Field, petrographic, and geochemical characterization of stratigraphy at the base of the Vinalhaven pluton, Vinalhaven Island, ME

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INTRODUCTION

Because crustal melts may form by crustal underplating (Huppert and Sparks, 1988; Bergantz, 1989), mafic and silicic magma can coexist in time, increasing the opportunity for different magmas to occupy a single chamber (Wiebe, 1996). Early studies suggested that silicic magma chambers act as a density trap for mafic magma, causing it to pool at the base of the chamber (Vogel, 1982; Mattson et al. 1986). A series of mafic replenishments into a chamber can define stratigraphy and accentuate previously existing cumulate layering. Both mingling and mixing relationships between mafic and silicic magma can follow, depending on the physical and thermal characteristics of each.

The Vinalhaven pluton preserves excellent examples of stratigraphy produced in a magma chamber. This study investigates the field relations, petrographical and geochemical aspects of three stratigraphic sections located in one portion of the base of the Vinalhaven magma chamber. The sections preserve mafic replenishment and hybridization events, and by using these features, a petrological and structural evolution of one portion of a magma chamber are described.

METHODS

Time spent in the field was used for detailed geologic mapping of the field area and sample collection. Physical and structural mapping techniques were used to create three stratigraphic sections, structural cross-sections and a geologic map of the field area. Samples were collected in a fashion that would best characterize the three stratigraphic sections petrographically and geochemically. Thin-sections were made for 42 samples, which were analyzed for mineralogical and textural characteristics. Major and trace element analysis was conducted on 27 samples by XRF at Franklin & Marshall College. Twelve of those were selected and sent for INAA at the Oregon State University Reactor Center. The field relations, petrographical and geochemical data was used both separately and in accordance with each other to describe the evolution of the three stratigraphic sections.

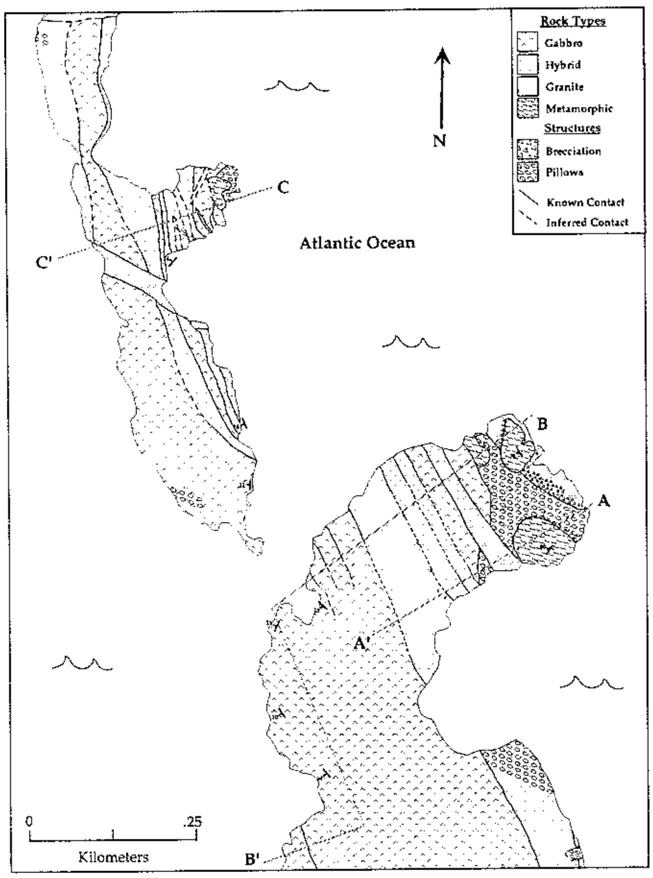


Figure 1: Geologic map of north Coomb's Neck and Neck Island. Lettered lines represent where stratigraphic sections were taken.

STRATIGRAPHY AND PETROGRAPHY

The field area consists of a peninsula, Coomb's Neck, and neighboring islands, which are located on the eastern shore of Vinalhaven Island. Two stratigraphic sections were made from the northern end of Coomb's Neck, and the third is located on Neck Island (Fig.1). They were labeled from south to north as sections A, B, and C. Petrographical and field descriptions of each section follow.

Stratigraphic section A: The base of this 26m thick section is dominated by coarse-grained granite encasing metamorphic blocks and gabbroic pillows (Fig.2). The pillows grade up-section into a massive gabbro replenishment, which grades into hybridized rock of various compositions dominate the upper portion of the section. The four gabbro samples from this section were taken from pillows within a replenishment. Three are characterized by the presence of quartz and potassium feldspar in low quantities (<5%), while hornblende+biotite compose up to 25% of the rock. The other pillow differs, in that it has no quartz, low hornblende and biotite, and contains olivine. The hybridized rocks of the section contain several features worth mentioning. The modal abundance of both quartz and alkali feldspar increase upward in the section, from 1 and 5% to 17 and 25%, respectively. Hornblende also increases up-section, while Pyroxene and plagioclase decrease. Texturally, these rocks show features typical of hybrids, such as hydrous minerals mantling non-hydrous minerals, and rapakivi and antirapakivi mantling in feldspars. These reaction relationships also increase up-section.

Stratigraphic section B: Coarse-grained granite surrounding brecciated metamorphic blocks make up the base of this 78m thick section (Fig.2). Above, gabbroic pillows with a fine-grained granitic matrix trend into a massive gabbroic replenishment. This replenishment contains ≈20% biotite+hornblende near the base, and accessory quartz. Up-section in the same replenishment, a decrease in biotite and a disappearance of hornblende and quartz correspond to the appearance of 4 modal% olivine. This layer grades into hybridized rock, which is followed by another hybrid unit. The upper hybrid is characterized by an increase in quartz and alkali feldspar upwards (<8% each to 30% each), while pyroxene and plagioclase decrease. In thin-section, the hybrid shows typical textures that are associated with magma mixing. The upper 40m of this section is composed of a series of gabbroic replenishments, which are similar in outcrop and mineralogy. Each show ophitic texture, and contain similar amounts of olivine and pyroxene: roughly 10 and 20%, respectively. They have <10 modal% horneblende+biotite. The opx/cpx ratio decreases upward through each replenishment.

Stratigraphic section C: This 24m, thick section is located on Neck Island (Fig.2). Its base is again dominated by coarse-grained granite encasing metamorphic blocks. Above these are gabbroic pillows, which are followed by layers of alternating gabbroic and hybrid rocks. Contacts between overlying hybrid rock and underlying gabbro units are sharp. The hybrid rocks are characterized by their high abundance of alkali feldspar, quartz and hornblende, and thin-section textures representing mixed magmas. The gabbros in this section differ from those of other sections, in that they contain up to 20% olivine and only 1-3% biotite and hornblende.

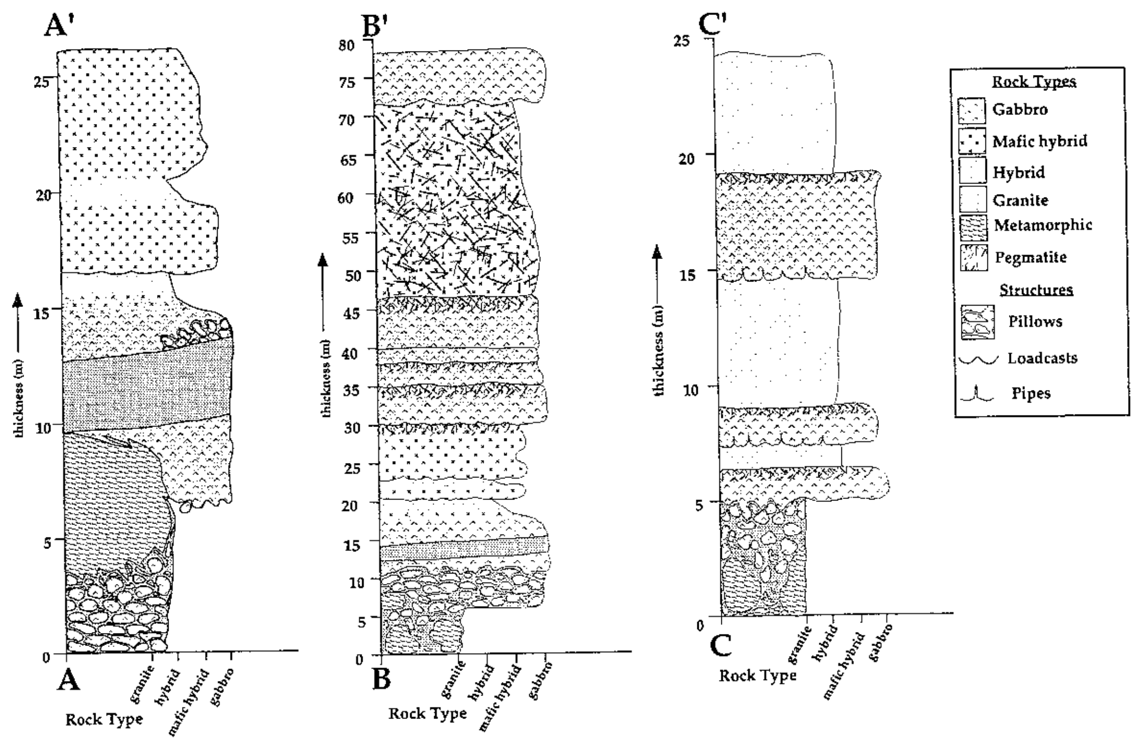


Figure 2: Three stratigraphic sections from north Coomb's Neck and Neck Island. See figure 1 for positions on map.

GEOCHEMISTRY

Major, trace and REE analyses were conducted on selected samples. These data were used to characterize the rocks and attempt to constrain their petrogenesis. All samples plot between 45% and 75% SiO2, and show increasing alkali content and decreasing Mg# with higher SiO2 levels. Spider plots for REE analysis on all samples chosen for INAA are shown(Fig.3).

Plots showing geochemical behavior compared to stratigraphic height exhibit some systematic relationships. Samples collected from the basal quench of replenishments, which cooled rapidly against the underlying layer upon injection in to the chamber, approximate melt compositions. Quench compositions for Mg#, Al2O3, La/Y, and Zn with respect to stratigraphic height are plotted (Fig.4). Samples from stratigraphic sections A and B, but not C, are shown in these figures. These plots represent the changing composition of mafic magma entering the chamber. Similar plots for 4 samples from within one hybridized layer show the abundance of Ni and the Mg# with respect to height (Fig.5).

DISCUSSION

A complex set of magma chamber processes are required to form the stratigraphy seen in the field area. Field relations show that layer thickness and orientation is locally variable. Distinct textural and mineralogical differences are revealed in similar rocks types and from within single replenishments. Geochemical data suggest that although fractionation plays a large role in single replenishment variation, other processes may have an effect on the mafic magma composition prior to injection. Though petrographic evidence suggests magma-mixing formed hybrid rocks, the time and place of this mixing is not totally clear.

Both mineralogically and geochemically, single replenishments show evidence that fractional crystallization has dictated vertical composition variation. The modal abundance of both hydrous and felsic minerals increase upward within individual replenishments. Mg# increases and compatible elements become concentrated near the base of

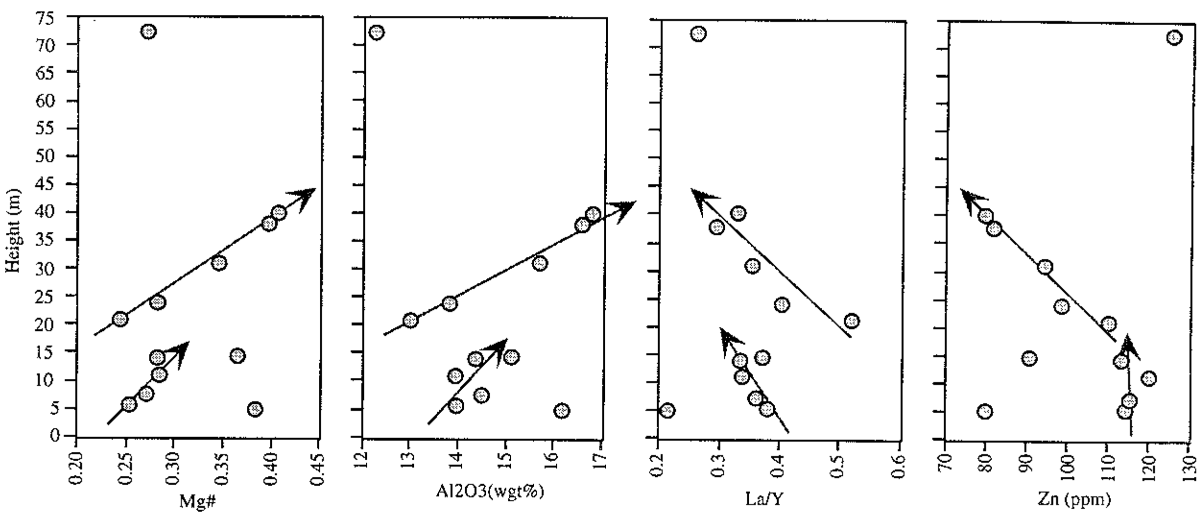
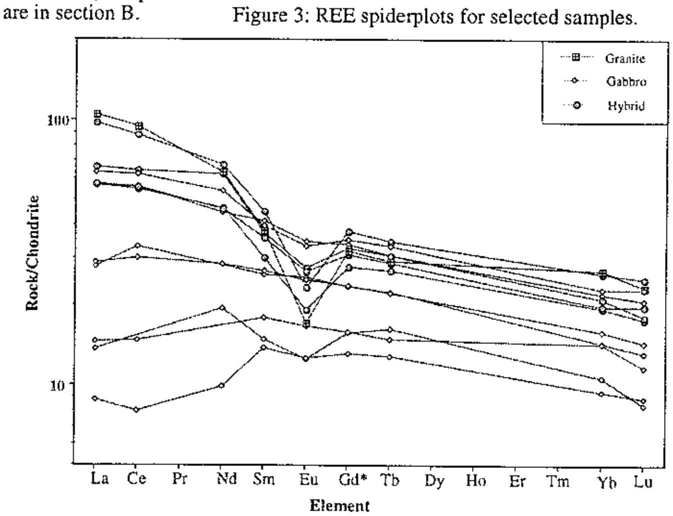


Figure 4: Plots for quench samples vs stratigraphic height. Below 20m, samples from sections A and B are plotted. Above 20m, all samples are in section B.

Figure 3: REE spiderplots for selected samples.



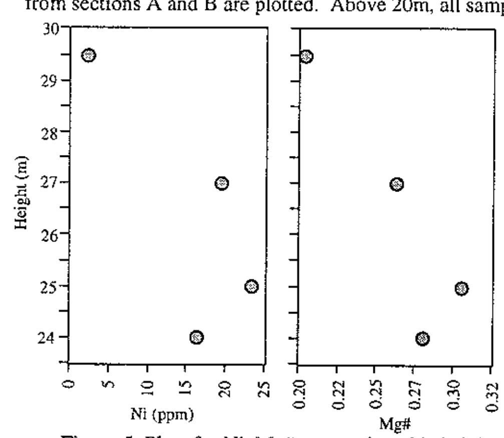


Figure 5: Plots for Ni, Mg# vs. stratigraphic height from within one hyrbid layer in section B.

layers, above the quench, suggesting crystal accumulation as a layer crystallizes. This trend is seen in hybridized units (Fig.5), as well as mafic units. The REE patterns (Fig.3) suggest that fractional crystallization has had significant effect on magmas as well, because steepening of the LREE slope corresponds to an increasingly negative Eu anomaly in most samples. However, mixing with crystal-poor silicic magma near to top of mafic replenishments could also produce the increasing silica content upwards within a replenishment. Though mixing is probably occurring at the tops of replenishments, this process alone does not account for the increase in mafic content just above the quench. Perhaps a combination of fractionation and mixing is responsible for the features seen.

Patterns found in geochemical variation of quench samples (Fig.4) suggest that either: 1) there are multiple mafic chambers responsible for the injections; 2)that there can be a significant time lapse between injections from the same source, during which time fractional crystallization, mixing and/or assimilation drastically changes the geochemistry of that source; 3)that stratigraphy represented in Coomb's Neck reflects a compositionally stratified source of mafic magma; or 4)that when magma enters the chamber, its composition is modified through mixing as it traverses the floor. Geochemical, petrographic and field evidence provide support for each of these models, though model 3 is most consistent with the observations. Above 20m height, aluminum and Mg# increase with each replenishment, while the La/Y ratio, which approximates the REE slope, decreases upward (Fig.4). This follows patterns produced through fractional crystallization and/or crustal assimilation, in which case the upper replenishments are less differentiated. This pattern could form if a chemically zoned magma chamber, resulting from fractionation and/or assimilation, was tapped from top to bottom to supply the mafic replenishments to the granitic chamber.

Several observations constrain the origin of hybrid magmas. Field relations represented in stratigraphic sections A and B show diffuse contacts between the upper portion of gabbroic layers and hybrid units. The hybrid units become more felsic upward, while showing more hybrid textures near the top-middle of the units. This suggests that mixing occurs at the top of mafic replenishments, presumably with crystal-poor silicic magma in the chamber. Thick hybrid sequences located in sections A and B formed, and were then buried by mafic replenishments, while crystal-poor silicic magma (which may have been partially hybridized) was displaced upward in the chamber. Field relations in stratigraphic section C, however, show sharp contacts between an overlying hybrid unit and gabbro. Based on these observations, hybridization must have occurred prior to the deposition of the hybrid layer. This may have occurred in the chamber, followed by transportation of homogeneous hybridized magma, or outside of chamber, in which case this rock represents a intermediate hybridized replenishment into the chamber.

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