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

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

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CALIBRATING NATURAL BASALTIC LAVA FLOWS WITH LARGE-SCALE LAVA EXPERIMENTS

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 significance of basaltic lava flows, many questions remain regarding the behavior of lava flowing across the surface and the interpretation of features found in ancient lavas. Documenting the effects of key parameters on lava flow processes is necessary for understanding the accretion of lava flow fields, assessing hazards, and understanding the significance of lava flow morphologies on Earth, the seafloor, and other planetary bodies.

With few exceptions, active lava flows are seldom carefully witnessed by scientists, as volcanic activity tends to occur in inaccessible locations and without much prior warning. For volcanologists studying lava flows, these unscheduled and uncontrolled "experiments" provide an important observational database, but only within the limits of Nature's whims, making it difficult to constrain the key parameters that influence the behavior of lava. Based largely on this information, and examining the overall morphologies and surface textures of lava flows, geologists attempt to interpret how lava behaves and to reconstruct eruptions in the geologic record.

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). Along with direct observations, numerical models and analog experiments (using wax, syrup, etc.) provide an excellent framework for understanding the behavior of basaltic lava flows (Fink and Griffiths, 1992). However, natural lava flows are influenced by a daunting array of parameters, for example, 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).

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, James Hall (1805) 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, a variety of specific topics related to the behavior of basaltic lava flows were investigated from the perspective of coordinated field investigations in young Icelandic lava flows and experiments with basaltic lava at Syracuse University. Experiments

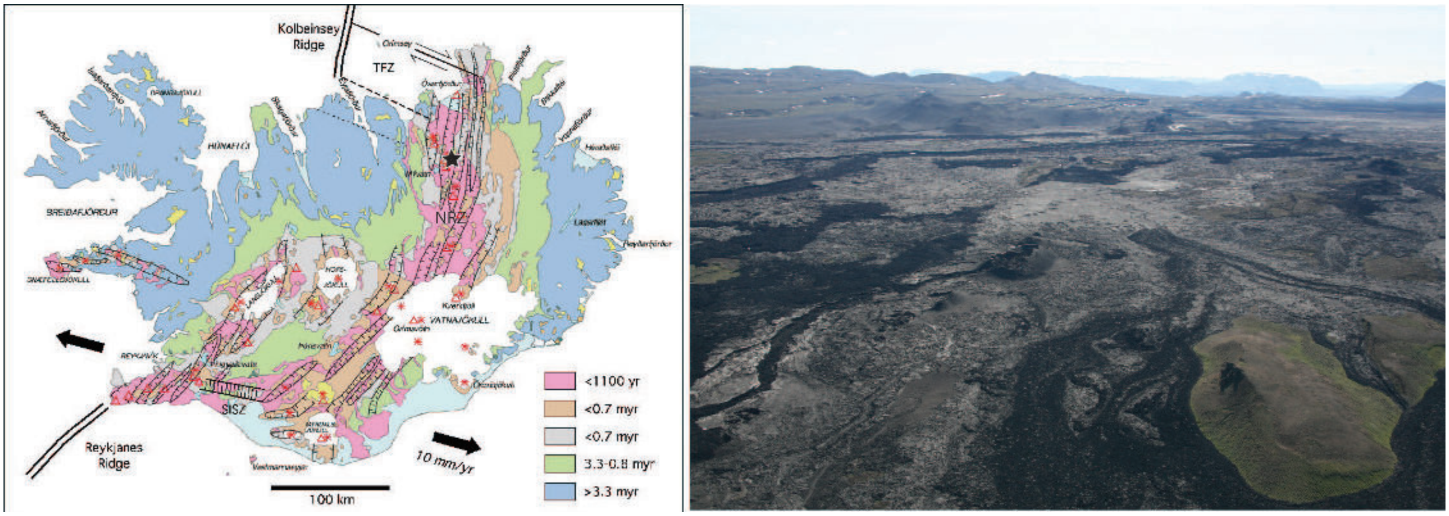

Figure 1. Geological map of Iceland showing the location of volcanic terrane younger than 1100 years (pink) and the Krafla Central Volcano (star) in the Northern Rift Zone (NRZ). SISZ- South Iceland Seismic Zone; TFZ- Tjörnes Fracture Zone. Hatched lines show major rift zones. Image to right shows a view to the south of young volcanic terrane just north of Krafla.

were designed to investigate processes associated with specific features that were well characterized in the 1984 Krafla lava flow field.

ICELAND FIELDWORK

The Mid-Atlantic Ridge comes ashore in Iceland to provide direct access to plate boundary processes analogous to those of accreting plate boundaries along mid-ocean ridges (Einarsson, 2008; Sæmundsson, 1978, 1979). Nearly the entire island is covered by basaltic lava flows. Uplift and glaciation create steep vertical relief and remarkable 3-D perspectives on the architecture of the lava pile that constitutes the upper crust. Under the influence of the Iceland Hot Spot, centered beneath the Vatnajökull Glacial Ice Cap, volcanic eruptions from central volcanoes and discrete rift zones are frequent (Thordarson and Höskuldsson, 2008).

The Krafla Fires eruption of the 1970's and 1980's in northern Iceland produced basaltic lava flows fed by eruptive fissures and small craters and a spectacular array of volcanic features (Fig. 1). The main eruptive centers and nearby areas were used as natural laboratories for the study of basaltic lava flows. Detailed examination of selected features of these lava flows resulted in the formulation of specific research questions and hypotheses for their mode(s) of formation. These questions were the basis for designing experiments to simulate the conditions under which they formed with basaltic lava at

Figure 2. Gas-fired tilt furnace operated by Professor Robert Wysocki for lava flow experiments in the Syracuse University Lava Project.

Syracuse University. Carefully documented lava flow experiments shed light on the formation of the features found in the natural lava flows.

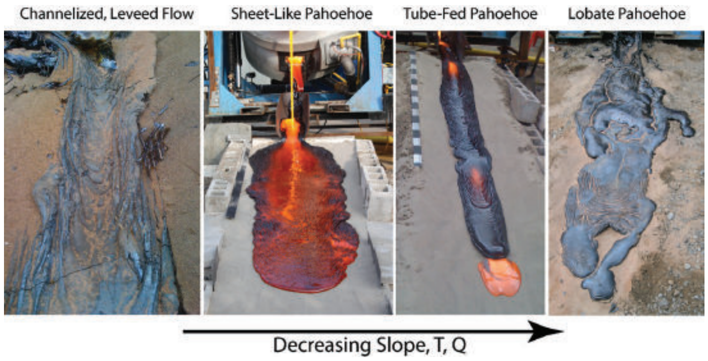

Figure 3. Range of different lava morphologies created by the Syracuse University Lava Project. Different morphologies reflect variations in experimental conditions of lava temperature (T), effusion rate (Q) and slope (all on dry sand).

EXPERIMENTS WITH THE SYRACUSE UNIVERSITY LAVA PROJECT

With a unique mix of science, art, and education, the Syracuse Lava Project (SLP- *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. 2). Its bathtub-size crucible is capable of pouring up to 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 150 individual flows have been made.

Distinctly different flow morphologies are created by varying the slope, flow rate, and temperature (Fig. 3). The flows were poured over dry sand surfaces inclined at 5° to 20° resulting in a variety of flow morphologies. In these flows the behavior and resulting morphologies are predictable and systematic. Large volume flows (400-500 lbs.) poured at relatively low effusion rates over gentle (5-10°) slopes result in lobate to ropey flows with hummocky upper surfaces. Flows developed by the growth of overlapping bulbous lobes at the distal end of the flow, similar to flow architecture at various scales in flood basalts (Self et al., 1998; Self et al., 1997). Flows range from sheet-like pahoehoe to tube-fed and inflated forms. At higher flow rates or steeper slopes, leveed channels form by the build-up of cool, viscous lava on the edges of the flow. The channel feeds an elongated, sheet like pahoehoe flow just as in natural flows (Cashman et al., 1999; Hamilton et al., 2013; Hon et al., 1994; Self et al., 1998). By varying the experimental set-up, it has been possible to investigate the behavior of lava flows moving over substrates with different topographies, compositions and textures (Edwards et al., 2013; Karson and Wysocki, 2012; Lev et al., 2012).

For all the experiments for the 2014 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. FLIR (Forward-Looking InfraRed) video was also recorded. After cooling in air, lava flow lobes were dissected and sampled for more detailed investigations as necessary.

KECK RESEARCH PROJECTS

Development of Basaltic Surface Textures at the Pahoehoe-'A'a Transition (Mary Bromfield, Syracuse University) In the lava flow field of Krafla caldera, pahoehoe lavas flowed over small cliffs (1-3 m high), transforming to a'a and back to pahoehoe on gentle slopes below. Across these intervals linear to ropey surfaces grade into more fragmental textures with discontinuous stretched and clustered, segments of ropey lava. Similar textures were reproduced in experimental lava flows over steps ~1 m high. Video analysis and constraints from petrographic comparisons between the Krafla and SU lavas form the basis for the interpretation of the formation of these transitional textures as a function of variations in viscosity and strain rate.

Ponding of Basaltic Lava Flows (Nick Browne, Pomona College) Lava lakes or ponds are common features of the central Krafla vent area. Lava pooled in self-leveed basins until it solidified or until its bounding walls were breached and it drained out. Several lava ponds near Leirhnjúkur Hill are particularly well preserved and were investigated for comparison with other ponded basaltic lavas and with small-scale experimental lava pools generated at SU. Theoretical models for volume flux and heat loss were applied to this range of features.

Rootless Spatter Cone Spacing as a Function of Water Vapor Budget (Nell Davis, Williams College) The ca. 2000 yr. old Laxáhraun lava flow in northern Iceland is considered to have flowed across marshy ground (Thorarinsson, 1979) resulting in a distinctive surface morphology with numerous steep-sided, rootless, spatter cones, typically 2-4 m high. The spatter cones occur in clusters, locally with a regular spacing. Spatial analysis of these patterns suggests that their distribution is related to availability of water in the wet substrate during the eruption. Experiments at SU with lava flowing over wet sand produced small-scale analogs of these structures.

Formation and Evolution of Lava Tubes (Christopher Pelland (Lafayette College) Numerous examples of lava tubes (or pyroducts) (Lockwood and Hazlett, 2010) occur on moderate to steep (10-20°) slopes in the 1984 Krafla flow field. Drain-out and collapse of these conduits allowed detailed examination of their dimensions and fine-scale structures. In order to further investigate the formation and evolution of lava tubes, small-scale (~10 cm high x 1-2.5 m long) tubes were created experimentally at SU. Simple tubes with varying dimensions were formed by channeling lava between spaced steel plates. The spacing of the pre-formed channel was varied to create tubes with different cross sectional forms. Theoretical heat loss models help explain the dimensions of the lava tubes in both nature and experiments (Kauahikaua et al., 1998; Kauahikaua et al., 2003; Keszthelyi and Self, 1998).

Lava Flow Directions from Anisotropy of Magnetic Susceptibility (Willa Rowan, Oberlin College) Anisotropy of magnetic susceptibility (AMS) is a widely used approach to determining flow directions in extrusive and intrusive rocks (Canon-Tapia and Aubourg, 2004; Staudigel et al., 1992; Varga et al., 2008). Previous studies on experimental lava have been limited to samples with volumes of a few cubic centimeters. In this study, AMS of oriented samples of lava flow lobes from Krafla (few meters long) and SU experiments (~1 m long) were measured and compared to flow directions determined from macroscopic structures.

Mechanisms Controlling Flow Lobe Break-Outs (Kelsa Wagner, University of the South) Inspired by observations of smooth, lava flow lobe break-outs on flows transecting moderate slopes (5-15°) at Krafla, experiments at SU were designed to investigate how break-outs occur in small flow lobes (1-2 m long). By varying the slope (10-15°) and imposing low-relief (few cm) barriers, break-outs were created and documented. At least 2 different mechanisms were observed: tensile fracture from over-inflation of flows stalled at barriers, and tearing of flow fronts in areas of high shear strain. The form of these features is compared to the natural breakouts (Blake and Bruno, 2000; Hon et al., 1994; Peterson et al., 1994).

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