MACRORYTHMIC GABBRO TO GRANITE CYCLES OF CLAM COVE VINALHAVEN INTRUSION, MAINE

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INTRODUCTION

The rocks of the layered gabbro-diorite unit of the Silurian Vinalhaven mafic and silicic layered intrusion record the injections of mafic magmas into chambers of granitic liquid and crystal mush. The magma chamber, or chambers, likely waxed and waned over the course of 0.5-1.0 million years (Hawkins and Wiebe, unpublished U-Pb data). As crystals accumulated in the chamber, liquids of both mafic and felsic compositions were injected into it, where they rose until a point at which the dense mafic magma could not be contained by the surrounding crystal mush and began to spread out laterally along the magma chamber floor (Wiebe and Collins, 1998). As the mafic magma pooled, its edges came in contact with the cooler granitic matrix and quenched, yielding structures similar to pillow basalts. The injected magma gradually began to fractionally crystallize, as well as mix with the liquid of the pluton and settling crystals. The goal of this project is to characterize the mixing and fractional crystallization that occurred within individual mafic sheets of the gabbro-diorite unit, by carefully examining nearly 200 m of magma chamber stratigraphy.

FIELD RELATIONS

A stretch of coastline on southeast Vinalhaven Island (Fig. 1), from the middle of the swamp south of Clam Cove north to the contact between the fine-grained granite unit and the gabbro-diorite unit in Carvers Cove was mapped and sampled. Layering in the gabbro-diorite unit strikes approximately N 30º E, with a gentle (~20˚) northwesterly dip determined from the orientation of pipes of coarse-grained granite, believed to be formed as the granite was pushed upward by the pressure of the heavier mafic injection (Wiebe, 1993; Wiebe and Collins, 1998). Approximately 200 m of gabbro-diorite stratigraphy is exposed along this section of the Vinalhaven coast as well as a number of composite dikes, which contained commingling mafic and felsic magma and intrude the gabbro-diorite.

The stratigraphically lowest part of the section is comprised of coarse-grained gabbro. Moving upsection the rocks become dioritic, and these diorites continue upsection toward Clam Cove. The proportion of mafic minerals in these diorites decreases systematically upsection. Immediately south of Clam Cove, the diorite contains abundant quartz grains rimmed by hornblende. Stratigraphically above this diorite is fine-grained gabbro, which immediately grades upward into coarse-grained gabbro. This coarse-grained gabbro closely resembles that seen at the base of the section. Above the gabbro, the rocks again become more felsic. These diorites are very heterogeneous but in general become more felsic upsection. Stratigraphically lower diorites contain plagioclase, pyroxene and biotite. With increasing stratigraphic height, alkali feldspar and quartz appear, and pyroxene decreases.

Plagioclase xenocrysts and rapakivi feldspar are present in these diorites, becoming more abundant in stratigraphically higher diorites. Diorite eventually grades upward to coarse-grained granite.

25 m outcrops are dominated by composite dikes which contain both quenched blobs of mafic magma and angular blocks of crystallized diorite and gabbro within a porphyrytic matrix.

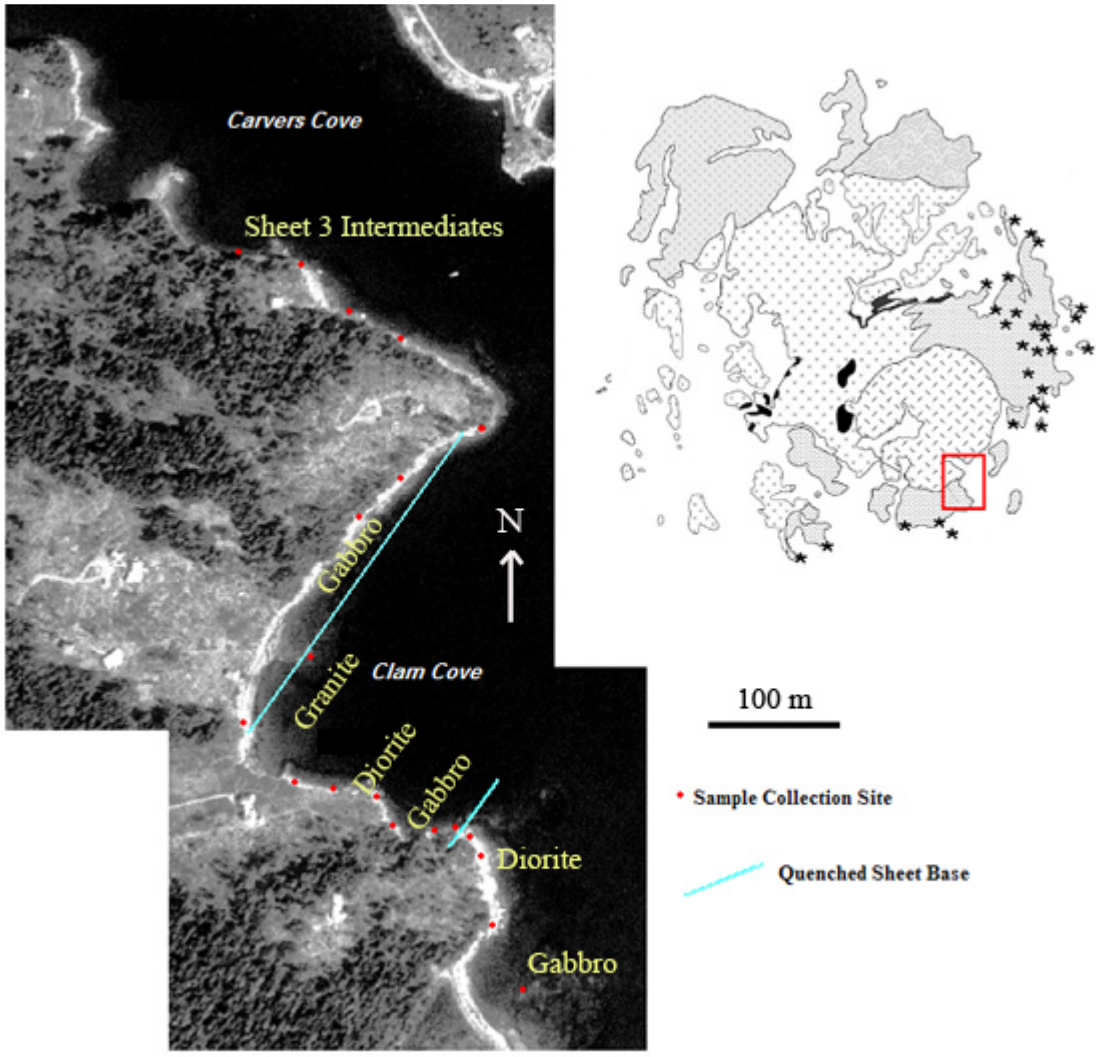


Fig. 1: Aerial photograph of field area and location on Vinalhaven Island. Rock types are listed and approximate traces of basal quench are indicated

Fine-grained gabbro makes a sharp contact with the underlying granite. Pillow-like structures are seen at the base of this gabbro where it overlies either coarse-grained granite or plagioclase-rich porphyry. Pipes of coarse-grained granite intrude up through fine-grained gabbro at one location on the coast. The fine-grained gabbro again grades upward into coarse-grained olivine-pyroxene gabbro.
Approximately 15 m above the fine-grained gabbro and extending upward for approximately

Above this dike-rich section is the stratigraphically highest diorite. It is more mafic than lower diorites, dominated by pyroxene and large plagioclase lathes exhibiting a cumulate texture. This diorite does not tend to become more felsic going upsection, and ends where the gabbro-diorite unit is intruded by the fine-grained granite unit.

The gabbro-diorite unit is comprised of a stack of sheets. Each sheet has a base of fine-grained,

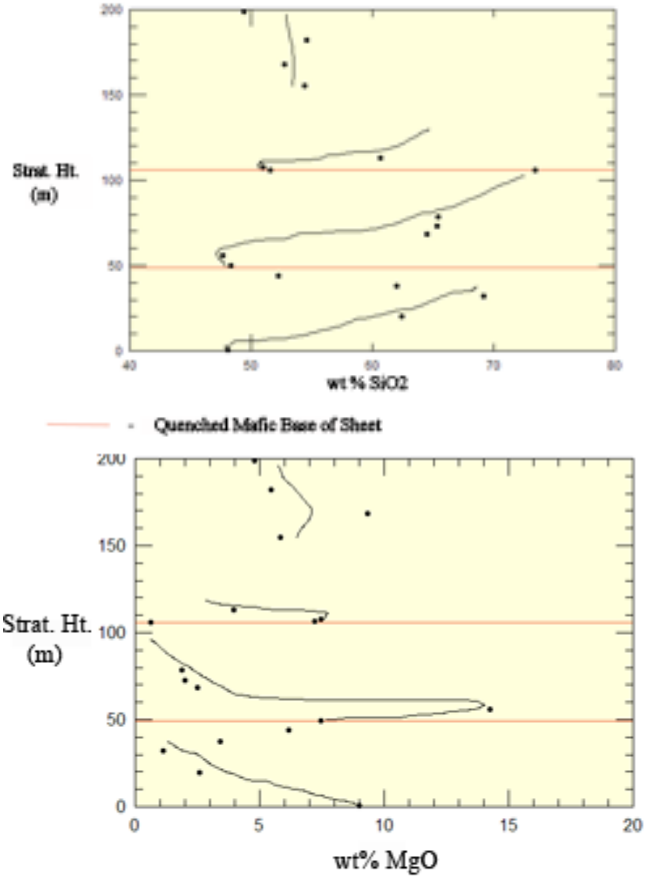
quenched, pyroxene gabbro overlain by coarse-grained, olivine-pyroxene gabbro. The gabbros are overlain by heterogeneous diorites, which comprise the bulk of each sheet. The diorites become more felsic going upwards from the gabbros. Alkali feldspar and quartz do not occur in diorite immediately above gabbro, but appear in stratigraphically higher diorite, as pyroxene becomes less abundant. The most felsic rocks in a sheet are either diorite or granite.

The Clam Cove section is comprised of the upper part of one sheet, all of a second sheet, and the lower portion of a third sheet. Each macrorythmic sheet in the gabbro-diorite unit, is interpreted to have formed by mixing between a mafic magma, represented by the fine-grained gabbro, and the granitic liquid and crystal mush present in the magma chamber. The gradational change from gabbro to granite seen in each gabbro-diorite sheet, as well as the rapakivi feldspar and amphibole rimmed quartz grains in the diorites, suggests the diorites formed as a result of hybridization between mafic and felsic magmas. Diorites are therefore considered to be hybrid rocks formed by mixing of the two magmas.

GEOCHEMISTRY

Major and trace element geochemical data were obtained by X-Ray Fluorescence at Franklin & Marshall College. Sample preparation was completed in the XRF lab at the University of Massachusetts Amherst.

There is a large range in composition of the rocks from the coast in the Clam Cove area. From gabbro to granite, the rocks range in composition from 47.65—73.43 wt% SiO_2 and 0.62—14.23 wt% MgO (Fig. 2).



Figs. 2a, b: Changes in MgO and SiO2 with stratigraphic height show variation of rock type within the gabbro-diorite unit.

Geochemical changes through sheet stratigraphy support field observations suggesting hybridization.

The gabbroic quenched bases of the two sheets are similar with SiO_2 48.41—51.62 wt% and MgO 7.26—7.47 wt% and a Ni content of 101.9—155.7 ppm. Within a few meters, the rocks' SiO2 content drops slightly to 47.65—51.02 wt% and the MgO content increases to 7.46—14.23 wt%, with a Ni content as high as 369.8 ppm. This change marks the transition from quench to coarse-grained gabbro, and the increase of Ni is likely tied to the appearance of cumulate olivine in the coarse-grained gabbro and suggests it was formed by fractional crystallization. A plot of Ni against SiO_2 shows a concave-up curve suggesting fractional

crystallization (Fig. 3).

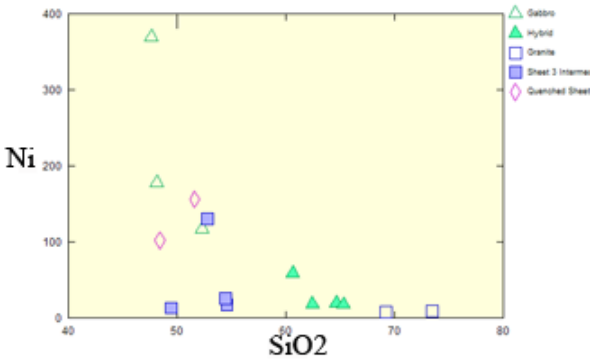


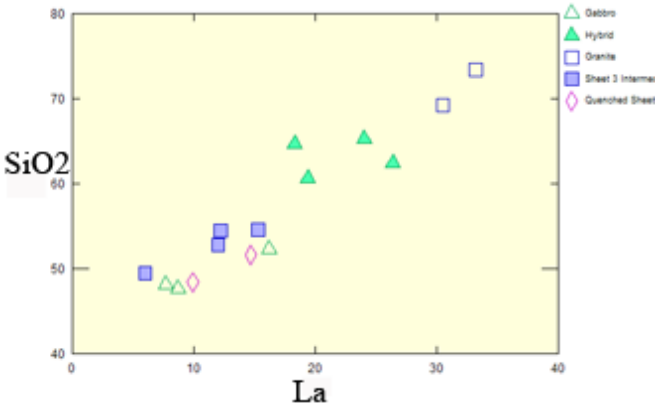
Fig. 3: Ni amounts do not change constantly with change in SiO2.

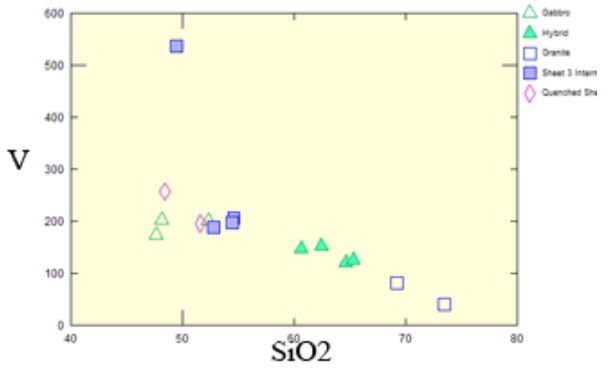
The hybrid rocks located low in the stratigraphic column contain 62.00-69.19 wt% SiO_2 and 1.18-3.40 wt% MgO. Incompatible elements such as Zr (197-219 ppm), Ba (248.8-345.3 ppm) and Y (51.8-58.1 ppm) are in high abundance, and generally increase towards the top of each sheet.

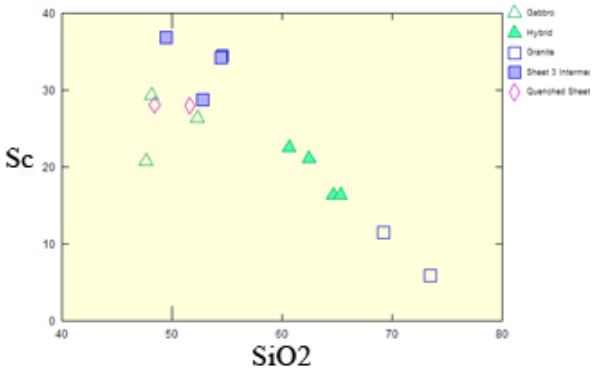
Diorites from the stratigraphically highest gabbro-diorite sheet (Sheet 3 Intermediates) do not show the same geochemical trends as the diorites from the lower two sheets. The range of SiO2 is from 49.47-54.59 wt%, and MgO 4.8-9.3 wt% making the Sheet 3 Intermediates significantly less silicic than the rocks in the lower two sheets. Compatible trace element abundances are variable, with one sample containing very high amounts of Cr (570.3 ppm) and Ni (130.5 ppm) while another contains 537.3 ppm V. Field relations on the coast of Carvers Cove suggested no radical changes through stratigraphy, and the outcrop was relatively extensive in the area.

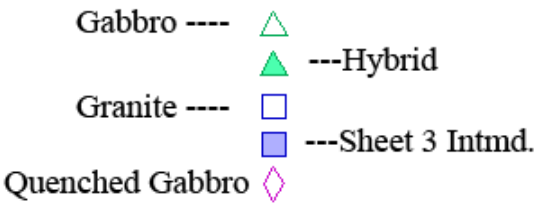
When incompatible trace elements are plotted against a major oxide such as SiO_2, the results are variable. For most elements, diorites in the two lowest sheets lie on a mixing line directly between the gabbros and granites. The Sheet 3 Intermediates, although also diorites, plot differently. In plots such as La/SiO_2 they plot in the same area as the gabbros, but in V/SiO_2 they appear to lie on a line between the gabbro and granites. In a plot of Sc/SiO_2 the Sheet 3

Intermediates plot off the gabbro-granite mixing line (Fig. 4a, 4b, 4c).









Figs. 4a, b, c: The variation of trace elements La, Sc, v with changing SiO2

DISCUSSION

Field, petrographic, and geochemical data suggest the diorites of the two lowest sheets formed by mixing between gabbroic magma and preexisting granitic liquid and crystal mush. Geochemical data suggest that mixing occurred between granite and a mafic magma represented by the fine-grained gabbro at the base of each sheet. Amphibole-rimmed quartz grains and rapakivi feldspars in the hybrid rocks indicate a change in magma composition after the initial crystallization of alkali feldspar and quartz. Fractional crystallization of the mafic magma occurred, producing the coarse-grained, high Mg, Ni gabbros immediately above the quenched gabbro in each sheet.

The Sheet 3 Intermediate rocks are puzzling as their geochemistry and mineralogy distinguish them from stratigraphically lower diorites. There are no field relationships along the coast of Carvers Cove to suggest a higher mafic injection, nor any significant gradational change in the rocks. The Sheet 3 Intermediates are not merely stratigraphically above lower diorites, they are also hundreds of meters distant along strike. Their presence indicates that the processes of magma emplacement within the intrusion were variable.

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