PETROLOGY OF MAFIC, INTERMEDIATE AND SILCIC LAVAS IN AN ABANDONED RIFT ZONE, LAXÁRDALSFJÖLL, ICELAND

EMILY BALDWIN
The Colorado College
Sponsor: Jeff Noblett

INTRODUCTION

Iceland is located along the Mid-Atlantic Ridge, where the rift zone intersects the Icelandic mantle plume. The elevated topography of Iceland relative to normal mid-ocean ridges reflects an increase in magmatic productivity caused by ridge-plume interaction. As Iceland is the only place on Earth where an active oceanic spreading center is exposed subaerially, it provides an ideal opportunity for observing two primary crust-forming processes: tectonic rifting and hot spot volcanism.

Volcanism in Iceland is concentrated along discrete rift zones. These rift zones are periodically abandoned as the mid-ocean ridge drifts westward with respect to the plume. New rifts propagate in the hot crust overlying the hotspot, causing the older rift to be abandoned. This process of rift activation and extinction takes approximately 4 million years to complete and occurs every 8-12 million years (Hardarson et al., 1997).

The sequence of lavas in the study area were erupted from the most recently abandoned of these rifts, the Skagi/Snaefellsnes Volcanic Zone, which went extinct circa 7 Ma (Saemundsson, 1979). This research is part of a larger effort to characterize the nature of volcanism along a rift during its final phases of activity. Of particular interest in this area is whether the variety of units observed were derived from a single or multiple sources and whether those sources evolved over time.

Field Location

The field area is located in Laxárdalsfjöll, a NW-trending ridge on the southern edge of the Skagi Peninsula, north-central Iceland. The 6 km^2 study area exposes a ~900 m sequence of Tertiary lavas along the northeastern side of Laxárdalur.

METHODS

During the 2004 field season, unit contacts, major structures and sample locations were mapped on a 1:10,000 topographic map. Of the 35 samples collected, 22 were studied in thin section and 12 were analyzed by XRF, 8 by ICP-MS. Thin sections were made at the Thin Section Lab at the University of Oregon. Geochemical analysis was conducted by the GeoAnalytical Laboratory at Washington State University. These analyses confirm the presence of four major stratigraphic units: a rhyolite and coarse plagioclase-phyric andesite separating lower and upper basalts flows.

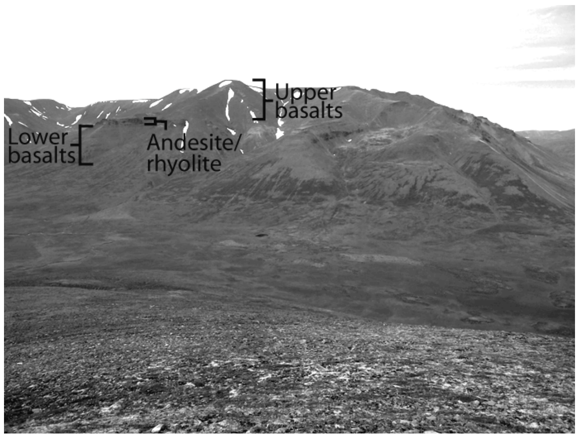

Figure 1. A generalized stratigraphy of the field area in Laxárdalsfjöll. Photo by Brennan Jordan.

PETROGRAPHY AND STRATIGRAPHY

Lower Basalts

The lower basalts span roughly 190 vertical meters from the lowest exposed basalt flow (elevation ~490 m) to the lower limit of the andesite (elevation ~ 680 m). The 19 basalt flows measured in this section are typically gray, aphanitic, and less than 10 m thick.

In thin section, the lower basalts can be microporphyritic, with phenocrysts of plagioclase, clinopyroxene and minor orthopyroxene (<3%). The modal abundance of both clinopyroxene and plagioclase (An_{55-66}) is ~40%. The samples contain up to 20% opaques. The lower basalts contain some hematite banding and zeolite amygdules.

Andesite

The andesite unit overlying the lower basalts is characterized by a notable abundance (up to 35%) and size (up to 2.5 cm in diameter) of partially resorbed, subhedral, plagioclase phenocrysts. The unit ranges from 20 to 70 m thick. In thin section, the andesite has a very fine-grained groundmass with euhedral to subhedral phenocrysts of plagioclase that are visible to the naked eye (some up to 6 mm in size). Clinopyroxene and opaques are present but less abundant than in the basalts.

Rhyolite

The rhyolite overlies the andesite and is of variable thickness. The combined cliff-forming andesite and rhyolite units form a distinctive marker layer throughout the study area. One outcrop shows evidence of magma mixing between the two units in the form of cuspate contacts, blebs, and apophyses, variable degrees of flow banding and an absence of plagioclase phenocrysts in the rhyolite. In thin section, the rhyolite displays a granophyric groundmass with few phenocrysts; secondary hematite and zeolites are present.

Upper Basalts

The upper basalt unit overlying the andesite rises to the ridge summit that marks the northern boundary of the study area. The 300-meter thick basalt stack contains between 10 and 15 individual flows, which are gray, aphanitic and typically less than 20 m thick.

There is greater petrographic variability in the upper basalts than the lower basalts. In general, they contain 40% plagioclase (An_{58-66}), and 30% clinopyroxene. The upper basalts are more weathered and contain fewer opaques (12%) than the lower unit.

GEOCHEMISTRY

The samples range from 48.1 to 75.3 wt. % SiO_2 and plot on TAS diagrams as basalts, basaltic andesites, andesites, dacite and rhyolite. The basalts are moderately to highly evolved (48.1-53.2 wt. % SiO_2, 3.5-7.0 wt. % MgO) and the upper basalts are generally more evolved than the lower basalts. AFM diagrams show all are tholeiitic in composition. Weathering and hydrothermal alteration seem to have had little effect on the bulk rock chemistry.

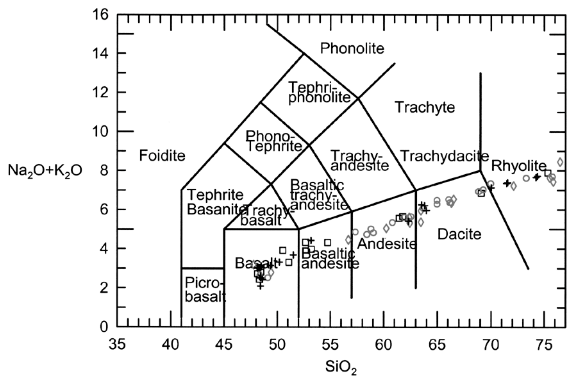

Figure 2. TAS diagram showing the classification of samples collected on Skagi. Different symbols denote different samplers: squares = Baldwin, circles = Schuyler, diamonds = Adzima, crosses = Kapelanczyk (all this volume).

On incompatible trace element diagrams, the samples are enriched relative to chondrite or N-MORB; all have a strong negative Sr anomaly and a slight negative Eu anomaly develops progressively in the more silicic units. REE diagrams show slight LREE enrichment; the basalts are 50-100 times chondrite. In both incompatible trace element and REE diagrams, the upper basalts are enriched with respect to the lower basalts.

Tectonic discrimination diagrams consistently place the samples in E-MORB fields, although the upper and lower basalts frequently form separate clusters. The lavas best match E-MORB and OIB incompatible trace element diagrams.

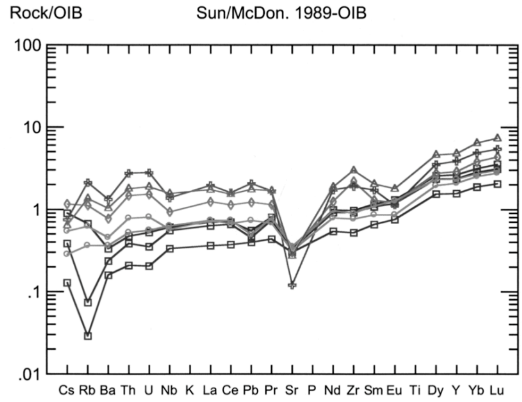

Figure 3. Incompatible trace element diagram normalized to Ocean Island Basalts. All samples show a strong negative Sr anomaly and a negative Eu and positive Zr anomaly develops progressively in the silicic lavas. Squares = lower basalts, circles = upper basalts, diamonds = andesites, triangles= dacites, and crosses = rhyolites.

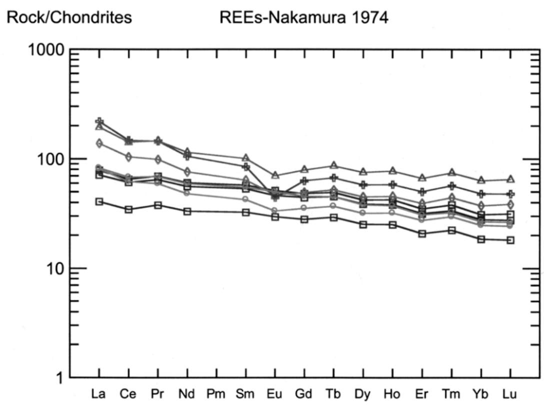

Figure 4. REE diagram normalized to chondrite. Samples are 50-200 times chondrite, show enrichment in LREEs and a Eu anomaly in the silicic units. Same symbols as Figure 3.

DISCUSSION

Nature of Source

The tholeiitic composition of these samples and their enrichment in incompatible trace elements and REEs relative to N-MORB or chondrite is consistent with previous research from Skagi by Sigurdsson, et al. (1978). This enrichment in trace elements indicates the lavas did not erupt from a shallow, depleted asthenospheric source. The cause of enrichment cannot be determined within the scope of this research, but likely reflects input from the mantle plume.

G.R. Foulger (2005) presents an alternative to the plume interpretation of Iceland, suggesting that the enriched magmas originate from a reservoir of previously-depleted asthenosphere that has been refertilized by 400 Mya subducted crust. The geochemical data do not support this theory, as the Skagi lavas lack the Nb-Ta trough characteristic of subduction related melts (Fig. 3).

On REE and incompatible trace element diagrams the upper and lower basalts display generally parallel patterns with overlapping range, suggesting they derived from a common source. The two units show variable enrichment in LREEs and the upper basalts are enriched in the most incompatible elements and develop a slight negative Eu anomaly relative to the lower basalts. Although the geochemical variations between the upper and lower basalts could reflect differing source magmas, these deviations are more likely the result of processes affecting the melts as they rose to the surface (assimilation, magma mingling/melting and fractional crystallization).

Evolutionary Processes of Melts

Assimilation and Magma Mingling/Mixing

It is difficult to distinguish geochemical differences between assimilation of partially-melted Icelandic crust and mingling or mixing of contemporary magmas, as partial melting is a form of magma mixing. The lack of a pronounced Zr spike suggests no older continental crust was incorporated into the magmas (Fig. 3).

Field evidence for small scale magma mingling exists between the andesite and the rhyolite. Geochemical evidence for magma mingling is provided by these samples, as well as others collected by Adzima, Schuyler, and Kapelanczyk (this volume), on plots of MgO vs. P_2O_5 and TiO_2, where the andesites do not follow the roughly chevron-shaped curve defined by the tholeiitic fractionation trend. Most andesites lie on a distinct mixing trend between the basalts and dacites (Brennan Jordan, personal communication).

Microprobe data collected by Adzima (this volume) on the plagioclase-phyric andesite give values of An_{87}, suggesting the phenocrysts formed in a basaltic magma chamber and later mixed with dacites and rhyolites to form the andesite.

The origin of the felsic magmas is unclear at this time. They could represent either partial melts of the Icelandic crust or extreme fractionates of the tholeiitic basalts. Because they have likely derived from sources similar to the basalts, evidence for magma mingling may be hidden in what appears to be a fractionation trend.

Fractional Crystallization

The continual trend from basalts through rhyolite and the volumetric decrease towards the silicic lavas suggests the samples may be related through fractional crystallization. This trend could also reflect mixing in a bimodal system between magmas with similar sources.

Other evidence for fractional crystallization can be found on Harker diagrams which show decreasing Fe, Mg, Ca, Mn and Ti and increasing Na, and K with respect to silica

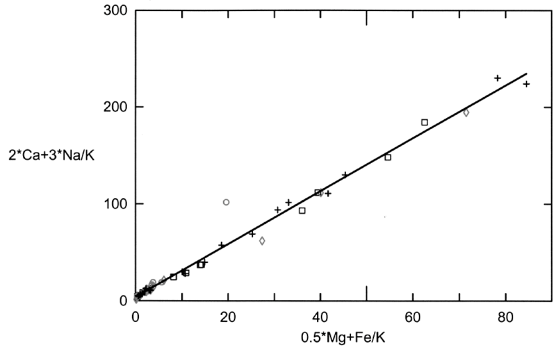

Figure 5. Pearce Element Diagram showing all Skagi samples; the line has a slope of 2.72. Slopes of 1 to infinity indicate plagioclase and olivine fractionation, horizontal and vertical slopes show olivine and plagioclase fractionation, respectively (Russell and Stanley, 1990). Same symbols as Figure 2.

from mafic to felsic samples. Intermediate and silicic lavas are progressively more enriched in the incompatible trace elements and REEs than the basalts. Trace element analysis shows decreasing Eu, Sr, Sc, Cr, Ni, and V and suggests the possible fractionation of plagioclase, pyroxene, olivine, spinel, and magnetite. The depletion of magnetite from lower to upper basalts is confirmed petrographically based on modal abundances.

The Pearce Element diagram shown in Figure 5 indicates fractionation of plagioclase and olivine and strongly supports the fractionation of rhyolites from basalts. However, if the compositions of both end-members in a bimodal system plot along the same fractionation trend, the mixing product would fall on the line and would be indistinguishable from a fractionation sequence.

CONCLUSION

The geochemical data suggest that the flows originated from an enriched mantle source, not a shallow asthenospheric N-MOR mantle. This is consistent with the plume interpretation of Iceland. Dacites and rhyolites may be crustal melts or fractionates from a basaltic parent. Trace element variations suggest that the andesites are the result of mixing basaltic and dacitic magmas.

REFERENCES CITED

Foulger, G.R., Iceland and the North Atlantic Igneous Province: www.mantleplumes.org/Iceland.html, last updated, February 8, 2005.

Hardarson, B.S., Fitton, J.G., Ellam, R.M., and Pringle, M.S., 1997, Rift relocation -a geochemical and geochronological investigation of a palaeo-rift in Northwest Iceland: Earth and Planetary Science Letters, v. 153, no. 3-4, p. 181-196.

Russel, J.K., and Stanley, C.R., eds., 1990, Theory and application of Pearce Element Ratios to geochemical data analysis: Geological Association of Canada, v. 8, p. 76.

Saemundsson, K., 1979, Outline of the geology of Iceland: Jökull, v. 29, p. 7-28.

Sigurdsson, H., Schilling, J.-G., and Meyer, P.S., 1978, Skagi and Langjokull volcanic zones in Iceland I: Petrology and structure: Journal of Geophysical Research, v. 83, n. B8, p. 3971-3982.