PETROLOGICAL AND GEOCHEMICAL ANALYSIS OF A TERTIARY VOLCANIC SEQUENCE IN LANGADALSFJALL, NORTH-CENTRAL ICELAND: EVIDENCE FOR MAGMA MIXING

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INTRODUCTION

Iceland is an island located directly on the Mid-Atlantic Ridge (MAR), between the Reykjanes Ridge to the south and the Kolbeinsey Ridge to the north. Iceland lies over a mantle plume (Hardarson et al., 1997) causing basalts to be produced at an accelerated rate (Tronnes, 2002).

The location of the MAR as an axis of active magmatism in Iceland is not stationary and has shifted multiple times in the past (Hardarson et al., 1997). Over time the MAR moves westward relative to the mantle plume. In order to stay re-centered over the plume the ridge has made a series of "jumps," roughly every 8-12 million years, leaving behind abandoned rifts as a record of ridge movement (Hardarson et al., 1997).

For this project, a closer look was taken at one of these abandoned rifts, the Snaefellsnes Rift in north-central Iceland. This rift became active at about 15 Ma and was abandoned at about 7 Ma (Hardarson et al., 1997). My research was done in the Langadalsfjall mountains on the Skagi Peninsula, in the eastern section of the Snaefellsnes rift, where there are well-exposed flows of basalt, andesite and rhyolite. These flows erupted from the Snaefellsnes rift during its dying stages approximately 7 to 8 Myr ago. The main goals of this paper are to determine the basic petrology of the area and to examine in detail the petrogenesis of one of the units, a plagioclase-phyric andesite. Andesites are relatively rare in rift and plume settings, but their presence and genesis may provide insights into crustal growth mechanisms in plume-dominated systems.

PETROGRAPHY

The rocks are divisible into three main groups: basaltic flows; andesitic flows (one of which is coarsely plagioclase-phyric); and rhyolitic rocks (a dike and a flow). The general geology of the field area is shown in the map in Figure 1 and stratigraphic column in Figure 2. Two other units are present only locally

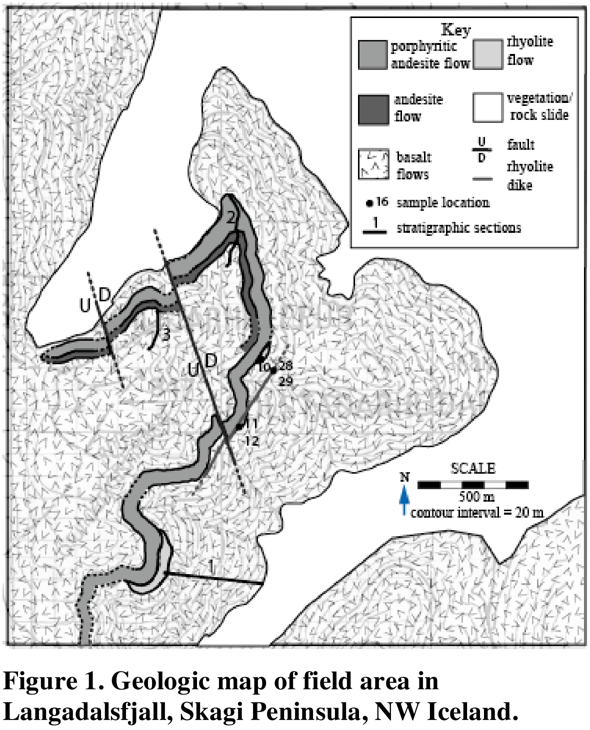

Figure 1. Geologic map of field area in Langadalsfjall, Skagi Peninsula, NW Iceland.

within the area: a plagioclase-phyric tuff that overlies the plagioclase-phyric andesite and a basaltic scoria located above the second andesite (Fig. 2). These were not mapped.

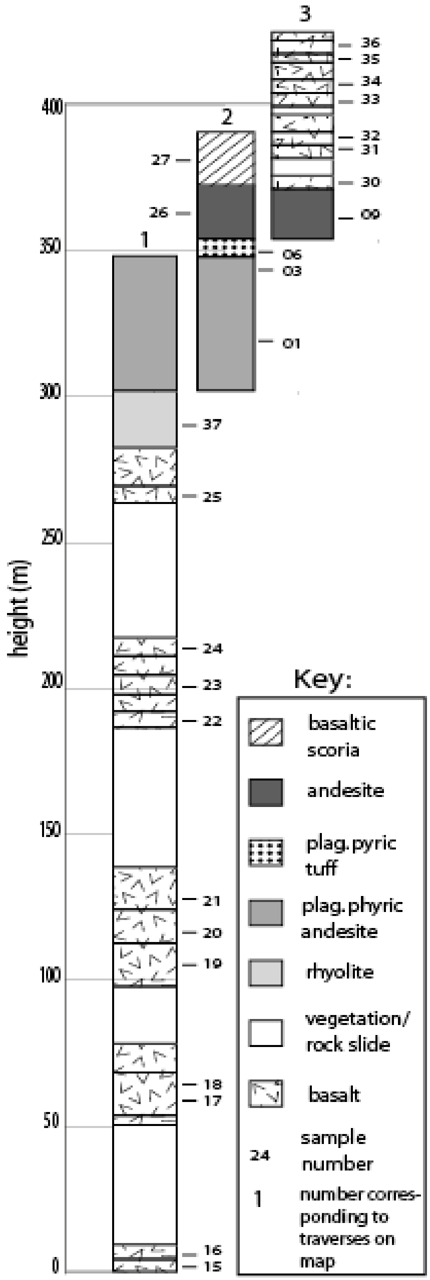

Figure 2. Sratigraphic section compiled from three different traverses (Fig. 1).

The basalts are aphanitic to porphyritic in hand sample. Vesicles are common, and stratigraphically lower samples tend to have amygdules containing zeolites. Phenocrysts are found in nearly all of the basalts.

Plagioclase, (bytownite—based on SEM/EDS analyses), is the dominant phenocryst phase, with augite, olivine and Fe-Ti oxide phenocrysts present in smaller amounts.

The coarsely plagioclase-phyric andesite (Fig. 3) creates prominent outcrops in the field. It is flow banded and characterized by mm to dm-scale swirls and bands of intermingling mafic and felsic material. It contains large subhedral to euhedral phenocrysts (up to 2 cm in diameter) that make up 10-20% of the rock.

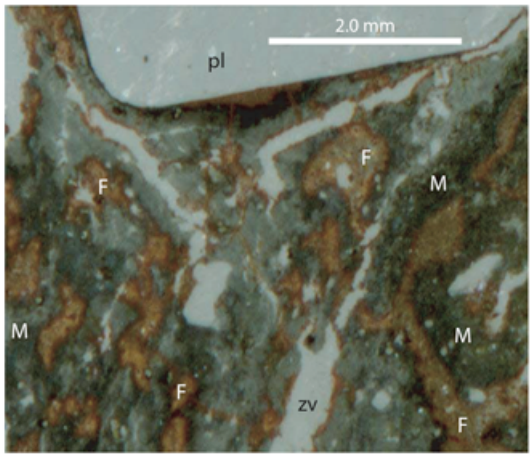

Figure 3. Photo of thin section of plagioclase-phyric andesite displaying intermingling of lighter felsic material (F) with darker mafic material (M). pl= plagioclase phenocryst, ZV= zeolite vein.

These phenocrysts have compositions ranging from An_{68} to An_{90}, and display peripheral oscillatory zoning and albite twinning. The edges often show sieve textures, and some phenocrysts have been partially resorbed and/or are embayed. The plagioclase-phyric andesite also contains phenocrysts of olivine and augite.

The other andesite flow contains smaller plagioclase (andesine) phenocrysts (up to 1.5mm) as well as olivine, augite and Fe-Ti oxide phenocrysts.

The rhyolite flow is locally present stratigraphically below the plagioclase-phyric andesite (Figs. 1 and 2). It contains phenocrysts of plagioclase (oligoclase), hedenbergite, and olivine. The other rhyolite, a dike running SW-NE through the field area, is petrographically similar except that it lacks olivine phenocrysts. Both rhyolites have undergone much alteration.

GEOCHEMISTRY

Whole-rock compositions (determined by XRF and ICP-MS at Washington State University) indicate that the basalts are tholeiitic and resemble E-MORBs. Most of the basalts are compositionally evolved, with Mg # for the basalts ranging from 32-46 (except one sample, LNK016, which had an Mg # of 60).

The range of compositions, from mafic to felsic, of all of the rocks in the field area follows a sub-alkaline trend similar to many Icelandic tholeiite suites (Fig 4). REE diagrams show a slight negative Eu anomaly for the plagioclase-phyric andesite, similar to the REE patterns of the rhyolites but dissimilar

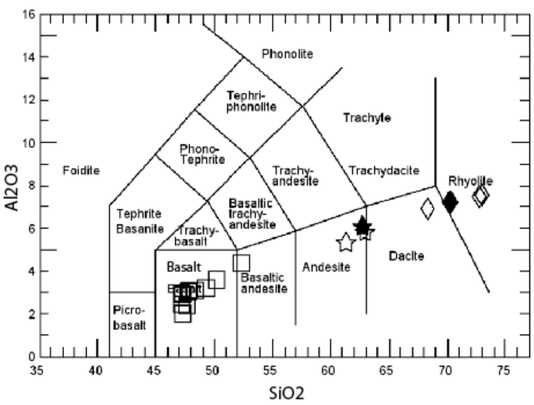

Figure 4. Diagram showing total alkali content vs. silica content. Samples follow a trend common for tholeiitic suites of rocks from Iceland. For identification of symbols see Figure 5.

from straight REE patterns of the basalts.

Mineral analyses (by SEM/EDS) indicate mingling of mafic and felsic magmas in the plagioclase-phyric andesite. The lighter groundmass contains sodium-rich plagioclase and iron-rich pyroxenes, while the darker groundmass contains plagioclase (An_{38}) and more magnesium-rich pyroxenes. The plagioclase phenocrysts in the same rock range from An_{90} in the cores to An_{68} in the narrow rims, with little variation within the cores. Pyroxene phenocrysts are more magnesian than even the pyroxenes in the dark groundmass. These characteristics suggest a basaltic parent magma for the phenocrysts.

INTERPRETATION

Fractional Crystallization

Harker, Fenner and Pearce diagrams support a common origin for the assemblage of rocks from my field area and adjacent field areas. They suggest that the basalts are related to each other through fractionation of plagioclase, olivine, Fe-Ti oxides, and possibly augite, consistent with observed phenocryst assemblages. The plagioclase-phyric andesite and rhyolite flows, as will be discussed in the following sections, are believed to have formed by other processes.

Magma Mixing

Textural and chemical characteristics of the plagioclase-phyric andesite support an origin by mixing of mafic and felsic magmas. However, using the compositions of the rhyolite flow and different basalt flows from my field area as hypothetical mixing end-members, it does not appear possible to form the andesite by simple mixing of two magmas. By including the plagioclase phenocrysts as a third independent mixing component, however, a reasonable mixing model can be calculated.

Harker diagrams (Al_2O_3, CaO, and Na_2O vs. SiO_2) were used to determine possible mixing

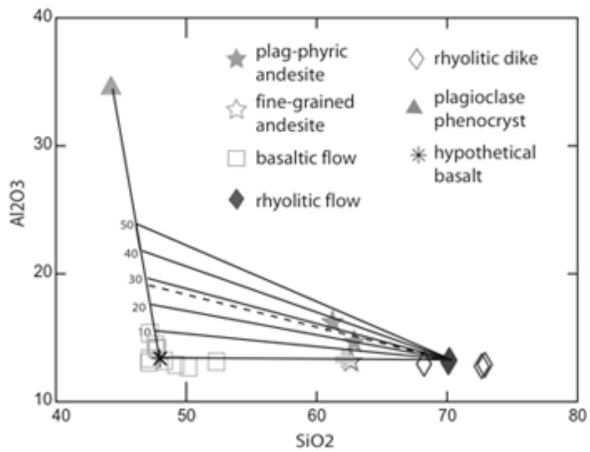

Figure 5. Diagram of SiO_2 vs. Al_2O_3 showing mixing lines used to determine the percentage of plagioclase phenocrysts, rhyolite, and basalt required to form the plagioclase-phyric andesite.

proportions of plagioclase phenocrysts, basalt and rhyolite (Fig. 5). It was determined that, using a hypothetical basalt that was suitable with the actual basalt samples (48 wt. % SiO_2, 1.96 wt. % Na_2O, 13.37 wt % Al_2O_3, and 12.74 wt. % CaO), it was possible to create a mixture consistent with the observed 10-20% modal plagioclase phenocrysts. Based on these calculations, constrained by the observed modal content of plagioclase phenocrysts in the andesite, the best-fit mixing model is 65% rhyolite, 24% basalt, and 11% plagioclase phenocrysts.

REE results are consistent with this mixing model. The proportions of rhyolite, basalt, and plagioclase phenocrysts calculated above were used to calculate an REE pattern for the hypothetical mixture. To check the validity of the results, a number of mixtures were made using different basalts for which REE data were available. The approximate REE contents of the plagioclase phenocrysts were based on REE distribution coefficients calculated by MacDonough and Frey (1989) for basaltic plagioclase. Resultant graphs showed a close association between the REE pattern of these mixtures and those of the actual plagioclase-phyric andesite (Fig. 6).

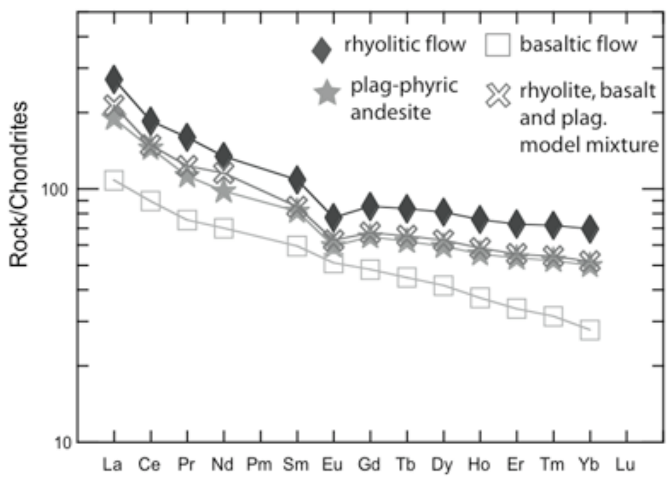

Figure 6. Diagram showing REE patterns for the rhyolite, the plag-phyric andesite, a basalt (sample LNK021), and a calculated mixture of all three (using the data from basalt sample LNK021). The mixture shows a close correlation to the actual plag-phyric andesite as do other mixtures calculated using different basaltic end-members.

Partial Melting of the Crust

Based on current data, the origin of the rhyolite remains uncertain. There is not enough evidence to definitively support either crystal fractionation of basalt or partial melting of older crust. However, I hypothesize that their formation is most likely due to partial melting of the crust for the following reasons.

Iceland has a bimodal volcanic system in which basalt and rhyolite flows are common (85% and 12% respectively) but andesite flows are rare (3%) (Gunnarson et al., 1997). It was argued by Gunnarson et al. (1997) that Icelandic rhyolites are formed by two stage partial melting of crustal material. Partial melting processes can create felsic magmas in equilibrium with olivine and pyroxene (generally uncommon in rhyolites) due to melting at high temperatures under water-poor conditions. The presence of these phenocrysts in the samples from the rhyolite flow leads me to hypothesize that they formed by this process rather than by fractional crystallization, during which hydrous ferromagnesian silicates (such as biotite and hornblende, which are not found in the flow) are typically stable. Thus it seems unlikely that this rhyolite flow would have formed by fractional crystallization of basalt.

CONCLUSIONS

Major element oxides and trace element data suggest that the basalts are genetically related through crystal fractionation. Geochemical and petrographic data are consistent with a magma mixing origin for the plagioclase-phyric andesite, with mafic magma, felsic magma, and plagioclase phenocrysts. Also, the phenocryst assemblage in the rhyolite indicates the likelihood of formation by partial melting of the crust. Overall, these findings indicate that volcanic activity in the dying Snaefellsnes rift was compositionally diverse and physically complex.

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