GEOCHEMICAL AND PETROGRAPHIC ANALYSIS OF THE VOLCANIC ROCKS OF CENTRAL LANGADALSFJALL, NORTH-CENTRAL ICELAND: EVIDENCE FOR CRYSTAL FRACTIONALIZATION AND MAGMA MIXING?

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INTRODUCTION

Iceland has a complex history of volcanism, plume interaction, and ridge migration. The movement of the mid-Atlantic ridge relative to a mantle plume is commonly invoked to explain the repeated eastward repositioning of the spreading axis in Iceland. Helgason (1984) proposed that frequent shifts in the volcanic zone are common. Aeromagnetic surveys (Kristjansson & Jonsson, 1998) suggest the presence of a former rift zone in western Iceland older than 7 Ma. Schilling et al. (1978) propose a transient stage of rifting for the Skagi Peninsula 0.5-2.5 Ma that was only ephemeral and never reached thermal maturity.

The Langidalur and Langadalsfjall area on the Skagi Peninsula offers a prime field location to study an off-rift basin and mantle processes along the mid-Atlantic ridge. Individual volcanic flows are well exposed except where post-glacial landslides have deposited colluvium. Mafic, intermediate, and felsic rocks are present in the area.

Detailed field mapping and chemical analysis can provide insight into the petrogenesis of the volcanic materials. Three potential end-member theories explaining magmatic differentiation must be accounted for: (1) differing degrees of partial melting; (2) crystal fractionalization of genetically related melts; and (3) mixing of magmas of both co-genetic and differing origin. Although we cannot rule out theory 1 due to insufficient data, geochemical and petrographic evidence suggest both crystal fractionalization and magma mixing processes.

Field Area

Jóhannesson and Saemundsson (1998a) mapped widespread basalt with isolated exposures of extrusive and intrusive felsic rock around the Skagi area. Tectonic mapping (Jóhannesson & Saemundsson, 1998b) delineated three volcanic centers located around the Langadalsfjall area, with a monoclinic flexure zone running down the Langadalsfjall range.

The Langadalsfjall area is characterized by a succession of Tertiary volcanic flows. The 1:500,000 bedrock geology map by Jóhannesson and Saemundsson (1998a) indicates the presence of felsic extrusive rocks. No rhyolites were discovered during my field mapping, and bulk rock compositions of sampled flows indicate only basalt, basaltic andesite, and andesite. Dacitic fiamme are associated with the andesite plagioclase porphyry. Meganck (this volume) documents rhyolitic material several kilometers southeast of the central Langadalsfjall area.

Individual lava flows in Langadalsfjall can be distinguished by several features. Many individual flows show vesicular grading, with vesicles increasing in size and abundance near the top of individual flows. Many flows contain a flow-top breccia zone with a dull red color indicating oxidation. These brecciated zones can reach several meters in thickness. Finally, red baked horizons represent the rapid oxidation of soil layers as molten lava poured out over the soil during an eruptive event.

Four distinctive map units can be distinguished in the field: (1) a lower volcanic series; (2) the Golf Ball Unit (GBU); (3) an upper volcanic series; and (4) a plagioclase-phyric series.

Bulk rock composition and CIPW normative analysis indicates that the lower volcanic series consists of tholeiitic basalts with occasional diabase present. An upper volcanic flow series of tholeiitic and olivine tholeiitic basalt is separated from the similar lower flow series by a physically and compositionally distinct unit. This distinctive unit has been labeled the Golf Ball Unit after the plagioclase-phyric andesite containing plagioclase phenocrysts several cm in diameter. Volcanic tuff locally containing fiamme is intimately associated with the GBU. In a nearby location to the southwest, Meganck (this volume) documents rhyolite associated with GBU. Another plagioclase-phyric unit with mm-sized phenocrysts crops out in the northwest part of my field area, above the upper volcanic flow series. Olivine- and hypersthene-normative, these plagioclase-phyric flows consist primarily of olivine tholeiites. Olivine tholeiite dikes cut the upper volcanic series in the center and northwest of the field area.

Petrography

Thin section analysis of samples collected from the lower and upper sections of the lava pile reveals porphyritic, intergranular to intersertal textures in basalts and a diabase. Some samples are aphyric with calcic plagioclase laths 1-2 mm in size. The groundmass contains clinopyroxene, plagioclase laths, and iron-titanium oxides. Plagioclase phenocrysts show sieve-textured cores, opaque inclusions, compositional zoning, and skeletal melt pockets. Pyroxenes are strongly zoned with thin rims. Some are poikilitic. Olivine is present, although it is often slightly to very iddingsitized. Fresh glass is present, though in most cases the glass is devitrified. Amygdules may contain zeolites. Magma mixing/mingling is indicated in three samples by (1) color variation, (2) mineralogical differences (mainly the amount of iron-titanium oxides and pyroxene), and (3) the amount of basaltic glass present.

Ca-rich plagioclase phenocrysts with sieve-textured cores characterize the porphyritic andesite that defines the Golf Ball Unit. The groundmass consists of over 50% plagioclase laths less than 0.1 mm in size. Anhedral iron-titanium oxides and clinopyroxene less than 0.1 mm are also present in the groundmass. Altered basaltic glass also occurs.

The groundmass in the upper plagioclase-phyric unit contains plagioclase laths, clinopyroxene, and iron-titanium oxides. Calcic plagioclase phenocrysts show compositional zoning and a sieve texture. Olivine and clinopyroxene phenocrysts are slightly altered.

The dikes intruding the volcanic succession near Hafnaklettar are subophitic, porphyritic basalts with phenocrysts of calcic plagioclase, clinopyroxene, and olivine. The olivine is iddingsitized. Often associated with the clinopyroxene phenocrysts, the plagioclase has sieve texture and dramatic concentric zoning. The groundmass consists of plagioclase laths, granular clinopyroxene, and iron-titanium oxides. Petrographic similarities suggest that the dikes may originate from a common parent magma.

Major Elements

Major-element Harker variation diagrams reveal the expected linear variation for a group of co-genetic lavas. MgO and CaO correlate negatively with SiO_2 and the trends are smoothly decreasing. Consistent with petrographic observations, it is likely that the trends indicate the fractionation of olivine, clinopyroxene, and Ca-rich plagioclase. Na_2O and K_2O correlate positively with SiO_2 concentration, while P_2O_5 shows initial enrichment and then depletion at ~50 wt% SiO_2. The depletion of P_2O_5 is probably indicative of apatite crystallization. Similarly, after initial enrichment, TiO_2 and Fe_2O_3 concentrations *simultaneously* decrease, indicating the crystallization of Ti-bearing clinopyroxene and Fe-Ti oxides. These trends are supported by petrographic observations showing that olivine has a Mg-rich core increasingly enriched in Fe towards the rim and possible Fe enrichment in clinopyroxene. In particular samples, clinopyroxene rims are strongly resorbed, and a second period of clinopyroxene phenocryst growth is indicated by inclusion-rich, resorbed rims.

Trace Elements

Trace element data provide additional petrogenetic information. Trace element ratios clearly distinguish the andesite and dacites in the GBU from the basalts of the three other units. For example, Zr/Nb, Zr/Ni (fig. 1), Zr/Cr, K/Cr (fig. 2), Rb/Sr, and Zr/Y ratios indicate that the andesite and dacite glasses are clearly distinct and are neither parental nor evolved end-members of the trend. The dike which was analyzed has trace element ratios similar to the three other units and appears to be the least evolved of the co-genetic suite present.

Evidence for an Enriched Source?

Following the arguments in Wilson (1989), distinguishing between N-MORB and E-MORB compositions can indicate a likely source region of mantle melting. Trace element concentrations from Langadalsfjall most closely resemble the E-MORB and ocean island tholeiite data from the Basaltic Volcanism Study Project (1981, pp.144), suggesting an enriched mantle source. With the exception of samples in the Golf Ball Unit, Zr/Nb ratios for the samples are around 10, in line with E-MORB values from Wood et al. (1979). Spider diagrams normalized to N-MORB (Sun &McDonough, 1989) (fig. 3) have a negative slope, indicating that the incompatible elements are 10-100 times more enriched than for an N-MORB source. There is a clear parallel relationship between the dacite fiamme and andesite GBU, suggesting that they may be genetically related but distinct from the upper and lower basalt flow units and the plagioclase-phyric unit. These three samples have spidergrams with slopes distinct from the rest of the basalt samples, in particular from Pb to Lu in the accompanying figure (Fig. 3). Therefore they must have a different source region or have been contaminated. The trace element data suggest that the erupted basalts are derived from an enriched mantle component, in line with current theories of a mantle plume beneath Iceland. However, the andesite in the GBU has a Zr/Nb value of 17.1, which is between those for E-MORBs (~10) and N-MORBs (>30) (Wood et al., 1979). This intermediate value may reflect a hybrid mantle source (mixed N-MORB and E-MORB).

Ar-Ar Age Dating

In order to obtain age dates for representative units in each field area, samples were sent to

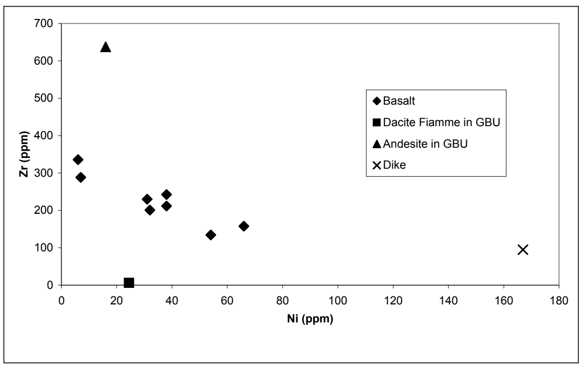

Figure 1. Plot of Zr (ppm) vs. Ni (ppm). The andesite and dacite fiamme samples in the GBU do not fall on the evolutionary trend defined by the basalts and dike.

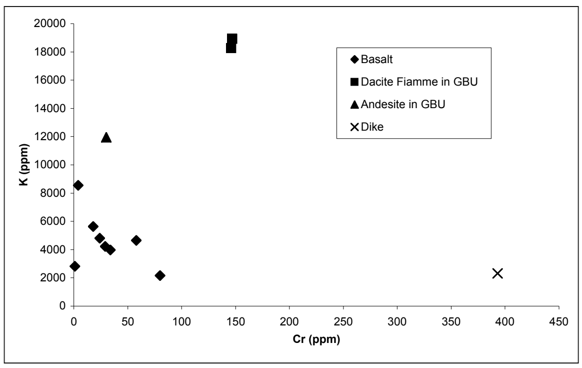

Figure 2. Plot of K (ppm) vs. Cr (ppm). The andesite and dacite fiamme samples in the GBU do not fall on the evolutionary trend defined by the basalts and dike.

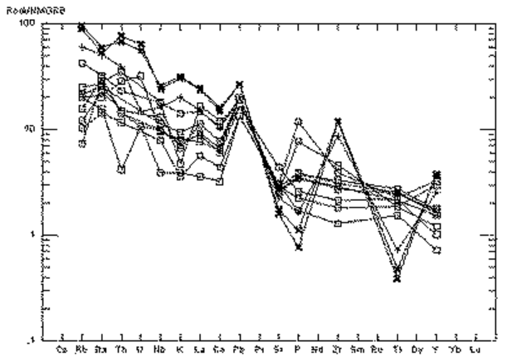

Figure 3. Spidergram showing a plot of trace element concentrations (ppm) against normalized abundance to N-MORB (Sun &McDonough, 1989). Boxes represent basaltic samples; cross represents andesite in Golf Ball Unit; x represents dacite fiamme glass samples.

Oregon State University for Ar/Ar analysis. Sample KW15-9 is an andesite from the Golf Ball Unit. The normal isochron reveals an age of 7.80 +/- 0.07 Ma (2 _ error). Although the analysis shows several well determined steps, they do not form a plateau. The normal isochron yields a preferred orientation using heating increments greater than 850 degrees.

Samples from adjacent field areas in Langadalsfjall yield maximum and minimum age dates for the field area. The basalt at the bottom of Meganck's area (this volume) yields a maximum age date of 8.59 +/- 0.13 Ma and the porphyritic basalt at the top of Kramer's area (this volume) yields a minimum age date of 7.08 +/- 0.06 Ma. Thus the volcanic activity in the Langadalsfjall area occurred over a 1.5 million year period. The andesite in the Golf Ball Unit is statistically indistinguishable from the rhyolite to the southeast in Meganck's area (this volume) (7.82 +/- 0.04 Ma). This suggests that the Golf Ball Unit and the rhyolite are synchronous and closely related.

CONCLUSION

Detailed petrographic analysis combined with major and trace element data suggest fractional crystallization processes as well as magma mixing. The dikes are the most primitive magmas in the field area and may be representative of the parental magmas (for all units excluding the GBU). Trace element data suggest that the volcanic flows are enriched with respect to N-MORB sources, possibly indicating the presence of a mantle plume. There is a distinct difference between the Golf Ball Unit and the remaining basaltic flows. Trace element differences indicate that the tuff and andesite in the GBU are not genetically related to the bulk of the basaltic flows. The magma mingling observed in thin section appears to be mixing of co-genetic magmas. Partial melting models were not analyzed due to an incomplete suite of trace element analyses; however, the strongest lines of evidence for magmatic differentiation support both fractional crystallization and magma mixing processes.

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