Origin & Evolution of Magma in the Gouldsboro Granite, Schoodic Peninsula, Maine

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Introduction

The Gouldsboro granite is located on the Schoodic Peninsula (Figure 1) within the coastal Maine magmatic province. This study focuses on the origin and significance of zones of chilled felsic and intermediate inclusions found within a southern portion of the granite. These inclusions range in diameter from several 10's of centimeters to 2 meters. They are fine-grained with rounded to crenulate boundaries which suggest they represent chilled liquids that were quenched within the cooler granite crystal mush. Because of their large and very irregular shapes, these inclusions will be termed blobs to distinguish them from the smaller, widely distributed mafic enclaves in the pluton.

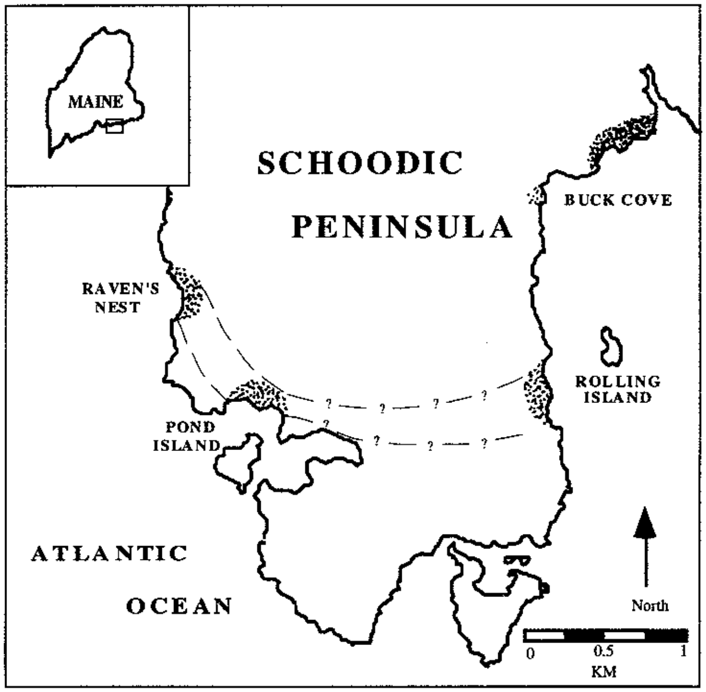

Figure 1. Map of the Schoodic Peninsula. Outcrops of composite areas are shown. Areas in which felsic blobs crop out are light gray. The dark gray area is comprised of the intermediate blobs.

Geologic setting

The coastal Maine magmatic province cocsists of over 100 plutons which intruded into metasedimentary and metavolcanic rocks of the Avalon terrane (Hogan & Sinha, 1989, West et al., 1992). Accretion of terranes onto Avalon occurred during early Silurian time and was accompanied by deformation and metamorphism (West et al., 1992). During or following the collision, the tectonic setting switched to an extensional regime, and bimodal plutonism began. The plutons appear to have been emplaced in the metamorphic terranes along transcurrent faults of a transtensional fault zone (Hogan & Sinha, 1989).

Field relations

The Gouldsboro granite is a thin, sheet-like pluton approximately 0.8 km thick (Hodge et al., 1982). The pluton is dominantly a massive, two-feldspar granite containing miarolitic cavities. Scarce mafic enclaves are distributed throughout the granite. Many basaltic and silicic dikes cut the granite. Basaltic dikes range in thickness from less than 1 meter to more than 30 meters, and typically trend N-S to N30°E. Silicic dikes range in thickness from 10 cm to 5 meters, and parallel the trends of the basaltic dikes.

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Of particular interest to the study are distinct zones of felsic and intermediate blobs located within the granite (figure 1). Composite areas of granite and felsic blobs outcrop at Raven's nest, and near Pond Island and Rolling Island. The felsic blobs are up to 2 meters in diameter, with rounded, crenulate boundaries and compose approximately 5-15% of the outcrop area. The intermediate blobs are elongate and sheet-like, up to 2.5 meters long, and comprise up to 30% of the outcrop area.

Petrography

The Gouldsboro pluton is a fine- to medium-grained, hornblende-granite, dominated by a granophyric texture. Primary minerals include quartz (35-45 modal %), plagioclase (10-20%), alkali feldspar (30-35%), horneblende (1-5%), traces of biotite, zircon, titanite, and opaque minerals. Quartz typically occurs as euhedral to subhedral crystals up to 3 mm in size, and also occurs interstitially and in the granophyre. Plagioclase occurs as euhedral to subhedral crystals up to 3 mm in size. Both quartz and plagioclase commonly show evidence of partial resorption. Perthitic alkali feldspar occurs interstitially and in the granophyre. In the granophyre the alkali feldspar is mesoperthitic. Primary hornblende occurs as small scattered subhedral crystals. Secondary (subsolidus) minerals include hornblende or actinolite (including pseudomorphs of clinopyroxene), and minor epidote, albite, biotite, and stilpnomelane. Secondary hornblende occurs in clusters of anhedral crystals with opaque minerals, zircon and titanite, and as minor pseudomorphs of clinopyroxene.

The felsic blobs (Pond Island group) are fine-grained, amygdaloidal silicic rocks. Spherical amygdules comprise approximately 3-10% of the blobs. Euhedral feldspar crystals project into the amygdules and the amygdules are commonly filled by quartz and minor calcite. Primary minerals include euhedral plagioclase (20%), interstitial quartz (25%), hornblende (25%), and opaque minerals. Secondary minerals include hornblende or actinolite and opaque minerals. Quartz xenocrysts and granitic xenoliths are common in the blobs. Plagioclase and quartz are partially resorbed.

The intermediate blobs (Buck Cove) are fine-grained, amygdaloidal intermediate rocks. Spherical amygdules comprise approximately 5-15% of the blobs, and are concentrated in the center, away from chilled margins. Actinolite and epidote commonly fill them. Primary minerals include subhedral to anhedral plagioclase (45%), interstitial quartz, anhedral hornblende (35-45%), biotite (1-5%), opaque minerals(3-5%) and titanite (trace). Secondary minerals include hornblende or actinolite and minor epidote. Xenocrysts of quartz and feldspar occur in the blobs. Plagioclase is commonly dusty and altered to albite, and occurs as small euhedral phenocrysts and anhedral crystals in the groundmass. Primary hornblende occurs as small euhedral phenocrysts. Secondary hornblende/actinolite occurs as anhedral crystals in the groundmass, and as clinopyroxene pseudomorphs.

Geochemistry

34 rocks from the Gouldsboro pluton were analyzed for major and trace elements. Major elements plus Rb, Sr, Y, Zr, Nb, Ni, Ga, Cu, Zn, U, Th, V, and Cr were determined using X-ray fluorescence. All other trace elements were measured with an inductively coupled plasma spectrometer. In addition, analyses of 32 rocks collected from the same area by R. A. Wiebe were added to the data to complement my data set.

Samples of the Gouldsboro granite range in composition from 72% to 78% SiO2. Most elements show tight trends when plotted against Si02. Figure 2 shows Al2O3 plotted against SiO2. CaO, Fe2O3, MgO, and TiO2 show similar trends. Incompatible elements are enriched as SiO2 increases, consistent with fractionation of a plagioclase and a mafic mineral. There are, however, major differences in the alkali elements. Some granites are depleted in K2O, Ba, and Rb, and show a distinct separation from those granites with normal K2O levels. These granites primarily occur near the intermediate blobs, but also occur to a limited extent with the felsic blobs. Fractional crystallization does not appear to be a possible mechanism to generate such a separation.

SiO2 compositions of the felsic blobs range from about 64% to 71%. They are trachytic to trachydacitic in composition, based on K2O+Na2O vs. SiO2 (Le Bas et al., 1986). The blobs, like the granites, tend to plot as a single group, except for the alkalies, where they plot as two distinct groups (figure 2). One group normal K2O (referred to as high-K) levels, ranging from 2-3%. The other is depleted in K2O (low-K) and Ba, and range in composition from 0.3-1.2% K2O.

Intermediate blobs range in composition from about 54-60% SiO2. They are trachyandesites to basaltic andesites in composition (Le Bas et al., 1986). Trends are fairly coherent for most major elements (figure 2). Alkalies show a wider scatter, but no distinct separation.

Dikes range from basaltic to rhyolitic in composition. Basaltic dikes range from about 44-53% SiO2. For most elements, the dikes show a wide scatter (figure 2). Also plotted with the dikes are two enclaves of basalt found in the felsic blobs, which are mildly to greatly enriched in K2O.

Intermediate dikes contain 55-56% SiO2. They are basaltic andesites in composition (Le Bas et al., 1986). These dikes plot fairly consistently with the intermediate blobs for most major elements, but show a wider scatter in some trace elements.

Felsic dikes range in SiO2 from 70-73%. They are dacitic to rhyolitic in composition (Le Bas et al., 1986). The dikes show tight trends for most elements, and plot consistently with the granites (figure 2). The alkalies show a distinct separation which mimics that of the granites, with dikes that are normal in K2O composition, and those that are depleted.

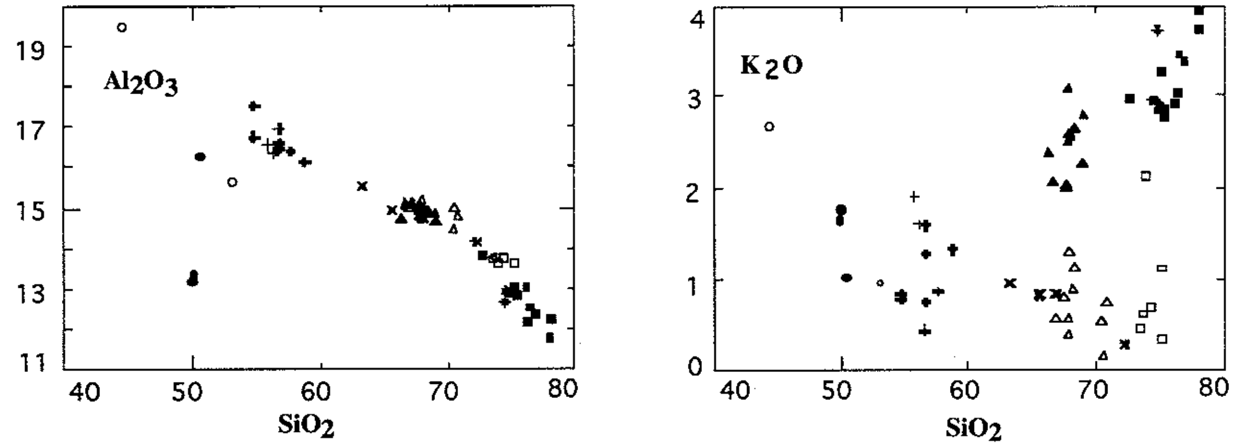

Figure 2. Weight percent Al2O3 and K2O versus SiO2. Closed squares are high-K granites. Open squares are low-K granites. Asterix are silicic dikes. Thin crosses are intermediate dikes. Closed circles are basaltic dikes. Open circles are basaltic inclusions within felsic blobs. Bold crosses are intermediate blobs. X's are felsic blobs found are Buck Cove. Closed triangles are high-K blobs. Open triangles are low-K blobs.

Evidence for contemporaneous liquid compositions

Field relations suggest that the granite was at least part liquid, when it commingled with intermediate and felsic liquids within the magma chamber. Aphyric dikes cut the granite in several places and are compositionally indistinguishable from the granite, suggesting that the dikes and the granite compositionally equivalent liquids. The blobs are extremely fine-grained, with few phenocrysts, and clearly were a liquid when they were quenched.

There is good evidence which suggests that the intermediate and felsic magmas were available over a wide area. Intermediate dikes, whose compositions mimic that of the intermediate blobs, sharply intrude the Pond Island composite area where felsic blobs outcrop (figure 1). Furthermore, felsic blobs crop out in close proximity to the intermediate blobs at Buck Cove, approximately 3 km away from the main concentration of felsic blob outcrops.

Origin of compositional variation in the granite

The compositional variation shown by the granite in most of the SiO2 versus oxide plots suggests that fractional crystallization operated within the magma chamber (figure 2). Compositional variation may largely be explained by fractional crystallization of plagioclase and clinopyroxene, the primary phenocrystic phases. This fractionation appears to be responsible for the depletion of Ca and Mg, and the enrichment of incompatible elements in the residual liquid.

Trends of the alkalies are not consistent with fractional crystallization. Alkali exchange appears to be a viable process to explain the distinct groups of low-K and high-K rocks. According to Watson (1982), and Johnston and Wyllie (1988), diffusivity coefficients of the alkalies are an order of magnitude higher than other elements, allowing for greater mobility within magma. If alkali exchange is a possible mechanism, it is necessary to resolve between which liquids the exchange occurs. Commingling of the felsic and basaltic magmas may be the source of alkali exchange. Mafic magmas commingle with the host granite and the intermediate blobs in the Buck Cove area. Basaltic enclaves are also found within felsic blobs at the Raven's Nest area. Furthermore, the Gouldsboro granite is underlain by a sill of gabbro (Hodge et al., 1982) which could provide the source of basalts within the composite zones, as well as other basaltic dikes of the pluton. The interaction of basaltic and acidic melts results in the 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.

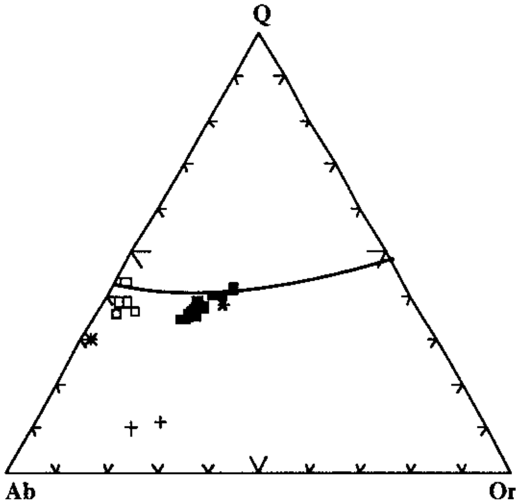

Figure 3. Granites, and silicic and intermediate dikes plotted on the O-Ab-Or-H2O ternary system. composition of granites and silicic dikes approach the 0.5 kbar isobar (Tuttle & Bowen, 1958). Symbols as in figure 2.

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.

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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