PETROLOGY AND GEOCHEMISTRY OF THE GOULDSBORO GRANITE, GOULDSBORO POINT AND DYER NECK, MAINE

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Introduction

The area encompassing the eastern Maine coast from Penobscot Bay to Passamaquoddy is known as the coastal Maine magmatic province. The geology of this area is dominated by the intrusion of many mafic and felsic plutons, ranging in age from Late Silurian to Early Carboniferous (Hogan and Sinha, 1989). For the most part, many of these plutons have not been studied in any detail. The Gouldsboro granite, a granitic body exposed in coastal outcrop from Schoodic Point east to Petit Manan Point, is one such pluton.

The aim of this project is to characterize the Gouldsboro granite (GG) in detail from the field relations, petrography and geochemistry of the rocks. The data and observations are used to constrain the timing of emplacement of the magma relative to adjacent magma batches, to document any physical and/or compositional gradients that may have existed in the magma chamber, and to evaluate the importance of various processes (e.g., fractional crystallization, magma mingling/mixing) that might have affected the magma.

Field Relations

The GG's exposed area is approximately 360 km^2 and the pluton apparently dips to the southeast. Field work focused on exposures on Gouldsboro Point and Dyer Neck studied in a series of coastal traverses that moved from the upper (southern) to lower (northern) margins of the pluton (Fig. 1). The GG is in contact with a coarse grained rapakivi granite along its upper margin. The rapakivi granite was previously mapped as GG (Osberg et al., 1985), but is clearly a separate pluton and the focus of another Keck project (see Cunningham, this volume). Inclusions of the rapakivi granite are found in the GG at the contact on Dyer Neck suggesting the intrusive, and therefore younger, nature of the GG into the rapakivi. The inclusions have crenulate contacts with host GG as do contacts between these two plutons on Dyer Neck, suggesting that the two magmas were above their solidii when they came into contact with one another. However, the contact on Gouldsboro Point shows a zone of sugary, fine-grained GG in sharp contact with the rapakivi granite, indicating quenching of the GG against relatively cold rapakivi granite at that locality. On its lower margin, the GG has been mapped (Osberg et al., 1985) as being in contact with the Stueben Granite. Field study did not extend to this contact, but the GG was observed in contact with a metabasalt in some localities just south of the mapped GG-Stueben contact (Fig. 1). The contact is not sharp but is a "mixed" zone of metabasalt and GG with metabasaltic xenoliths.

The GG is typically a medium-grained, equigranular, pink granite containing alkali feldspar, plagioclase and quartz. Ferromagnesian minerals include biotite and hornblende and the color index in the granite is consistently low (5-15). Although the mineralogical character of the GG is relatively constant throughout the exposures studied, there is a slight coarsening trend from the upper margin inwards. This is especially true of the quenched margin on Gouldsboro Point between the GG and the rapakivi granite, where the GG is fine-grained with plentiful vugs. Within 10 m of the chilled margin, the rock coarsens to 5 mm (average grain size) and varies little within the rest of the pluton. Other features include basaltic and composite dikes present in most exposures. On Dyer Neck, the GG appears to be intruded and mingled with mafic and silicic magmas or mixed magmas in several locations. Dark, "salt-and-pepper" enclaves with crenulate boundaries are present throughout the GG and range from 3 to 30 cm in diameter.

Petrography

Twenty-five thin sections representative of the various field occurrences of the GG were examined. The GG is massive, generally medium-grained (1-5 mm) and hypidiomorphic. Dominant minerals are quartz, plagioclase and alkali feldspar. Plagioclase and perthitic alkali feldspar occur as euhedral to subhedral crystals and quartz forms anhedral to subhedral crystals. Ubiquitous biotite is a green variety, generally very altered, and occurs as anhedral crystals ~5 mm in size. Scarce amphibole is present in some samples and is generally very altered. Amphibole occurs as a brown variety, crystals are subhedral and ~3 to 5 mm in size. Accessory minerals include zircon and opaque minerals, and alteration products include epidote.

At the contact with the rapakivi granite on Gouldsboro Point, the GG differs from most other exposures in that it exhibits slightly coarser (up to 7 mm) grains of anhedral quartz, as well as grains of quartz and plagioclase (5 to 7 mm) which exhibit embayed margins and resorption textures. GG at the contact with the metabasalt contains euhedral plagioclase crystals ~3 to 5 mm in diameter which are zoned and exhibit embayed margins.

Most GG samples away from contacts contain plagioclase as euhedral and often strongly zoned crystals. Micrograncophyric texture involving alkali feldspar and quartz is present in many samples. In some cases it is interstitial between discrete grains of quartz and alkali feldspar, and in others, microgranophyric coronas form a "sunburst" pattern around zoned plagioclase crystals.

Whole-Rock Chemistry

25 representative GG samples were analyzed for major and trace elements using XRF and ICP-AES methods. The results define two groups: one of samples with silica contents >74 wt % and the other with samples of silica contents between ~70.5 and 73 wt %. All samples in the low-silica group are from zones of mixing/mingling or assimilation of country rock, but contaminating material was avoided in preparing samples for chemistry.

Major Element Chemistry

The majority of the samples are peraluminous granites, although some plot as trondhjemite (after Barker, 1979). Harker diagrams (Fig. 2) show different trends in CaO and Al_2O_3 vs. SiO_2 for the low- and high-silica groups. Within the entire suite, $Fe_2O_3^T$, MnO and TiO_2 (not shown) generally decrease with increasing SiO_2, but MgO, Na_2O, and K_2O exhibit less distinct trends. CIPW normative Q-Ab-Or plots show that the GG samples do not lie along the granite minimum or cotectic, but rather are shifted towards the Ab field (Fig. 3).

Trace Element Chemistry

For the GG suite, Rb, U, and Th increase and Sc and Ni decrease with increasing silica. However, V, Ba, Zn, Ga, Cu, Be, Y, Zr, Nb, Ce and Yb show no clear trends with silica, instead, considerable scatter is observed. Multi-element diagrams (Fig. 4) exhibit overlap in element concentration between the low- and high-silica groups. Fairly wide ranges in Nb, Ce, Zr, Y and Yb contents within the entire suite do not correlate with field location nor silica content.

The GG plots in the VAG and WPG fields on tectonic discrimination plots (Fig. 5) of Pearce et al. (1984). Discrimination diagrams for A- vs. I-/S-type granites (Whalen et al., 1987) show most GG samples to be I-/S-type with a few samples reaching into the A-type field (Fig. 6). Most of these latter samples occur near the quenched margin between the GG and rapakivi granite on Gouldsboro Point.

Discussion

The GG appears to be the youngest pluton in the area encompassed by field study on this project. The crenulate contacts on Dyer Neck with rapakivi granite imply that the two plutons are probably very close in age. However, the quenched margin on Gouldsboro Point and inclusions of rapakivi granite in the GG suggest that the GG is the intrusive and therefore younger of the two plutons. The contact with metabasalt is obviously intrusive although the size and orientation of the metabasalt, as well as its relationship to other plutons, is not clear.

Overall, the pluton appears fairly homogenous in terms of mineralogy, structure and texture as observed in the field. The only variation was coarsening away from the quenched zone at the sharp contact on Gouldsboro Point between the GG and the rapakivi granite. However, this transition is fairly small scale. Major element and trace element abundances show no correlation to stratigraphic position from the upper to lower margin, nor laterally across the pluton.

Petrographic analyses reveal that the micrographophyric texture is absent at the margins, but is present in most samples located away from contacts. Microgranophyric texture indicates a rapid and simultaneous cooling period of alkali feldspar and quartz (Hibbard, 1995). The absence of microgranophyric texture or difference in its character from one locality to the next may be due to changes in cooling patterns within the pluton. The texture forms interstitially or as coronas around crystals with zoned or resorption textures, indicating that it was the product of final quenching of remaining melt during solidification of the GG.

Major element contents within the high-silica group are broadly consistent with ~15% crystallization of plagioclase + amphibole (Fig. 2). However, Na_2O contents do not fit this fractionation model; some other process(es) may have modified Na_2O contents (see below). Sr is consistent with ~10% plagioclase fractionation, however the wide scatter in most other trace elements vs. silica cannot be explained by either plagioclase (± amphibole) fractionation. In particular, the abundances of Ce, Yb, Y, Nb and Zr may be controlled by fractionation of accessory minerals (e.g., zircon, iron oxides, etc.).

The plagioclase + amphibole fractionation model does not explain CaO and Al_2O_3 trends in the low-silica group. This group consists of only four samples located near zones of mixing/assimilation, and hybridization processes may be responsible for this group's characteristics. However, the contaminating material was not sampled and mafic end member chemistry is unknown, making magma mixing processes difficult to model.

The shift into the Ab field (Fig. 3) of the GG suite may be explained by plagioclase accumulation. An alternative explanation for the relative enrichment of Na_2O may be source rock composition. Yet another explanation may be selective diffusion processes. Wiebe (1993) has suggested that a double diffusive boundary may form in some magma chambers between a mafic magma and an overlying silicic magma. Alkalis may be exchanged across this boundary with movement of Na_2O into the silicic melt and movement of K_2O into the mafic melt. However, there is no field evidence to suggest the existence of this boundary nor is there field evidence for underlying mafic magma.

Comparison of the GG and other granites of the Cadillac Mountain intrusive suite (Wiebe et al., 1994) shows that the GG is geochemically similar to the Southwest Harbor (SHG). The SHG is also a fine to medium-grained, two-feldspar, biotite ± hornblende, peraluminous granite. Major element variations in SHG resemble those of the GG and most samples from both the GG and SHG plot as I-/S-type granites (Fig. 6) and between the VAG and WPG fields (Fig. 5). Other granites from the Cadillac Mountain suite (the Somesville and Pretty Marsh granites) are also geochemically similar to the GG. However, the Cadillac Mountain Granite differs from the GG in that it exhibits A-type characteristics (Figs. 5 and 6) and abundant field evidence for interaction with mafic magma(s).

Conclusions

Field relationships demonstrate the intrusive and fairly homogenous petrologic nature of the GG. Small scale and/or subtle textural variations (e.g. chilled margins, change in character of microgranophyric texture) exist within the pluton. Major element chemistry defines two groups based on silica content. Compositional variations among samples in the high-silica group can by explained by plagioclase + amphibole ± accessory mineral fractionation. In contrast, the low-silica group may have been affected by contamination (and/or other) processes. The GG is most similar to the SHG, Somesville and Pretty Marsh granites in the Maine magmatic province, thus probably has a similar petrogenesis.

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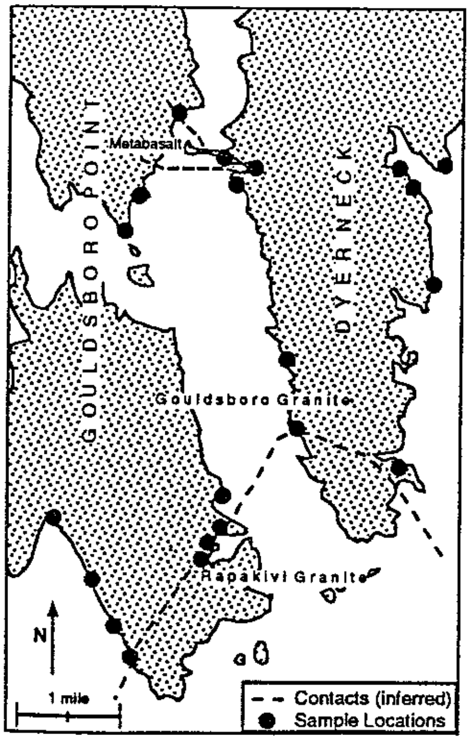

Figure 1. Map of Gouldsboro Point and Dyer Neck, Maine (after Osberg et al., 1985).

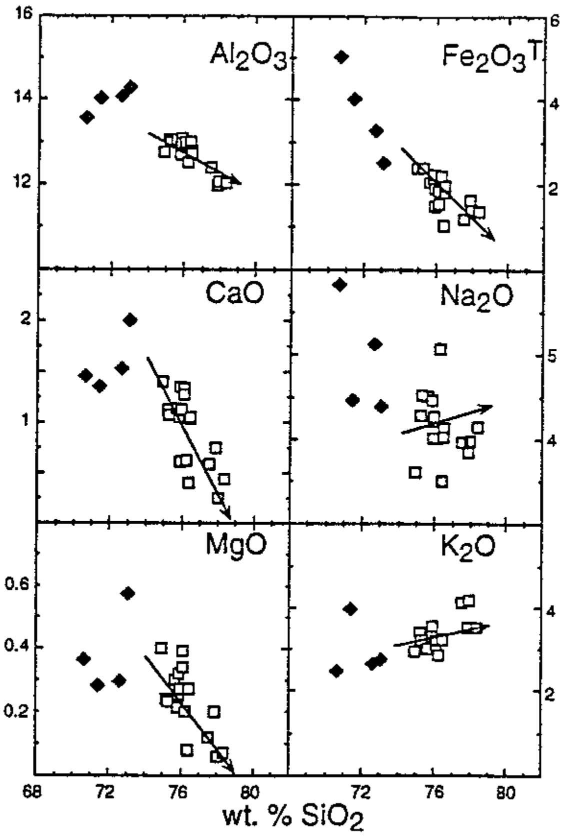

Figure 2. Major oxides (in wt. %) vs. silica. Open squares = high-silica group; filled diamonds = low-silica group. Vectors represent 15% crystallization of plag + amph (50:50).

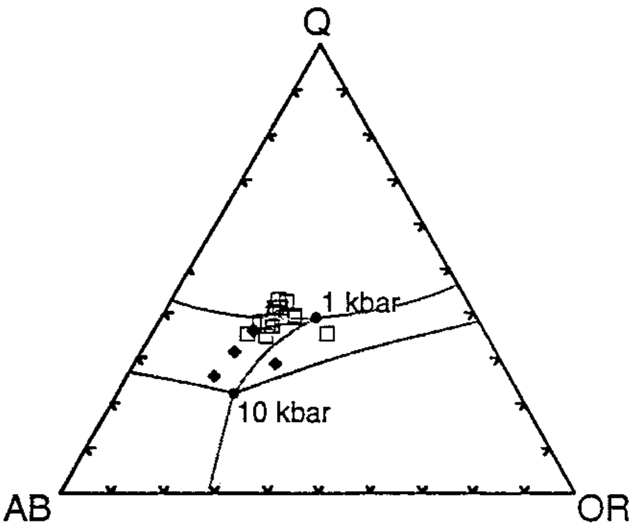

Figure 3. CIPW normative Q-Ab-Or for GG samples (symbols as in Fig. 2). The granite minimum and cotectics for $P_{total}=P_{H_2O}=1$ to 10 kbar are also shown.

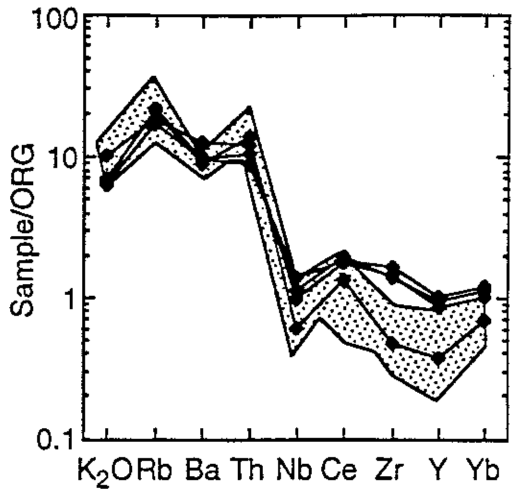

Figure 4. Ocean ridge granite (ORG; Pearce et al., 1984) normalized patterns for GG low-silica (filled diamonds) and high-silica (shaded field) samples.

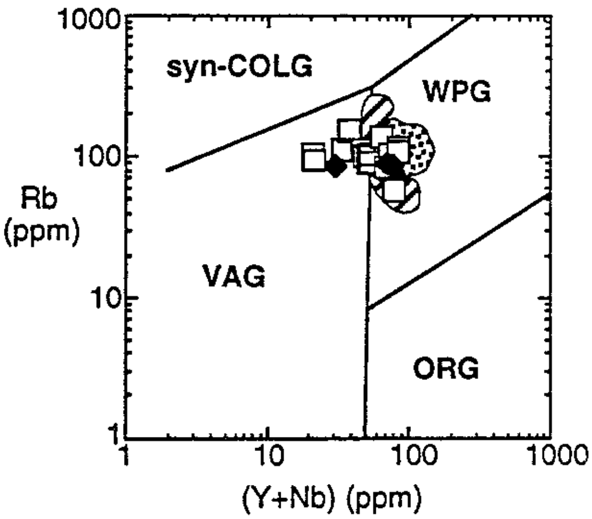

Figure 5. Tectonic discrimination diagram Rb vs. (Y+Nb) showing various granite types (Pearce et al., 1984). Symbols as in Fig. 2; ruled field = SHG, Somesville and Pretty Marsh granites; dotted field = Cadillac Mountain Granite.

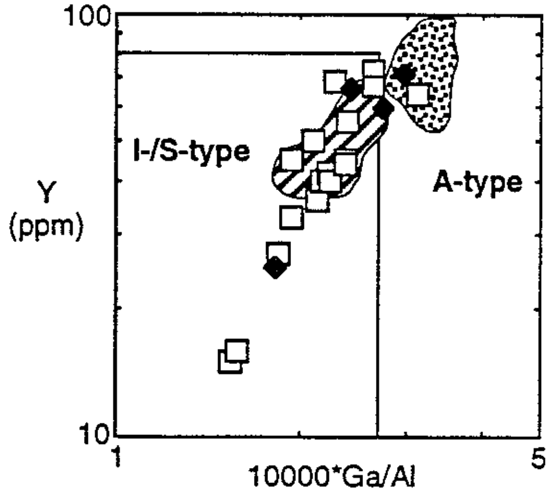

Figure 6. Discrimination diagram Y vs. 10000*Ga/Al showing I-/S-type and A-type granites (Whalen et al., 1987). Symbols and fields as in Fig. 5.