Petrogenesis of the Corea Rapakivi Pluton, Coastal Maine Magmatic Province

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Introduction

The Corea Rapakivi Granite (CRG) crops out over an estimated 20 kilometer area of the Coastal Maine Magmatic Province, a province of over 100 spatially associated felsic and mafic plutons emplaced from the late Silurian to the early Carboniferous. Gravity studies (Hodge, *et al*, 1982) and regional mapping (Wiebe, 1993) indicate that the granitic plutons are thin, sheet-like bodies with floors that dip shallowly to the south. This study characterizes the CRG, a coarse grained, A-type, granitic pluton well exposed in coastal outcrops. The rapakivi texture, which consists of potassic feldspars mantled by plagioclase, has been considered by some to be an indicator of interaction between mafic and felsic magmas. Consequently, formation of the rapakivi texture in the Corea pluton is of special interest to this study.

Field Relationships

The CRG is intruded (?) by the fine grained Gouldsboro Granite (GG), although thin metavolcanic septa often complicate the contacts. Detailed mapping of these contacts suggests that the CRG is older than the GG; small (0.5 meter) rounded inclusions of CRG in the GG are observed at one locality. Parallel to the northeastern (basal) CRG/GG contact a ten meter thick, sheet-like gabbroic body intrudes the CRG. The following field relationships suggest that the CRG was a plastic crystal mush at the time of gabbroic intrusion: 1) gabbroic pillows are suspended in the CRG 2) plastic dikes of CRG and gabbro cross cut one another 3) both types of dikes display irregular, cuspate edges. A hybrid zone is present near the contact. Spatial relations between the gabbroic pillows, the preferential accumulations of CRG feldspars on one side of CRG dikes, and the regional southerly dip provide evidence that the gabbroic unit intruded the base of the CRG chamber.

Crystal size increases towards the center of the CRG. The middle of the intrusion is massive and dominated by very coarse grained, euhedral crystals of alkali feldspar. Approximately 30% of the alkali feldspars are mantled by plagioclase in a rapakivi texture. This texture becomes less common towards the contacts. Both mafic and silicic enclaves (3 cm to several meters) occur throughout the pluton. These enclaves comprise less than 1% of the pluton, and are often elongate parallel to the pluton contacts. Mafic schlieren are also observed. They resemble trough bands and ladder dikes of the Sierran granites, and may result from convection within the pluton.

Petrography

The CRG is composed primarily (85-90%) of sub to euhedral phenocrysts of alkali feldspar and plagioclase, and equant quartz crystals. The alkali feldspars (0.5-3 cm) are often optically zoned, and the majority display mesoperthitic to perthitic textures. Mineral inclusions are common in the feldspar phenocrysts. Inclusions include (0.1-0.3 mm) anhedral "stringy" quartz, subhedral plagioclase, with occasional subhedral biotite, sphene, and hornblende. The quartz and plagioclase inclusions often increase in number toward the edges of the K-feldspar phenocrysts. Plagioclase rims occur as partial to complete borders on approximately 30% of the alkali feldspar crystals. The rimmed alkali feldspars are ovoid to subhedral, while unrimmed crystals display euhedral grain boundaries. The boundary between each K-feldspar crystal and its respective plagioclase mantle is irregular. Some crystals display a thin band of anhedral quartz inclusions between the alkali feldspar crystal and the mantle. The outer boundary of rapakivi crystals are commonly euhedral and composed of several optically continuous plagioclase laths. Plagioclase crystals occur as mantles, as a phenocryst phase, and as interstitial patches. Plagioclase phenocrysts range in size from 1-1.5 mm, are sub to euhedral, and often exhibit zoning. Some phenocrysts are mantled by an overgrowth of plagioclase, reminiscent of rapakivi texture. Interstitial plagioclase is smaller (0.2 mm), sub to euhedral, and devoid of inclusions. Quartz is both a phenocryst and an interstitial component. The quartz phenocrysts occur as round, polygranular patches (0.5-1 cm areas) which contain no inclusions. The interstitial quartz is subhedral and 0.2 mm in size. Patches of 0.2 mm quartz often occur with plagioclase as inclusions in alkali feldspar or between crystal boundaries.

Biotite, hornblende, sphene, and opaques are the predominant mafic minerals found in the CRG. The mafic minerals generally occur in patches between the quartz and feldspar phenocrysts or as inclusions in K-feldspar crystals. Biotite is subhedral, 0.25-3 mm, and contains inclusions of sphene, opaques, and rutile. A migration of K toward the basalt, and migration of Na and 2+ cations toward the rhyolite which balance the charge gradient (Johnston & Wyllie, 1988). A basaltic enclave found within a felsic blob demonstrates such an exchange; the basalt is greatly enriched in K2O, and the granite is depleted in K2O. Low-K and high-K felsic blobs occur in close proximity. In some instances, the Low-K and high-K blobs are in direct contact. Field relations from the Raven's Nest area (Figure 1) show that low-K blobs are located in the central section of the outcrop, while high-K blobs are on either side of them (Wiebe, per. comm.). If this zone represents magma eruptions out of the chamber, this distribution suggests that the low-K rocks may have originated deeper in the magma chamber.

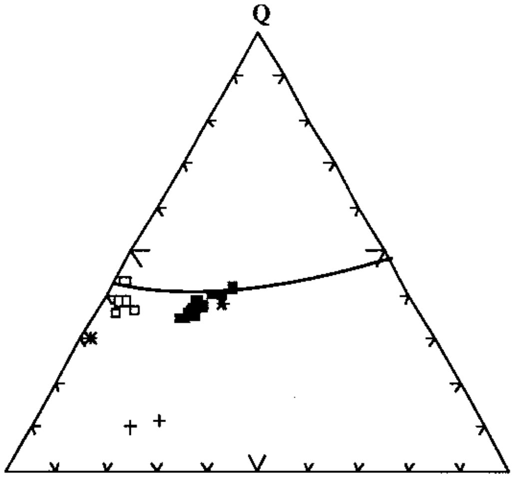

Figure 3. Granites, and silicic and intermediate dikes plotted on the O-Ab-Or-H2O ternary system. composition of granites and silicic dikes approach the 0.5 kbar isobar (Tuttle & Bowen, 1958). Symbols as in figure 2.

Granites that are depleted in K are mainly located in the Buck Cove area (intermediate blob composite area), but also exist in the more felsic composite areas. In the host granites, plagioclase and quartz are more pervasively resorbed than other areas of the pluton. Resorption may be due either to a release in pressure or reheating. Figure 3 shows that the granite compositions approach the 0.5 kbar isobar within the Q-Ab-Or-H2O system. Upward movement of the magma would move the liquid into the feldspar field if it were rising faster than the magma could equilibrate, and quartz would be resorbed. To this I attribute the resorption seen in the granites away from the composite areas. Within the composite areas, disequilibrium in the ternary system would not produce the increased resorption of the plagioclase and quartz. Reheating of the host granite is necessary.

References

Hodge, D.S., Abbey, D.A., Harbin, M.A., Patterson, J.L., Ring, M.J., and Sweeney, J.F., 1982. Gravity studies of subsurface mass distributions of granitic rocks in Maine and New Hampshire: American Journal of Science, v. 282, p. 1289- 1324.

Hogan, J.P., and Sinha, A.K., 1989. Compositional variation of plutonism in the coastal Maine magmatic province: mode of origin and tectonic setting: IN: Tucker, R.D. and Marvinney, R.G. (eds.), Studies of Maine Geology: Igneous and Metamorphic Geology. Maine Geological Survey, Department of Conservation, v. 4, p. 1-33.

Johnston, A.D., and Wyllie, P.J., 1988. Interaction of granitic and basic magmas: experimental observations on contamination processes at 10 kbar with H2O: Contributions to Mineralogy and Petrology, v. 98, p.352-362.

Tuttle, O.F., and Bowen, N.L., 1958, Origin of granite in light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geological Society of Ameria Memoir 74, 153 p.

Watson, E.B., and Jurewicz, S.R., 1984. Behavior of alkalies during diffusive interaction of granitic xenoliths with basaltic magma: Journal of Geology, v. 92, p. 121-131.

biotite strain texture is also observed in almost every sample. Sphene is sub to euhedral, 0.5-1.5 mm, and often intergrown with opaques. The opaques (0.5-1 mm) occur as inclusions in every mineral. Accessory minerals include zircon and apatite, while chlorite and epidote are common alteration products.

Inclusions of plagioclase, quartz, and mafic minerals in the rapakivi feldspars indicate that initially two feldspars, mafic minerals, and quartz were on the liquidus. Dissolution textures at the rapakivi mantle boundary suggest that a shift in magmatic conditions occurred, rendering K-feldspar unstable. The subsequent mantling of both K-feldspar and plagioclase crystals with plagioclase provides evidence that K-feldspar moved off the liquidus. Interstitial plagioclase, quartz, biotite, hornblende, sphene, and opaque oxides were the last phases to crystallize.

The Corea pluton contains 8 different types of fine grained enclaves, which were distinguished in the field by their appearance in handsample. In thin section all the enclaves appear to have the same mineralogy as the CRG, differing only in modal amounts and texture. Each enclave contains quartz, alkali feldspar, plagioclase, biotite, hornblende, sphene, and opaques. While all the enclaves are fine grained (0.1-1 mm minerals), several contain crystals of rapakivi feldspar (0.5-2 cm) which are presumably xenocrysts from the host CRG granite.

The gabbroic layer presumed to be the base of the magma chamber is composed primarily of 3 cm subhedral clinopyroxene oikocrysts and 0.5-6 mm sub to euhedral plagioclase laths. Plagioclase occurs as phenocrysts and as inclusions in the oikocrysts. The plagioclase crystals within the oikocrysts display coronae of amphibole. Other predominant mafic phases include 1-7 mm biotite with few to no inclusions, 0.5-2.5 mm circular opaques that are often enclosed by a rim of amphibole, and hornblende.

Geochemistry

Samples were collected and analyzed for major and minor elements by X-ray Fluorescence (XRF) at the University of Massachusetts. The rocks were coarse crushed with an iron mortar and pestle, and powered in a tungsten-carbide shatterbox. They were then pressed in duplicate into pellets for minor element analysis, and fused in duplicate with a lithium tetraboric flux for major element analysis. Five granite samples were prepared and sent to the University of Oregon for Neutron Activation Analysis (INAA).

All the CRG samples and 3 enclaves plot within the subalkaline field on a SiO_2 vs alkalis diagram. The other 3 enclaves and 2 of the rocks hypothesized to represent mafic liquids plot in the alkaline field. Normative QAP diagrams demonstrate that all the CRG samples and all but the three alkaline enclaves plot within the granite field. The alkaline enclaves and the mafic liquids plot within the granodiorite field. The CRG varies little in chemical composition; SiO_2 ranges from 68 to 77 percent. In contrast, the enclaves exhibit a wider silica range of 56 to 77 percent. Silica decreases toward the center of the pluton, while MgO increases. Harker plots of the CRG and enclaves reveal a strong negative correlation between Al_2O_3 and silica, and a negative correlation with silica for TiO_2, P_2O_5, MnO, Fe_2O_3, MgO, and CaO (fig. 1). Na_2O correlates negatively for the CRG and the enclaves, and positively for the mafic liquids. K_2O shows a positive correlation for all the samples. Plots of Zr/Nb and Ce/La as well show positive linear trends.

Trace elements plots normalized to 2 times chondrite display 100x chondrite concentrations in the incompatibles (fig. 2a). A REE plot shows a similar trend of 100x chondrite concentrations in the LREEs grading to 10x chondrite in the middle and HREEs (fig. 2b). Negative anomalies are observed for Ti, P, Eu, Nb, and Ta.

Discussion

Harker diagrams show tight linear trends for the CRG samples. The subalkaline enclaves, which fall within the same SiO2 range as the CRG (68-77% SiO_2), generally follow the CRG trends. This evidence suggests that the subalkaline enclaves are genetically related to the CRG. The alkaline enclaves fall just off the CRG trends, while the mafic rocks often show too poor a correlation with one another to establish a definitive trend.

Trace element chemistry of CRG samples shows similar slopes on trace element spider diagrams, and linear Zr/Nb and Ce/La trends. This suggests that the all the granites share the same history. The negative Eu and Sr anomalies implies plagioclase fractionation. The negative Nb and small negative Ta anomalies along with the coexistence of alkaline and subalkaline rocks are characteristic of arc signatures.

The spatial distribution of silica and MgO in the CRG is not consistent with a simple fractional crystallization model to explain the chemical variation. Silica tends to decrease, while magnesium tends to increase from the base of the chamber toward the center of the pluton. This is opposite the expected trend for fractional crystallization. The positive slope of the K_2O Harker diagram supports this conclusion. Fractional crystallization requires the systematic removal of K_2O and Na_2O to explain the simultaneous precipitation of two feldspars (petrographically indicated). Because chemical trends for the CRG are inconsistent with fractional crystallization, fractional crystallization cannot be used to explain all the observed variation. A positive K_2O slope combined with the observed negative Na_2O slope is consistent with the resorption of K-feldspar and subsequent plagioclase precipitation. This chemical model is supported petrologically by the rapakivi texture.

Chemical variation cannot be explained by a simple 2 component mixing model, as mafic liquids and 3 enclaves do not plot on an extension of the CRG trend. Future studies will attempt to categorize this pluton using multicomponent AFC and mixing models that consider physical and chemical conditions required to produce a rapakivi granite in the context of associated mafic and felsic magmas.

References Cited

Hodge, D.S., Abbey, D.A., Harbin, M. A., Patterson, J. L., Ring, M. J., and Sweeney, J. F., 1982, Gravity studies of subsurface mass distributions of granitic rocks in Maine and New Hampshire: Amer. Jour. Sci., v. 282, p. 1289-1324.

Wiebe, R. A., 1993, Basaltic injections into floored silicic magma chambers: EOS, v. 74, No. 1, p. 1-3.

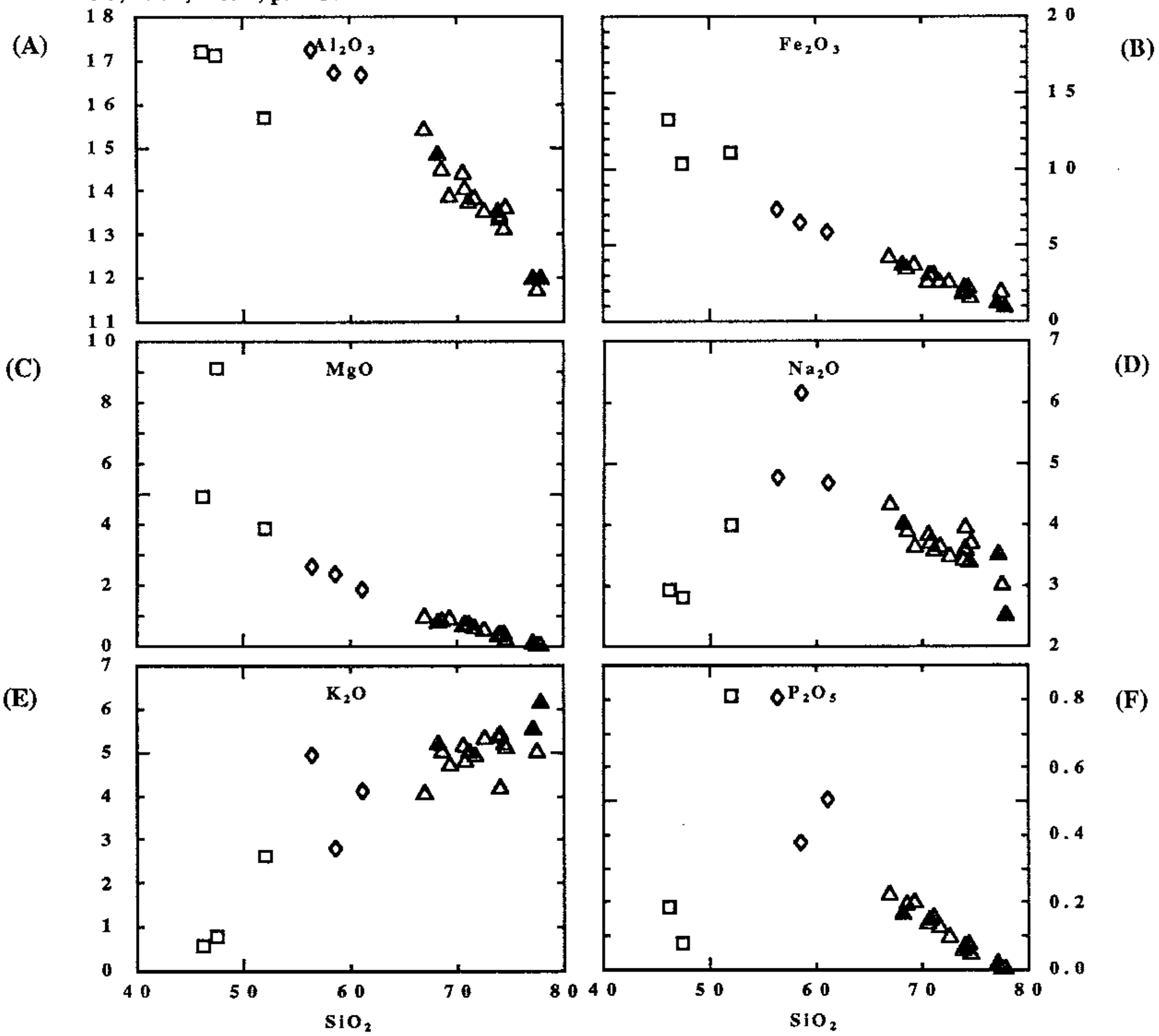

Figure 1 Harker diagrams. Open triangles - CRG, filled triangles - subalkaline enclaves, diamonds - alkaline enclaves, and squares - mafic liquids. CRG and subalkaline enclave samples follow tight trends; alkaline enclaves and mafic liquids do not fall on these trends.

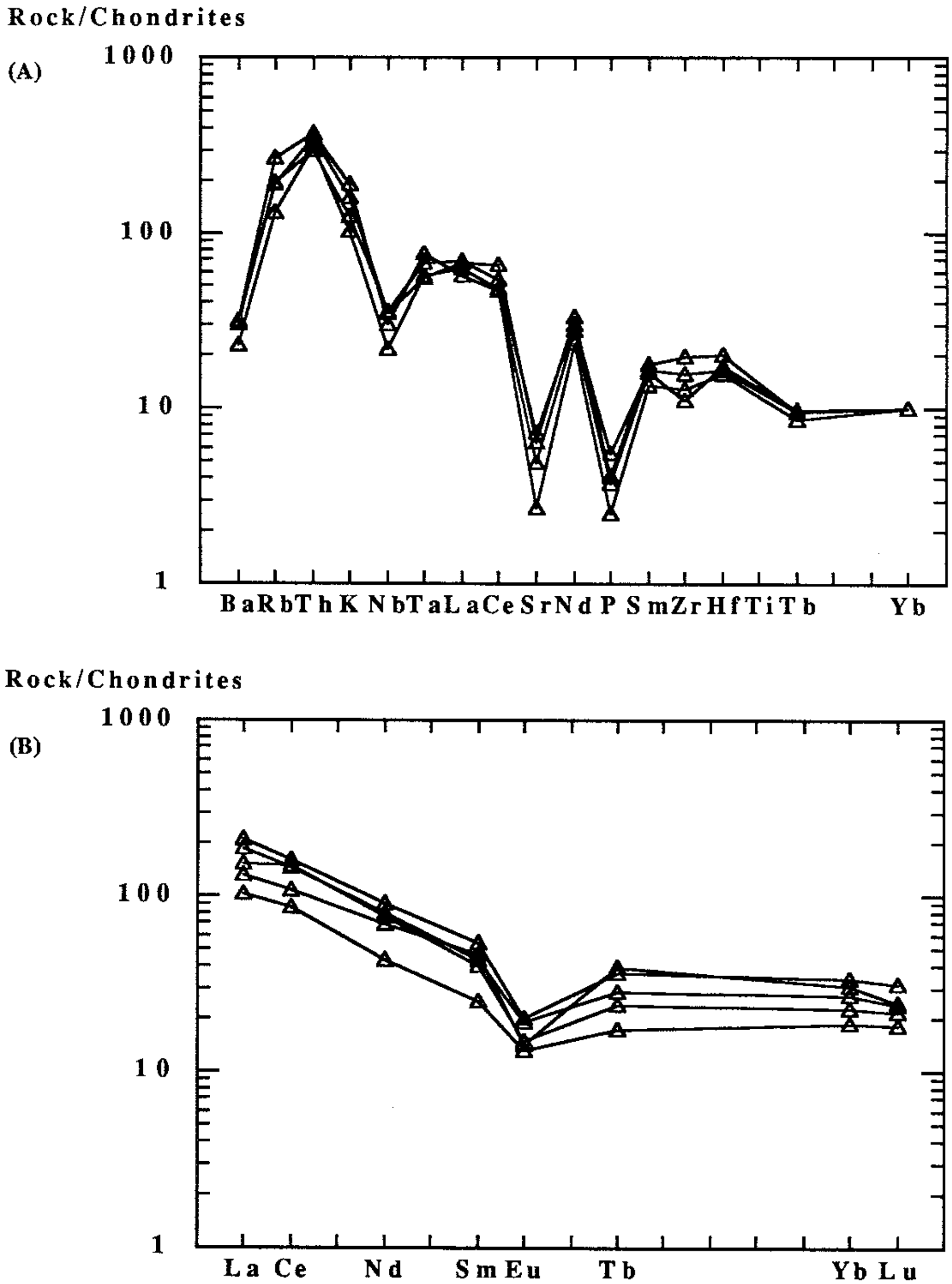

Figure 2 (A) Trace element spidergram (B) REE plot for selected CRG samples showing 100x - 10x chondrite concentrations. Negative anomalies for Ti, P, Eu, Nb, and Ta are observed.

Hybridization between Interleaved Sills of Mafic and Felsic Magmas
Pleasant Bay, Maine

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Introduction

The Pleasant Bay intrusion is located between Bar Harbor and Machias, Maine. Gravity data indicates a basin form (Biggi and Hodge, 1982) with dimensions of 12 km by 20 km and a maximum thickness of approximately 3 km. Open vugs suggest a shallow emplacement. The rock consists of 90% layered gabbro and mafic diorite that vary in grain size and texture. The other 10% can be found in the granitic pipes as silicic filter-pressed material. Bickford (1960) computed a minimum thickness of 15,000 feet of layered gabbro in the Pleasant Bay area. Within this layered gabbro are layers and lenses of medium-grained leucocratic diorite to granodiorite which contain gabbroic pillows and mafic inclusions. There also are layers and lenses of fine-grained gabbro which show chilled bottom margins (and occasionally also a chilled top margin). Basaltic dikes, prevalent in the granite surrounding the pluton, may be the source that fed the chilled replenishments.

In an area west of the central region of the Pleasant Bay intrusion, at the southwestern tip of Guard Point, there is a section where all the different rock types of the pluton are present. They can be subdivided into two macrorhythmic units with chilled gabbroic bases that grade upward to medium-grained gabbro, diorite, and highly silicic filter-pressed material. The top of each macrorhythmic unit is truncated by the chilled base of the overlying unit, a record of the infusion of basaltic magma into the magma chamber (Wiebe, 1993). The purpose of this project is to study the field relations and the petrographic and geochemical changes throughout a macrorhythmic unit in order to determine the mixing history of the Pleasant Bay intrusion.

Field Observations

At the southwestern tip of Guard Point, there is a nearly complete section of layered gabbro, beginning from the chilled gabbroic base to coarse gabbro to granodiortie and the contact with the next chill. At the chilled contact there are sunken lobes comparable to sedimentary load cast structures, as well as chilled pillows and the upward flares of granitic mush, due to turbulent interactions with the overlying mafic material. Along the edge of the bay, especially concentrated at the western edge of Guard Point, there are numerous exposures of granitic pipes. The layered gabbro continues in the second macrorhythmic unit, located across a small bay, but for the first 100 meters or so, the layering is complicated by multiple basaltic injections. Many exposures of granitic pipes are also found at the top of the second macrorhythmic unit.

Methods

Samples were taken at measured locations according to changes in mineralogy and texture seen in the hand samples in the field. In the second macrorhythmic unit, the layering was complicated by basaltic injections. As a result, the only samples used for thin sections and geochemical analyses were collected after the gradation was more homogenous. Thin sections were made from twenty-six samples altogether: fourteen from the first unit, eight from the second unit, and four from the area of granitic pipe exposures. Twenty-three of these samples, from both units, were prepared and analyzed for major and trace elements using X-ray fluorescence at the facilities at the Department of Geology and Geography at the University of Massachusetts, Amherst. Five samples from the first unit were selected for INAA analysis and were sent to the Radiation Center at Oregon State University.

Petrography

The mineralogy of the hand samples for the basaltic rocks appear fairly uniform. The most noticeable change is that the minerals become more coarse-grained up-section. In thin section, the chilled basalt is very fine-grained, and consists of mostly plagioclase, with quartz, hornblende, biotite, and opaques. The mineralogy of the basaltic pillow is similar to the mineralogy of the chill at the base of the unit. Moving up-section, another compositional change in the mineralogy shows the increasing presence of biotite.