermal Research, v. 54, p. 19-32.

Hon, K., Kauahikaua, J. P., Denlinger, R., and Mackay, K., 1994, Emplacement and inflation of pahoehoe sheet flows: Observations and measurements of active lava flows on Kilauea Volcano, Hawaii: Geological Society of America Bulletin, v. 106, no. 3, p. 351-370.

Karson, J. A., and Wysocki, R. J., 2012, Do-it-yourself lava flows: Science, art and education in the Syracuse University Lava Project: Earth, v. September 2012, p. 38-45.

Kauahikaua, J., Cashman, K. V., Mattox, T. N., Heliker, C. C., Hon, K. A., Mangan, M. T., and Thornber, C. R., 1998, Observations on basaltic lava streams in tubes from Kilauea Volcano, island of Hawai'i: Journal of Geophysical Research, v. 103, p. 27303-27323.

Kauahikaua, J., Sherrod, D. R., Cashman, K. V., Heliker, C., Hon, K., Mattoxx, T. N., and Johnson, J. A., 2003, Hawaiian Lava-flow dynamics during the Pu'u "O'o-Kupaianaha Eruption: A tale of two decades: U.S. Geological Survey Professional Paper, v. 1676, p. 63-88.

Leslie, M., Wetzel, T., Wirth, K., and Craddock, J., Petrography and structure of the Keweenaw Chengwatana Volcanics near Dresser, Wisconsin, Institute on Lake Superior Geology Annual Meeting, Proceedings and Abstracts, May 1994, v. 40, p. 35-36.

Lev, E., Spiegelman, M., Wysocki, R. J., and Karson, J. A., 2012, Investigating lava flow rheology using video analysis and numerical flow models: Journal of Volcanology and Geothermal Research, v. 24-248, p. 62-73.

Lockwood, J. P., and Hazlett, R. W., 2010, Volcanoes: Global Perspectives, Oxford, UK, Wiley-Blackwell, 541 pp.

Newcomb, S., 2009, The world in a crucible: Laboratory practice and geological theory at the beginning of geology: Geological Society of America, Special Paper, v. 149, p. 204 pp.

Philpotts, A. R., and Carroll, M., 1996, Physical properties of partly melted tholeiitic basalt: Geology, v. 24, p. 1029-1032.

Sæmundsson, K., 1978, Fissure swarms and central volcanoes of the neovolcanic zones of Iceland: Geological Journal, v. 10, p. 415-432.

-, 1979, Outline of the geology of Iceland: Jökull, v. 29, p. 7-28.

-, 1991, Jardfræði Kröflukerfisins, in Náttúra Myvatns, Arntor Gardarsson og Árni Einarsson, ritstjórar, Hið íslenska náttúrufræðifélag, Reykjavík, p 24-95 (in Icelandic).

Thordarson, T., and Höskuldsson, A., 2008, Postglacial volcanism in Iceland: Jökull, v. 58, p. 197-228.

Thordarson, T. D., and Self, S., 1998, The Roza member, Columbia River Basalt group: A gigantic pahoehoe lava flow field formed by endogenous processes? : Journal of Geophysical Research, v. 103, p. 27411–27445.