KECK GEOLOGY CONSORTIUM

21ST KECK RESEARCH SYMPOSIUM IN GEOLOGY SHORT CONTRIBUTIONS

April 2008

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The Árnes central volcano, Northwestern Iceland
Brennan Jordan (University of South Dakota), Bob Wiebe (Franklin & Marshall College), Paul Olin (Washington State U.)
Students: Michael Bernstein, Elizabeth Drewes, Kamilla Fellah, Daniel Hadley, Caitlyn Perlman, Lynne Stewart

Origin of big garnets in amphibolites during high-grade metamorphism, Adirondacks, NY
Kurt Hollocher (Union College)
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Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
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The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
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Funding provided by:
Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium: Projects 2007-2008
Short Contributions – Iceland

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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PETROGENESIS OF LAVAS OF THE SOUTHERN FLANK OF THE ARNES CENTRAL VOLCANO, ICELAND

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INTRODUCTION

Iceland is composed mainly of volcanic rocks derived from the interaction of a mantle plume and mid-ocean ridge activity. Most of the rocks in Iceland are tholeiitic basalts, which would be expected at a mid-ocean ridge. However, approximately 10-12% of the exposed rocks are silicic in composition, which is unusual in this tectonic setting (Gunnarrson, 1998). Volcanic rocks in Iceland are strongly bimodal, consisting mainly of basalts and rhyolites and of only 3% intermediate rocks (Gunnarrson, 1998). With high volumes of silicic volcanic rocks in a predominantly basaltic province, Icelandic geology may shed light on the ongoing debate surrounding the formation of large volumes of silicic magma. Two competing hypotheses for the creation of silicic magmas at central volcanoes in Iceland are, 1) extreme fractional crystallization (e.g., Furman, 1992) and 2) partial melting of hydrothermally altered meta-basalts (e.g., Gunnarsson, 1998).

The Arnes central volcano, which erupted at ~11 Ma in the Skagi-Snaefellsnes rift zone in the Westfjords, is the focus of this study. The general geology and distribution of silicic rocks in the Westfjords was compiled on the national geologic map of Iceland (Jóhannesson and Saemundsson, 1998). This study focuses on the southern-most portion of the Arnes central volcano, informally referred to as Area X, with more detailed field maps, mineralogical, geochemical, and petrographic data. The results are evaluated with respect to opposing hypotheses for the origin of silicic magmas in Iceland.

METHODS

The locations of samples, hypothesized flow contacts, and defined rock units were mapped using differentially corrected handheld GPS. Representative samples were collected from all distinct lithologies within each unit. Twenty-one samples were thin sectioned at Oberlin College, where the mineralogy and texture were further examined with a petrographic microscope. Fifteen of the samples deemed most relevant in determining the nature of the field area were analyzed for major and trace element chemistry using X-ray fluorescence spectroscopy at Washington State University. All XRF data reported in this study reflect values normalized to a sum of 100%.

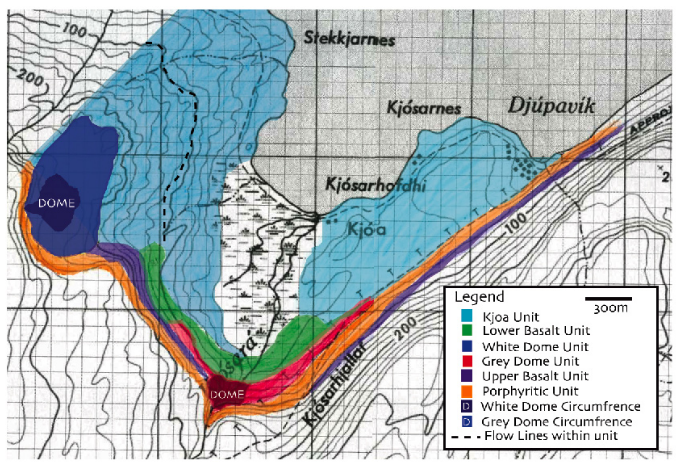

Figure 1: Unit map Area X

FIELD RELATIONS

The study area consisted of three square kilometers west of the town of Djupavik. I recognized six distinctive map units: the Kjoa unit, the lower basalt unit, the white dome unit, the grey dome unit, the upper basalt unit, and the porphyritic unit (Fig. 1).

The lowest unit in the study area is the Kjoa unit, which consists of massive rhyolite at the base of each flow and finely jointed rhyolite near the top. This unit is 40-200 m thick, and it consists of at least two distinct flows separated by 10-20 cm of vessiculated rock. Though no second contact was found, it is likely that a third flow based on the presence of several massive to jointed outcrop sequences. The flows have a gentle southeasterly dip. The Kjoa unit has the largest volume of the six mapped units in the map area.

The unit that overlies the Kjoa unit is comprised of several flows, all of which are basalts of slightly different composition and mineralogy. These basalts are designated the lower basalt unit. The flows in this unit range in thickness from 2-10 m.

The white dome unit (WDU) overlies the Kjoa and lower basalt units. A brecciated, red, glassy layer approximately 10 cm in thickness identifies the contact between the WDU and the Kjoa unit. Within the WDU is a spherulitic rhyolite layer which is most clearly exposed along the northern and southern margins of the unit. At the center of the WDU is a mass of white to light grey silicic glass and vapor phase-altered rhyolite 300 m in diameter. The physical characteristics of this rock mass are consistent with origin as a lava dome; they include common structural formations such as vertical banding and climbing flows that border a lightly colored, dome shaped mound.

The grey dome unit (GDU) in the southern portion of Area X lies at approximately the same stratigraphic level as the WDU. This unit includes a 60-70-m-high, 90-m-wide dome-shaped mass as well as a single lava flow to either side. Vertical, curvilinear flow banding, as well as a pronounced dome shape evidence the grey dome. Basaltic flows above this unit thin over the top of the dome, suggesting the dome was a topographic high around which younger lavas flowed.

The upper basalt unit (UBU) consists of three basalt flows that make up a large part of the steep cliffs in Area X. The flows in the UBU sandwich the porphyritic unit, discussed below, which consists of a much larger volume of and a different suite of phenocrysts and has thus been designated as a separate unit. In the east towards Djupavik, two 5-m-thick basaltic flows are stacked above the porphyritic unit. In the western cliff wall, another basaltic flow of similar composition underlies the porphyritic unit. The UBU appears to continue stratigraphically higher outside of the study area towards the north.

The porphyritic unit is a set of two to three lithologically distinct basalt flows that contains 10% phenocrysts up to 10 mm in length. Each flow is 7-10 m thick. This porphyritic unit thins over the grey dome, but is several flows thick over the white dome. This suggests that the grey dome is slightly younger than the white dome, and thus was still a topographic high when the porphyritic lava flowed over Area X.

PETROGRAPHY AND GEOCHEMISTRY

The lower basalt unit is chemically uniform with 49 wt% SiO_2. Phenocrysts vary volumetrically from 2-4%. Plagioclase is the most abundant phenocryst phase, but resorbed clinopyroxenes are present in some samples. Small scale magma mingling is evident in thin section in one sample, between two magmas with apparently basaltic composition. The two magmas can be distinguished by the amount of plagioclase in the matrix.

The Kjoa unit consists of rhyolites ranging in SiO_2 composition from 71-73 wt%. The unit becomes increasingly more silicic up section. The samples from this unit all have 2-3% phenocrysts by volume. Plagioclase makes up 83% of the phenocrysts by volume, resorbed clinopyroxene 10%, oxides 3%, orthoclase 2%, and hornblende 2%. Plagioclase and clinopyroxene phenocrysts possess glomerophyric texture in the younger flows but the oldest flow does not. The matrix possesses intergranular texture in all the samples.

The white dome unit is rhyolitic, and shows compositional variation, with SiO2 content ranging from 71-73 wt%. Samples in this unit are porphyritic, with phenocrysts from 5-10% by volume. Plagio-

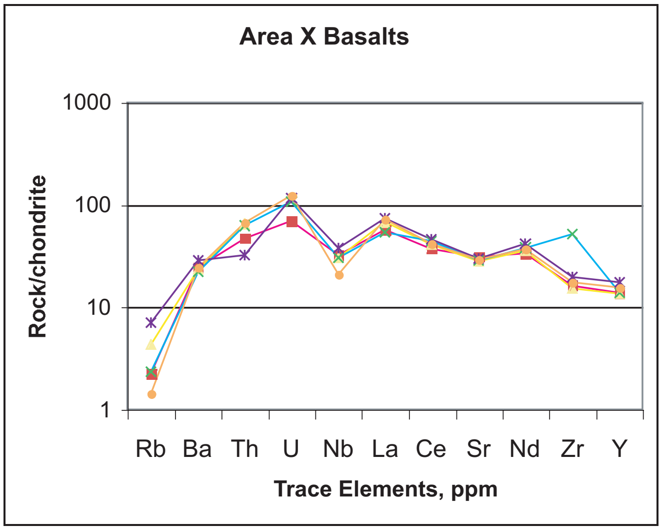

Figure 2: Spider diagram of basaltic units

clase is the most abundant phenocryst phase, ranging from 40-95% of the phenocryst volume, and most crystals are resorbed. Orthoclase is abundant as a secondary mineral in altered samples, making up 50% of the mineral volume alongside some secondary quartz. Clinopyroxene and oxides are also present, accounting for 2-3% of the phenocrysts in this unit.

The grey dome unit is a dacite to rhyolite having a SiO_2 composition that ranges from 67-72% by weight. Phenocryst volume is between 1-4%, and phenocrysts are primarily plagioclase, oxides, and clinopyroxene in order of abundance. In some samples, mafic minerals exhibit glomerophyric texture. Clinopyroxene has been resorbed in samples where it was present.

The upper basalt unit flows are 49 wt% SiO_2. Phenocrysts constitute 2-5% of the rock, and of them 85-95% are plagioclase with laths up to 9 mm in length. In some flows clinopyroxene phenocrysts occur. The matrix texture varies across flows from subophitic to coarse intergranular, and sometimes contains oxides as well. Plagioclase and clinopyroxenes possess glomerophyric texture in some flows.

The porphyritic unit is 48 wt% SiO_2 and the matrix texture is intergranular. Up to 10% of the rock is phenocrysts, of which 96% are plagioclase laths up to 10 mm in length, 2% resorbed olivines, and 2% resorbed clinopyroxene.

A spider diagram (Fig. 2) normalized to chondrite (Wood et al., 1979) shows an overall E-MORB pattern in the basaltic magma. This pattern is consistent with the prevalent theory regarding Icelandic magmatism as plume influenced MORB.

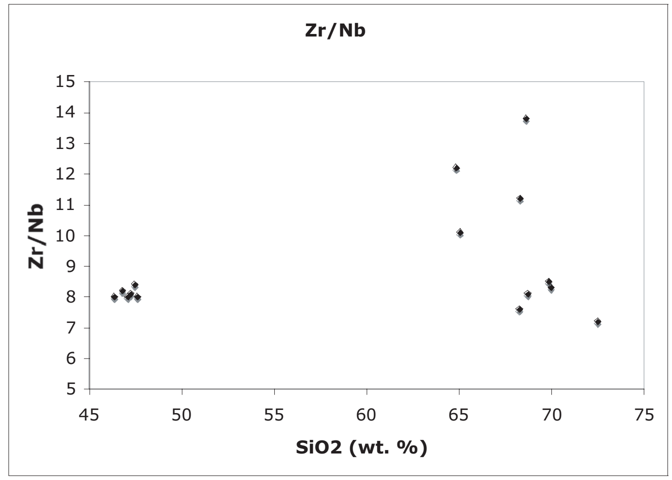

Figure 3: Zr/Nb plot against SiO_2 content. Ratios for basalts cluster around 8, suggesting E-MORB and a mantle plume influence.

The influence of the mantle plume magma is suggested by Zr/Nb ratios that range from values of 7-14 (Fig. 3) with ratios for basaltic magma clustering around 8. Zr/Nb ratios of <10 generally indicate E-MORB, whereas higher ratios of values >30 tend to suggest N-MORB source (Hardarson et al., 1997). MORBs near plumes logically exhibit lower Zr/Nb ratio values along a mixing line between OIB and MORB values (Winters, 2001). The ratios for basalts are all less than 10, supporting the theory suggested by interpretation of the spider diagram that E-MORB influence was more significant in the production of the basaltic magma than MORB. Harker diagrams (Fig. 4) show continuous trends suggesting a relationship between the basalts and silicic rocks. The continuous decrease of both CaO and Al_2O_3 suggest early formation and fractionation of Ca-rich plagioclase and clinopyroxene, which is consistent with the phenocryst mineralogy of the samples. A steady increase in K_2O suggests

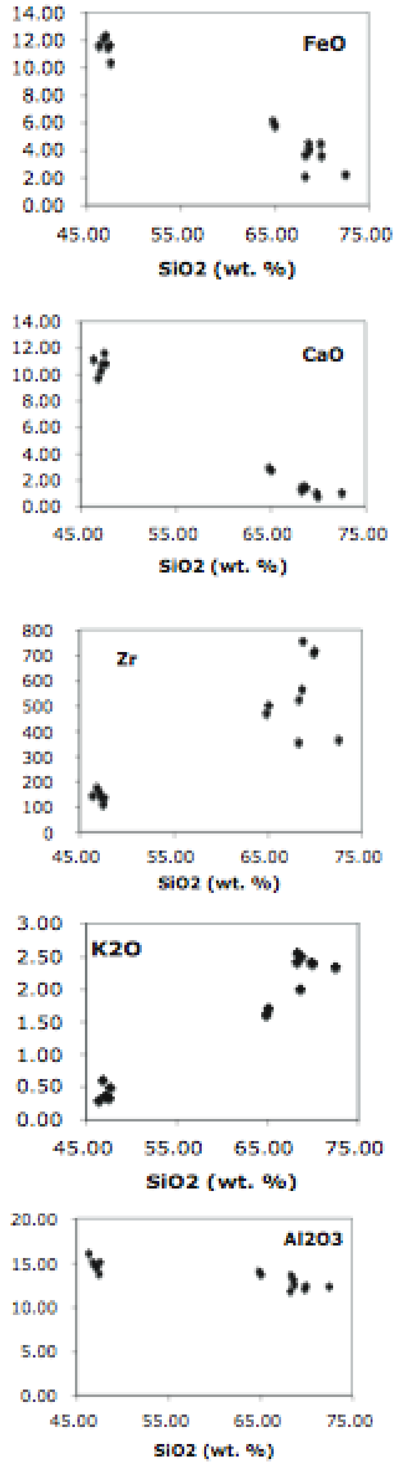

Figure 4: Harker diagrams showing evidence of fractional crystallization.

that alkali elements were not incorporated into the magma, which is consistent with the observed mineral assemblages. Zr correlates negatively with SiO_2 among the more silicic samples, suggesting zircon fractionation.

DISCUSSION

The purpose of this study was to determine the origin of silicic rocks from the area surrounding the Arnes central volcano in northern Iceland and to evaluate the influence of the mantle plume in this process. Previous hypotheses regarding the origin of silicic magmas in Iceland include extreme fractionation of a basaltic parent and partial melting of basaltic crust. Some of these studies have shown a possible relationship between the movement of the plume and rift abandonment and the formation of silicic lavas (Jordan, 2004). Jordan has suggested that as the rift drifts off the plume, the only means of producing silicic lava is by extreme fractional crystallization.

The enrichment in the basalts of incompatible elements as compared to a typical MORB, as well as the fact that Zr/Nb ratios are low, suggest significant plume influence. If no plume were present under Iceland, typical MORB trace element patterns would be expected. The data collected supports the plume theory by showing a characteristically plume influenced trace element distribution in the basalts of the Arnes central volcano.

The strong fractionation patterns observed in the Harker diagrams support previous work stating that extreme fractionation is responsible for the formation of rhyolitic lavas. Positive correlation between K_2O and SiO_2 could be consistent with either fractionation or decreasing degrees of partial melting to form a rhyolite. However, the negative correlation between Zr and SiO_2 can only be explained by fractionation because the source rock, basaltic crust, is very unlikely to contain zircon (Jordan, 2004).

ACKNOWLEDGEMENTS

I would like to thank my project leader, Brennan Jordan, Paul Olin, Bob Wiebe, and my fellow students for all the help in the field. I greatly appreciate all the time and effort my sponsor Steve Wojtal and professor Zeb Page have contributed while working with me. I would also like to thank Holly Frey, Matt Manon, Dennis Hubbard, Karla Hubbard, Pete Munk, and Retha Ball.

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