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Keck Geology Consortium
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Tectonic and Climatic Forcing of the Swiss Alps
John Garver (Union College), Mark Brandon (Yale University), Alison Anders (University of Illinois), Jeff Rahl (Washington and Lee University), Devin McPhillips (Yale University)
Students: William Barnhart, Kat Compton, Rosalba Queirolo, Lindsay Rathnow, Scott Reynhout, Libby Ritz, Jessica Stanley, Michael Werner, Elizabeth Wong

Geologic Controls on Viticulture in the Walla Walla Valley, Washington
Kevin Pogue (Whitman College) and Chris Oze (Bryn Mawr College)
Students: Ruth Indrick, Karl Lang, Season Martin, Anna Mazzariello, John Nowinski, Anna Weber

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)
Students: Denny Alden, Erica Emerson, Kathryn Stack

Carbonate Depositional Systems of St. Croix, US Virgin Islands
Dennis Hubbard and Karla Parsons-Hubbard (Oberlin College), Karl Wirth (Macalester College)
Students: Monica Arienzo, Ashley Burkett, Alexander Burpee, Sarah Chamlee, Timmons Erickson Andrew Estep, Dana Fisco, Matthew Klinman, Caitlin Tems, Selina Tirtajana

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)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
Greg Wiles (The College of Wooster)
Students: Erica Erlanger, Alex Trutko, Adam Plourde

The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
Tim Ku (Wesleyan University) Suzanne O'Connell (Wesleyan University), Anna Martini (Amherst College)
Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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

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THE ÁRNES CENTRAL VOLCANO, NORTHWEST ICELAND

BRENNAN JORDAN: University of South Dakota
ROBERT WIEBE: Franklin and Marshall College
PAUL OLIN: Washington State University

INTRODUCTION

Iceland is a 103,000 km^2 island in the North Atlantic, midway between the northern British Isles and Greenland. Iceland lies astride the Mid-Atlantic Ridge, which rises above sea level at Iceland because of excess magmatism due to the intersection of the ridge with the Iceland hotspot, generally interpreted as a mantle plume. The Mid-Atlantic Ridge drifts west in the hotspot reference frame, and when an active rift has drifted far enough off of the hotspot it is abandoned in favor of a new rift which develops over the hotspot. These rift relocation events have occurred at least twice in the geologic history of Iceland (e.g., Hardarson et al., 1997), and a third rift relocation event may be ongoing with propagation of the eastern rift zone at the expense of the western rift zone. The last abandoned rift system in Iceland is the Skagi-Snaefellsnes rift zone which was active between 15 and 7 Ma (Fig. 1).

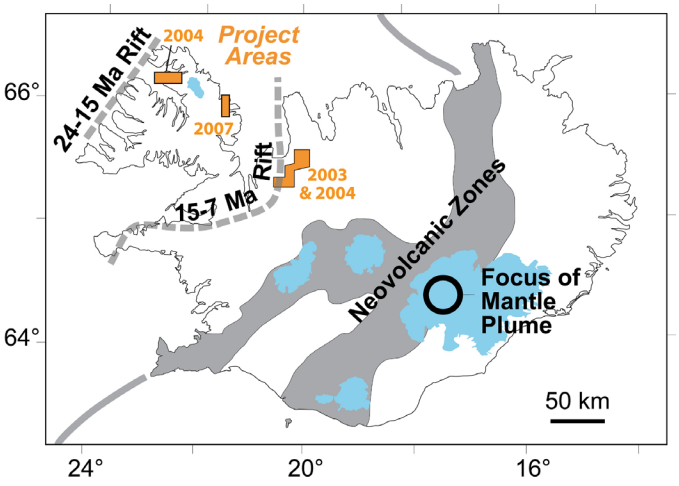

Figure 1. Map of Iceland showing the 2003, 2004, and 2007 Keck project areas, the position of the hypothesized mantle plume, neovolcanic zones, and the last two abandoned rifts.

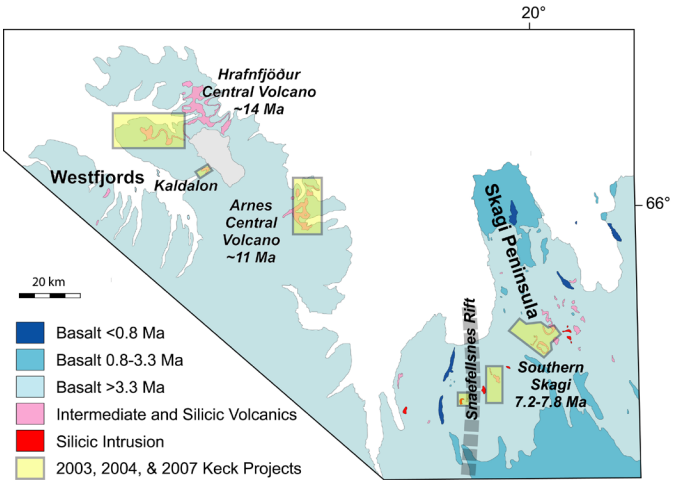

Figure 2. Geologic map of the northern Westfjords region and Skagi Peninsula showing 2003, 2004, and 2007 Keck project areas (after Jóhannesson and Saemundsson, 1998).

Previous Iceland Keck projects in 2003 and 2004 focused on rocks erupted in the Skagi-Snaefellsnes rift zone at different times in the history of the rift. The 2003 project and half of the 2004 project focused on the southern Skagi Peninsula, where central volcanoes were erupted right up to the abandonment of the rift at about 7 Ma. The second half of the 2004 project focused on the southern portion of the Hrafnfjörður central volcano in the Westfjords which erupted at about 14 Ma, when the rift was young, and presumably near the hotspot (Figs. 2 and 3). The overarching goal of these projects was to try to understand how crustal magmatic processes varied as the rift drifted away from the hotspot.

The project director's report from the 2004 project (Jordan et al., 2005) stated, "…an exciting next step would be to conduct a similar study of the Árnes central volcano that lies between the two 2004 study areas." We are pleased to report that the 2007 Iceland Keck project was the realization of this "exciting next step".

STUDENT PROJECTS

Upon arrival in Iceland we took a three-day field trip through the neovolcanic zones to observe modern analogues of the Tertiary volcanics we would see in the Westfjords. We traveled to the study area, conducted a brief reconnaissance of potential student field areas, and quickly settled into fieldwork. We conducted two weeks of fieldwork in the main study area, and then traveled to another site in the Westfjords, the glacial valley Kaldalon (40 km as the crow flies but >150 km of fjord-tracing road travel), to conduct a reconnaissance of the silicic dome there. Karen Harpp (Colgate University) made a sponsor visit to the project during the Kaldalon reconnaissance and was joined by Denny Geist (University of Idaho).

Fieldwork consisted of characterizing volcanic lithologies and field relations, geologic mapping, and collecting samples for laboratory analysis. Upon returning to their home institutions, students prepared samples for thin sectioning and sent off samples for X-ray fluorescence (XRF) analysis. Some student were able to apply additional techniques including inductively coupled plasma mass spectrometry (ICP-MS) analysis for a broader suite of trace elements, and electron microprobe or scanning electron microscope energy dispersive spectroscopy (SEM-EDS) analysis of mineral compositions. Brief descriptions of the student projects are presented below in an order progressing from north to south (Fig. 3).

Michael Bernstein, Amherst College, studied the volcanic rocks exposed in the mountain Krossnesfjall (Fig. 4), immediately north of camp on the peninsula Krossnes. His steep, lithologically-varied study area included a significant abundance of intermediate lavas and several intrusions. With extra support from his home institution, Mike was able to analyze larger sample suite by both XRF and ICP-MS. He also made SEM-EDS analyses of mineral compositions. Mike found a relevant "in press" paper on which he leveraged strong trace element arguments in favor of the origin of Árnes silicic

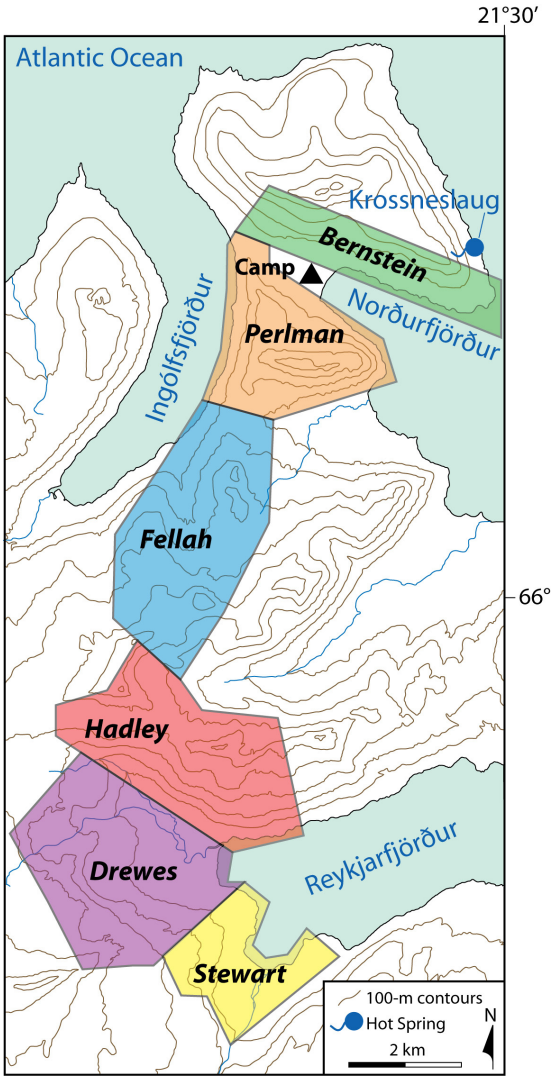

Figure 3. Map of Árnes area, showing the student study areas by last name.

magmas by fractionation.

Caitlyn Perlman, Colgate University, studied the sequence exposed in the mountain Hlíðarhusafjall, rising above Norðurfjörður just south of camp. Most of the south face and east tip of the mountain was too steep to access in the field, but Caitlyn mapped the north face and western slopes, a sequence dominated by intermediate and silicic lavas. Caitlyn did her own ICP-MS analyses at Colgate. Caitlyn also analyzed the samples collected during reconnaissance of the rhyolites at Kaldalon, though these results are not discussed in her contribution in this volume.

Kamilla Fellah, The College of Wooster, worked in

Figure 4. Camp in the "village" of Norðurfjörður beneath the peak Krossnesfjall (646 m). The cliffs expose andesites (low) and basalts (high) in Mike Bernstein's field area.

a field area overlooking Ingólfsfjörður. Her area stretched quite a distance south from the access road, and was characterized by several high rhyolitic peaks, Eyrarháls and Eyrarfell, and, at the southern end, reached up to the basaltic peak Glifsa. Kamilla recognized several possible silicic vents in her area. Kamilla was able to get electron microprobe analyses of plagioclase feldspars in her rocks. The focus of Kamilla's analytical work was on the rhyolitic end of the spectrum which she interpreted to be the product of fractionation of a basaltic parent magma.

Daniel Hadley, Augustana College, faced the challenge of a 300-meter ascent every day before he even started looking at rocks (fig. 5). He studied the rocks north of Reykjarfjarðardalur at the head of Reykjarfjörður, including the peak Reykjarfjarðarfjall. With the support of his home institution, Dan was able to study a somewhat larger suite of rocks. His area featured a wide spectrum of compositions and some intriguing field relations. Dan recognized a wide range in some incompatible trace elements in the Árnes rhyolites, and developed an argument for the role of trace-phases in fractionating these elements. Dan also recognized that the bulk composition of these lavas suggests an affinity for modern flank zones (areas where volcanism occurs away from the main rifts), which may have implications for the overarching question being considered in the three Iceland Keck projects.

Elizabeth Drewes, DePauw University, studied the south side of Reykjarfjarðardalur and worked part way up the basaltic peak Burfell. Her study area included rhyolites and basalts, with few intermediates. Beth collected a sample from Burfell that was the most primitive basalt collected in the Árnes project with 9.5 wt% MgO. Beth observed textural evidence for commingling of magmas, but the comingling magmas were not compositionally distinct enough to produce chemical trends or distinct intermediate magmas.

Lynne Stewart, Oberlin College, focused primarily on the rocks of the southern flank of the Árnes central volcano, as exposed in the southwest corner of Reykjarfjörður. This area included a spectrum of silicic rocks, dacite to rhyolite, in three distinct silicic units, including two well defined domes. Like several others, Lynne also gave consideration to the origin of the basaltic lavas and, based on relatively low Zr/Nb, argued for a mantle plume influence. Lynne also spent several days studying a rhyolitic sill east of the "village" of Árnes, though that work is not discussed in her contribution in this volume

Figure 5. Dan Hadley taking notes in his study area, with a view to the south across the valley Reykjarfjarðardalur to the basaltic peak Burfell in Beth Drewes' area.

PROJECT RESULTS

Mapping

As a group we mapped approximately 34 km^2 of the Árnes central volcano. This represents >80% of the non-basaltic volcanic rocks of the system as compiled on the Iceland geologic map of (Jóhannesson and Saemundsson, 1998). Mapping and subsequent geochemical analysis revealed a full spectrum of lava compositions from primitive basalt to high-silica rhyolite. Intermediate lavas were more abundant in the northern three map areas and were absent from the southern two areas. Based on regional observations it appears that the non-basaltic portion of the lava sequence west of Ingólfsfjörður (only major exposure we did not visit) is probably mostly intermediate.

While several faults with modest offset were recognized, the area has undergone notably less faulting than the southern Skagi area studied in 2003 and 2004. The southern Hrafnfjörður central volcano, also studied in 2004, was similarly less deformed that the southern Skagi area. These observations suggest the logical possibility that the final stages of rifting prior to abandonment are characterized by more tectonic deformation as the magmatic system wanes.

Petrology

In trying to evaluate how crustal magmatic systems varied over the lifetime of a rift from its inception to abandonment one aspect that we have investigated in all three Iceland Keck projects is the processes by which intermediate and silicic magmas are generated in Iceland, a fundamentally basaltic province. End member hypotheses for the origin of silicic magmas are crustal melting (e.g., Gunnarson, 1998) versus high degrees of fractional crystallization from a basaltic parent (e.g., Furman, 1992). Distinguishing between these models hinges on having significant compositional diversity, including intermediates.

Every time we entered a new area in the three Iceland Keck projects we were uncertain as to how much compositional diversity we would find. We were pleased to find abundant silicic and intermediate rocks in the Árnes central volcano. This summary paper will not detail the evidence, but our results for Árnes suggest that intermediate magmas were derived primarily by fractional crystallization of basaltic parent magmas, and that the rhyolitic magmas were probably derived by further fractionation from the intermediate magmas. There is no indication of magma mixing as a mechanism to produce intermediate magmas, and no need to invoke crustal melting to explain the origin of the rhyolites.

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