PETROLOGIC AND GEOCHEMICAL CHARACTERIZATION OF SELJAFJALL ANDESITES: THE MISSING LINK OF FRACTIONAL CRYSTALLIZATION

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INTRODUCTION

Several competing ideas have emerged to explain the generation of silicic rocks in Iceland: fractional crystallization and partial melting of crustal material. For example, using geochemical analysis Furman et al. (1992) shows fractional crystallization was the mechanism responsible for the differentiation

Figure 1. Geologic map showing general field relationships and geochemical sample locations. Open hexagons are ICP and closed hexagons are XRF. Giersfjall field area (Johnson, this volume) is to the west and north; the Leirufjordur (Styger, this volume) field area is to the east.

of the evolved basalts and rhyolites at the Austurhorn complex in southeast Iceland. Magma mixing was also considered, but the data and models could not show that magma mixing alone could produce the evolved basalts and rhyolites. Gunnarson et al. (1998) proposes that partial melting of crustal material, not fractional crystallization, as being the mechanism at the Torfajokull central volcano. This study shows that the intermediate rocks in the Westfjords are andesites, and are the product of fractional crystallization of a basaltic parent.

There have been two recorded rift jumps in western Iceland due to the migration of the rift away from Iceland hotspot (Hardarsson et al., 1997). This study examines rocks from the Westfjords, which record the early stages of the Snaefellsnes rift when it was centered on the Iceland hotspot about 14 Ma. Other 2003 and 2004 Keck projects examined silicic rocks on the Skagi peninsula that erupted during the waning stages of magmatism at the Snaefellsnes rift, when it had drifted off the hotspot at about 7 Ma.

The compilation of Johanesson and Saemundsson (1998) identified a 10-12 km^2 exposure of Tertiary aged "acid extrusive" near Grunnavik in the Westfjords. This study utilizes petrography and major and trace element geochemistry to address the fundamental question of how these evolved rocks were formed. Seljafjall is a major

mountain, which includes a part of the silicic body mapped by Johanesson and Saemundsson (1998). To the southeast of Seljafjall is Leirufjordur; Styger (cf., this volume) examined silicic rocks near Leirufjordur that are mapped as contiguous with the extrusive rocks of this study. To the west and adjacent to Seljafjall is Giersfjall, a mountain that consists of a series of basalt flows mapped and sampled by Johnson (cf., this volume).

Field Results

Mapping and sampling was done for the purpose of understanding the geology of this silicic body. The area was mapped on 1:10,000 and 1:20,000 topographic maps with the aid of GPS.

At Seljafjall, the andesite is a cliff-forming unit underlain by flood basalts. Talus conceals the lower contact of the andesite with the flood basalts. Baked horizons are not found suggesting the andesite is a single layer. The upper extent of the andesite is eroded away at Seljafjall, but based on field observations, it is at least 200-300 m thick. The andesite is aphanitic and lacks vesicles and phenocrysts. It is generally black to dark grey to buff. Weathering locally produces a red surface.

Within the andesite unit, there are two inclusion-rich zones. The inclusions are usually angular, <2 cm, and may be black or

buff colored. The groundmass surrounding the inclusions is aphanitic and black. Found only in two areas of the northeastern part of the field area (Fig. 1), the relationship between the inclusion-rich zones and the rest of the andesite unit is gradational. Flow banding is more prevalent in the northeastern part of the field area.

Two major dikes are also present within the andesite unit. The southern dike is aphanitic and basaltic. The northern dike is located between the two inclusion rich-zones. It is gabbroic.

Flood basalts are the most abundant rock type in the region. For a more detailed description, see Johnson and Styger (both in this volume).

Petrography

The andesite unit is typically aphanitic to fine grained (<1mm). In thin section, andesite contains plagioclase phenocrysts. Groundmass is generally trachytic, but the top and bottom of the exposed andesite unit tend to lack trachytic textures. The mineral assemblage is predominantly plagioclase 50-75% with smaller amounts of pyroxene 0-15%, olivine 0-15%, Fe-Ti oxides 5-20%, and trace apatite.

Rocks from the inclusion-rich zones contain textures with varying grain sizes and mineral assemblages. The aphanitic groundmass is principally plagioclase with trace amounts of Fe-Ti oxides and altered olivine. The
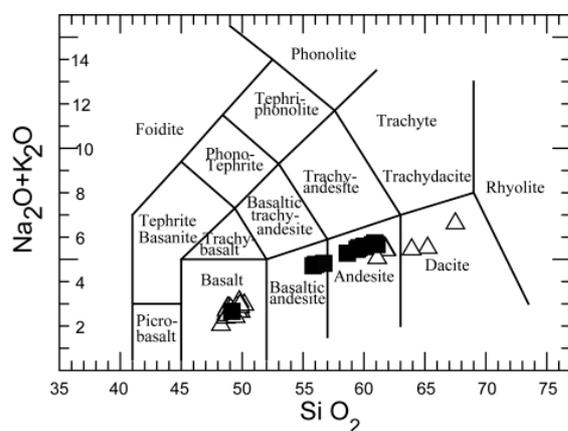
Figure 2. Total Alkalis vs. Silica plot showing a continuum of compositions from all three Westfjords field areas. Closed squares are samples from Seljafjall; open triangles are the Giersfjall (Johnson, this volume) and Leirufjordur suite (Styger, this volume).
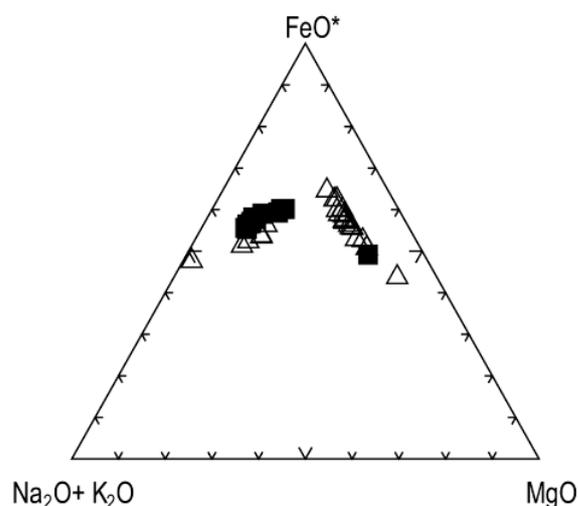
Figure 3. AFM diagram. The Westfjords rocks show a tholeiitic trend. Seljafjall data are squares, triangles are other Westfjords data.

inclusions contain varying amounts of clinopyroxene, plagioclase, and olivine. Boundaries between the groundmass and inclusions are usually sharp, but may also be diffuse. Crystal alignments in some inclusions differ from those in the surrounding groundmass. Inclusions are typically more coarsely grained than the groundmass. This means that the inclusions were likely crystallized before the groundmass.

The flood basalt unit is more porphyritic. The mineral assemblage is plagioclase 50-55%, olivine 20-35%, and Fe-Ti oxides 5-20%. Plagioclase and olivine occur as phenocrysts. Olivine crystals show variable alteration to iddingsite. There is an absence of vesicles and trachytic textures. The northern gabbroic dike is composed primarily of plagioclase and clinopyroxene.

Geochemical Methods

Twelve samples were chosen for XRF analysis, four of which were also analyzed by ICP-MS. Samples were analyzed at Washington State University.

The aim of the sample selection was to determine the geochemical diversity of the andesite, analyze the inclusions vs. the groundmass from the inclusion rich zone, and determine if the dikes are related to the andesite unit. Because of the subtle visual differences between the inclusions and groundmass, it was not possible to separate the
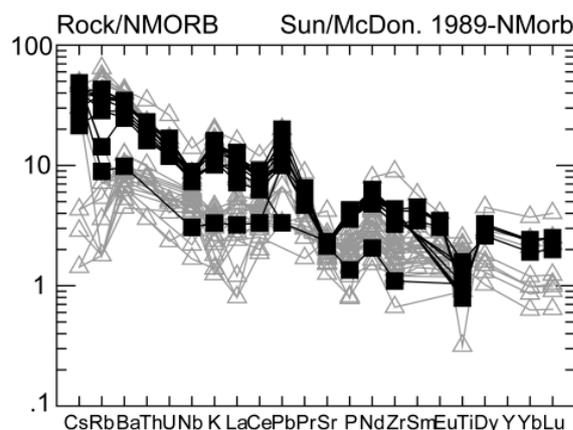
Figure 4. Whole rock element concentration normalized to N-MORB. Solid squares are from Seljafjall and open triangles that plot as more enriched are the Leirufjordur dacites. The lowest Seljafjall plot is the basaltic dike.

inclusions from the inclusion-rich zone samples. Four inclusion-bearing samples were analyzed for whole rock geochemistry.

Geochemical Results
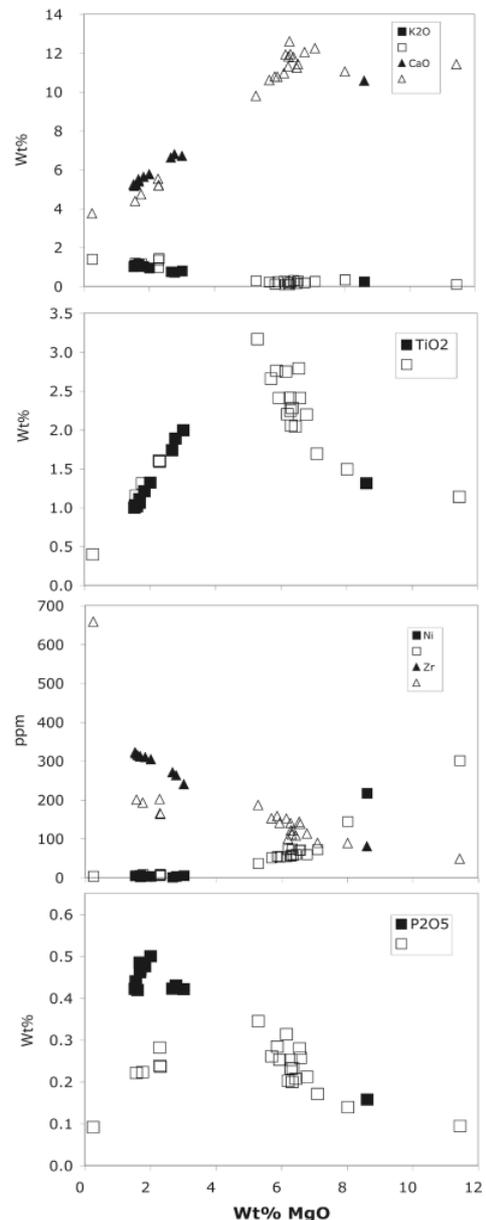
Figure 5. Fenner diagrams of selected major and trace elements. Closed symbols are from Seljafjall; the open symbols represent data of other Westfjords rocks.

Analyzed samples are chemically andesites and basaltic andesites, and range from 55-61 wt. % SiO_2. The Seljafjall suite falls between the Westfjords basalts and the more evolved portion of the Leirufjordur suite (Styger this volume) on a total alkali vs. silica (TAS) diagram (Fig. 2). he lone basalt of the

Seljafjall suite is the southern dike that plots among the Westfjords basalts.

Plotted on an AFM diagram, the rocks of this study follow a tholeiitic trend (Fig. 3). Andesites show high FeO, geochemically similar to the high Fe, low Al "Icelandite" described from the Thingmuli central volcano by Carmichael (1964).

All the Seljafjall samples are enriched relative to N-MORB (Fig. 4). The Seljafjall andesites show similar elemental patterns as the Westfjords basalts and the enriched Leirufjordur dacites. Notable depletion of Sr and Ti is in all the samples. Westfjords basalts show less enrichment in LILE.

DISCUSSION

This study addresses how intermediate and felsic rocks are generated in a tectonic setting such as Iceland. Geochemistry and petrography demonstrate that the Seljafjall andesites were formed by fractional crystallization of a basaltic magma. Based on the spatial relationships and geochemistry, these rocks are interpreted to be co-genetic with lavas from Giersfjall and Leirufjordur.

Fenner diagrams demonstrate the order of fractional crystallization (Fig. 5). Fractionation of olivine is demonstrated by decreasing Ni with decreasing MgO. Plagioclase fractionation is marked by the decline of CaO. Decreases of CaO/Al_2O_3 and Sc (not shown) are consistent with significant fractionation of clinopyroxene. TiO_2 and FeO are conserved or with low levels of fractionation until about 5% MgO at which point they simultaneously decrease with V (not shown). This indicates fractional crystallization of Fe-Ti oxides. P_2O_5 is conserved until about 1.5 wt.% MgO at which point it decreases, indicating the fractionation of apatite. There are different, but parallel, differences between the Seljafjall andesites and Leirufjordur andesites/dacites. Seljafjall and Leirufjordur likely have slightly different fractionation histories and levels that show on only some of the geochemical plots. The well-developed linear trends point to fractional

crystallization as the dominant mechanism for the differentiation of these rocks.

Data for the intermediate and felsic rocks are inconsistent with formation by partial melting of basaltic crust. Zr is an incompatible element that prefers to go into the melt. If a low level of partial melting occurs, then the Zr concentration ought to be very high; greater amounts levels of partial melting result in lower concentrations of incompatible elements like zircon. Thus if partial melting of basalt is responsible for the variations of the more felsic Westfjords rocks, Zr should positively correlate with SiO_2. Comparing the Leirufjordur dacites/andesites with the Seljafjall andesites (Fig. 5), the opposite is found. The Seljafjall andesites show higher Zr meaning partial melting of crustal material is unlikely. Furman et al. (1992) observes that the only way for partial melting of crust to reproduce the trends of P_2O_5 and Zr is for the apatite and zircon to be present in the parent basalt, which is unlikely.

The inclusion-rich zones initially suggested that magma mixing was possible. Further evidence from the whole rock geochemistry shows the inclusion-rich samples indistinguishable from the rest of the andesites. The peaks shown on the Fenner diagrams of Ti, Fe, and P_2O_5 occur at different MgO levels. This means that the andesites and inclusion-rich zones are magmatically co-genetic material and magma mixing between a felsic and mafic end member cannot explain the data

CONCLUSIONS

Fractional crystallization generated the evolved rocks in Seljafjall. The Westfjords basalt represents the material that was fractionated to produce the andesites and dacites.

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