

# Petrography and petrogenesis of metamorphic blocks at the base of a granitic pluton, Vinalhaven Island, southeastern Maine

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## INTRODUCTION

The Penobscot Bay region of Maine has been interpreted as a series of tectonostratigraphic terranes that were amalgamated to ancestral North America during the Devonian Acadian Orogeny (Stewart et al., 1995). Vinalhaven Island lies within one of these terranes, the Ellsworth Terrane, a peri-Gondwanan terrane which formed in the late Cambrian to early Ordovician. The Ellsworth Schist, which does not outcrop on Vinalhaven Island but comprises much of the Ellsworth Terrane, has been subjected to multiple deformational events and greenschist facies metamorphism (Stewart and Flohr, 1996). Stewart and others (1995) note that Devonian deformation and high-grade metamorphism is weak or absent in the Ellsworth Terrane, which is a distinguishing feature when compared to terranes further west. The lack of Devonian deformation and metamorphism here allows the pre-Silurian and Silurian history of the rocks to be observed, including deformation and metamorphism that occurred within the Silurian orogenic belt that existed along margin of Gondwana prior to the Acadian Orogeny.

The majority of Vinalhaven Island is occupied by a  $361 \pm 7$  Ma Devonian granitic pluton which intruded into volcanic and metamorphic country rocks during the final stages of the Acadian Orogeny (Mitchell and Rhodes, 1989). The northwest portion of the island contains a suite of bimodal volcanic rocks of probable Silurian age, believed to be contemporaneous with the Vinalhaven Granite. In the northeast there is regionally metamorphosed rock of pre-Silurian age, referred to as the Calderwood Formation. At the south end of the island there is a layer of gabbro present which marks the accumulation of basaltic magma which was injected and settled into the still-molten bottom of the pluton. Blocks of country rock also fell into the magma chamber while it was active, all of which are now found with the gabbro at the base of the pluton. I focused my research on blocks of this country rock at three separate locations: Bob Meadow Point, Round Neck and Clayter's Beach (Fig. 1).

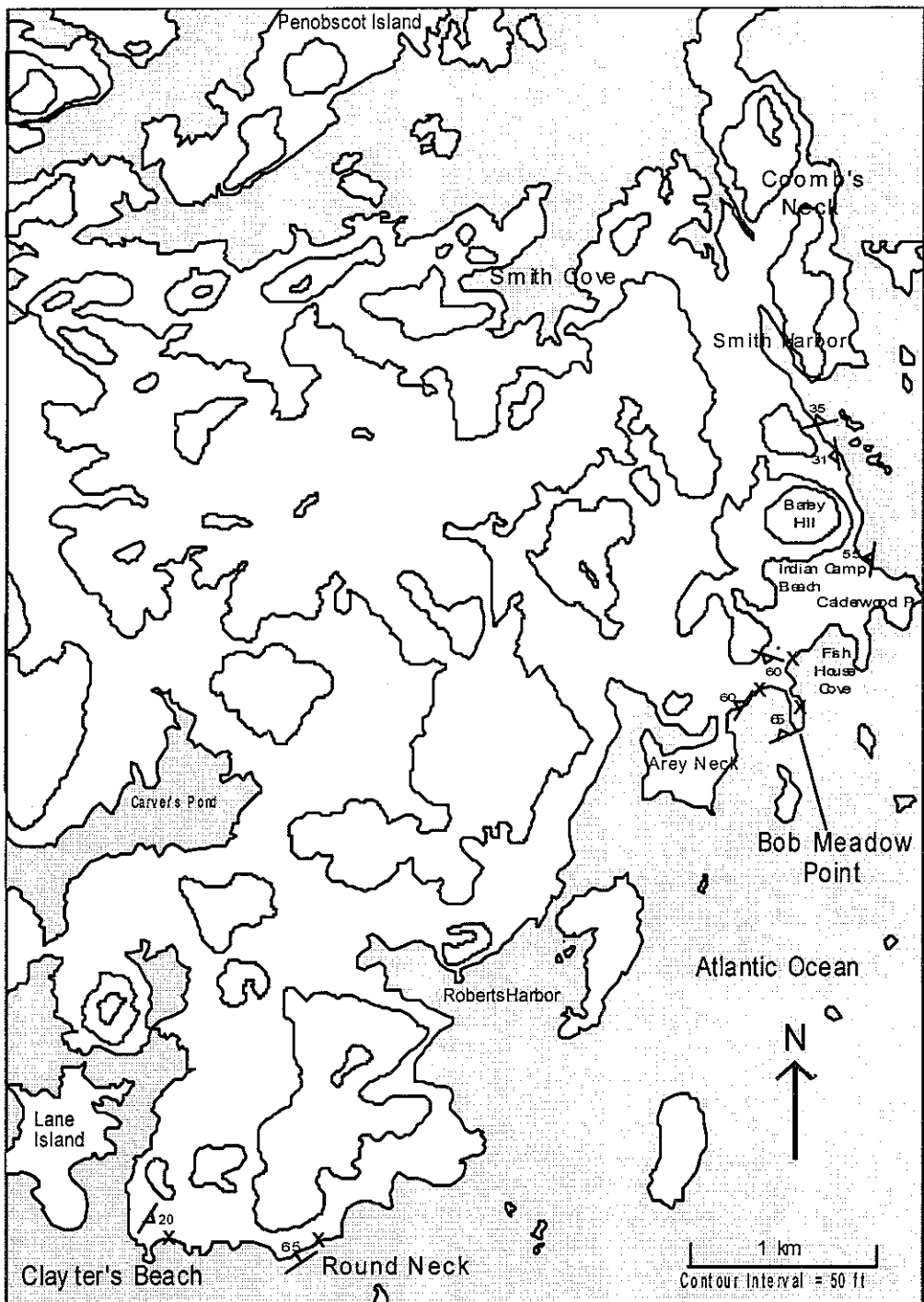
The purpose of my study was first to describe the contact relationship between the metamorphic blocks and the surrounding plutonic rocks. My next objective was to characterize the selected metamorphic blocks, including the size of the blocks themselves, the thickness and nature of the units comprising the blocks, and the relationship between units. Based on petrography, I have attempted to construct a metamorphic history for each block, explaining the depositional environment and tectonic setting for the protolith, as well as deformational and metamorphic events that affected them. The final purpose was to investigate the origin of these blocks by comparing the rock types to the volcanic package and the Calderwood Formation which represent country rock to the Vinalhaven Granite.

## FIELD RELATIONSHIPS

Contact relationships and rock types are illustrated in Figure 2. Where exposed, the metamorphic blocks are in contact with coarse-grained granite and/or porphyritic granite. Flow alignment of the phenocrysts is common at the contact. Both types of granite contain angular mafic enclaves and smaller pieces of metamorphic rock. Medium-grained gabbro is then in contact with the granite(s), approximately 5 to 20 meters away from the metamorphic block. Mafic dikes intrude the gabbro, but are crosscut by the granites. The gabbro and the metamorphic blocks often contain a network of granitic dikes or veins, derived from the neighboring granite.

The three metamorphic blocks have distinct petrographic and structural differences. The block exposed at Bob Meadow Point is the largest block of country rock found within the pluton (approximately 2 km x 0.5 km; as mapped by Olcott Gates, unpublished). It is composed of interlayered quartzose gneiss, kyanite-bearing biotite gneiss, and an intermediate gneiss, as well as mafic dikes which nearly parallel foliation. The thickness of individual layers ranges from 3 cm to 24 m. Shear within the block is concentrated in the biotite gneiss layers because it deforms more ductily than does the quartzose gneiss. Tight fold hinges belonging to an F1 event are also observable at this location, which may account for differences in the orientation of foliation between outcrops. Bob Meadow Point is the most southerly exposure of this particular block, but it also outcrops at Smith Harbor and Smith Cove (Fig. 1). At Round Neck there are four blocks of country rock exposed which range in size from 4m x

8m to 10m x 25m. Three of these blocks belong to the same sequence of contact metamorphosed sedimentary units, ranging in thickness from 0.4 m to 9.2 m. The fourth block at Round Neck is a biotite schist that appears unrelated to the other three blocks because it has experienced regional metamorphism. Clayter's Beach contains only one metamorphic block, containing a single unit of psammitic gneiss, which extends for 70m along the coast.



**Figure 1.** Map showing location of the three study areas: Bob Meadow Point, Round Neck and Clayter's Beach. The symbol X marks metamorphic block locations. The orientation of fabric within each block is also shown, demonstrating the variation present between separate blocks, as well as within the large block that is interpreted to extend northward from Bob Meadow Point to Smith Cove.

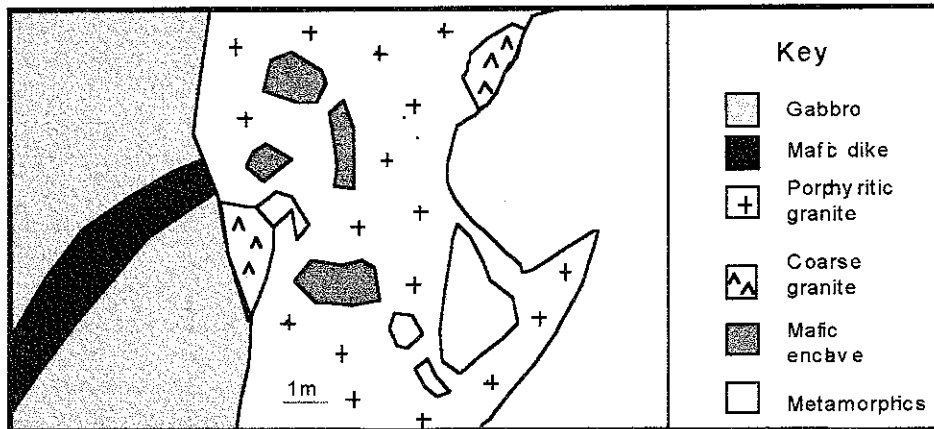


Figure 2. Representative sketch of the contact relationship between metamorphic blocks and the plutonic rocks.

### PETROGRAPHIC DESCRIPTION

**Bob Meadow Point.** The three interlayered units at Bob Meadow Point are: 1) A black biotite gneiss with ~30% quartz, ~25% biotite, ~25% clinopyroxene, and subordinate plagioclase, hornblende, kyanite, pyrophyllite, chlorite, muscovite and opaques; 2) A light gray quartzose gneiss containing ~80% quartz, with subordinate plagioclase, hornblende, and actinolite; and 3) An intermediate gneiss that has a similar mineralogy to the biotite gneiss, but has a lesser percent of biotite and a greater percent of quartz. The mafic dikes contain plagioclase, biotite, hornblende and minor clinopyroxene.

The foliation of the biotite gneiss ( $S_1$ ) is defined by the alignment of micas and the alternation of quartz-feldspar, augite and biotite layers which range from being microscopic to 2 cm thick. In contrast, aligned pods of hornblende and actinolite define the foliation in the quartzose gneiss. The  $S_1$  fabric is folded into tight folds ( $F_2$ ) that can be observed in hand sample.

**Round Neck.** There are six units of contact metamorphosed sedimentary rock present at Round Neck. Beginning at the base of the section they include: massive meta-pelitic sandstone, meta-calc-silicate, meta-felsic breccia, meta-conglomerate, laminated meta-pelitic sandstone, and meta-mafic breccia. The massive meta-pelitic sandstone is composed of ~75% quartz, with subordinate K feldspar, plagioclase, andalusite, biotite, muscovite, chlorite, opaques and nodules of epidote and biotite with quartz. The laminated unit differs in that it preserves cross-bedding and lacks the distinctive nodules of epidote and biotite with quartz. The calc silicate unit contains quartz, plagioclase, diopside and grossular. The association of diopside and garnet indicates that the rock has experienced sillimanite zone metamorphism, reaching temperatures between 650-900 degrees Celsius. The two meta-breccias are distinguished by both clast and matrix composition. The felsic breccia contains fine-grained felsic lithic fragments and a matrix of quartz, plagioclase, muscovite, andalusite, biotite and K feldspar. The mafic breccia lacks muscovite, andalusite and K feldspar in the matrix, and contains lithic fragments rich in hornblende, chlorite, opaques and biotite. The meta-conglomerate is clast supported, with a matrix of fine-grained quartz and feldspar. The clasts range in size from pebble to cobble (4 mm to 10 cm) with a general fining upward trend. Clast lithologies include gneiss, black quartzite and volcanics. The unit is fluvial and fills a channel scour depression in the underlying unit.

**Clayter's Beach.** A psammitic gneiss is the single unit present at this location. Its mode includes 50% quartz, 33% plagioclase, 6% microcline, 6% andalusite, 2% biotite, 2% muscovite, and 1% opaques. A fabric is evident in thin section, defined by bands which vary in grain size and the relative percentage of plagioclase and biotite.

### DISCUSSION

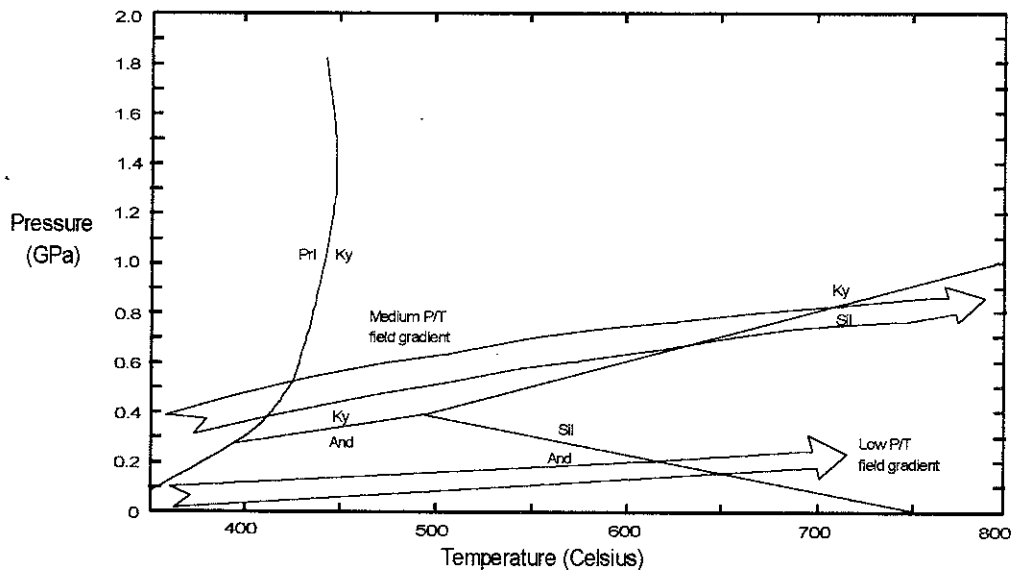
The origin and metamorphic history of each of the three blocks in this study appear to be distinct. The block exposed at Bob Meadow Point most likely represents regionally metamorphosed rocks of the Cambrian to Ordovician Ellsworth Terrane. It has experienced at least two deformational events, similar to the Ellsworth Schist. The presence of kyanite indicates that it has been subjected to pressures above 0.3 GPa and temperatures above 400 degrees Celsius (Fig. 3). This is inconsistent with the Greenschist Facies phase assemblages observed by workers within the Ellsworth Schist and the Calderwood Formation, and may represent an overprinting of

Acadian metamorphism. The protoliths for the interlayered gneiss may have been a sequence of mafic and felsic volcanic units or a sequence of sedimentary units derived from both mafic and felsic source rock. If the former is true, it suggests a tectonic setting with bimodal volcanism.

The units at Round Neck are distinct in that primary textures such as bedding, cross-bedding, and channel scour are beautifully preserved. They have not experienced regional metamorphism and therefore did not form prior to the Acadian Orogeny. Yet, formation and lithification must have taken place before the injection of the granitic magma in the Devonian Period. Given this time frame, it is possible that this block may be associated with the bimodal volcanic rocks in the northwest section of Vinalhaven Island. The protoliths represented include psammite, conglomerate, mafic breccia, felsic breccia and calcareous sandstone. It is evident that the depositional environment shifted several times. This is most easily explained by both changes in sea level and the influx of sediment.

Clayter's Beach offers a single unit of psammitic gneiss. The block's metamorphic history is somewhat unclear because it does not easily fit the regional models. It has experienced only one minor deformational event, recorded as a weakly developed foliation. The presence of layering based on composition and grain size resembles primary bedding.

Each block was subjected to high temperatures during emplacement of the pluton. At Round Neck, the presence of diopside and grossular in the meta-calc-silicate unit suggests temperatures around 650-900 degrees Celsius. Units at Round Neck and Clayter's Beach contain andalusite which forms at temperatures approaching 750 degrees Celsius (Fig. 3).



**Figure 3.** Petrogenetic grid for aluminous rocks. Field boundaries for kyanite and andalusite are shown. The medium P/T field gradient and the low P/T field gradient are indicated by arrows. After Spear and Cheney (1989).

#### REFERENCES CITED

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