KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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ORIGIN OF SILICIC VOLCANISM AT SAURATINDUR, NORTHWEST ICELAND

THAD STODDARD, University of South Dakota
Research Advisor: Brennan Jordan

INTRODUCTION

Iceland is located above a mantle plume modulated by a mid-ocean ridge (Hardarson et al., 1997). This leads to high levels of volcanic activity. The dominant magma seen in Iceland is basalt due to the Mid-Atlantic Ridge that splits Iceland (Hardarson et al., 1997). The presence of silicic magmas raises questions about how they formed. The predominant processes that can form silicic magmas in an oceanic setting are extreme fractionation of a basaltic parent magma and crustal melting (Gunnarsson et. al., 1998; Martin and Sigmarsson 2007; Jonasson, 2007). Intermediate magmas can form by fractional crystallization of a basaltic parent magma or mixing of basalt and rhyolite magmas, with or without assimilation of country rock.
This paper will focus on a silicic unit at Sauratindur, Iceland. Sauratindur is a peak with a maximum elevation of 856 m. It is on the southern side of the fjord Isafjardardjup in northwest Iceland. The unit of interest is an isolated silicic unit in an area that is otherwise entirely basaltic (Jóhannesson, H., and Sae-

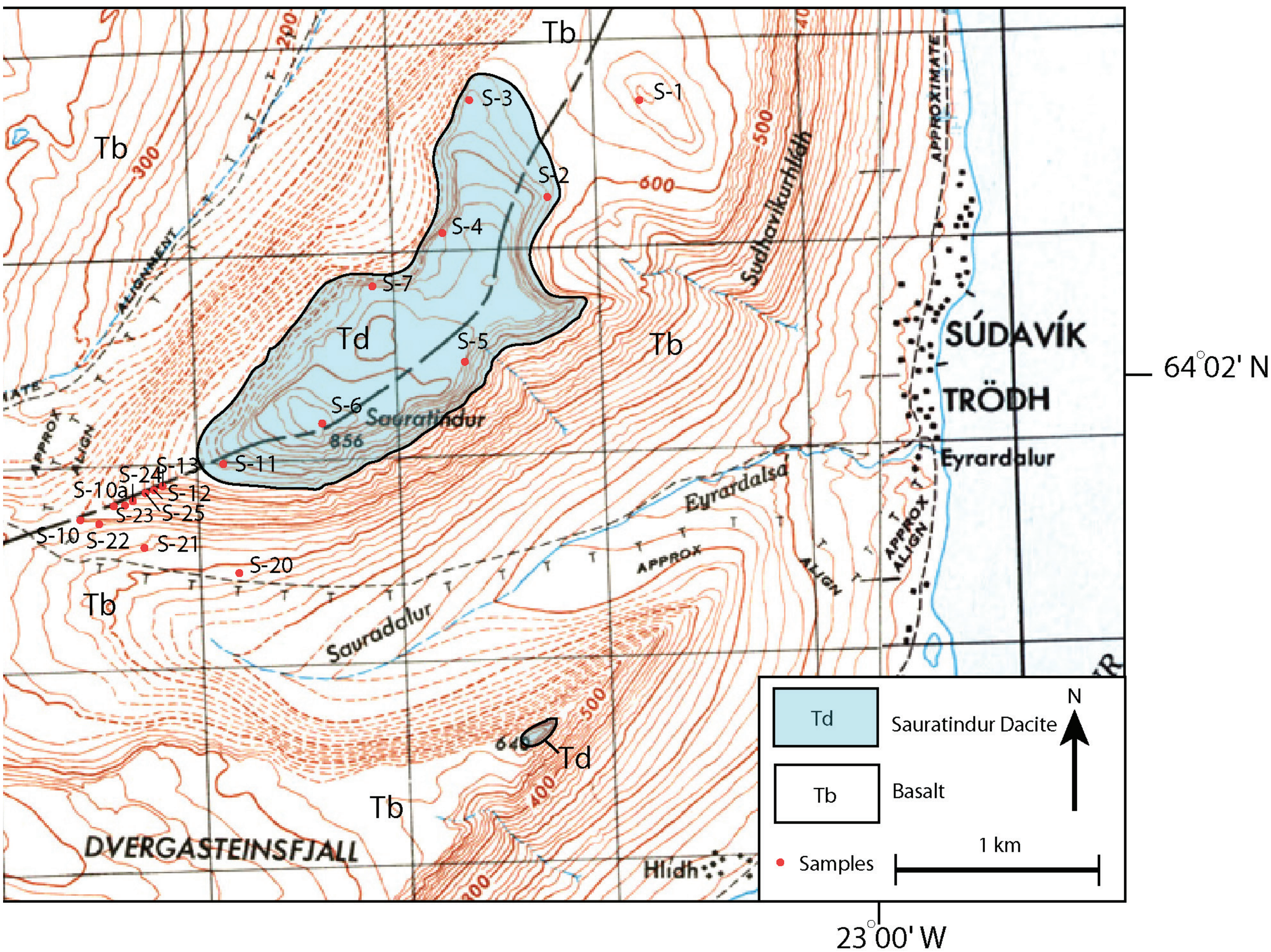

Figure 1. Geologic map of Sauratindur and surrounding area with sample locations.

mundsson, K., 1998). There is no clear association with a central volcano although one may have eroded from an adjacent fjord. Projecting this unit into regional stratigraphy will lead to an approximate age. Analyzing the occurrence of the unit and associated basalts will give information on how this silicic unit was formed. Thin section observations of the silicic unit and associated basalts will show what minerals make up the phenocrysts and groundmass. Analysis of the geochemistry of the units will exhibit trends that can be used to interpret the origin of the silicic unit. Understanding the evolution of this unit will help shed light on the primary processes by which silicic magma forms in an oceanic setting.

SAURATINDUR FIELD DESCRIPTION

The silicic unit exposed at the top of Sauratindur (Fig. 1) is termed the Sauratindur dacite based on a plot of total alkalis vs. silica (Fig. 2). The base of the unit is at an elevation of approximately 660 m. The top of the unit is the summit at 856 m. The thickness of this unit is ~196 m, a minimum because the present thickness has likely been reduced by erosion. The unit also crops out in a small isolated peak to the south across the valley Sauradalur on the east side of Dvergasteinsfjall with an exposure thickness of ~60 m. Where exposed in steep cliffs there is wide (>2 m) columnar jointing of the unit, and in outcrop it exhibits platy jointing. The unit is exposed in steep glacier carved cliffs on the northwest and southeast while there are gentle slopes on the northeast and southwest sides of the main exposure. The area is covered with

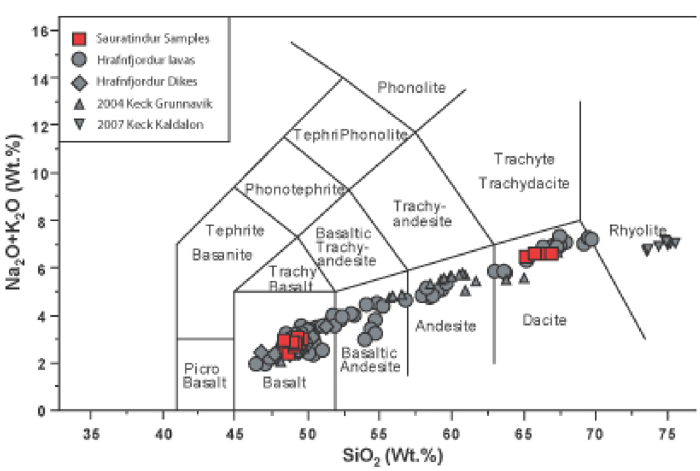

Figure 2. Classification (after LeBas et al, 1986) of samples from the Sauratindur field area and other data from Westfjords Keck projects.

ice-wedged and heavily fractured rocks on the surface. Samples were collected from the freshest rock available but some fractures and alteration in some samples was unavoidable. The dacite hand samples have a medium-gray to dark-gray color on fresh surfaces and brown on fractured/weathered surfaces. The samples are sparsely porphyritic with an aphinitic groundmass and plagioclase phenocrysts (~1%).

Underlying the Sauratindur dacite is a sequence of basalts. The outcrop thickness of individual basaltic lavas is 5-15 m and columnar jointing is exhibited. Numerous basalt flows are exposed in the valley north of Sauratindur. In hand sample the color of the basalts are light-gray to gray on fresh surfaces and rusty-brown to dark-brown on fractured/weathered surfaces. They are porphyritic with an aphanitic groundmass. Plagioclase and altered olivine phenocrysts constitute 3-15% of the rock. Some phenocrysts have a glomerophyric texture. There are fractures running through some samples with evidence of alteration.

AGE AND CORRELATION

To find an approximate age for the Sauratindur dacite it was projected into a paleomagnetic column of Kristjansson and Johannesson (1996) 1.5 km south using a strike of N29ºE and dip of 3.5ºSE. Based on correlation of this column a column further southwest dated by the K-Ar method by McDougall et al. (1984) the age of the Sauratindur unit is 13.1-14.1 million years old. Projecting the unit northeast across the Isafjardardjup establishes the approximate relationship to other silicic centers studied in Keck projects. With this projection across the fjord the Sauratindur dacite is stratigraphically above the 2004 Grunnavik study area on the far southern edge of the Hrafnfjordur central volcano, which appears to correlate with the other 2011 study areas in the eastern Hrafnfjordur central volcano. The Sauratindur dacite projects stratigraphically below the rhyolites of the Kaldalon area sampled during the 2007 Keck project.

PETROGRAPHY

In thin section the Sauratindur dacite is porphyritic with an aphanitic groundmass. All samples have an intergranular texture with phenocrysts comprising

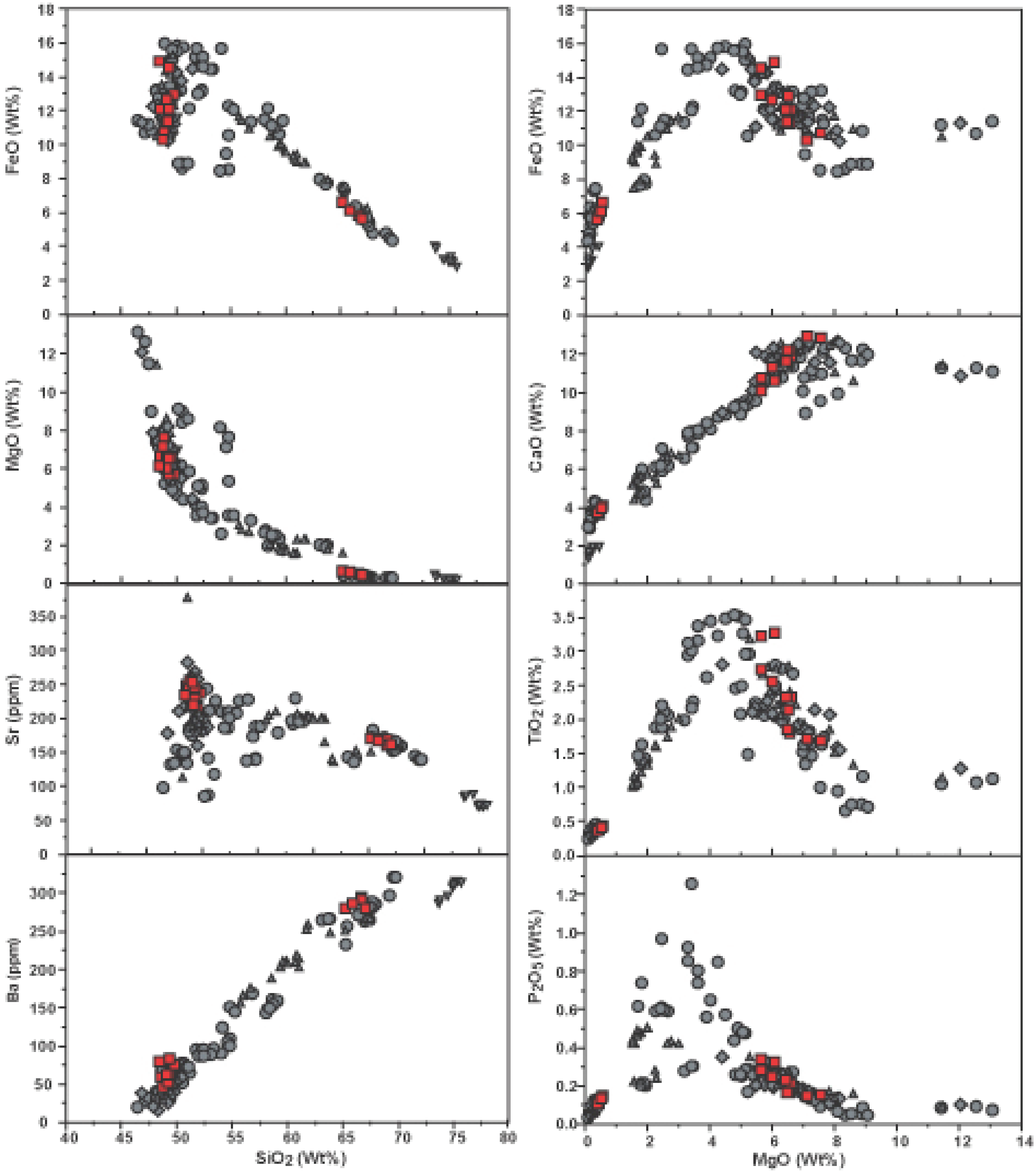

Figure 3. Geochemical variation diagrams of Sauratindur samples and other Westfjords Keck data. Symbols are as defined in Figure 2.

1-5% of the rocks. Phenocrysts are plagioclase and subordinate clinopyroxene with minor hornblende and orthopyroxene. In addition to the sparse large phenocrysts visible in hand sample (1-1.5 mm), there are more abundant fine (0.2-0.5 mm) plagioclase phenocrysts, some exhibit modest simple or oscillatory zoning. The large plagioclase grains are subhedral and elongate while the smaller phenocrysts of variable abundance are euhedral. The groundmass commonly has a pilotaxitic texture, but samples 07-TS-11 and 04-TS-11 have a trachytic texture indicating flow. Hornblende phenocrysts (0.5-1 mm) are brown and commonly partially broken down to clinopyroxene. Present to varying degrees in some samples there are irregular masses of microcrystalline oxides that are the result of resorption of mafic minerals such as pyroxene and hornblende. In some samples there are fractures with alteration running through the thin section.

Thin sections of the associated basalt samples are porphyritic with an aphanitic groundmass. Most samples have an intergranular pilotaxitic texture. Some samples exhibit a diktytakitic texture. Phenocrysts, often in a glomerophyric texture, comprise 3-15% of the rocks. Plagioclase (1-3 mm) is the dominant phenocryst with subordinate olivine and clinopyroxene. Plagioclase phenocrysts often have melt inclusions and are commonly subhedral. Olivine (0.5-1 mm) phenocrysts are anhedral with fractures exhibiting iddingsite alteration. Clinopyroxene (0.5-1 mm) phenocrysts are anhedral and are the least abundant.

GEOCHEMISTRY

Five samples of the Sauratindur dacite have a range of 65.3-66.7 wt.% SiO_2 (Fig. 3). The dacite is highly enriched with incompatible elements compared to the basalts, e.g., K_2O 1.4-1.6 wt.%, Ba 279-293 ppm, and Zr 491-545 ppm. Many elements exhibit systematic variations with SiO_2; CaO, FeO, MgO and Sr decrease with increasing SiO_2, while K_2O and Ba increase with increasing SiO_2. On some variation diagrams trends in the basalt data project towards the dacites, on others the dacites could be linked with the basalts on inflected trends. In some plots the Sauratindur dacite is compositionally distinct from the dacite lavas in the Hrafnfjordur Keck project and other silicic lavas in northwest Iceland from the 2004 and 2007 projects. The Sauratindur dacite appears to plot on trends with the other regional data, but when evaluating the relationship on multiple diagrams, there is no consistent relationship. However, the dacite trends are generally parallel with other Keck field areas suggests the possibility of a similar process of formation.

The underlying basalts are moderately evolved and have a range of 5.6-7.6 wt.% MgO (Fig. 3). As MgO decreases FeO, TiO_2, K_2O, and Na_2O increase. FeO and TiO_2 increase until MgO reaches about 4.5 wt.% then decline. K_2O and Na_2O increase steadily as MgO decreases. The ratio CaO/Al_2O_3 decreases as MgO decreases. Incompatible trace elements like Ba and Zr show a trend of increasing abundance with decreasing MgO, while Ni decreases along with MgO. The basalt data from the Sauratindur field area follows the trends of the larger data set from other Westfjords-based Iceland Keck projects (Fig. 3).

DISCUSSION/INTERPRETATION

Examining variation diagrams, fractional crystallization of a basaltic parent rock is a plausible explanation for how the Sauratindur dacite formed. Trends in geochemical data discussed in the previous section and depicted in Figure 3, can potentially be explained by fractional crystallization of a sequence of miner-

a. Calculation

Oxide	Parent Magma	Daughter Magma	Observed Difference	Calculated Difference
SiO_2	48.98	49.56	0.57	0.69
TiO_2	1.69	3.21	1.52	1.19
Al_2O_3	15.54	13.50	-2.05	-1.95
FeOtot	10.69	14.55	3.86	4.05
MgO	7.61	5.66	-1.95	-1.92
CaO	12.86	10.13	-2.73	-2.67
Na_2O	2.29	2.73	0.45	0.24
K_2O	0.18	0.31	0.13	0.16
P_2O_5	0.15	0.33	0.18	0.20

b. Fractionating assemblage

Mineral	Wt.%
Plagioclase	52.3%
Olivine	6.2%
Pyroxene	36.5%
Titanomag.	5.0%

Table 1. Mass balance modeling

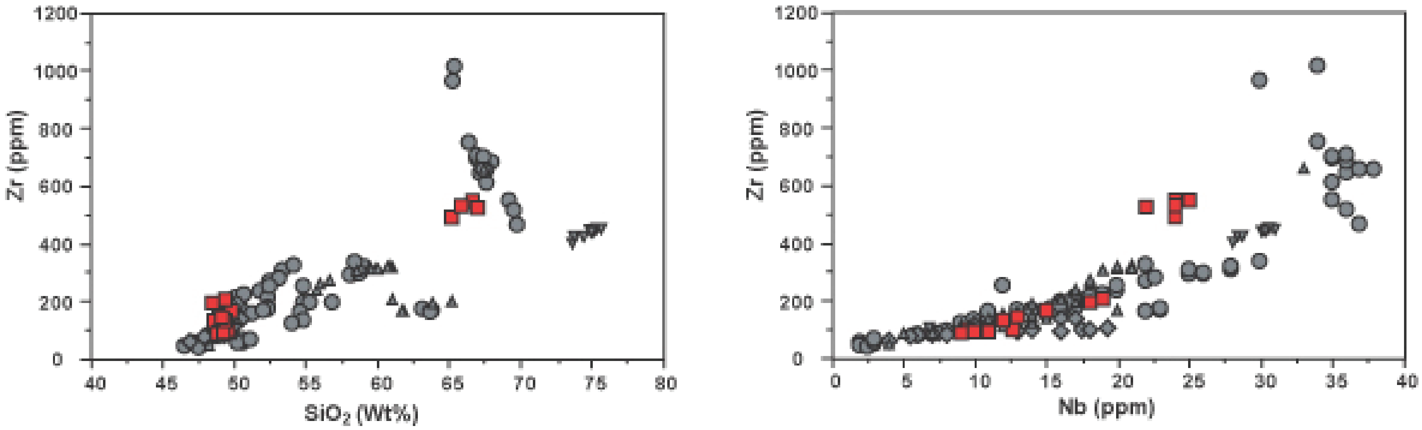

Figure 4. Variation diagrams of Zr vs. SiO_2 and Nb for Sauratindur samples and other Westfjords Keck data. Symbols are as defined in Figure 2.

als. The most primitive lava in my data set could be produced by olivine-dominated fractionation from the most primitive lava in the Keck regional data set. The spectrum of basaltic compositions at Sauratindur could be explained by the fractionation of olivine, plagioclase, and clinopyroxene. Inflections to decreasing FeO, TiO_2, and P_2O_5 could be explained by fractionation of Fe-Ti oxides occurring at 4.5 wt% MgO which would remove FeO and TiO_2, while fractionation of apatite occurring at 3.2 wt% MgO which would explain the decrease in P_2O_5.

To quantitatively test the plausibility of fractional crystallization I did mass balance modeling utilizing the software Petrograph (Petralli et al., 2005) which applies the method of Stormer and Nicholls (1978). The mass balance model was used to test the hypothesis that the Sauratindur data set could be derived from the most primitive basalt in the regional Keck data set. The first model run tested the hypothesis that the Sauratindur basalts could all be related by fractional crystallization. The results are presented in Table 1, the evolved magma could be derived from the parent magma by 60.5% crystallization of an assemblage of 52% plagioclase, 36% pyroxene, 6% Olivine, and 5% titanomagnetite. The sum of the squares of the residuals is 0.2 which is well below the standard of 2, indicating a successful model.

Additional mass balance models were run to test the hypothesis that the most primitive basalt in the 2011 Keck data set could be the parent of my most primitive basalt sample. Results showed that this hypothesis is plausible with 19% fractionation of a mineral assemblage of 76% olivine and 24% plagioclase. While the sum of the squares of the residuals was 2.5, which failed the criteria for a successful model, this model could likely be improved with the inclusion of spinel. However, the model does suggest that the most primitive Sauratindur basaltic lava could be the product of ~20% olivine-dominated fractional crystallization (with subordinate plagioclase) of the most primitive lava in the Keck regional data set (possibly near primary). Another model was run to test if the Sauratindur dacite could have been derived by fractional crystallization from the most evolved Sauratindur basalt. The model was successful (sum of square of the residuals of 0.07) with 66.2% fractionation with an assemblage of 38% pyroxene, 36% plagioclase, 18% titanomagnetite, 4% olivine, 1.9% ilmenite, and 0.9% apatite. Linking the sequence of mass balance models results suggests that it is plausible the Sauratindur dacite could be the ultimate product of 89% fractional crystallization, starting with a near primary basaltic magma.

To further test the plausibility that the Sauratindur dacite is the product of a high degree of fractionation from a basaltic parent I examined trace element patterns (Fig. 4). Plotting Zr against SiO_2 also shows a trend suggesting that the dacite could be derived from a basaltic parent magma. However, on a plot of Zr vs. Nb (Fig. 4), the basalts all plot on a straight line of constant Zr/Nb, but the dacite plots on its own trend distinctly above the basalt trend. This step can not be explained by fractional crystallization. Thus the formation of the Sauratindur dacite is best explained by crustal melting. Gunnarsson et al. (1998) and

Jonasson (2007) contend that the rhyolites of Iceland are the product of crustal melting. Martin and Sigmarsson (2007) find that while rhyolites in the man rift zones are formed by crustal melting, those in the off-rift flank zones form by fractional crystallization dominated processes. Thus, the results presented here suggest that the Sauratindur dacite was formed by crustal melting in the main rift zone, the 15-7 Ma Skagi-Snaefellsnes rift zone.

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