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

April 2015
Union College, Schenectady, NY

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ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
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Research Advisor: Andrew Horst

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1358987
ExxonMobil Corporation

Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
28th Annual Symposium Volume
25th April, 2015
ISBN: 1528-7491

COMPARING THE ANISOTROPY OF MAGNETIC SUSCEPTIBILITY OF NATURAL AND EXPERIMENTAL LAVA FLOWS

WILLA ROWAN, Oberlin College
Research Advisor: Andrew Horst

INTRODUCTION

Anisotropy of magnetic susceptibility (AMS) is a useful petrofabric tool for analyzing the flow direction and shearing history of igneous rocks (Knight and Walker, 2008; Cañón-Tapia, 2005). The magnetic susceptibility of a rock sample is said to be anisotropic when its magnetic response varies with respect to the orientation of the specimen in a magnetic field (Tauxe, 2009). Previous studies of the AMS of lava flows have investigated aspects including flow direction and deformation history using AMS (Cañón-Tapia, 1997; Herrero-Bervera et al., 2002; Loock et al., 2008), although due to the danger and spontaneity of volcanic eruptions it is difficult to observe the emplacement of lava flows for direct comparison to AMS data.

Only one study so far has measured the AMS of experimental lava flows (Cañón-Tapia and Pinkerton, 2000), using small-scale (10 cm) lava flows subjected to shear stresses at varying temperatures. We will present results of the first AMS study of experimental lava flows on a natural scale. As shown in the experimental study by Cañón-Tapia and Pinkerton (2000), AMS is influenced by a variety of components during emplacement, such as shearing, quenching rate, and the temperature at which shearing occurs. Due to these factors, interpreting AMS results can be aided by implementing video and temperature recordings of the emplacement of the lava flow, a task which is most easily accomplished with experimental lava flows. Comparing these AMS results to natural lava flows in a setting like Iceland in turn aids in interpreting aspects of the natural flows that could not be measured during emplacement.

STUDY AREA

Krafla fissure zone, Iceland

The Krafla fissure zone in Northeast Iceland is a series of fissure eruptions 80 km in length that experienced its most recent rifting episode from 1974-89 (Einarsson, 2008). The specific part of the eruptions sampled in this study are small breakouts from large flows emplaced between 25 and 50 m from the nearest fissure site (Fig. 1). The area is characterized by largely flat pahoehoe flows.

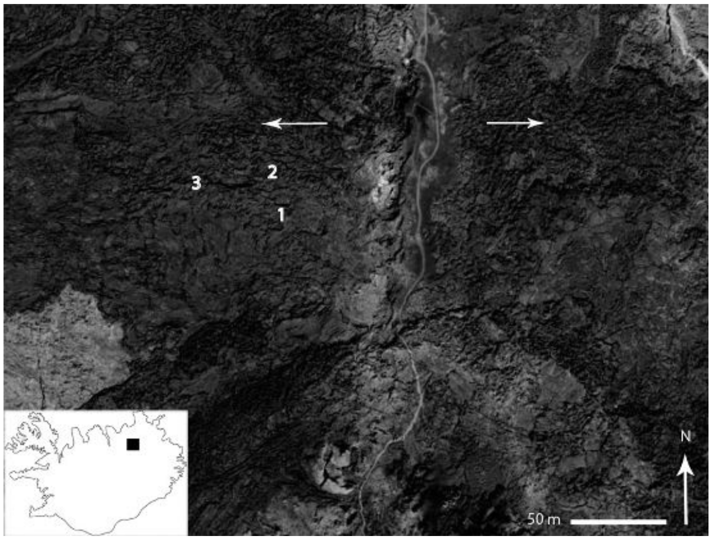

Figure 1. Aerial photo of Krafla fissure zone with inset map of Iceland showing location of Krafla. Dirt foot path in center traces east flank of the fissure, which is lighter in color than surrounding flow. Sampled lobes are numbered, and observed average flow direction away from fissure indicated with arrows. Photo courtesy of ja.is.

METHODS

Sample areas in Iceland were identified by locating three relatively undisturbed, intact, shallow-sloped pahoehoe lobes 1-16 m in length that displayed linear or semi radial flow patterns, as evidenced by nested U-shaped pahoehoe coils oriented to the same direction. Oriented samples were collected from coils or other parts that could be successfully removed with a rock hammer and chisel. Care was taken to ensure sampling of both edges and middle of a lobe for comparison between assumed sheared and non-sheared portions. Before dislodging samples, they were marked with a north arrow, the top of the sample was indicated, and strike and dip of three sides of the lava sample were recorded and marked for additional accuracy. Care was taken to sample both lobe centers and margins. Location of samples within lobes, as well as relevant measurements of slope, size, and strike and dip were taken for each lobe.

At Syracuse, sections of flows were chosen for sampling if they were breakouts that had exhibited linear or semi radial flow direction down a measured continuous slope. Two breakouts were chosen, each approximately 0.5 m in length. Once cooled, the breakouts were marked with a north arrow and moved off-site to make way for the next lava pour. More north arrows were placed parallel to the original, and the entire lava sample was broken up with a rock hammer so individual samples from the center and sides could be marked additionally.

All oriented samples were prepared in the Syracuse rock cutting lab by re-orienting to north and top, and cutting samples into 2 cm x 2 cm cubes. Because these lava samples were, by nature, glassy, it was necessary to coat all samples with epoxy before cutting to reduce shattering. Some shattering did occur, but in most cases enough material remained in the sample to obtain whole or partial cubes that could still be measured for AMS.

The sample cubes were taken to the Paleomagnetism lab of the Department of Geological Sciences at the University of Michigan for measuring AMS on a KLY-2 Kappabridge using the 15-step method.

RESULTS

The bulk susceptibility values for all lava flows sampled did not differ significantly and had an average of 6.86x10-3. The F-values for all samples were above the critical value of 3, making them statistically significant. There was not a significant correlation between the AMS of samples from the middle and sides of the flows.

The AMS data collected from the Iceland and Syracuse lava samples were used to construct Flinn diagrams (Fig. 2), which plot the ratio of maximum to intermediate susceptibility axes (K1/K2) to the ratio of intermediate to minimum susceptibility axes (K2/K3). Equal area projections were also constructed from the principal directions of the three susceptibility axes (Fig. 5). The results reveal some flows that display clustering as a whole and some that display too much scatter to draw significant conclusions.

Overall, the AMS of Iceland and Syracuse lava samples display a large variety of ellipsoid shapes, with no significant correlation in regards to the AMS and the position of the samples on the edges or in the middle of the flow. Many samples display ellipsoids close to a spherical shape, with some flows exhibiting more oblate or prolate shapes.

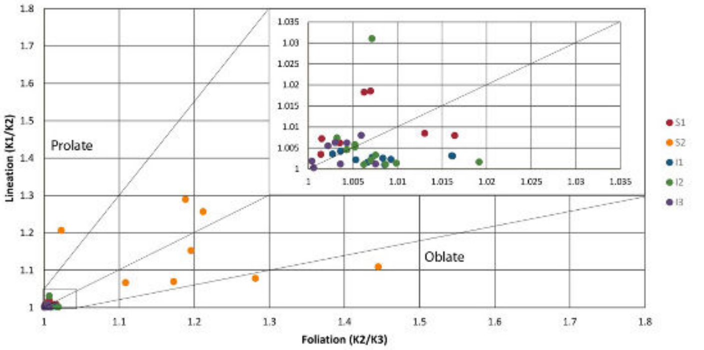

Figure 2. Flinn diagram for Iceland (I1-I3) and Syracuse (S1-S2) flows. Callout box shows zoomed view of S1 and all Iceland flows due to scale differences. Graph points show scatter, but clustering displays ellipsoid shapes close to spherical.

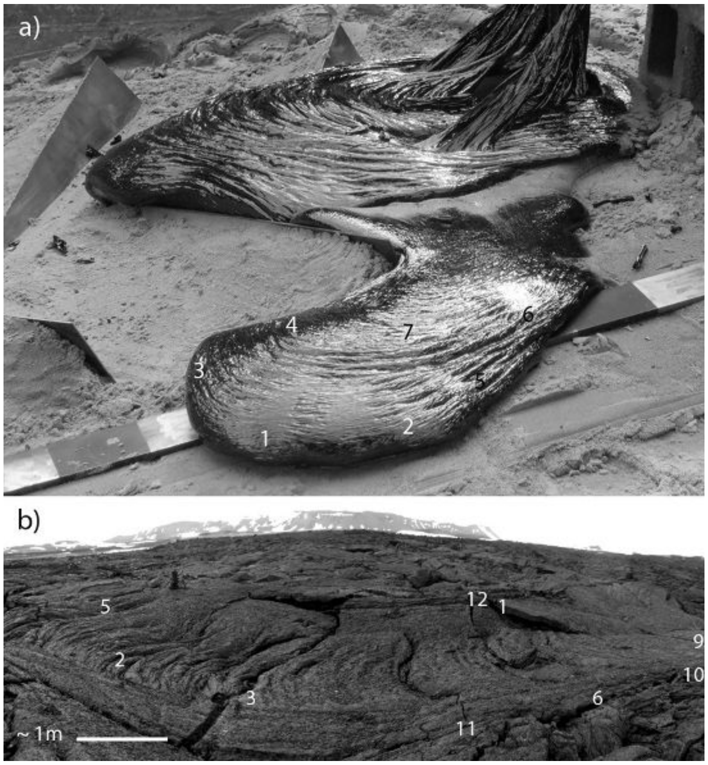

Figure 3. Image of a) Syracuse and b) Iceland lava flows with locations of numbered samples indicated.

Some flows contain samples exhibiting similar ellipsoid shapes to one another as well as principal directions for a relevant susceptibility axis, such as the maximum axis for prolate ellipsoid clusters or the minimum axis for oblate ones. The respective lobes and flows from Iceland and Syracuse displaying the most coherent results are featured below (Fig. 3 and 4). AMS results are presented as Flinn diagrams and principal directions of maximum, intermediate, and minimum susceptibility axes plotted on equal area projections (Fig. 4). Previous studies of the AMS of lava flows that involve more sampling within a given area or sampling strategies that target a large flow holistically instead of separate lobes have been successful in constraining flow direction (Herrero-Bervera, E. et al., 2002, Callot, J.-P. et al., 2004).

The lobe sampled in Iceland displayed below (Fig. 3, 4) has a dip and dip direction of flow of 260 and 7 degrees, measured in the field based on surface texture and position with respect to the Krafla fissure. The trend and plunge of the line perpendicular to the average principal direction of the minimum susceptibility axes sampled from that lobe is 263 and 26 degrees.

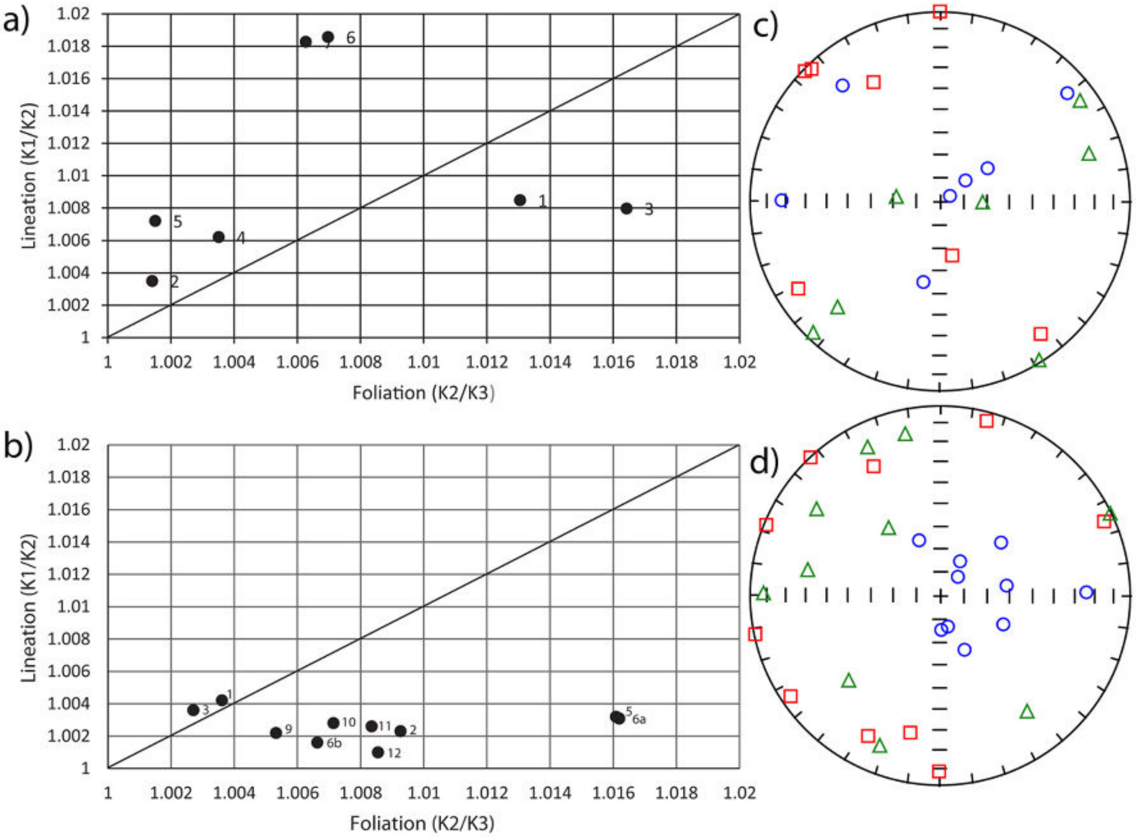

Figure 4. Flinn diagrams for a) Syracuse and b) Iceland flows; principal directions of susceptibility axes (K1, K2, K3) for c) Syracuse and d) Iceland flows, plotted on equal area projections.

The degree of anisotropy for samples collected from the second Syracuse flow were higher in anisotropy by an order of magnitude to all other samples, and further investigation of a subset of both Syracuse flow samples revealed a high saturation magnetization that was too high to attribute to magnetite alone. The saturation magnetization is closer to that of native iron (Fig. 5). It is probable, then, that the lava used in the experimental lava flows contained a minute percentage of iron that dominated any magnetic signal that the magnetite in the sample may have had. Positively identifying iron crystals in thin section was not possible due to the assumed extremely low percent iron composition that the sample must possess.

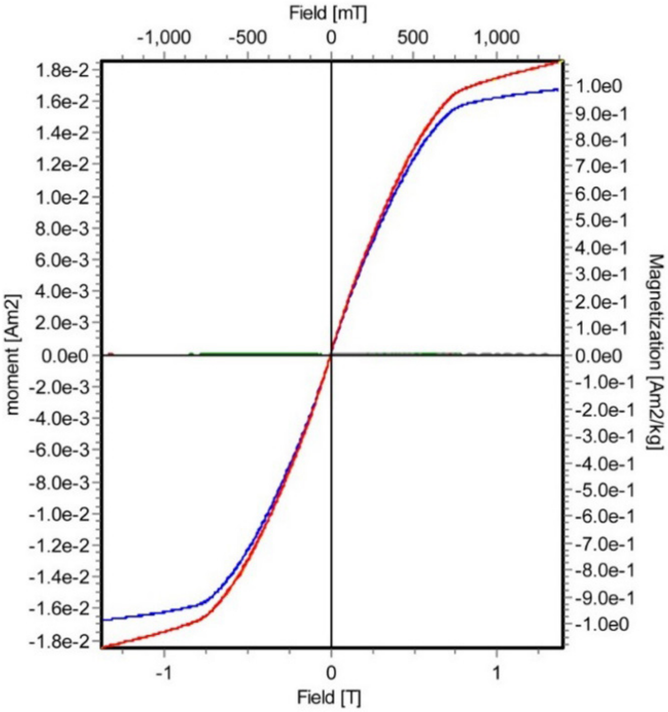

Figure 5. Hysteresis loop showing magnetization of a Syracuse lava sample. Red line indicates total magnetization, with saturation occurring at change in slope at approximately 1.0 Am2/kg. Blue line indicates ferromagnetic contribution (paramagnetic slope subtracted). Level of magnetization indicates the magnetic signal cannot come from magnetite alone and most closely resembles that of native iron. Figure courtesy of Andrew Horst.

CONCLUSIONS

In general, the AMS measurements of the lava flows do not show enough clustering between sheared and non-sheared samples to interpret the effect of shearing on the AMS of lava flows. The variability in AMS measurements, however, shines light on the complex and interconnected factors that influence the AMS of lava flows. If the methods employed in the previous experimental study by Cañón-Tapia and Pinkerton (2000) of measuring temperature at time of shearing, quench rate, and amount of shearing could be employed in further AMS studies of the Syracuse University lava experiments, then factors influencing AMS results may be more easily constrained and interpreted. Finding samples not contaminated by iron will allow comparisons to natural lava flows such as Iceland to be made.

Some of the lava flows displayed clustering of AMS data that can be used to interpret flow direction. The Iceland lava flow featured in the results section displays an oblate AMS ellipsoid, suggesting that the minimum susceptibility axis would be perpendicular to the direction of lava flow. The inferred flow direction from the AMS data (trend and plunge of 263 and 26 degrees) is consistent with field measurements of the direction of flow (trend and plunge of 260 and 7 degrees).

Potential sources of error include loss of precision from taking block samples for subsequent re-orientation and cutting. Drilling cores and orienting in-situ with a sun compass would yield more precise orientation. Measuring the internal temperature of Syracuse lava flows as they are emplaced was not possible; only surface temperatures were recorded with a FLIR camera. Comparing internal temperature measurements synchronized with video of flow emplacement could be used to approximate factors influencing AMS.

ACKNOWLEDGEMENTS

Many thanks to the Keck Geology Consortium for providing this opportunity, to Jeff Karson and Rick Hazlett for leading the project and providing mentorship, and to Andrew Horst for guidance throughout the entire project and for mentoring an additional trip to Iceland through a research assistantship provided by Oberlin College. Thanks as well to Samantha Nemkin at the University of Michigan for aiding in measuring AMS in the Paleomagnetism laboratory at the Department of Geological Sciences.

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