Mafic and silicic magma interaction and plutonic stratigraphy on the southeastern coast of Vinalhaven Island, Maine

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Introduction

The Vinalhaven Island pluton is located in Penobscot Bay at the southern end of the bimodal late Devonian to early Carboniferous Coastal Maine Magmatic Province (Hogan and Sinha, 1989). The southeastern corner of Vinalhaven Island contains mafic and silicic rocks that are both commingled in single layers, stratified as mafic and silicic layering, and mixed into hybridized melts. This study describes the observed field relations along the southeastern corner of Vinalhaven in an effort to discern the stratigraphic sequence of deposition on the magma chamber floor, and seeks to understand the styles of magma mingling and mixing that are present. Chemical data obtained from collected samples is used to supplement description, and to infer history and relationships of different melts.

Field Relations

The southern shore of Vinalhaven Island is dominated by the interaction of mafic and silicic magmas at the base of the magma chamber. Although there is limited exposure of contacts between stratigraphic layers, faint chill horizons in a large gabbroic layer indicate that these layers strike northeast 60 degrees, and dip15-25 degrees to the northwest. The shoreline in the southeastern corner of the island parallels this strike for aproximently one kilometer, and then runs perpendicular to it for three-quarters of a kilometer (figure 1). With this fortuitous orientation of the pluton, shape of the shore, and relatively continuouse well-exposed coastline outcrops, a stratigraphic sequence of layers may be established from field observations. There are three distinct layers identified on the southeastern shore of Vinalhaven Island: (1) a layer of contemporaneously and non-contemporaneously commingled granitic, gabbroic, and intermediate rocks, (2) a massive layer of poikilitic gabbro, and (3) a sequence of intermediate hybridized rock that displays distinct compositional layering.

The lowest layer certainly contains the most complex history of intrusion and mingling. There is a minimum of two granitic melts, three basaltic melts, two intermediate gabbros, and a zone of homogeneous gabbro. Among most of the rocks either crosscutting brittle or contemporary liquid contacts are observable, enabling relative age relations to be established. The simplest description of the layer is that coarse grain granite is commingled with an intermediate gabbro and basalt, then crosscut by fine-grain granite, and continuously transgressed by mafic dikes. One of these dikes is massive, with a circumference that likely exceeds 300 meters, and was definitely a conduit for large volumes of mafic material into the chamber. There are multiple areas of both zones and piles of pillowed basaltic magmas in felsic matrix. Pipes of felsic material rising through mafic magma due to density instability are seen throughout the layer. These pipes were uniquely exposed on the interface of the large feeder and the host rock indicating the angle that the dike cut across the layer, and the amount of rotation of the layer.

Overlying this commingled layer is a thick series of layered, coarse poikilitic gabbros that extend for approximately 275 meters along the eastern shore. There is little evidence for rhythmic basal chills of multiple pulses of mafic magma, but some gradation of grain size is apparent, indicating successive injections of mafic magma. The third layer is a 100-meter thick series of intermediate hybrids directly overlaying the gabbro layer. There are clear boundaries between each of the hybrids, indicating that the compositional variation in this limited area is not simply gradational. Two of the hybrids have load cast structures at their interface that would be indicative of immiscible interaction of two highly contrasting melts.

Whole Rock Chemistry

Major and trace element analysis was completed on thirty-three samples from Vinalhaven's southeastern shore. All major, minor, and trace elements were determined using X-ray fluorescence (XRF) at Franklin and

Marshall College in Lancaster Pennsylvania. Rare earth elements were analyzed for seven samples through Instrumental Neutron Activation Analysis (INAA) at the Oregon State University Radiation Center.

The mafic rocks in the area occur in three forms: layers or large zones of gabbro, basaltic pillows, and mafic dikes. The majority of these rocks have less than 52% SiO_2, and combined Na_2O and K_2O below 4% (figure 2). The sequence of three samples from the thick layer of gabbro show a roughly linear progression in increasing mafic composition, moving from bottom to top of the layer (figure 3). This composition variation is subtle (MgO ranges from 7.1% to 10.25%) but distinctive in many of the elements. Instrumental neutron activation analysis was completed on two samples in the gabbro layer (98MR-41, 98MR-43), the chilled base of the gabbro layer (98MR-23), and the large mafic dike below (98MR-21). Samples 98MR-41 and 98MR-43 are generally depleted in light rare earth elements relative to samples 98MR-21 and 98MR-23, with boths sets showing a decrease of heavy rare earth elements (figure 3). There is a small peak in Eu for samples 98MR-41 and 98MR-43, and a decrease in Eu for samples 98MR-21 and 98MR-23. The most dramatic deviation from the couplets is the increase of Lu in sample 98MR-23 and 98MR-41, when 98MR-43 and 98MR-21 have a decreasing heavy rare earth element trends. The pillows and dikes in the area have a wider range of chemical composition, with an SiO_2 range for the pillows between 46% and 52%, and between 47% and 69% for the dikes . The only samples that contain andesitic chemical percentages are both dikes, and are likely contaminated by host felsic magma. There is no distinctive trend in the compositions of the dikes or pillows that would imply a history of evolution with injection. The majority of the pillowed basalts have a tight range of element composition with CaO at 9% to 11%, MgO between 8% and 11%, and a combined Na_2O and K_2O between 2% and 5.5% (figure 2).

Granitic samples fall into an SiO_2 range of 65-75% weight percentage. Both samples of coarse grain granite had 73% SiO_2, whereas the fine grain granite had between 69 – 71% SiO_2. The two samples of pillow pile matrix material contain dramatically different SiO_2 percentages, one containing 66.7% and the other containing 75.7% SiO_2. Each of the granites have combined Na_2O and K_2O percent compositions between 7% and 9%. There is a linear trend to the major element compositions for all the granites, implying that some genetic relationships exists for them (figure 5).

The intermediate and hybrid samples displayed a wide range of all chemical compositions from near mafic to highly felsic. The set of four leuco-gabbros tend to clump on variation diagrams of major and trace elements. Their SiO_2 weight percentage is between 54% and 57%, and combined K_2O and Na_2O weight percentage near 4% to 5% (figure 5). The chemistry from the series of hybrids fills the spectrum of possible compositions. The weight percentage of SiO_2 ranges from near is 47% to 68%. Other element compositions vary equally as much, and there is no linear trend when these samples are plotted on variation diagrams. Rare earth element analysis of samples 98MR-25B, 98MR-25D, and 98MR-25H, which are from differing levels in the hybrid layers, indicate high amounts of U and Th in the hybrids, a depression of Eu for samples 98MR-25D and 98MR-25H, and a drastic decrease in Sc for all three samples (figure 6).

Discussion

The dramatic physical relationships of mafic and silicic magmas within the lowest layer along the southeastern corner of Vinalhaven indicate an environment of dynamic magma replenishment and mingling. In this layer there is a minimum of five different magmas represented, and it is likely that many more are present. The basaltic pillows observed in the lowest layer are created by the interaction of thermally and rheologically contrasting intruding mafic magma and host felsic magma (Sparks and Marshall, 1986). These pillows indicate that there were small intrusions of highly varying magma compositions along with the large basic intrusions that entered through the massive dike and led to the formation of the large gabbro layer. The clear outcropping of such a massive conduit for mafic magma intrusion into the chamber is a unique characteristic of this area. The position in the stratigraphy of this dike and the gabbro layer imply that the dike may have been a feeder for the gabbro above. Chemically the base of the gabbro and the dike have very similar compositions which support a relationship between the two (figures 2 and 3).

The gabbro layer is the result of sill like spreading of mafic magma along the floor of the pluton. It has a chilled fine-grain base, a petrographically cumulus texture in its center, and an upper level that appears hybridized by rising pegmatic material and overlying felsic melt. The gabbro layer had an increase in basic composition moving from bottom to the top, implying that there was increasingly more mafic composition to the incoming gabbro, and not a gradual evolution of the layer as a single unit (figure 3). The series of intermediate hybrids has distinct compositional interfaces, which indicate that there was not a gradational interaction of the underlying gabbroic melt and the rest of the felsic magma in the chamber. The presence of load-cast structures between some of the hybrids clearly shows that there were rheological and compositional differences that did not allow mixing of the melts, and instead the melts behaved as immiscible contemporaneous liquids.

References Cited

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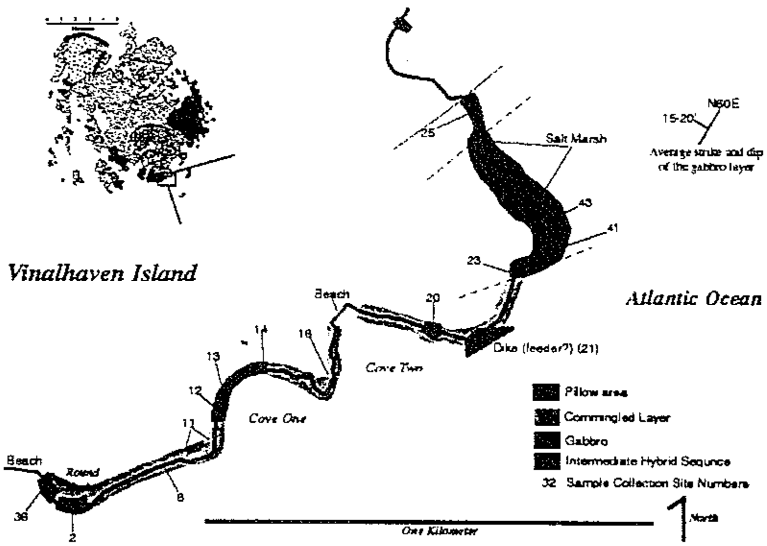

Figure 1 - The southeastern corner of Vinalhaven Island. The three layers assessed in this study are identified, along with areas of pillows, the gabbro at the beach of Cove One, and the massive dike. (Inset map is adapted from Mitchell and Rhodes, 1989)

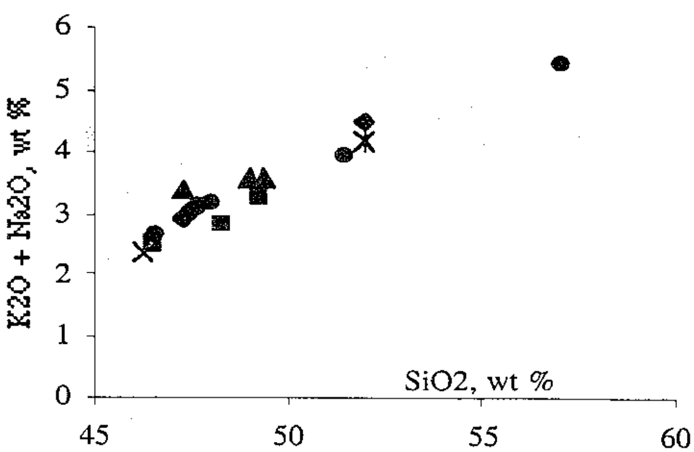

Figure 2 – Variation diagram of SiO_2 verses NaO_2 and K_2O for all mafic samples. Sample 98MR-13 is an area of homogeneous gabbro, and sample 98MR-25B is the interpreted interface of the gabbro layer and the hybrid layer.

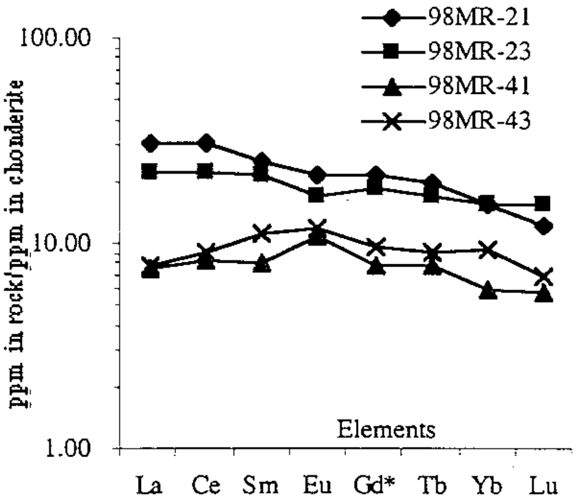

Figure 3 – Rare earth element analysis of gabbros and the massive mafic dike located stratigraphically below.

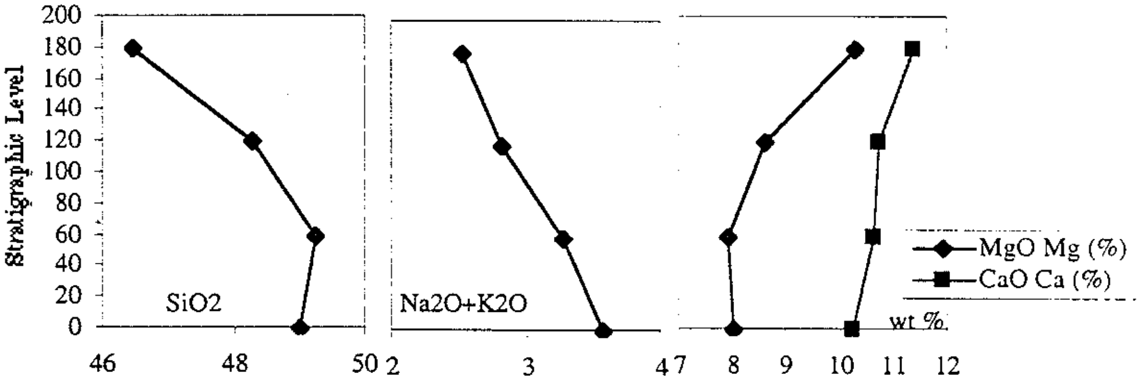

Figure 4 - Weight percentage of selected major elements against the stratigraphic position of the gabbro samples, and the mafic dike below the gabbro.

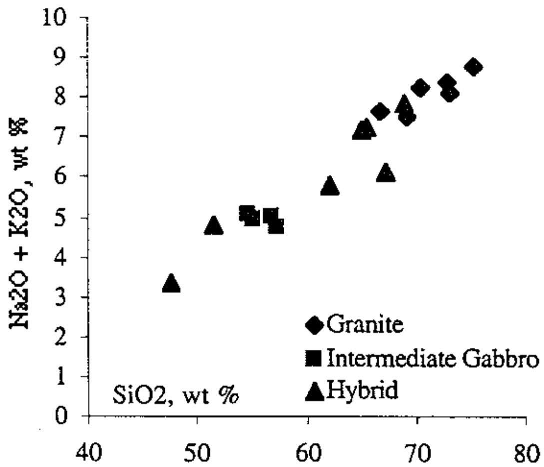

Figure 5 - Variation diagram of the granitic and intermediate rocks. Note the large spread of hybrid samples, tight clump of intermediate gabbros, and linear pattern of the granites.

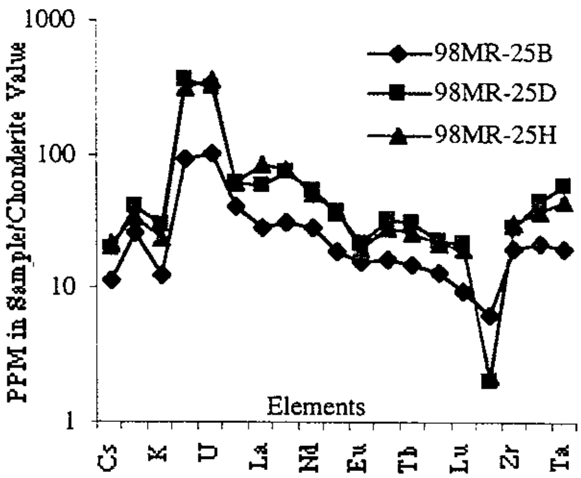

Figure 6 - Spider Diagram of selected hybrid samples.