THE ANISOTROPIC MAGNETIC SUSCEPTIBILITY OF PROTEROZOIC NORTHSHORE VOLCANIC RHYOLITES, KEWEENAW RIFT

RYAN PORTER
Whitman College
Sponsor: Kevin Pogue

INTRODUCTION

The North Shore Volcanic Group (NSVG) in Minnesota is part of the 1.1 Ga Midcontinent Rift System. In the area between Silver Bay and Duluth, 10% of the NSVG is composed of rhyolite and icelandite (Green and Fitz, 1992). While Green and Fitz (1992) have each contributed to an understanding of the petrology of the flows through chemical and field analysis, little geophysical work has been done on these flows. This project explores the effectiveness of anisotropic magnetic susceptibility (AMS) as a means of determining flow direction for relatively old extrusive rocks. AMS has been recognized as a potential technique for analyzing rocks since 1954 when John W. Graham published a paper entitled *Magnetic Anisotropy; an unexploited petrofabric element* (Tarling, 1993). Since then, AMS has been used on a variety of materials ranging from flood basalts to mafic dikes, however, little research has been done using AMS to analyze extrusive felsics such as rhyolites (Glen et al. 1997; Craddock and McKiernan, 2006). The purpose of this project was to test the effectiveness of AMS on rocks of this age and lithology and to determine flow direction of the lava when these rocks were emplaced in order to further understand lava emplacement during the Keweenawan rifting of North America.

FIELD DESCRIPTION

The volcanics associated with the mid-continent rift are almost exclusively flood basalts and diabase. Felsics and intermediates make up only 10% of the NSVG. As the rift spread, it is believed that the initial volcanism was primarily mafic in composition but then as volcanism subsided a felsic “shield” was emplaced above the flood basalts in certain areas (Green, 1983). Vervoot (1996) suggests a model where the flood basalts were emplaced during a period of rapid rifting beginning 1107 +/- 2 Ma. As spreading slowed, the crust experienced partial melting which led to the emplacement of felsic rocks on the surface. Two of these felsic units were chosen based on their location relative to the rift and their mode of emplacement. The first unit, the Palisade Head formation, is interpreted to be a rheoignimbrite and crops out in Tetagouche State Park (Green and Fitz, 1992). The outcrop is a large hill that forms 30 meter cliffs above Lake Superior and the surrounding landscape. The rheoignimbrite is at least 90 meters thick, 1097 +/- 2 Ma and extends 23 km north of the park (Vervoot, 1996; Green and Fitz, 1992). Except for a few isolated outcrops the formation is almost entirely covered by Quaternary glacial till. The formation has fiamme texture and welded shards throughout which led to its classification as a rheoignimbrite (Green and Fitz, 1992). The Lakewood unit crops out along the shore of Lake Superior, approximately 7 kilometers north of Duluth. It is interpreted to be a lava flow by Green and Fitz (1992). Flow banding and layering are present in this unit, but we avoided these complex zones for AMS samples. The unit is 78 meters thick and the outcrop where it was sampled extends several kilometers inland though it is almost entirely covered by Quaternary glacial deposits.

METHODS

To determine the AMS fabric of these rocks, three oriented samples were taken from four locations in the Palisade rheoignimbrite and three locations in the Lakewood rhyolite. They were chosen to represent the bottom, middle and top of the flows. This was done to determine if AMS fabrics varied depending on the location of the sample within the flow. The AMS fabric is ideally a proxy for the flow direction of the lava. As the lava flows shear forces are exerted on oblong mineral grains causing them to rotate in the lava until the grains are elongate in the direction of flow. This alignment of mineral grains produces a magnetic field that is stronger in the direction of flow than in other directions, these magnetic fields are referred to as the AMS fabric. These samples were analyzed at the Institute of Rock Magnetism (IRM) located at the University of Minnesota, Minneapolis. In order to analyze the samples with the magnetic anisotropy bridge they were cut into approximately twenty, one-inch cubes, each of which was analyzed individually in the bridge. An issue that often came up while cutting cubes was that they often broke along preexisting fractures. This meant that a few samples had to be vacuum impregnated while other cubes were held together with nonmagnetic glue. Once the cubes were cut, they were then inserted into the "Roly-Poly" magnetic anisotropy bridge. The "Roly Poly" is a room temperature low field magnetic anisotropy bridge built at the IRM. The bridge produces a magnetic field that alternated at 680 Hz and has a strength of .01 to 1 mT. It rotates the sample at three orthogonal orientations in 1.8° increments. A measurement is taken at each increment by the receiver coils which are accurate to 1.2E-6 SI. A total of 600 measurements are taken per sample which is analyzed in approximately 2 minutes. This information is compiled by the attached computer to produce an AMS ellipsoid. The ellipsoid is based off of the orientations and relative strengths of the Kmin, Kint, and Kmax axes, which are named after the strength of the relative magnetic fields. In order to filter the data, the average lineation is taken for each sample site. Any cube with a lineation value less than the average is removed. The orientations of the Kmin and Kmax of the remaining cubes are plotted on a stereonet to display the data visually.

RESULTS

The data produced by the AMS shows extreme variability. Ideally, the AMS fabric should be accurate to within a few degrees and give a definite flow direction for the lava. The Kmax orientation should be aligned with the direction of flow and the Kmin orientation perpendicular to any cleavage or foliations in the rock and parallel to the orientation of greatest compressive stress (Borradaile, 1988). MacDonald (1987) also makes the claim that it is possible to see imbrications in mineral grains due to flow which would result in high angle Kmax orientations. Unfortunately, this did not appear to be the general case. The data shows large variations in the orientation of the Kmax and Kmin axes. It is displayed for the Palisade rheoignimbrite in Figure 1 and for the Lakewood flow in Figure 2. The Palisade results show clumping of the Kmax orientations at low angles near each of the poles, and high angle Kmin orientations. There is no similar pattern for the Lakewood flow which shows a much greater variation in the orientation of the magnetic axes.

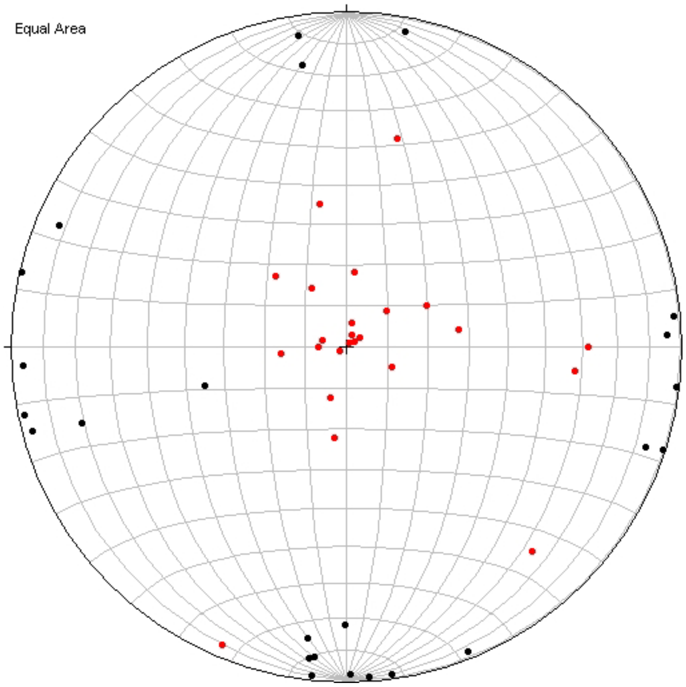

Figure 1. Stereonet showing the Kmax (black) and Kmin (red) orientations for the Palisade Rheoignimbrite. Stereonet Produced using StereoWin 1.2

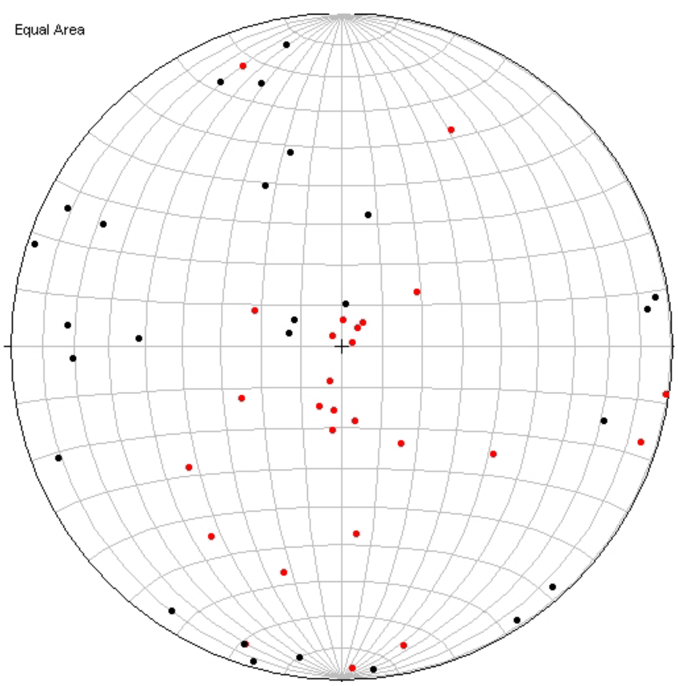

Figure 2. Stereonet showing the Kmax (black) and Kmin (red) orientations for the Lakewood Rhyolite Flow. Stereonet Produced using StereoWin 1.2

CONCLUSIONS

While the data from this experiment is not as conclusive as was originally anticipated, it is explainable when examined in the context of lithology and mode of emplacement of these particular rocks. The rhyolites examined are less than ideal for analysis using AMS due to the high viscosity and the weathering these rocks have experienced over the years. The high viscosity can potentially prevent the mineral grains from rotating in the lava while weathering has been demonstrated to decrease the consistency of AMS fabrics (Tarling, 1993). While these factors may have negatively affected the clarity of the results, there is a fair amount of evidence to suggest that the technique worked on both samples. While determining exact flow direction is difficult, differentiating between flows and rheoignimbrites is possible. Ellwood (1982) suggests that rheoignimbrites will have a strong horizontal component due to compaction as the ash falls and then flows. This seems to accurately explain the results for the Palisade rheoignimbrite where the Kmin values are largely vertical due to the compressive stress exerted as the rock was initially emplaced as ash. The Kmax values are largely horizontal due to the lava flowing. The varying Kmax directions are problematic but can be explained if the lava did not flow far enough or had too much viscosity to produce a definite direction of flow. The Lakewood AMS fabric is less interpretable than the Palisade rheoignimbrite. If the Kmin and Kmax values are in fact proxies for flow direction then the lava flow for this sample would be highly erratic. While this seems unlikely at first, near the sample site flow banding was present in the rock that showed significant variation in orientation in distances as small as 10 cm. If this flow banding is used to indicate flow direction, then the AMS data may be correct for this particular unit. While these results would not allow us to determine the flow direction for the flow as a whole it does give interesting insight into how varied the flow directions were within the flow. These variations could stem from flow over a rough surfaces or more likely due to the high viscosity of the lava. The initial results from this research are less than ideal but given the relative simplicity of the technique, a further examination into the feasibility of AMS studies on felsic extrusive material is warranted.

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