Geochemistry and Petrography of Mafic and Felsic Dikes, Vinalhaven Island, Maine

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INTRODUCTION:

Vinalhaven Island, of the East Penobscot Bay area is part of the coastal Maine Magmatic Province (Hogan and Sinha, 1997). The island is composed of an Ordovician metamorphic package, the Calderwood Formation, a Silurian bimodal volcanic sequence, including rhyolites, ash flow tuffs, breccias, and a quartz bearing diabase unit. The center of the island is composed of the granite pluton, both fine and coarse grained varieties, and further south, a gabbro pluton and a metamorphic block of unidentified origin. Mafic and felsic dikes are found to intrude the Calderwood Formation, the northern volcanic rocks, the metamorphic block to the south, and in fewer instances, the gabbro pluton. No dikes are found to intrude the granite pluton. The goal of this study is to describe, in detail, the field relations of several dikes observed on the island, to conduct petrographic analyses of selected samples, and to analyze the major, trace, and rare earth element geochemistry of a representative group of dikes sampled from the island. It is thought that all the dikes witnessed were intruded prior to the emplacement of the granite pluton. The petrographic and geochemical analyses serve to divide the dikes into compositional groupings: mafic and felsic, and to determine which samples may have the same parental source based on petrographic textures and geochemical trends.

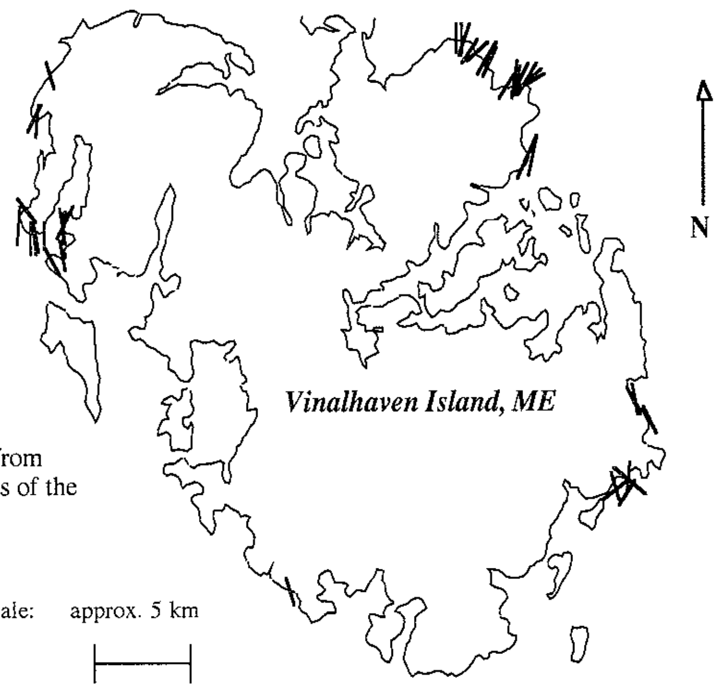

Figure 1. Map of Vinalhaven Island modified from Mitchell and Rhodes (1989) including the trends of the dikes sampled.

Scale: approx. 5 km

METHODS:

A representative collection of mafic and felsic samples were prepared for major, trace, and rare earth element analyses. Ten grams of whole rock powder was sent to Oregon State University to be analyzed for rare earth elements and other immobile elements using the INAA (instrumental neutron activation analysis) for 11 selected samples. Whole rock powder for 22 selected samples was taken to Franklin and Marshall College, Lancaster PA, to conduct major and trace element analyses using the XRF (x-ray fluorescence spectroscopy) procedure.

RESULTS:

Petrography: The mafic dikes found on the island are aphanitic to porphyritic. They are composed of plagioclase feldspar, clinopyroxene, orthopyroxene, hornblende, and chlorite as a secondary mineral. Porphyritic samples have phenocrysts of plagioclase feldspar ranging in size from 0.5 to 4.0 mm in length. Hornblende and augite also occur in few samples as phenocrysts.

The felsic dikes on Vinalhaven Island vary widely in their textures and compositions. Sample 98MC-24 displays devitrification texture surrounding euhedral phenocrysts of quartz and plagioclase feldspar. Two samples are porphyritic, with phenocrysts of plagioclase feldspar, up to 10mm in length, and quartz, ranging in size from 1.0mm to greater than 4.5 mm.

Two samples in particular show characteristics not seen in other samples analyzed. 98MC-39A and 98MC-39C are porphyritic and are composed of approximately 60% plagioclase feldspar, 20-30% chlorite as a secondary mineral, as well as minor amounts of augite, hornblende, and quartz. These samples display characteristics in their plagioclase grains that are typical of rocks that have been exposed to some degree of magma mixing. The phenocrysts found in these samples have a convolute zonation texture (MacKenzie *et al.*, 1982). Not all plagioclase phenocrysts in these samples display this texture; many show no evidence of mixing. Quartz is found both within the groundmass of these two samples and as phenocrysts. Sample 98MC-39A contains a partially resorbed quartz grain out of equilibrium with the groundmass, as evidenced by an augite rim surrounding the phenocryst.

Geochemistry: Major element distributions are plotted on Harker-type diagrams. SiO2 compositions range from 46.11% to 54.45% for all the mafic dikes, and from 75.86% to 81.67% for the four felsic dikes. As expected, the Harker diagrams show two main groupings of samples. Strong negative correlations are seen in the plots of SiO_2 vs. TiO_2, Fe_2O_3, MnO, CaO, and V. Positive correlations, although weak, are seen in the plots of SiO2 vs. Na2O and K2O. The plots of SiO2 vs. Cr and P2O5 show a wide variation in oxide values for all mafic samples. This could indicate crystal fractionation according to Rollinson (1993).

Trace element analyses are plotted separately for dike that intrude the Calderwood Formation, the volcanic rocks in the northern portion of the island, and the felsic dikes that intrude the Calderwood Formation. Data for these trace element analyses are plotted on MORB-normalized spider plots after Pearce (1983).

The Calderwood mafic dikes show parallel trends for all trace elements plotted. Overall, these samples are enriched in Rb and depleted in Y and Sc, as well as the transition metals Cr and Ni (figure 2). The felsic dikes found to intrude the Calderwood Formation show strongly parallel trends on the MORB-normalized spider plot (figure 3). These samples are enriched in Rb and Th, and depleted in Sr, Sc, and Cr. The mafic dikes from the northern section of Vinalhaven also have parallel trends, with the exception of sample 98MC-9 (figure 4). Overall, these mafic samples are also enriched in Rb. Sample 98MC-9 is strongly depleted in metals Cr and Ni relative to the other samples. Since Cr is compatible in olivine, clinopyroxene, and orthopyroxene, the low levels may be explained by a fractionation process.

Rare earth element geochemistry by INAA for four felsic samples are plotted on spider diagrams normalized to chondrites after Nakamura (1974). The samples show parallel trends, with some minor variation in sample 98MC-24. This sample has the highest value for Tb, Yb, and Lu, as well as the largest Eu anomaly (figure 5).

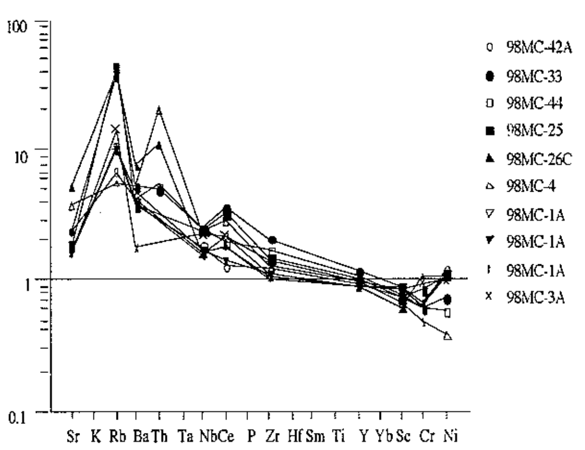

Figure 2. MORB-normalized spider plot after Pearce (1983) for the Calderwood mafic dikes.

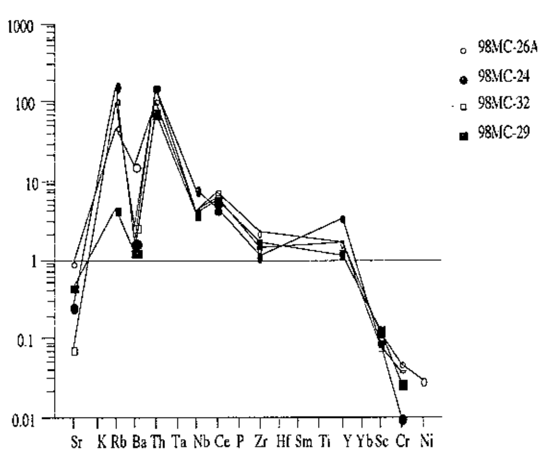

Figure 3. MORB-normalized spider plot after Pearce (1983) for the Calderwood felsic dikes.

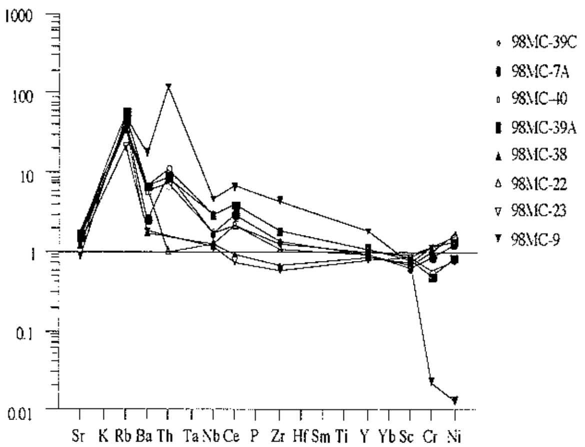

Figure 4. MORB-normalized spider plot after Pearce (1983) for the mafic northern volcanic dikes

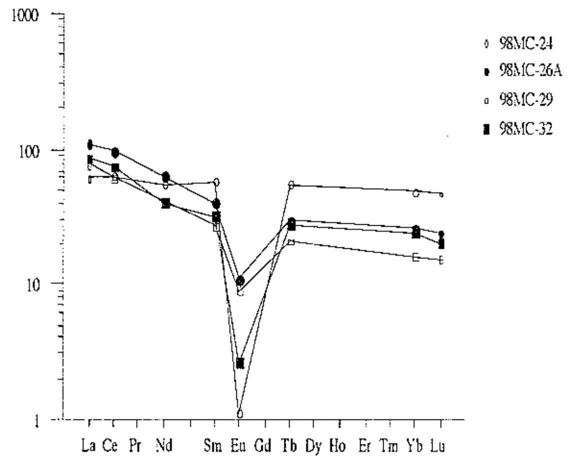

Figure 5. Chondrite normalized spider plot after Nakamura (1974) for the Calderwood felsic dikes.

DISCUSSION:

Geochemical classifications: The trace element discrimination distributions for the basaltic samples are used to ascertain the tectonic framework that is associated with the magmatic source of the samples. A Cr vs. Y plot after Pearce (1982) shows fields for volcanic arc basalts, mid-ocean ridge basalts, and within plate basalts. The basaltic samples from Vinalhaven Island plot within the volcanic arc field. Another discrimination diagram, Ti vs. V after Shervais (1982), shows fields for arc tholeiites, MORB, back arc basin basalts, ocean island and alkali basalts. When the mafic samples are plotted on a Ti vs. V diagram, the samples lie in the arc tholeiite field.

The rare earth element data for the four felsic samples gives evidence that the samples come from a common felsic magma source. The source for these samples is based on Weaver and Tarney's (1984) classification of upper continental and lower continental crust. Although the trends are not exact, they match the Weaver and Tarney's upper continental crust trend more than the lower continental crust trend, and are therefore thought to have formed from the upper continental crust.

Evidence for Magma Mingling: While there is extensive evidence for magma mingling in the gabbro on Vinalhaven Island, there is no evidence that mingling is recorded by the dikes on the island. The gabbro shows pillow structures, pipe structures, and hybridized zones where mafic and felsic magmas are in close interaction. Petrographic analyses, as described above, yield the only possible evidence for magma mingling among the dikes sampled. Furthermore, the only samples which provide evidence for magma mingling are those taken from location 98MC-39.

According to Baldridge et al. (1996), the presence of quartz as phenocrysts and a groundmass mineral in the samples from location 98MC-39 may be indicative of magma mixing or mingling. The evidence for quartz in basaltic rocks, commonly observed as partially resorbed phenocrysts with augite rims, is an indication of disequilibrium that is not yet fully understood. A partially resorbed quartz phenocryst, complete with augite rim is found in sample 98MC-39A.

Sample 98MC-39C also displays disequilibrium textures, possibly related to magma mixing or mingling processes. Plagioclase phenocrysts have partially resorbed and convolute textures. The convolute texture shows a solid plagioclase core surrounded by a fritted rim that is in turn surrounded by a solid rim. The fritted rim represents the disequilibrium conditions that the rock was subjected to, followed by the continued growth of the grain. Later equilibrium conditions are represented by the inner solid plagioclase rim.

Relationships to Other Units on Vinalhaven Island: When compared to the dikes that were collected from the same region on the island as the diabase (Klemetti, 1999), the samples show some similarities seen in the geochemical analyses, such as an enrichment in Rb and depletion toward Cr and Ni. The diabase samples show a greater depletion in transition metals Cr and Ni than the volcanic samples do, with the exception of sample 98MC-9, which varies from the other volcanic samples. Sample 98MC-9 is still more depleted in these trace elements than even the diabase samples. From these trace element plots, it seems as if the diabase may share a parental magmatic source with that of the mafic dikes studied from the island, although major element and rare earth element comparisons may be more conclusive.

CONCLUSIONS:

1.) Vinalhaven Island is composed of bimodal rock types including several intrusive dikes, which are mostly mafic, but also felsic.
2.) Based on field relations, the dikes on Vinalhaven Island may be classified relatively, as being older than the formation that they cut, and in some instances, by the cross-cutting relations among dikes.
3.) The mafic samples are classified as basalt porphyries and aphanitic basalts, whereas the felsic samples are quartz porphyries, and a single granitic porphyry.
4.) Most of the dike samples show no evidence of the magma mingling that is seen in other rock types on Vinalhaven Island, for instance, the gabbroic pluton with hybridized areas and petrographic textures characteristic of magma mingled rocks. There is however one location, 98MC-39, where magma mixing, or mingling may have occurred, as evidenced by petrographic textures.
5.) According to the geochemical data for selected samples, the felsic samples evolved from one felsic magma source, from the upper continental crust. Although the mafic samples do not possess such convincing evidence, have come from a common mafic magma source, as volcanic arc basalts, more specifically volcanic arc tholeiites.
6.) The mafic samples on the island are related by crystal fractionation from a mafic magma, based on correlations of Ni and Mg.
7.) Sample 98MC-9 intrudes the youngest volcanic unit on Vinalhaven Island, and may therefore be the youngest dike collected for analysis from the island. It may differ by source; a more accurate conclusion may be made through analysis of INAA data.

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