# TWO SNAPSHOTS OF THE EVOLUTION OF THE TERTIARY SNAEFELLSNES RIFT, ICELAND

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## INTRODUCTION

Iceland marks the intersection of the Mid-Atlantic Ridge with a mantle plume. Plume-ridge interaction drives high magmatic productivity, and has resulted in the genesis of anomalously thick crust under Iceland. As a result, Iceland is the only place on earth where an active mid-ocean ridge is exposed above sea level.

The Mid-Atlantic Ridge migrates westward in the plume reference frame, so over time the ridge and plume should be separated, but the ridge system has re-centered over the plume by a series of jumps (Hardarson et al., 1997). Abandoned rifts are recognized as regional synclines analogous to the syncline that has developed in response to the modern rift (Saemundsson, 1979). The last abandoned rift was the Snaefellsnes rift which became active at about 15 Ma and was abandoned at about 7 Ma (Fig. 1).

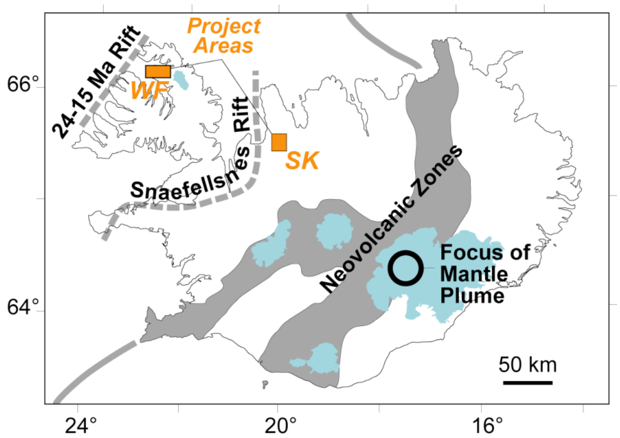


**Figure 1. Map of Iceland showing the project areas (SK = Skagi; WF = Westfjords), mantle plume, neovolcanic zones, and the last two abandoned rifts.**

The Iceland Keck 2003 project focused on the waning phase of the Snaefellsnes rift, mapping volcanic rocks in three mountain ranges near the rift axis. Many interesting petrologic and structural observations were made by students in 2003. The Iceland Keck 2004 project picked up where the 2003 project left off. The first half of this project was spent in the southern Skagi Peninsula expanding on mapping and petrology done in the 2003 project (Fig. 2). A focus in this area was a coarsely porphyritic andesite informally called the “golf ball unit” in 2003, now named the Strjugsskarð andesite.

To conceptually expand on the 2003 project we wanted to study an area in which volcanic rocks were erupted from the Snaefellsnes rift earlier in its history, when the rift would have been centered on the plume. The second half of the project was conducted in the Westfjords of northwestern Iceland (Fig. 2). The volcanic rocks there are about 14 Ma, reflecting the early history of the Snaefellsnes rift.

## STUDENT PROJECTS

Four students undertook projects in the southern Skagi Peninsula and three students did their projects in the Westfjords. After field trip to the neovolcanic zones and a short introduction to each area, students got 8-10 days to do their mapping, sampling, and description of the volcanic stratigraphy. The student projects are briefly summarized below.

### Skagi – 8 Ma

**Charlene (Char) Adzima**, The College of Wooster, performed a detailed study of the anomalous Strjugsskarð andesite (Figs. 3 and

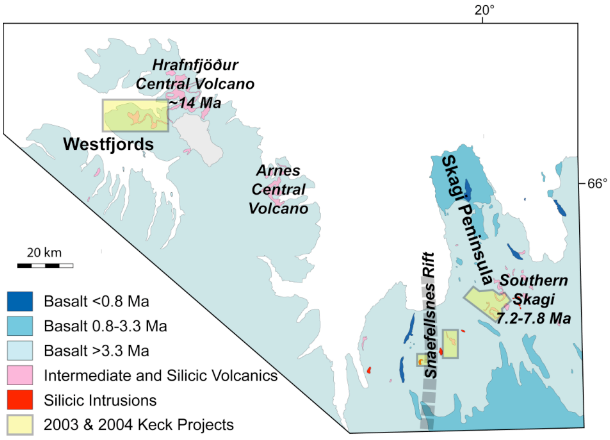


**Figure 2. Map showing the general geology of northwest Iceland and areas studied in the 2003 and 2004 Keck projects.**

4) in the areas that it had been mapped on the mountain Langadalsfjall during the 2003 project. She measured six sections though the andesite and associated volcaniclastic rocks. In addition to XRF and ICP-MS analyses of the rocks she also analyzed several samples by electron microprobe, providing critical evidence for the origin of this unit by mixing.

**Lara Kapelanczyk**, Smith College, mapped the volcanic rocks above the valley Strjugsskarð in Langadalsfjall. She was able to document the northern most extent of the Strjugsskarð andesite in the central area of its exposure. Lara documented mingling textures and augmented her petrography with SEM-EDS analysis of mineral phases.

**Emily (Ross) Baldwin**, Colorado College, Mapped a portion of the mountain Laxárdalsfjöll above the valley Laxárdalur.

**Figure 3. An exposure of Strjugsskarð andesite showing coarse plagioclase phenocrysts and a lens with low phenocryst abundance revealing the complex physical volcanology of this unit.**

**Figure 4. Ross Baldwin mapping in southern Laxárdalsfjöll. The cliff is Strjugsskarð andesite overlying her lower basalt series.**

Her rugged field area (Fig. 4) included complex, valley-parallel faults that cut a stratigraphy that included the Strjugsskarð andesite and a thick rhyolite. Field relations in Laxárdalsfjöll cleared up some critical stratigraphic relationships that were left unresolved by the 2003 project.

**Lebn Schyuler**, Whitman College, also mapped in southern Laxárdalsfjöll, an area with a more diverse array of rocks than had been encountered elsewhere in our mapping in the southern Skagi Peninsula. A thick, and structurally complex, rhyolite exposure may reflect vent of the main rhyolite in the area. Lebn identified a suite of intermediate rocks that define a mixing trend not previously recognized. Lebn also volunteered for a second mapping project in the Westfjords that helped in defining regional relationships.

## Westfjords – 14 Ma

**Sheena Styger**, University of the Pacific, mapped in a backcountry field site above the fjord Leirufjörður. She mapped a rugged dacite dome called Tröllafell, and a suite of andesite to dacite lavas within the basalt

**Figure 5. Seljafjall in the Westfjords. The cliff exposes a thick andesite lava mapped by Jerod Randall.**

stratigraphy. An interesting angle she pursued in the lab was x-ray diffraction analysis of the groundmass mineralogy of her rocks.

**Jerod Randall**, Beloit College, mapped an extensive andesite lava exposed in the steep cliffs of the mountain Seljafjall (Fig. 5). The long daily hike and the challenging terrain of his study area required frequent rotation of assisting faculty! The intermediate rocks of Seljafjall define compositional trends distinct from the nearby lavas of Leirufjordur.

**Sara Johnson**, Beloit College, conducted a detailed study of the basalt stratigraphy of our Westfjords study area, measuring three sections with a total of 91 lavas in the mountains above our base at Grunnavík. By focusing on basalts Sara also provided the compositional constraints necessary to understand the evolution of more evolved rocks in the other Westfjords study areas.

# PROJECT RESULTS

The detailed results of student projects are presented in the extended abstracts that follow this project overview, but some broad scientific observations are highlighted here.

## Mapping

In both the southern Skagi Peninsula and Westfjords study areas we encountered a considerable range of lithologies and complex physical volcanological relationships. In the Skagi area we expanded the known extent of the anomalous Strjugsskarð andesite, and greatly improved our understanding of the lateral and stratigraphic variability of this unit. We also found more extensive rhyolite lavas and rhyolite dikes. Additional intermediate units were found that are stratigraphically associated with the Strjugsskarð andesite and rhyolites, but define new geochemical trends. The southern Skagi area is more structurally complex than the Westfjords study area, with numerous, generally northwest-striking, normal faults dissecting the area.

Coming into the Westfjords, the compilation of Jóhannesson and Saemundsson (1998) indicated the presence of "acid volcanics" so we were prepared to encounter intermediate or silcic volcanic rocks. We mapped two quite different intermediate lavas. The lava Jerod Randall mapped in Seljafjall was 200-300 m thick (Fig. 5) for much of its extent and disrupts the regional stratigraphy; the andesite-dacite lava Sheena Styger mapped was ~50 m thick and lies within a conformable stratigraphy. Though we did not get to the area where the flows come together, it appears that the thinner lava is stratigraphically below the thick Seljafjall andesite. The basalts studied by Sara Johnson also project under the Seljafjall andesite. The lowermost basalt was dated by the $^{40}Ar/^{39}Ar$ method yielding an age of 14.20 ± 0.33 Ma (at 2σ).

## Petrology

All students performed petrographic analysis of a representative suite of the samples they collected in Iceland. Additionally 101 samples were analyzed for major, minor, and trace elements by x-ray fluorescence, and a subset of 39 of these were analyzed for a larger suite of trace elements by ICP-MS. Analytical work was done by the GeoAnalytical Labs at Washington State University. Some students had the opportunity to apply other techniques including electron microprobe analysis, SEM-EDS, and x-ray diffraction.

Texturally and mineralogically, most basalts were representative of the tholeiitic lavas that dominate the Tertiary rocks of Iceland (Saemundsson, 1979). However, in both project areas many intermediate and silicic rocks were also sampled. Some textural features in the Strjugsskarð andesite indicate magma mingling and mixing, consistent with compositional evidence discussed below. Electron microprobe and SEM-EDS analysis of the coarse plagioclase phenocrysts in this unit revealed calcic compostions (up to $An_{90}$), indicating an origin in basaltic magma.

Compositionally, the samples analyzed are classified across the spectrum, from basalt to rhyolite (Fig. 6). Intermediate and silicic compositions are overrepresented in Figure 6 as they were sampled intensively because of their petrologic importance. We did not encounter any rhyolites in the Westfjords study area, though the dacite of the Tröllafell dome may reflect more silicic rocks closer to the core of the Hrafnfjordur central volcano.

Major and trace element analyses of rocks from the southern Skagi area allowed us to refine our understanding of the Strjugsskarð andesite. Clear textural, mineralogical, and composition evidence indicates that this unit is the result of mixing of a plagioclase ultraphyric basalt with a zoned dacite to rhyolite magma. This probably reflects lateral dike propagation of the basalt into the silicic magma chamber as has been documented geophysically (in real time) in the Krafla fires eruption of 1976-1984 and petrologically in the 1470s eruptions in the Torfajökull caldera (Blake, 1984).

The origin of dacites and rhyolites in the southern Skagi area remains equivocal. What is clear is that the rhyolites are the result of fractionation of the dacites. The question is, are the dacites the result of crustal melting, or extreme fractionation of a basaltic parent?

In contrast with intermediate rocks of the Skagi area, geochemical evidence suggests that the andesites and dacites of the Westfjords originated by high degrees (up to 90%) of fractionation of a basaltic parent. Geochemical trends indicate that the intermediate units reflect two distinct magmatic systems (Fig. 6).

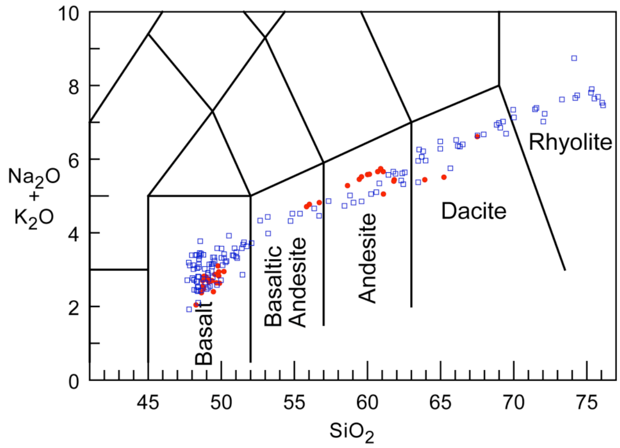


**Figure 6. Classification of 171 volcanic rocks from the Iceland Keck 2003 and 2004 projects. Skagi rocks in blue, Westfjords rocks in red.**

# FUTURE WORK

We are pleased with the mapping and petrology we have done in two years in northwest Iceland. In the Skagi area additional work will be necessary to document the full extent of the Strjugsskarð andesite. Additional mapping may also reveal new silicic and intermediate volcanic rocks. We have only begun to work on the fringe of the Hravnfjordur central volcano in the Westfjords. In the comparative analysis of these volcanic centers, an exciting next step would be to conduct a similar study of the Arnes central volcano that lies between the two 2004 study areas (Fig. 2).

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