

## BATTLE ISLAND – A GEOLOGICAL TREASURE IN EASTERN LABRADOR

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### ABSTRACT

*Battle Island is a popular tourist destination in southeast Labrador because of its cultural heritage, as represented by the once-abandoned fishing settlement of Battle Harbour and now restored by the Battle Harbour Historic Trust. It is not only its cultural heritage that has significance, however: amongst its many natural attributes, Battle Island displays some superb geological features.*

*Most of the island is underlain by a sequence of metamorphosed supracrustal rocks derived from arenaceous and calcareous protoliths. The supracrustal sequence of rocks from northeast to southwest across the island consists of i) crossbedded psammite, ii) calc-silicate and semipelitic schist, iii) psammite, iv) calc-silicate rocks and minor marble and v) calcareous psammite; this sequence probably represents the original stratigraphic depositional order. The calc-silicate and semipelitic schist unit contains a wide, concordant amphibolite that, in detail, comprises two subunits. The amphibolite is interpreted as representing two, now-metamorphosed, mafic sills that both followed the same intrusive conduit. All of these rocks were subjected to severe deformation, are now steeply dipping and, probably, stratigraphically overturned. Accompanying metamorphism reached amphibolite facies, later declining to greenschist conditions.*

*These rocks were synchronously or subsequently intruded by large volumes of granitic pegmatite that exhibit a wide range of boudinage and buckling features. Judging from their varied deformational states, the pegmatites were emplaced over an extended period, during transition from ductile to brittle conditions. A preliminary date from one pegmatite indicates a Grenvillian age of  $1017 \pm 9$  Ma.*

*Final events include the development of north-northeast-trending hematized brittle fractures and faults, interpreted to be related to rifting that led to the formation of Iapetus Ocean (615–540 Ma). The youngest bedrock feature on the island is an east-northeast-trending undeformed/unmetamorphosed dyke, the age of which is only constrained to postdating the brittle faulting.*

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### INTRODUCTION

The settlement of Battle Harbour, situated on Battle Island, was established in the 1770s as a fishing station. Throughout the 19<sup>th</sup> century, it was the site of a thriving salt-fish-, salmon- and seal-processing complex, and was the economic and social centre of southern Labrador (Figure 1). The once-abandoned settlement has recently been given a new lease on life as a result of a 7-year restoration project undertaken by the Battle Harbour Historic Trust, and is now a major tourist destination in southern Labrador (Plate 1). Access to the settlement is gained during the summer months by a 45-minute ferry trip from Mary's Harbour, which, itself, can be reached via Highway 510. The settlement is uninhabited during the winter.

The settlement of Battle Harbour takes advantage of a narrow sheltered channel (a tickle) between Battle Island and neighbouring Great Caribou Island to the west, utilizing the channel as an excellent natural harbour (Figure 2). In addition to Battle and Great Caribou islands, there are a number of smaller islands in the surrounding area and several offshore reefs, especially to the northeast.

The island is elongate in a northwest–southeast direction and can be divided topographically into two parts (Plate 1). The northeastern part is higher, more rugged and has more rock exposure, in contrast to the lower southwestern third, which is largely covered by vegetation. The two parts are separated by a west-facing cliff that terminates at either end of the island to form the precipitous northeastern walls

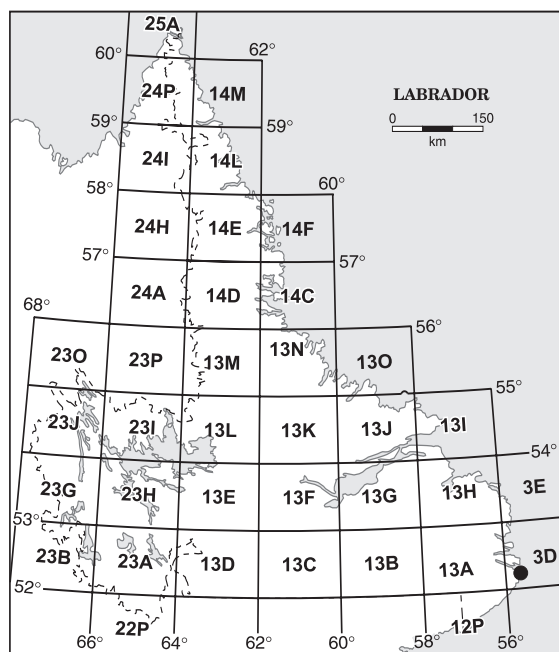


Figure 1. Location of Battle Island.

of small gulches. The settlement of Battle Harbour is located entirely on the sheltered lower southwestern part. The contrast in elevation and vegetation cover is easily explicable in terms of the underlying bedrock (see detailed descriptions that follow).

As the title of this article implies, Battle Island has remarkable geological diversity for its small size (1 km long by 0.5 km wide; Figure 2). It includes rocks of arenaceous and calcareous supracrustal parentage, now metamorphosed to amphibolite facies, but still preserving some original sedimentary features. It has metamorphosed mafic igneous rocks (amphibolite) that originally formed as two basaltic sills. Battle Island also hosts an impressive display of granitic pegmatites that, sporadically, contain atypical minerals, but, ubiquitously, display a spectacular range of deformational states. The youngest rock is an unmetamorphosed basaltic dyke, the exact age of which is unknown. All geological features on the island are superbly exposed and easily accessible.

## PREVIOUS INVESTIGATIONS

The earliest geological description of Battle Island is that of Kranck (1939), who, in a generalized manner, recognized most of the units described herein. He recorded quartz-rich gneiss on the higher, northeastern side of the island, noting that primary bedding, including crossbedding, was preserved. He also made mention of the amphibolite that transects the central part of the island and described lime-rich gneiss (containing quartz, calcite, actinolite, epidote, and brown mica), interbedded with impure limestone



Plate 1. Aerial view of Battle Island and the settlement of Battle Harbour; looking northeast.

and quartzitic layers on the lower, southwestern side of the island. He noted numerous granitic pegmatite dykes and irregular intrusions, and recorded evidence of strong deformation, including well-developed linear fabrics.

The area was visited during 1:100 000-scale reconnaissance geological mapping of the St. Lewis River region (Gower *et al.*, 1988a and b). In the report of Gower *et al.* (1988a), the metamorphosed supracrustal rocks are described in more detail, and photographs of the crossbedded quartz-rich rocks and calc-silicate units are included. A previously undocumented, undeformed and unmetamorphosed mafic dyke, situated at the southern end of Battle Island, was also recorded. Reference to the surrounding region, but not specifically Battle Island, is included in the geochronological reports of Tucker and Gower (1994) and Wasteneys *et al.* (1997). A field guide for part of southeast Labrador prepared by Gower *et al.* (1996) includes Battle Harbour as one of the excursion stops.

The most recent work, prior to this investigation, is that carried out in 1999 under the leadership of S. Carr, accompanied by M. Coleman, J. Czajkowski and J. Peressini (Czajkowski *et al.*, 2000; Peressini, 2000). Collectively, they carried out detailed mapping of Battle Island, parts of Great Caribou Island, and some of the small islets in the vicinity of Battle Island. Peressini (2000) provided a geological map of Battle Island, gave descriptions of the metasedimentary units, included structural information, described one of the granitic pegmatites in detail (termed the Battle Harbour pegmatite), and reported preliminary U-Pb data for it. Details of the Grenvillian age obtained from the pegmatite are given later in this report. The report of Czajkowski *et al.* (2000)

focuses on the structural history of Battle Harbour and adjoining Great Caribou Island, identifying three deformational events, the first two of which are considered to have occurred during Grenvillian deformation.

## PRESENT INVESTIGATION

The present investigation was carried out at the invitation of the Battle Harbour Historic Trust as part of its Expert-in-Residence program, which involved the author spending a week at Battle Harbour (August 11<sup>th</sup>–19<sup>th</sup>, 2007). In addition to acting as a resource person for visitors to Battle Harbour, time was spent carrying out a detailed geological remapping of Battle Island and collecting samples for petrographic, whole-rock geochemical, and geochronological follow-up studies (Figure 2). It should be noted that although Battle Island was entirely remapped during the present investigation, the map does not differ substantially from that of Carr and her colleagues.

Petrographic descriptions of units are included in this report, but geochemical and geochronological results are not yet available. An expanded version of this report, designed for hands-on use at Battle Harbour, will include that information. It will also contain, i) side-bars giving non-technical explanations of some geological features that are well displayed on Battle Island, ii) a glossary of technical terms, and iii) a list of minerals mentioned and their chemical formulae. A shorter, non-technical brochure/walking guide, designed specifically for visitors to Battle Harbour, is also planned.

## REGIONAL SETTING

Battle Island is situated in the Pinware terrane (Gower *et al.*, 1988a), which is the most southerly of those recognized within the eastern Grenville Province. Rocks interpreted to be of supracrustal origin (and which are also well represented on Battle Island) are among the oldest present. They include quartzite, calc-silicate rocks, pelitic schist, inhomogeneous-textured quartzofeldspathic rocks thought to have been derived from felsic volcanoclastic rocks, and a minor component of mafic rocks probably derived from an extrusive basaltic protolith. These rocks are mostly situated in the Henley Harbour–Red Bay area, well south of Battle Harbour, but minor remnants are found throughout the Pinware terrane. Labradorian (1710–1600 Ma) ages of 1640±7 Ma and 1637±8 Ma have been obtained from rocks of probable volcanoclastic origin (Tucker and Gower, 1994; Wasteneys *et al.*, 1997, respectively).

Foliated to gneissic granitoid rocks underlie a significant proportion of the Pinware terrane, two of which have yielded ages of 1650±18 Ma and 1649±7 Ma (Wasteneys *et al.*, 1997). Associated with these, and still incompletely dis-

criminated from them, is a younger suite of granitoid rocks grouped as Pinwarian (1520–1460 Ma). Neither Labradorian nor Pinwarian plutonic rocks are known on Battle Island. Pinwarian rocks have, however, been dated in the vicinity, from Cape Charles and Wolf Cove. Granitoid rocks at both localities yielded Pinwarian ages of 1490±5 Ma and 1472±3 Ma, respectively (Tucker and Gower, 1994). A third sample, from a locality 6 km east of Lodge Bay, yielded imprecise data that was interpreted to indicate Labradorian inheritance, overprinted by Pinwarian and Grenvillian metamorphic effects.

Grenvillian orogenesis (1085–985 Ma) is ubiquitous in the Pinware terrane, where most events occurred between 1030 and 985 Ma. Most of the effects are metamorphic, but minor granitoid intrusive activity was widespread, including on Battle Island, much of which is made up of granitic pegmatite believed to have been emplaced at this time. Later, posttectonic granite plutons were subsequently emplaced elsewhere in the Pinware terrane, but not in the vicinity of Battle Island.

The Pinware terrane subsequently experienced the fringe effects of rifting related to the opening of the Iapetus Ocean, which took place over an extended period between 615 and 540 Ma. The predominant expression in the area is as north-northeast-trending brittle faults, in places occupied by huge quartz veins. Minor examples of brittle faulting are present on Battle Island.

## PROTEROZOIC SUPRACRUSTAL ROCKS

The following sections give detailed descriptions, including petrographic information, of all the units recognized on Battle Island. A geological map is shown as Figure 2. Supracrustal units are described from east to west across the island.

### Crossbedded Psammite

The easternmost unit (Plate 2) has a light grey, sugary texture where its weathered, brownish crust has been removed by erosion. It is a relatively homogeneous, fine- to medium-grained grey-brown psammite, about 100 m thick at its widest part, but of unknown total width, as its eastern boundary is not exposed. The rock is maroon where hematized.

Three features are characteristic of this unit. The first is the presence of bedding in the form of parallel and cross-stratified lamination. The laminae are enriched in biotite and opaque minerals. The cross-stratification, which was first described by Kranck (1939), is confined to particular layers that are commonly about 30 cm thick. Younging direction is

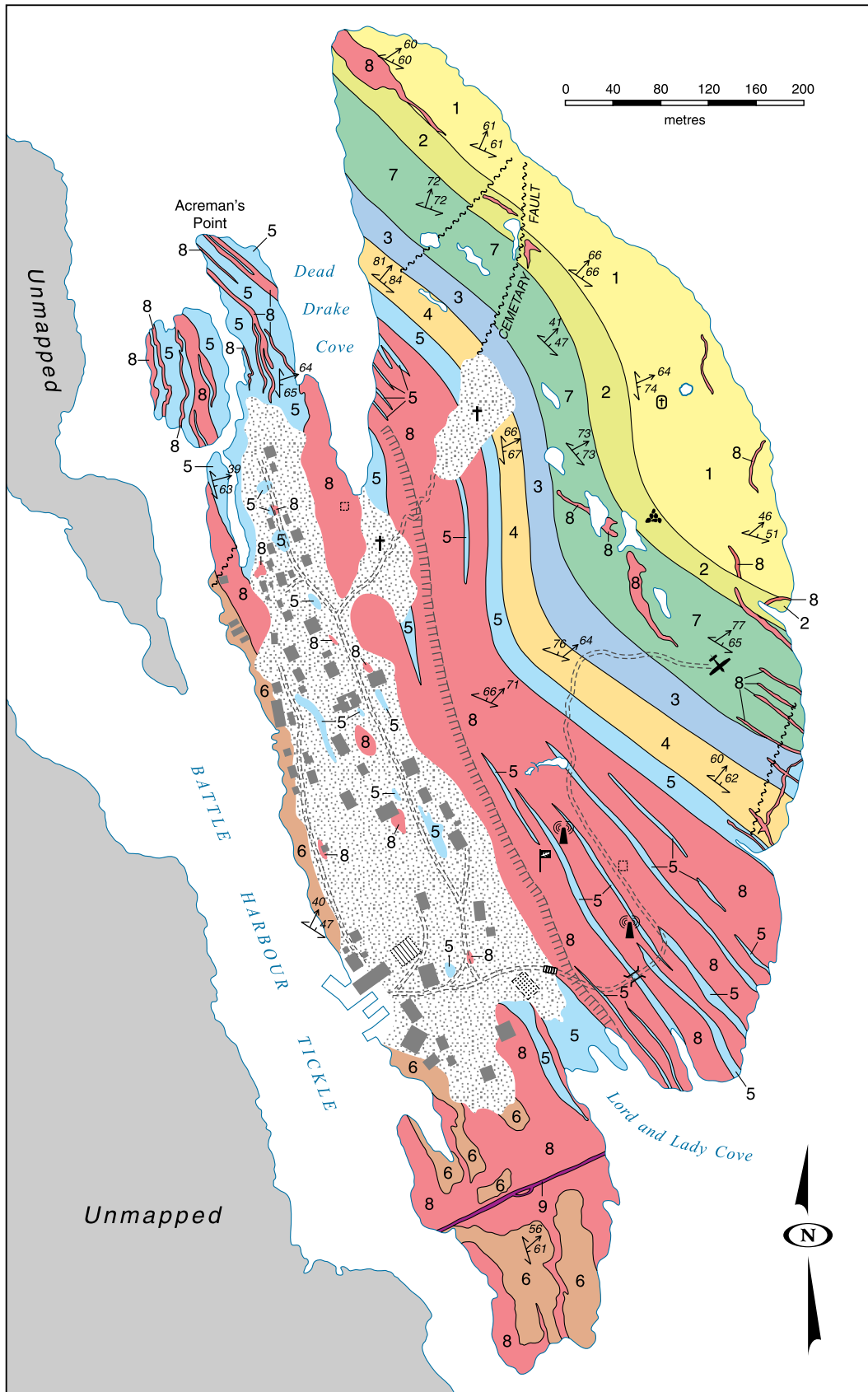


Figure 2. Caption on adjacent page.

## LEGEND

### PHANEROZOIC



Surficial deposits



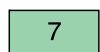
9 Diabase dyke: Brown-weathering, 2m wide, fine grained

### PROTEROZOIC

#### Intrusive rocks

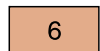


8 Granitic pegmatite: Pink-weathering, coarse to very coarse grained. Biotite or hornblende are typical mafic minerals, but, except in a few veins, are not abundant. Rare examples of pegmatite containing amazonite, fluorite, garnet or muscovite exist. Deformational state varies from severely boudinaged or buckled, to undeformed and planar



7 Amphibolite: Two types are present, interpreted to represent two separate sills following a common conduit. They are separated by discontinuous tabular lenses of calc-silicate rock. The eastern amphibolite is light-grey weathering, medium grained and strongly lineated. The western amphibolite is dark-grey to black-weathering, medium grained and weakly to moderately foliated

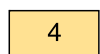
#### Supracrustal rocks



6 Calcareous psammite: Pale-grey to brownish-weathering, fine to medium grained, thin to thick bedded. The psammite is intercalated with calc-silicate layers



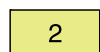
5 Calc-silicate rocks: Light to dark, green-grey-weathering, medium grained, thinly and continuously bedded; compositionally varied. Includes thin layers of psammite, semipelite, and rusty-weathering, sulphide-bearing pods



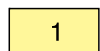
4 '20-m-wide' psammite: Grey, creamy or reddish-weathering, fine to medium grained, thin to thick bedded, but, overall, homogeneous in appearance



3 Schistose, micaceous calc-silicate rocks: Grey, greenish or black-weathering, fine to medium grained, very well bedded. Includes some psammitic layers. Alternation of rock types on centimetre to decimetre scale



2 Mixed psammite, calc-silicate schist, semipelitic schist, quartzite and calc-silicate hornfels: Grey, brown, green, creamy and white-weathering, medium to coarse grained, thin to thick bedded. Compositionally heterogeneous on centimetre to decimetre scale



1 Crossbedded psammite: Grey to brownish-weathering, fine to medium grained, thin to thick bedded and cross-bedded. Calcareous in part and characterized by amphibole porphyroblasts surrounded by mafic-mineral-depleted haloes

#### GEOLOGICAL SYMBOLS

Geological contact .....	———
Foliation and/or bedding with dip value .....	70
Lineation with plunge value .....	60
Brittle fault .....	~~~~~

#### OTHER FEATURES

Aircraft crash site	Steps
Flag pole	Bridge
Radio mast	Pathways
Garden	Building
Dam	Building foundation
Cemetery	Church
Bulldozer's (pet dog) grave site	Cairn
Fish flake	Rock cliff

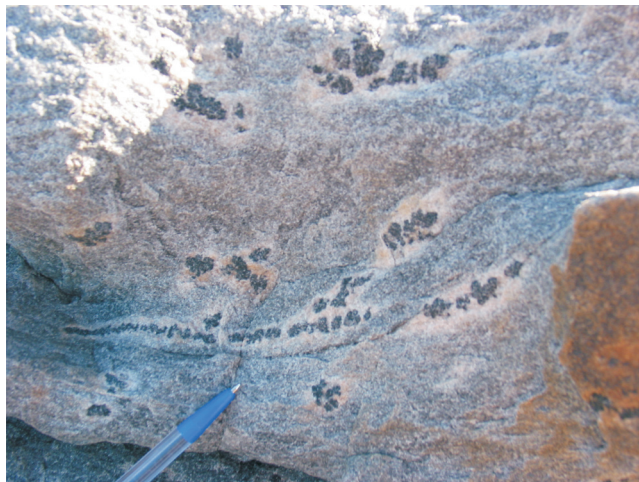
**Figure 2.** Geological map of Battle Island. The geological map is based on mapping carried out by the author during August, 2007. It, in essence, verifies earlier, detailed mapping carried out by S. Carr and co-workers and reported by Peressini (2000), from whom the foliation/lineation data are taken.



**Plate 2.** General view of crossbedded psammite intruded by concordant and discordant pegmatite (crossbedding not displayed in this photograph).

generally to the west, but, as tight folds were seen, some east-facing may also be present. This is the only locality in the Grenville Province in eastern Labrador where sedimentary structure in pre-Grenvillian rocks is unequivocally preserved. A thin section (CG07-130A) that includes two heavy mineral laminations consists mostly of recrystallized quartz, lesser plagioclase and interstitial well-twinned microcline associated with aligned flakes of buff-green biotite. Plagioclase is lightly to moderately sericitized. The heavy mineral layers consist mostly of an opaque oxide (likely ilmenomagnetite), but rounded zircon and apatite grains are also present. Titanite is also common in these layers, partly mantling the opaque oxide. Minor epidote and chlorite are found throughout.

The second feature is a spotted appearance due to amphibole poikiloblasts up to about 1 cm across and surrounded by haloes depleted in mafic minerals (Plate 3). In places the poikiloblasts are close enough to each other that the leucocratic haloes merge to enclose two or more cores, and, commonly, they are concentrated into particular zones typically extending along original bedding planes. Outside of the amphibole poikiloblasts, the mineral assemblage is similar to that seen in the previously described sample. The hornblende poikiloblasts are dark-green to blue-green and display sieve texture, enclosing abundant quartz, plagioclase and microcline. It seems fairly clear that as the poikiloblasts grew they simply enveloped the felsic minerals. The area around the poikiloblasts is depleted in biotite, which was consumed at the expense of amphibole growth. Other minerals present are an opaque oxide, apatite, epidote, chlorite and minor zircon. The epidote and chlorite are secondary or late-stage metamorphic minerals. The zircons are small and show a spatial affinity with the hornblende porphyroblasts



**Plate 3.** Hornblende porphyroblasts in eastern psammite. The light-coloured haloes around the porphyroblasts result from depletion of matrix biotite during porphyroblastesis.

and may, similarly, be a metamorphic product (thin section CG07-130B).

The third feature is the presence of a few yellowish-green layers, generally less than 1–2 cm in width. In thin section (CG07-130C), these are seen to be quartz-rich compared to the typical psammite described above, although still containing some plagioclase and microcline. The yellowish-green colour is due to markedly pleochroic epidote. Other minerals include relict, dark-green to blue-green amphibole, an opaque oxide, titanite (associated with the opaque mineral and epidote), apatite, minor chlorite (after amphibole), and a few small grains of zircon.

#### **Mixed Psammite, Calc-silicate Schist, Semipelitic Schist, Quartzite and Calc-silicate Hornfels**

West of the crossbedded psammite is a very variable metasedimentary unit, about 25 m thick. The rocks weather to various hues of grey, brown, green, cream and white, are mostly medium to coarse grained, and are thin to thick bedded. Lenses of quartz+feldspar or quartz, representing dismembered felsic intrusions and quartz veins, respectively, are also common.

From east to west the following rock types were noted, forming individual layers having widths ranging from about 0.5 m to 4 m: i) dark-grey micaceous amphibolite hosting quartz pods, ii) greenish epidote-rich rock containing amphibole porphyroblasts, iii) light-grey, homogeneous, less micaceous rock, iv) grey-brown psammite, v) pale-green, schistose, fine- to medium-grained semi-pelite, vi) a pale-green unit made up of alternating amphibole-rich material and psammitic partings, vi) brown, homogeneous psam-

mite, vii) psammite featuring narrow amphibole-rich partings, viii) grey to greenish, medium-grained homogeneous psammite having some lighter coloured partings, ix) variable psammite showing dark amphibole-rich layers, x) pale-green, fine-grained very schistose material, xi) brown-grey psammite containing lens-like, discontinuous layers grading westward into homogeneous psammite, and xii) white-weathering calc-silicate lenses up to a few metres in length, but rarely more than 30 cm thick, in contact with amphibolite. Pale-green epidote lenses, typically 5- to 10-cm thick, occur throughout the unit.

Four samples from this unit, representing the main lithological variants, were examined in thin section. The most mafic-mineral-rich rock type is a hornblende–biotite schist, also containing quartz, plagioclase, microcline, titanite, epidote, apatite, allanite and minor chlorite (CG07-131A). A mesocratic rock (CG07-131C) consists of quartz, plagioclase, phlogopitic mica, tremolite, clinozoisite and titanite. A leucocratic variant (CG07-131B) is a carbonate-rich calc-silicate rock, containing quartz, plagioclase, K-feldspar, carbonate, clinozoisite, actinolite, opaque mineral(s) and titanite. A white-weathering, hornfelsic-textured rock devoid of mafic minerals (CG07-131D), occurs as discontinuous lenses adjacent to the amphibolite to the west, and consists of quartz, carbonate, and diopside. The protolith for this unit was probably a heterogeneous sequence of lime-rich muds, grading into limestone, in places.

The next unit to the west, geographically, is amphibolite, but as this unit is interpreted to be intrusive, description of it is presented following the supracrustal rocks.

### Schistose Micaceous Calc-silicate Rocks

This unit (west of the amphibolite) is grey, greenish and black-weathering, fine to medium grained, very well layered, and shows alternation of rock types at the centimetre to decimetre scale. It consists mostly of schistose micaceous calc-silicate rocks, but also includes some psammitic material. A distinctive 3-m-wide pale-green rock (on which the hammer is resting in Plate 4) contains pods of orange-brown garnet (perhaps andradite) adjacent to the amphibolite.

The four samples of this unit examined in thin section are all calc-silicate rocks, although their mineral assemblages differ. The garnet-bearing rock (CG07-133A) also contains clinozoisite/zoisite, quartz, carbonate, diopside, highly sericitized plagioclase, titanite and minor, possibly secondary, tremolite. Clinozoisite/zoisite is partly symplectic with quartz. Quartz also occurs commonly as inclusions in garnet. Diopside is a major constituent of sample CG07-133B, where it is associated with plagioclase, phlogopitic mica and titanite. A few tremolite blades and chlorite flakes



**Plate 4.** Contact between dark amphibolite (left) and schistose micaceous calc-silicate unit (centre and right), showing distinctive pale-weathering zone on which the hammer is located. Garnet occurs in the hollow to the left of the hammer.

are also present. Sample CG07-133C contains tremolite as a major mineral, along with phlogopitic mica, clinozoisite, plagioclase and quartz. Minor titanite and allanite are present. The fourth sample (CG07-133D) contains plagioclase, tremolite, phlogopitic mica, microcline and titanite.

The mineral assemblages in this unit are very similar to those in the mixed unit on the eastern side of the amphibolite. If it is accepted that the amphibolite is intrusive, then it is not unreasonable to regard the rocks flanking the eastern and western sides of the amphibolite as being parts of a single unit prior to being separated by emplacement of the precursor mafic sill.

### '20-m-wide' Psammite

The contact between the schistose micaceous calc-silicate rocks and the psammite to the west is sharp and regular. The psammite is about 20 m wide, grey, creamy or reddish-weathering, fine to medium grained, homogeneous, and thin to thick bedded. The contact with calc-silicate rocks farther west is also sharp (Plate 5).

A single thin section from this unit (CG97-134) comprises quartz, plagioclase, microcline (all polygonal, equant and clearly thoroughly recrystallized), together with buff-brownish, ragged short laths of biotite, and small accessory grains of apatite, zircon, titanite and chlorite. The biotite is concentrated at grain interfaces between felsic minerals and is a typical example of the texture described by Gower (2007) in which the phyllosilicates flakes are of similar length to the felsic minerals on either side and are interpreted as the product of metamorphism of an intergranular mud.



**Plate 5.** Contact between 20-m-wide psammite (right) and calc-silicate rocks (centre and left).

The titanite and chlorite are secondary, derived, at least in part, from the retrogression of biotite. Most of the opaque mineral is secondary hematite or limonite, from the breakdown of primary opaque oxide, and perhaps from minor sulphide also.

#### Calc-silicate Rocks

The calc-silicate unit occupies a wide swath from the northwest tip of Battle Island to the central part of the southeastern shoreline, albeit heavily injected by granitic pegmatite. The rocks are generally light- to dark-green-weathering, medium grained, thin and well bedded, and mineralogically variable, both in composition and habit. Typically, the rocks have an obvious ribbed or pitted surface appearance due to alternating positively and recessively eroded layers and differential weathering of the various minerals present.

Apart from calc-silicate rocks, there are also amphibolitic, semipelitic and psammitic layers. Rusty-weathering, sulphide-bearing patches are widespread, locally forming pods up to about 1 m thick and 2 m long. Although the pods are rubiginous and have a sulphurous smell on fresh surface, sulphide content is minor.

Four samples collected near the contact with the psammite to the east were examined in thin section. Two of them (CG07-135A, CG07-135C) and the leucocratic part of a third (CG07-135D) have very similar mineral assemblages, although mineral proportions differ. The minerals are plagioclase, carbonate, K-feldspar, diopside, tremolite and titanite. The plagioclase, carbonate and K-feldspar are typically anhedral, show straight grain boundaries and 120° triple junctions, and are clearly recrystallized. Plagioclase is typically heavily sericitized and poorly twinned. K-feldspar

is well-twinned microcline. Identification of diopside is tentative; other possibilities not entirely ruled out are clinzoisite and idocrase. It is locally altered to tremolite, which is clearly posttectonic in places, growing discordantly to the prevailing fabric. Titanite is typically dark-brown and anhedral to subhedral. Sample CG07-135B and the melanocratic part of sample CG07-135D consist mostly of a pale-orange phlogopitic mica, diopside, tremolite, minor plagioclase, with minor opaque oxide mineral, apatite and possibly zircon (very small inclusions showing pleochroic haloes in phlogopitic mica). In sample CG07-135B, the diopside occurs as large poikiloblastic grains containing abundant inclusions of phlogopitic mica and plagioclase.

Five samples were examined in thin section from the western part of the calc-silicate unit, in the Acreman's Point area (CG07-136A to CG07-136E). All contain plagioclase, K-feldspar, phlogopitic mica, (an) opaque mineral(s), and titanite. Plagioclase is typically anhedral with straight grain boundaries and 120° triple junctions and heavily sericitized. K-feldspar shows the same habit, and is characteristically well-twinned microcline. The phlogopitic mica ranges from pale-orange to reddish-orange and typically defines a strong fabric. Both oxide and sulphide opaque minerals are present in all five samples, except in CG07-136E, in which only oxide was observed. Sulphide is especially abundant in CG07-136A and CG07-136B, which are both from gossanous rocks. The sulphide is thought to be mostly pyrite, but is suspected to be pyrrhotite in CG07-136A. Titanite varies from anhedral and amoeboid to euhedral. It is abnormally large in sample CG07-136E, where it occurs as grains up to 3 mm long. Other minerals include diopside and tremolite, the latter being secondary in sample CG07-136E and a stable metamorphic phase in CG07-136A, C and D. Neither diopside nor tremolite is present in CG07-136B, which is more psammitic than the other samples.

#### Calcareous Psammite

The calcareous psammite, forming the westernmost supracrustal unit on Battle Island, is pale-grey, green, or brownish-weathering, fine to medium grained, and thin to thick bedded. Bedding is defined by dark, amphibole- or biotite-rich layers. Locally, oblique layering is present that could be relict crossbedding. Some layers have a mottled texture that is attributed to incipient melting. The psammitic rocks are intercalated with calc-silicate layers, which locally also show oblique layering that resembles crossbedding. Three samples from this unit were examined in thin section (CG07-137A, B, and C).

Sample CG07-137A is a calcareous psammite and is distinct in the wide range of minerals present. Twelve minerals were identified in thin section; these are quartz, pla-



gioclase, K-feldspar, diopside, garnet, clinozoisite/epidote, hornblende, tremolite, carbonate, titanite, apatite and leucocoxene. The rock is clearly recrystallized, as shown by polygonization of several minerals, most notably quartz, plagioclase and carbonate, which all have straight grain boundaries and 120° triple junctions. K-feldspar is a very minor phase, more obvious in stained rock slabs than in thin section. Diopside occurs as pale-green, anhedral poikiloblasts, enclosing quartz and plagioclase, especially. Garnet is also poikiloblastic, enclosing quartz, clinozoisite/epidote, diopside, plagioclase and K-feldspar. The clinozoisite/epidote is colourless and shows its characteristic anomalous birefringence. No attempt was made to distinguish between clinozoisite and epidote, but the fact that the diopside is green (in contrast to colourless diopside seen in other Battle Island samples) suggests that the Fe content is higher in this sample than elsewhere, and that the mineral is likely epidote. Hornblende and tremolite are both secondary, as alteration products from diopside. Of the other minerals, titanite occurs as dark-brown euhedral grains, apatite forms small euhedral crystals, and leucocoxene comprises granular, amorphous-looking opaque material that is white in reflected light. This sample is clearly a disequilibrium mineral assemblage.

Sample CG07-137B and C are both psammitic rocks and, like CG07-137A, are mineralogically varied. Both contain quartz, plagioclase and K-feldspar, all of which have polygonal form and show straight grain boundaries. The mafic and accessory minerals differ between the two, however. CG07-137A contains dark-green (sodic?) amphibole, dark-brown titanite, zircon, apatite, biotite, epidote, and chlorite (the last three secondary after amphibole), whereas CG07-137C lacks amphibole, epidote and zircon.

## PROTEROZOIC INTRUSIVE ROCKS

### Amphibolite

The amphibolite can be subdivided into two subunits, separated by discontinuous lenses and tabular bodies of greenish-weathering calc-silicate rocks. The contact between the amphibolite and the 'Mixed psammite' unit to the east is sharp and concordant; the western boundary is separated from calc-silicate rocks by pegmatite sheets (Plate 4).

Amphibolite in the eastern half of the unit is more leucocratic than the west, but both subunits are medium to coarse grained, black to grey-weathering, variably foliated and very strongly lineated. The lineation is defined by hornblende, whereas the foliation is defined partly by biotite. The eastern leucocratic part shows streaky textures, due to variable concentrations of plagioclase and mafic minerals.

Apart from this streakiness, the rock is fairly uniform, except for the presence of small, elliptical, more melanocratic enclaves, which are numerous in some places. The amphibolite in the west is quite melanocratic near its contact against the lighter coloured eastern amphibolite, where it is also rusty-weathering and locally schistose.

Samples from both the eastern and western amphibolites were examined in thin section. The eastern amphibolite (CG07-132A) has a very strong fabric, defined by strings of segmented plagioclase grains, interspersed with elongate grains of pale-green amphibole (*cf.*, actinolitic hornblende) and laths of orange-brown biotite. Opaque minerals (mostly oxide, but some sulphide; both forming elongate strings and beads), yellow-brown rutile and minor chlorite after biotite are also present. The sample from the western amphibolite (CG07-132B) lacks the fabric of its eastern counterpart, showing a granoblastic texture instead. It also shows some mineralogical differences. The amphibole is typical hornblende, rather than being actinolitic and, instead of rutile, the rock contains very abundant titanite. The titanite occurs in clusters of equant grains, commonly cored by an opaque oxide. Minor sulphide, chlorite and K-feldspar are present, the last two minerals occurring as secondary spindles in biotite.

The lack of internal variability in both amphibolite units suggests that they are more likely to have been derived from intrusive than extrusive parents. They are interpreted as two separate diabase sills, the variation in colour index indicating some differentiation. If the units are differentiated, then the top of the unit is to the west, consistent with crossbedding evidence in the easternmost supracrustal unit. The stronger fabric and mineralogical contrasts in the eastern amphibolite provide evidence for a slightly lower grade, stretching deformational event not seen in the western amphibolite.

### Granitic Pegmatite

Pink- and white-weathering granitic pegmatite is found in all parts of Battle Island, but is particularly abundant along the spine of the island. The pegmatites vary in width from dykes tens of metres to veins less than 1 cm, but most intrusions are typically at the decimetre to metre scale. The rocks are almost all typical coarse- or very coarse-grained granitic pegmatite; only one, 10-cm-wide, aplitic vein was seen. Contacts against the host metasedimentary rocks are sharp, but typically irregular due to post-emplacement deformation. Both concordant and discordant pegmatites are present. Concordant screens of psammite and calc-silicate rock are abundant in the larger pegmatite, and have maintained their original pre-pegmatite-injection orientation, suggesting a passive, *lit-par-lit* type of intrusion. *En echelon*

pegmatites exhibiting bayonet terminations and bridge features are common.

Crosscutting relationships indicate several emplacement events, possibly over an extended period. The state of deformation varies greatly, suggesting a range of syn- to posttectonic emplacement ages.

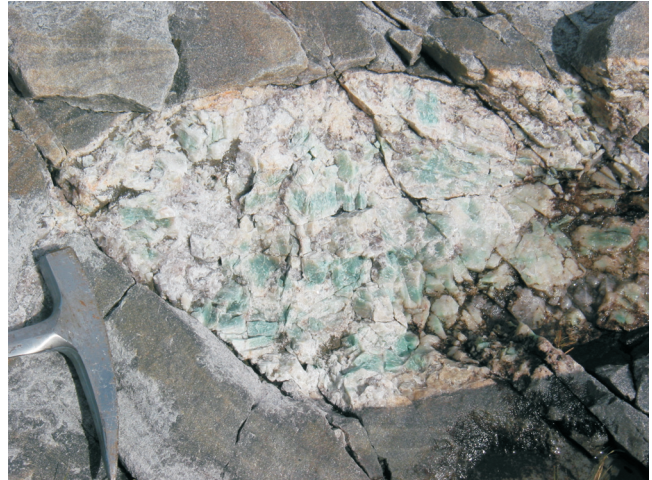
Two granitic pegmatites containing amazonite (green, Pb-bearing, K-feldspar; Plate 6) were found on the east side of Battle Island. Each can be traced for about 50 m. Both pegmatites are strongly boudinaged and appear to be among the earliest present on the island. One of the amazonite-bearing pegmatites was examined in thin section (CG07-138A). It comprises slightly recrystallized quartz, moderately sericitized, well-twinned plagioclase having albitic borders, well-twinned microcline, interstitial muscovite, an opaque oxide, partially metamict monazite, zircon, traces of chlorite, and a dark-brown poorly preserved mineral that is suspected to be allanite. The accessory minerals are unusually abundant in this pegmatite.

The amazonite-bearing pegmatites are crosscut by near planar, but still deformed, later granitic pegmatites. In one of them, a metallic, non-magnetic mineral showing iridescent-weathering colour (Cu-bearing?) is common. This pegmatite was also examined in thin section (CG07-138B). It contains unrecrystallized quartz, moderately sericitized plagioclase and well-twinned microcline, accompanied by very minor muscovite and an opaque oxide. The iridescent-weathering mineral was not captured in the thin section.

A sample of granitic pegmatite from Acreman's Point examined in thin section (CG07-136F) contains well-twinned, lightly altered plagioclase, well-twinned microcline, quartz, rare red-brown biotite, euhedral pyrite, and garnet (symplectically intergrown with quartz). It also contains an unidentified mineral thought to be metamict monazite. The mineral has square and rectangular cross sections, shows overgrowths, is typically surrounded by radiating fractures, and also occurs as inclusions in the garnet.

Other granitic pegmatites, which were not examined in thin section, were noted in the field as containing hornblende (in places as euhedral crystals several centimetres long and 2 to 3 cm in cross section), sparse biotite (up to about 5 cm across), minor muscovite, magnetite, or (in one case) purple fluorite.

A granitic pegmatite from the southern end of the island was previously collected for U-Pb geochronological study (Peressini, 2000). Six zircon fractions (three single zircons and three multi-grain fractions) were analyzed by S. Carr at Carleton University and yielded  $^{207}\text{Pb}/^{206}\text{Pb}$  ages between



**Plate 6.** *Boudin of amazonite-bearing pegmatite; amazonite is the green mineral.*



**Plate 7.** *Phanerozoic diabase dyke (exact age uncertain) discordantly intruding pegmatite (pink) and older psammite (grey).*

883.2+33.2/-34.0 Ma and 1137.8+251.6/-300.9 Ma. High errors from three fractions were recognized as due to analytical problems and were discarded. The remaining fractions gave a  $^{207}\text{Pb}/^{206}\text{Pb}$  age of 1017 ±9 Ma.

## PHANEROZOIC INTRUSIVE UNIT

### Diabase Dyke

A single, vertical, east-northeast-trending diabase dyke is present at the southern end of Battle Island (Plate 7). The dyke is about 2 m thick and has a smaller dyke (20 cm thick) branching off from it on its south side. It intrudes granitic pegmatite and earlier psammite, and also truncates north-northeast-trending, hematite-filled brittle fractures.

The dyke varies from fine to medium grained at its centre, to very fine grained at its chilled margins. The dyke is recessive-weathering with respect to its host rocks. It has a distinctive jointing pattern across its width, considered to be related to cooling normal to the dyke walls. K-feldspar in pegmatite adjacent to the dyke takes on a greenish hue, in contrast to its vivid pink farther away. This is interpreted as reduction of ferric to ferrous iron in the feldspar due to dyke emplacement. The dyke is unmetamorphosed and mineralogically fresh. It is the youngest bedrock unit on the island.

In thin section (CG07-139), the dyke comprises plagioclase, clinopyroxene, biotite, an opaque oxide and fine-grained, granular brown material. Plagioclase forms primary, well-twinned, and locally skeletal laths, and also occurs a local clusters of larger grains suggested here to represent slightly earlier crystallizing crystals that became attached to each other during magma ascent. The clinopyroxene occurs as brown primary grains, in ophitic texture with plagioclase. The biotite is orange-brown and ragged. The granular, brown material is too fine grained to be unequivocally identified, but it is suspected to be a Ti-bearing phase, possibly titanite.

## STRUCTURE

### FOLDING

The supracrustal units trend north-northwest, and mostly dip between 55° and 75° east-northeast. This means that the rocks are overturned, if the top-to-the-west-facing evidence given by crossbedding is accepted.

The earliest recognizable structures are isoclinal and tight folds, mostly within the calc-silicate units but also present elsewhere. Although the isoclinal folds initially appear to be contained within the general layering of the unit, their form is defined by a more attenuated version of the compositional layering, so there is no robust justification for considering the isoclinal folds to be the result of a different generation of deformation from the tight folds. Rather, they are interpreted here as having formed earlier (or subjected to higher strain) than the less flattened folds. The plunge of fold axes of both the isoclinal and tight folds is parallel to a ubiquitous down-dip stretching lineation. There is also evidence of considerable layer-parallel extension in the form of extremely dismembered early minor granitic pegmatite intrusions. One, somewhat equivocal example of a sigmoidal shear-sense indicator suggesting east-side-up sense of ductile movement was seen on the south side of the island (Plate 8). All these structures are modified by open folding that has warped the units into an open Z pattern (Figure 2).

S. Carr and colleagues referred to the original bedding as S1 surfaces. They assigned the deformation event that produced most of the deformation as D2 and considered it to be Grenvillian in age. The tight to isoclinal, northeast-plunging folds were termed F2 structures, the axial surfaces and the penetrative foliation which are labelled S2, and the strong down-dip lineation that is co-axial with the fold axes as L2. The deformation that produced the open folding (F3) is assigned as D3, and is interpreted to be a waning, post peak-metamorphic manifestation of the D2 event. Thus, essentially, they considered all the ductile deformation to be Grenvillian. The present author has reservations regarding this conclusion, given the regional context and widespread earlier orogenic events (Pinwarian, and, especially, Labradorian) known to have affected the area (Gower and Krogh, 2002, 2003; Gower, 2005). It should be added that this is not a new source of controversy, as the relative impact of Grenvillian versus earlier orogenesis has been disputed for decades in the eastern Grenville Province.

### Granitic Pegmatite Deformation

The granitic pegmatites clearly postdate the tight to isoclinal folding and associated stretching lineation, but are themselves openly folded and otherwise deformed to varying degrees. The multiple branching dykes, *en echelon* features, boudinage, buckling and crosscutting relationships testify to emplacement in numerous directions over an extended period during evolution from a ductile regime at the start to brittle conditions at the end. The latest pegmatites occupy brittle fractures. The deformation that affected the pegmatites is grouped as part of the D3 event by Carr and colleagues.

### Brittle Faults

The latest structures are brittle faults. They have a north to northeast trend and fault surfaces are characteristically maroon-weathering due to hematization. The faults range in appearance from hairline fractures to zones up to about 2 m wide. Slickensides were measured on two of the fault surfaces, in both cases plunging to the southwest at 22°. The larger faults commonly contain fault breccia, comprising angular fragments of wall rock within a comminuted, fine-grained matrix. The faults have both dextral and sinistral apparent displacement but dextral movement seems to be most common. Although displacements are typically a few centimetres to 1 m, two faults in the northeast part of the island have approximate apparent displacements of 5 and 15 m. The fault with the 15 m displacement has been named the Cemetery fault, as it can be traced from shoreline exposure into a gully containing surficial sediments where the most easterly of two small cemeteries on Battle Island is located.

The brittle faults affect all units, except the basaltic dyke, which truncates them; they are, therefore, post-pegmatite and pre-basaltic. Given their predominantly north-northeast trend, and age relationships to the pegmatites and basaltic dyke, it seems mostly likely that the faults belong to the same set of fractures as the ones occupied by the Long Range dykes and that they are all related to the rifting that preceded the opening of the Iapetus Ocean.

The final structural event recognized was formation of the east-northeast fracture now occupied by the undeformed and unmetamorphosed basaltic dyke.

## METAMORPHISM

A detailed study of the metamorphic assemblages has not been undertaken, and the information presented below is intended to offer no more than a preliminary grouping of the rocks into metamorphic assemblages (Table 1), and to deliver some empirical observations regarding textures.

### PSAMMITIC ROCKS

These rocks all contain quartz+plagioclase+K-feldspar +bronze to green biotite + an opaque oxide. Amphibole is found in four samples, and differs in each. It is clearly a prograde poikiloblastic phase in two of the samples, appears to be a stable member of the mineral paragenesis in a third and is likely relict in the fourth. Where it is poikiloblastic it is surrounded by biotite-depleted haloes, so biotite is certainly one of the reactants. The amphibole poikiloblasts contain rare epidote and titanite, so, if these were also reactants, they were not entirely consumed. In the sample in which amphibole is likely relict, the products are biotite, titanite, epidote and an opaque oxide, with subsequent replacement of biotite by chlorite, although some of the titanite appears to have been part of the pre-existing higher grade assemblage.

The assemblages indicate amphibolite-grade metamorphism and later localized retrogression to greenschist-facies conditions. The psammitic rocks contain a wide range of accessory minerals, and the opaque mineral is generally an oxide, in contrast to the calc-silicate rocks that contain sulphide but otherwise lack accessory minerals apart from titanite (which is generally abundant and forms large grains).

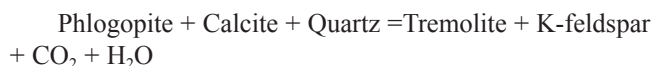
### QUARTZ-BEARING CALC-SILICATE ROCKS

The quartz-bearing calc-silicate rocks can be further divided into those having K-feldspar, diopside and carbonate versus those having phlogopitic mica. This subdivision correlates with a lower colour index and lower proportion of mafic minerals in K-feldspar–diopside–carbonate-bearing



**Plate 8.** *Gneissose rock made up of calc-silicate and psammitic rocks injected by numerous pegmatites, subsequently flattened and myonitized. The slightly sigmoidal form of layers in the central area provides a poor example of a kinematic indicator, suggesting a right-side-up sense of movement.*

samples. The two subgroups may be partly equivalent and linked by the reaction:



Two of the K-feldspar–diopside-bearing samples (CG07-133A and CG07-137A) contain an orange- to red-brown-weathering garnet (likely andradite/grossularite; Plate 9). Petrographic characteristics clearly demonstrate that these two samples represent disequilibrium assemblages (which would probably be rewarding to study in detail). Sample CG07-131D contains so little quartz that it is questionable whether the quartz can be regarded as part of the stable paragenesis.

The identification of the mineral listed as clinozoisite in the two phlogopitic mica samples is tentative. It occurs as colourless, anhedral (but having hint of hexagonal form), poikiloblastic grains containing abundant quartz inclusions and there are indications that it is partly replaced by tremolite. It has moderate birefringence and is biaxial positive.

### QUARTZ-ABSENT CALC-SILICATE ROCKS

The quartz-absent calc-silicate rocks have also been subdivided into three groups containing or lacking phlogopitic mica or K-feldspar, or containing both. The presence of K-feldspar in some samples, but its absence in others, could be due to the inability of the reaction cited above to proceed to the right because of exhaustion of quartz.

Table 1. Grouping of metamorphic rocks by mineral assemblages

Sample	Fabric	Qtz	Plag	K-fs	Bio	Bio colour	Diop	Clz	Carb	Gnt	Amph	Amphibole type	Oxd	Sul	Tit	Apt	Zir	All	Epid	Chl	Rut	Comments	
<b>Psammitic rocks</b>																							
CG07-130A	Granoblastic	X	X	X	X	Bronze							X		X	X	X	X				Heavy mineral layers rich in accessory phases	
CG07-130B	Granoblastic	X	X	X	X	Bronzy green			x			Relict(?) blue-green hornblende	X		s	X						s	
CG07-130C	Granoblastic	X	X	X	X	Bronzy green			X			Blue - dark green (Na?) hornblende	X		s	X	X	X				s	Amphibole poikiloblastic
CG07-131A	Schistose	X	X	X	X	Bronze			X			Stable hornblende	X		x	X	X	X				s	
CG07-134	Granoblastic	X	X	X	X	Bronzy green			X				X		x	X	X	X				s	
CG07-137B	Granoblastic	X	X	X	s	Green			X			Blue - dark green (Na?) hornblende	X		x	X	X	X				s	Amphibole poikiloblastic
CG07-137C	Grano/Schist	X	X	X	X	Bronze			X				X		x	X						s	
<b>Calc-silicate rocks with quartz</b>																							
<i>K-feldspar-Diopside-Carbonate</i>																							
CG07-131B	Granoblastic	X	X	X	X		X	X	X	s		Actinolite	x		X								Amphibole poikiloblastic
CG07-131D	Granoblastic	x	x	x	x		X	X	s			Tremolite	x		X								Garnet
CG07-133A	Granoblastic	X	x	x	x		X	X	X	s		Tremolite	x	X	X								Garnet poikiloblastic
CG07-137A	Granoblastic	X	X	X	x		X	X	X	s		Blue-green amph. & Tremolite	x		X	X	X						Garnet poikiloblastic
<i>Phologopitic mica</i>																							
CG07-131C	Schistose	X	X	X	X	Pale orange		X		X		Tremolite			X								Clinozoisite (poikiloblastic) identification uncertain, relict Clinozoisite (poikiloblastic) identification uncertain; relict
CG07-133C	Schistose	X	X	X	X	Orange		X		X		Tremolite			X			X					Clinozoisite (poikiloblastic) identification uncertain; relict
<b>Calc-silicate rocks lacking quartz</b>																							
<i>K-feldspar-Diopside-Carbonate</i>																							
CG07-135A	Granoblastic	X	x	X	X		X	X	s			Tremolite			X								Diopside and/or Clinozoisite?
CG07-135C	Granoblastic	X	X	X	X		X	X	s			Tremolite			X								Diopside and/or Clinozoisite?
CG07-135D - light	Granoblastic	X	X	X	X		X	X	s			Tremolite			X								Diopside and/or Clinozoisite?
<i>K-feldspar - Phologopitic mica</i>																							
CG07-133D	Schistose	X	X	X	X	Pale orange			X			Tremolite			X	X	X						High opaque mineral content
CG07-136B	Schistose	X	X	X	X	Orange			s			Tremolite	X		X	X							High opaque mineral content
CG07-136C	Schistose	X	X	X	X	Orange			X			Tremolite	X	X	X	X							High opaque mineral content
CG07-136D	Schistose	X	X	X	X	Orange			X			Tremolite	X	X	X	X							High opaque mineral content
CG07-136E	Granoblastic	X	X	X	X	Orange			s			Tremolite	X	X	X	X							High opaque mineral content
<i>Phologopitic mica</i>																							
CG07-133B	Granoblastic	X		x	x	Pale orange			s			Tremolite	x		X								Tremolite is posttectonic
CG07-135B	Schistose	X	X	X	X	Pale orange			X			Tremolite	x		X								Tremolite is posttectonic
CG07-135D - dark	Schistose	X	X	X	X	Orange		X	X			Tremolite	X	X	X								Tremolite is posttectonic
CG07-136A	Schistose	X	X	X	X	Orange		X	X			Tremolite	X	X	X								Tremolite is posttectonic
<b>Amphibolite</b>																							
CG07-132A	Schistose	X	X	X	X	Orange-brown			X			Actinolite	X	X	X	X							Tremolite is posttectonic
CG07-132B	Granoblastic	x	X	s	X	Orange-brown			X			Hornblende	X	X	X	X							Tremolite is posttectonic

Qtz - quartz; Plag - Plagioclase; K-fs - K-feldspar; Bio - Biotite; Diop - Diopside; Clz - Clinozoisite; Carb - carbonate; Gnt - garnet; Amph - amphibole; Oxd - opaque oxide; Sul - opaque sulphide; Tit - titanite; Apt - apatite; All - allanite; Epid - epidote; Chl - chlorite; Rut - rutile  
 X - Essential mineral or important accessory mineral  
 x - Minor mineral  
 s - Secondary and minor mineral



**Plate 9.** Garnet poikiloblasts (red) in calcareous psammite (mottled grey and creamy rock in upper half of image). The hollowed-out cores of the garnet suggest that their composition varies from core to rim, but the exact cause is unknown. The mottled appearance of the calcareous psammite may be the result of partial melting. The lower third of the image shows a later, discordant hornblende-bearing pegmatite.

Although some doubt is expressed regarding the identification of diopside versus the possibility that it is clinozoisite, it is probably diopside. The difficulty likely stems from the low Fe content in the rocks, because, if it is present, it normally provides both colour and refractive index contrasts between the two phases. In some of the samples, tremolite is clearly secondary, mostly as an alteration of diopside. In other samples, tremolite has grown across the penetrative fabric, thus postdating it and not part of the stable mineral assemblage.

## AMPHIBOLITE

The two samples of amphibolite both have similar mineral assemblages, but the more schistose of the two has experienced some retrogression, perhaps related to the deformation generating the schistosity. Evidence of the regression is seen by the presence of actinolite, alteration of biotite, and traces of rutile.

## GEOLOGICAL HISTORY

The earliest event that can be inferred was the deposition of sand, silt, calcareous sand and silt, grading into lime-rich sediment in places. These sediments were probably deposited in a shallow-water fluvial or marine environment. The time of deposition is uncertain, but thought to have been between 1800 and 1665 Ma, based on regional information (Gower and Krogh, 2002, 2003).

Deposition of the sediments was followed by burial and metamorphism, and the emplacement of two mafic sills, the second one following the conduit of the first. As there are hints of fractionation it is surmized that the sills were emplaced while the sediments were still flat-lying. The lack of wet-sediment structures is taken to mean that, although already indurated, the rocks had not yet been subjected to severe deformation when the sills were emplaced.

During the severe deformation that followed, the rocks were folded and achieved their present overturned attitude. The prominent down-dip lineation and the tight folds with fold axes co-axial to the lineation are also considered to have formed at this time. This deformation is interpreted here to have occurred during Labradorian thrusting at 1665 Ma, evidence of which is well preserved farther north on the north side of St. Lewis Inlet (Gower, 2005). A reminder is given that Carr and colleagues considered this deformation to be Grenvillian (see earlier page 64).

In the surrounding area there is abundant evidence of a major granitoid emplacement event at 1500 Ma, but that event has not been recognized on Battle Island.

The rocks were subsequently uplifted to a much higher crustal level and, by the time Grenvillian orogenesis took place in this area (ca. 1030–1000 Ma; *cf.*, Gower and Krogh, 2002), they were positioned around the ductile-brittle transition. This is inferred from the various deformational features exhibited by the granitic pegmatites. Some have clearly been buckled or boudinaged, whereas others occupy planar fractures and were emplaced under brittle conditions.

The next event was the formation of hematite-filled, north-northeast brittle faults showing both apparent sinistral and dextral sub-horizontal displacements. These were formed at ca. 615 Ma or earlier during early stages of rifting leading to the formation of the Iapetus Ocean. The 615 Ma constraint is imposed by the age of the Long Range dykes, which occupy some of the north-northeast fractures elsewhere in eastern Labrador (Kamo *et al.*, 1989; Kamo and Gower, 1994).

The final event was the emplacement of an east-northeast-trending basaltic dyke at an unknown time, but later than the hematite-filled brittle faults, which the dyke cross-cuts.

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