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THE AVALONIAN GEOLOGY OF SOUTHWEST BONAVISTA BAY: PORTIONS OF THE ST. BRENDAN'S (2C/13) AND EASTPORT (2C/12) MAP AREAS

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ABSTRACT

The map area is situated at the northwest terminus of the Avalon Zone, where uppermost Precambrian Avalonian rocks are separated from adjacent Gander Zone rocks by the Dover Fault, a 1-km-wide ductile fault zone. Other northeast-trending faults divide the area underlain by Avalonian rocks into lithologically and structurally contrasting regions.

Stratified rocks west of the Bloody Reach fault comprise the Musgravetown Group, a sequence predominated by shallow marine to terrestrial sedimentary rocks, but also containing a major volcanic component. The group is divisable into four formations that form a conformable succession, approximately 3 km thick, of latest Precambrian and possibly earliest Cambrian age. The rocks are disposed in open, locally periclinal folds that are provisionally interpreted as younger than earliest Cambrian. To the west, the Musgravetown Group is in fault contact with a narrow band of schistose volcanic rocks that are part of the Love Cove Group. The pervasive fabric that these rocks carry intensifies westward to the Dover Fault, where the volcanic rocks are reduced to mylonite.

The area east of the Bloody Reach fault is underlain by the Love Cove Group, the conformably overlying Connecting Point Group, and a thin outlier of Musgravetown Group rocks. Volcanic rocks, which predominate in the lower 1 km of the combined succession, pass upward into 1.7 km of epiclastic sediments comprising the lower three units of the Connecting Point Group. A distinctive mixtite separates those rocks from an overlying, 3-km-thick sequence of shale and turbidite.

The Love Cove Group and the lower 2 km of the Connecting Point Group form an overturned, eastward-younging succession that occupies the western inverted limb of a regional syncline. The remainder of the Connecting Point Group is either openly folded or homoclinal. East of the Bloody Reach fault, the Musgravetown Group forms a moderately dipping, west-younging homocline, and is unconformable upon the Love Cove Group. Auriferous alteration zones within the Love Cove Group are spatially associated with faults and granitoid intrusions.

INTRODUCTION

This paper summarizes the geological history of the uppermost Precambrian, Avalonian rocks exposed in the St. Brendan's (2C/13) map area and in the north-central portion of the adjacent Eastport (2C/12) map area (Figure 1). The results summarized below are the outcome of continued mapping and detailed sedimentological logging by the authors in the southwest Bonavista Bay region in 1987. A more detailed discussion of the results of the sedimentological studies is presented in an accompanying paper by Knight and O'Brien *(this volume)*. Initial results of the 1986 program, together with a discussion of the stratigraphic and tectonic problems of the region, are published in O'Brien (1987).

The area is accessible by small boat from any of the coastal communities in the southwest part of Bonavista Bay. The nearest road links to the area are at the towns of Dover, Hare Bay and Burnside. The five communities on Cottel Island are linked by road and serviced by Provincial Department of Transportation ferry service between Burnside and Perry's Cove.

Rocks of dominantly late Precambrian age, which lie east of the Dover Fault in the Bonavista Bay region, represent the northern terminus of the Avalon Zone (Williams, 1976) or Avalon Terrane (Williams and Hatcher, 1983), the most extensive of the tectonostratigraphic divisions of the Appalachian Orogen. The study area offers a superbly exposed cross-section through the uppermost Precambrian Avalonian succession, extending 30 km eastward from the zone-bounding Dover Fault. The rocks of the St. Brendan's map area west of the Dover Fault are part of the Gander Zone (Williams, 1976) or Gander Terrane (Williams and Hatcher, 1983), and are not a focus of this study. Descriptions of the geology of that portion of the map area are given in Blackwood (1976, 1977).

The details of mapping studies previously undertaken in the map area are available in the following publications:

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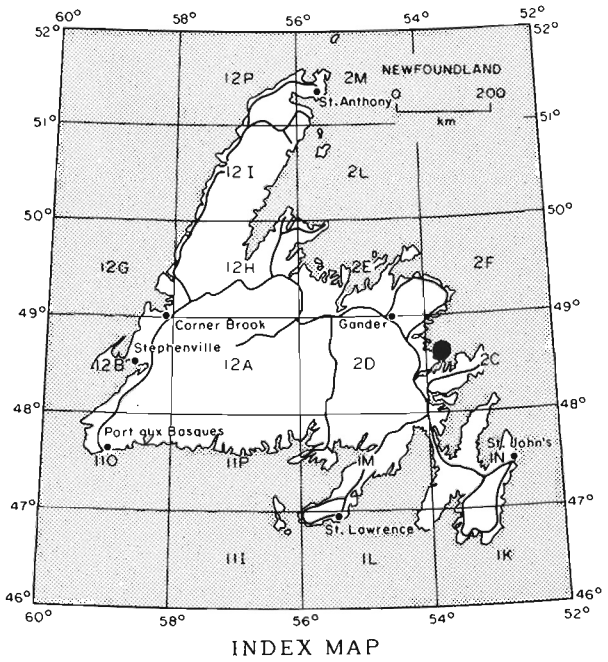

Figure 1. *Location of map area.*

Murray and Howley (1881), Hayes (1948), Widmer (1949), Christie (1950), Jenness (1963), Younce (1970), and Dalbello (1977). The reader is referred to O'Brien (1987) for details of these works that pertain to the regional geological setting.

Results of detailed structural analyses of the Dover Fault are presented in Blackwood and Kennedy (1975), Blackwood (1976, 1977), Dallmeyer *et al.* (1981) and Caron (1986).

GEOLOGY OF THE AVALONIAN ROCKS

The stratified rocks of the map area (Figure 2) comprise the northernmost exposures of the Love Cove (Jenness, 1963), Connecting Point (Hayes, 1948) and Musgravetown (Hayes, 1948) groups. These units consist of a variety of distinctive volcanic and sedimentary lithofacies, which are subdivided into 16 lithostratigraphic subunits that are mappable at 1:50,000 scale (O'Brien and Blackwood, 1987). The stratified rocks are intruded by plugs, dykes and sills of mafic and felsic composition.

The three major groups are essentially bounded by northeast-trending faults. In the west, the Dover Fault juxtaposes the more westerly of two belts of uppermost Precambrian Love Cove Group volcanic rocks with foliated granite and migmatite to the west (Blackwood, 1976, 1977). The eastern boundary of this belt of Love Cove Group rocks is the Howses Cove fault (Younce, 1970). This structure, and the Bloody Reach fault to the east, bound the main exposure area of the uppermost Precambrian Musgravetown Group. The latter unit contains the youngest rocks in the map area, which may be Tommotian (earliest Cambrian) in age; fossils have not been discovered in these rocks, therefore, this age assignment is provisional.

The Bloody Reach fault and another fault to the east, which trends northeastward through Cottel Island, delineate a second major belt of volcanic rocks. This belt includes the Love Cove Group, which here is intruded by granitoid rocks, and a thin succession of bimodal volcanic and red clastic rocks that is tentatively correlated with the lower portions of the Musgravetown Group to the west.

Rocks of the Connecting Point Group are exposed only to the east of the aforementioned fault through Cottel Island. This group conformably overlies the Love Cove Group and consists mainly of marine clastic sedimentary rocks.

Love Cove Group

The Love Cove Group is the oldest Avalonian stratigraphic element in the Bonavista Bay region (Jenness, 1963; Blackwood, 1976, 1977; O'Brien, 1987). In the northern Burin Peninsula, the group has been dated at 590 ± 30 Ma (Dallmeyer *et al.*, 1981a). Within the map area, rocks of this group lie in two geographically separate belts. The western belt constitutes the terminus of a 100-km-long, north-northeast-trending band of volcanic rocks that is bounded to the west, along its entire length, by the Dover Fault. The eastern belt, exposed in the core of a regional anticlinorium, is traceable continuously from the map area, southward through the type area at Clode Sound (Widmer, 1949) to the southern Burin Peninsula, (O'Brien *et al.*, 1977) for a total distance of 250 km.

Both belts are characterized, in most areas, by penetratively deformed volcanic rocks that are either vertical, steep upright or inverted. The Love Cove Group (Unit 1) in the map area has been subdivided into three assemblages of compositionally and texturally distinct lithofacies, corresponding to subunits 1a, 1b and 1c on Figure 2.

Subunit 1a underlies much of the western belt of the Love Cove Group, as well as the structurally lowest parts of the eastern belt. Its diagnostic lithology is schistose, sericitic, feldspar-rich, crystal and lithic tuff of intermediate to locally felsic and mafic composition (Plate 1). This rock type is associated with rhyolite flows, cherty tuff, coarse grained tuff-breccia and, in the area near Dover, volcanogenic sandstone. The contacts of this unit and others of the Love Cove Group are tectonic.

Subunit 1b is exposed only in the eastern belt. It includes variably foliated, mafic to intermediate, subaqueous flows, tuff and volcanic breccia. A particularly distinctive lithology, only locally developed, is a breccia with a shaly–mafic tuffaceous matrix. Two outcrops of this breccia contain recrystallized white marble clasts. The subunit's contacts are tectonic.

Subunit 1c is also exposed only in the eastern belt. It consists of approximately 800 m of intercalated felsic volcanic and shaly rocks that comprise the uppermost stratigraphic division of the Love Cove Group. The volcanic rock types within the subunit are variably schistose, vitric tuff, crystal

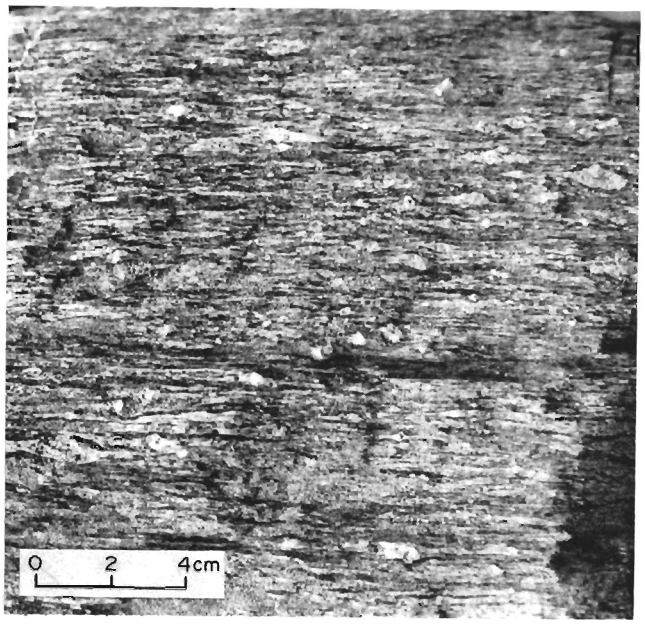

Plate 1. *Highly strained, schistose crystal–lithic tuff; subunit 1a is of the Love Cove Group near the Dover Fault.*

tuff, quartzphyric rhyolite, felsic agglomerate and sericite schist of volcanic protolith. These volcanic rocks occur as flows and pyroclastic layers between 1 m and several tens of metres thick, and are interstratified with grey to black shale that contain silicic laminae and thin chert beds.

The base of the Love Cove Group is not exposed. Approximately 1 km of section is exposed in the eastern belt. The maximum thickness of the Love Cove Group is unknown because its base is unexposed and internal contacts are tectonic.

Granitoids Intrusive into the Love Cove Group

Four small bodies of variably foliated, hornblende–biotite granodiorite (Unit 2) intrude the eastern belt of the Love Cove Group on the islands southwest of Cottel Island. The granodiorite is buff to grey, mainly fine grained and equigranular. It is cut by straight and irregularly bordered, fine grained diabase dykes, and contains cognate mafic inclusions that have irregular margins. The ferromagnesian minerals in the granodiorite are chloritized locally, and wispy veinlets and small pods of epidote are common features of the rock. These intrusions are brecciated, cleaved and increasingly finer grained at their margins, where screens of rhyolite and mafic volcanic rocks are preserved.

The pretectonic nature of the plutonic rocks of Unit 2, combined with their spatial association with the Precambrian Love Cove Group and the compositional similarity with dated (590 ± 30 Ma) Precambrian plutons within the Love Cove Group on the Burin Peninsula (Dallmeyer *et al.*, 1981a) are taken as indirect evidence of their Precambrian age and subvolcanic origin.

Connecting Point Group

The Connecting Point Group lies entirely to the east of, and conformably overlies, the Love Cove Group. Within the map area, the Connecting Point Group contains 10 lithofacies that comprise six lithostratigraphic units having a combined thickness of at least 3.5 km. The most complete stratigraphic section through that part of the group exposed in the map area occurs between Willis and Hail islands, on the overturned steep limb of a major syncline (Willis Reach syncline). The lower 1500 m of the group form an upward-coarsening stratigraphic succession, and consist of three lithostratigraphic divisions. Thin-bedded, green–grey and buff, tuffaceous sandstone and siltstone that contain intercalated black shale and pyroclastic rocks comprise Unit 3. It is succeeded conformably upward by Unit 4, a sequence of thick- to thin-bedded and amalgamated sandstone that locally contains thin-bedded, green–grey sandstone and shale intercalations (Plate 2). Grey–green to buff, thin-bedded sandstone, siltstone and shale, containing units of massive pebbly sandstone and black shale comprise Unit 5. The contact of Units 4 and 5 is gradational.

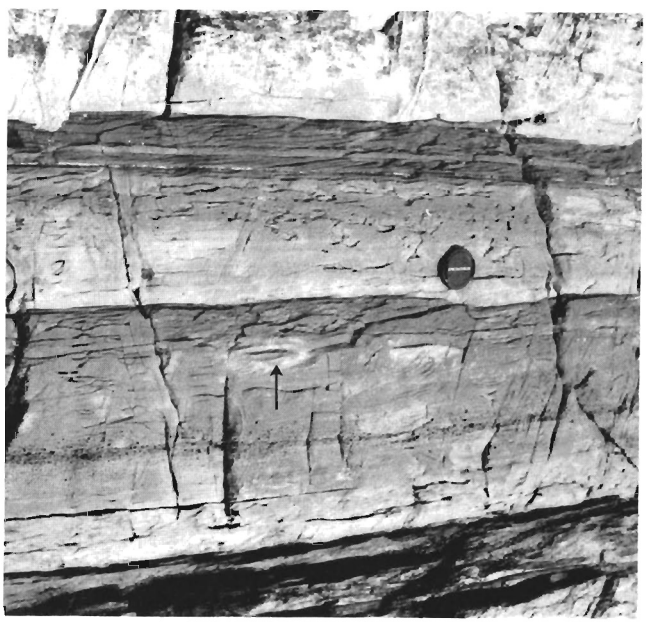

Plate 2. *Graded sandstone beds (Unit 4), Connecting Point Group; middle portion of lower bed contains coarser sand grains, suggesting beds are amalgamated. Note presence of small calcareous concretion (arrowed).*

Collectively, Units 3, 4 and 5 consist mainly of upward-coarsening megacycles of shale, thin-bedded mudstone and fine grained sandstone, thin- to thick-bedded, graded sandstone, and massive, pebbly and intraclastic coarse grained sandstone. The megasequence itself consists of 10-m-thick sequences that either coarsen and thicken upward (more common) or fine and thin upward (see Knight and O'Brien, *this volume*).

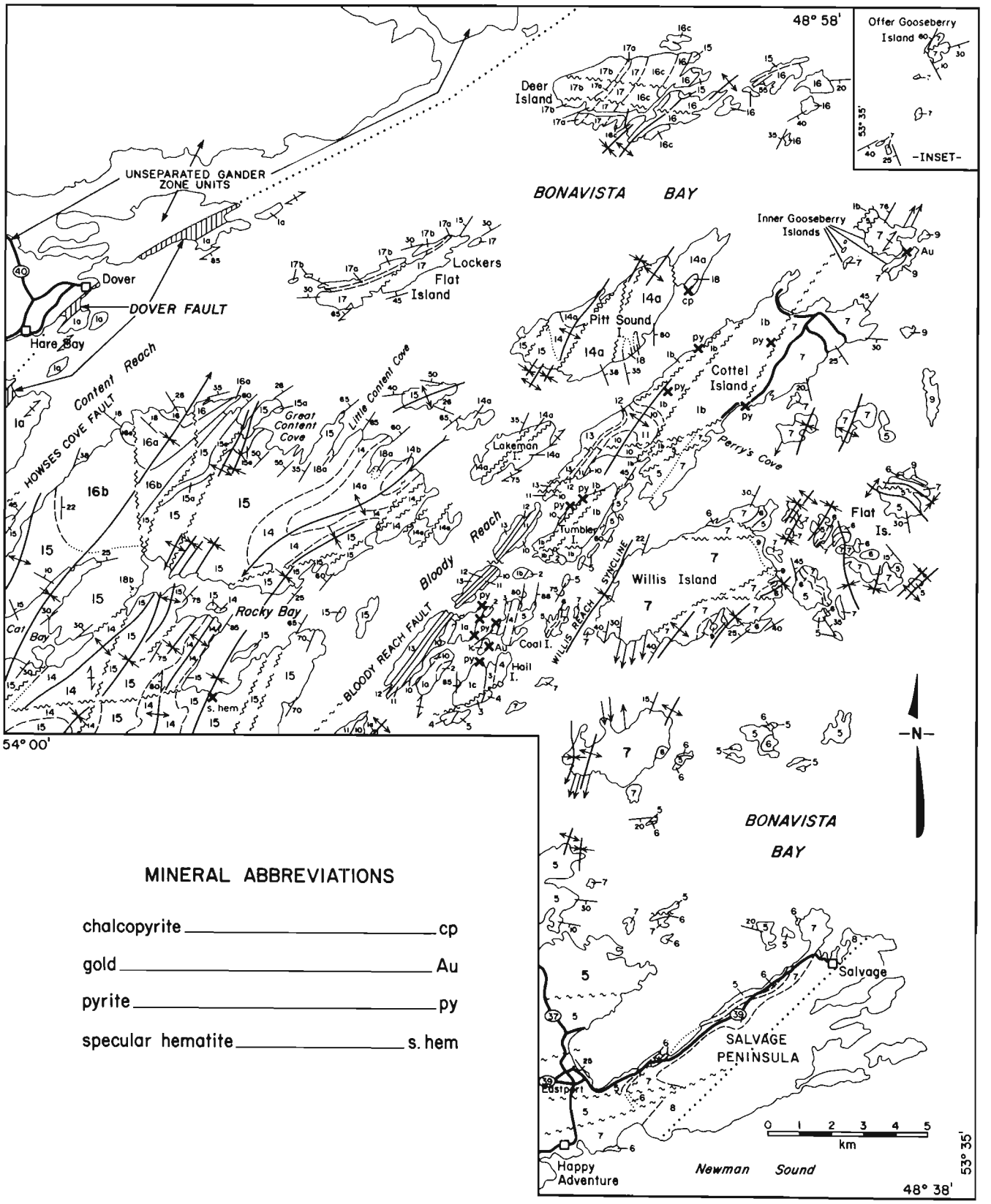

Figure 2. *Avalonian geology of southwest Bonavista Bay; parts of 2C/12 and 2C/13.*

DEVONIAN OR OLDER

18 *Equigranular gabbro and diorite plugs, dykes and sills;* 18a: *granodiorite;* 18b: *granite porphyry*

UPPER PRECAMBRIAN TO LOWER CAMBRIAN

Musgravetown Group (Units 10–17)

DEER END FORMATION

17 *Green and grey sandstone and laminated siltstone, micaceous grey siltstone, quartz-rich sandstone; minor red sandstone and variegated siltstone (Deer Island);* 17a: *white and light grey, massive, planar stratified and cross-stratified quartz arenite and quartzofeldspathic sandstone; minor red sandstone locally;* 17b: *green and grey, locally buff sandstone and siltstone with calcareous nodules; light- and dark-grey shale*

UPPER PRECAMBRIAN

Musgravetown Group

CROWN HILL FORMATION

16 *Red sandstone and granule conglomerate;* 16a: *red boulder to pebble conglomerate;* 16b: *red and green sandstone and siltstone; minor granule to pebble conglomerate;* 16c: *mainly red and locally variegated sandstone; minor thin-bedded granule conglomerate and quartzose sandstone; green sandstone*

ROCKY HARBOUR FORMATION

15 *Green, wispy-laminated, wispy-bedded and planar stratified sandstone; minor green sandstone and pebble conglomerate;* 15a: *rhyolite flows and sills; thin monolithic aquagene mafic breccia unit near top at Deer Island*

BULL ARM FORMATION (Units 10–14; Unit 14 only occurs west of Bloody Reach Fault; Units 10 to 13 only occur east of Bloody Reach Fault.)

14 *Red, buff and grey, flow-banded rhyolite intercalated with minor ash-flow tuff and rhyolite breccia;* 14a: *interbedded green sandstone and basalt; green and grey tuffaceous sandstone and conglomerates;* 14b: *mafic agglomerate and volcanic breccia; minor unseparated gabbro sills*

13 *Red and maroon, granule and pebble conglomerate; red sandstone at base; minor red shale*

12 *Green tuffaceous sandstone*

11 *Vesicular basalt and minor mafic tuff and breccia; minor red sandstone*

10 *Red, flow-banded rhyolite containing tuff and breccia at base and top*

9 *Equigranular diorite and gabbro*

Connecting Point Group (Units 3–8)

8 *Black shale, thin-bedded argillite, silicified thin- to medium-bedded turbidite sandstone*

7 *Shale, thin-bedded sandstone and siltstone, and thick units of sandstone; planar stratified and slumped sandstone*

6 *Mixtite containing pebble and block-sized lithoclasts of sedimentary rocks together with mafic and felsic volcanic and plutonic detritus*

5 *Grey-green to buff, thin-bedded sandstone, siltstone and shale containing units of massive pebbly sandstone and black shale*

4 *Thick- to thin-bedded and amalgamated turbidite sandstone containing minor thin-bedded, green-grey sandstone and shale*

3 *Thin-bedded, green-grey and buff tuffaceous sandstone and siltstone; black shale; rare pyroclastic rocks*

2 *Buff to grey, equigranular hornblende–biotite granodiorite and granite*

Love Cove Group

1 1a: *Schistose lithic and crystal tuff, quartz porphyritic rhyolite, felsic agglomerate and sericite schist; minor cherty tuff and local volcanogenic sandstone;* 1b: *mafic to intermediate flows, tuffs and volcanic breccias; minor shaly matrix breccia; feldsparphyric tuff and breccia of intermediate composition;* 1c: *grey to black shale with silicic laminae, thin chert beds and fine grained tuff; intercalated rhyolite and breccia*

Geological boundary (defined, approximate, assumed, gradational)

Bedding, tops known (inclined, overturned)

Schistosity or foliation (inclined, vertical)

Lineation

Syncline (arrow indicates plunge direction)

Anticline (arrow indicates plunge direction)

Fault zone (Dover Fault)

Fault (defined, approximate, assumed)

Limit of mapping

Unit 6 is a spectacular mixtite deposit that occupies a stratigraphic position either equivalent to, or slightly younger than the top of the coarsening-upward succession described above. On the west limb of the Willis Reach syncline, the unit is quite thin. Superb outcrops of the mixtite occur to the east of the syncline axis, notably on Flat Islands, the west shore of Eastport Bay, and on many of the islands between these localities.

The mixtite contains pebbles and blocks of older units of the Connecting Point Group, as well as rarer volcanic and intrusive clasts of mafic to felsic composition, presumably derived from the underlying Love Cove Group (Plate 3). Sedimentary blocks are folded, internally slumped and display chaotic to oriented internal fabric (see Plate 12 of Knight and O'Brien, *this volume).* The matrix of the mixtite is characteristically black or grey, brown-weathering, granular to sandy mudstone. The mixtite is associated with amalgamated sandstone beds that are commonly slumped and convoluted, and locally intruded by mafic dykes prior to lithification.

Plate 3. *Mixtite containing clasts of slumped siliceous argillite and rhyolite tuff in pebbly, granular mudstone matrix (Unit 6); Connecting Point Group. Canadian quarter for scale.*

That part of the Connecting Point Group directly above the mixtite is dominated by black and grey shale, grey–green, thin-bedded sandstone and siltstone, and thick units of thin-bedded and locally slumped sandstone (Unit 7; Plate 4). The shaly lithofacies are locally cut by synsedimentary mafic dykes similar to those that intrude Unit 6.

In the southeastern part of the area, the mixtite and overlying shale are succeeded by silicified, upward-coarsening megasequences of shale, turbidite sandstone and massive sandstone. These rocks, designated as Unit 8 on Figure 2, are well exposed on the Salvage Peninsula.

Plate 4. *Thick unit of thin-bedded, locally convoluted sandstone interbedded with shale (Unit 7); Connecting Point Group, Willis Island.*

The contact of the Connecting Point Group and the underlying Love Cove Group is exposed on the structurally inverted west limb of the Willis Reach syncline. At Hail Island and Coal Island, tuff and shale of subunit 1c of the Love Cove Group are intercalated with the lower 500 m of the Connecting Point Group. Elsewhere in the map area (e.g., Cottel Island, Tumbler Island) the contact is a fault.

Mafic Plutonic Rocks within the Connecting Point Group

The Connecting Point Group is intruded by a suite of pretectonic mafic sills, dykes and plugs (Unit 9) that outcrop in a broad zone that trends northeasterly across the central part of the Connecting Point Group outcrop belt. Most of the coarse grained plutonic rocks, particularly the plugs, are found in the northeast corner of the map area. The exact temporal relationship among the dykes, sills and plugs is not yet known, however, some of the mafic dykes are synsedimentary.

The diagnostic lithology of these intrusions is fine- to medium-grained, equigranular diorite; gabbro of similar texture is present locally. The rock is brown weathering, grey-green to dark green and contains rare mafic xenoliths 2 to 3 cm in diameter. The diorites are variably fractured and brecciated, and chlorite and epidote alteration is common. Near the contacts of the larger plugs, diorite is spatially associated, in places, with fine grained basalt porphyry.

Musgravetown Group

Within the map area, subaerial and subaqueous volcanic and sedimentary rocks of the Musgravetown Group outcrop in two areas, separated by the Bloody Reach fault. A thin, west-younging, north-northeast-striking bimodal volcanic

succession, capped by red sedimentary rocks, is exposed east of the fault. This succession is continuous southward into the type area of the group at Musgravetown (Hayes, 1948). The western belt of dominantly clastic sedimentary rocks continues southwestward for 100 km, parallel to and in tectonic contact with the western belt of the Love Cove Group. The succession is subdivided into four units of formational status, following the nomenclature used previously to denote these rocks (e.g., Jenness, 1963; Younce, 1970; O'Brien, 1987). Both eastern and western belts are discussed separately as their exact stratigraphic relationship is uncertain (see below).

Eastern Belt. The Musgravetown Group east of the Bloody Reach fault is an approximately 800-m-thick homoclinal succession of mainly subaerial volcanic and sedimentary rocks (Units 10 to 13). The lowest unit in the sequence consists of approximately 200 m of red to maroon, variably banded, very fine grained rhyolite (Unit 10). Intricately flow-banded rhyolite forms 90 percent of the exposures of this unit; spherulitic zones are present, but uncommon. A buff, lithic-rich ash flow occurs locally at the base of the rhyolite; a distinctive rhyolite breccia forms the top of the unit.

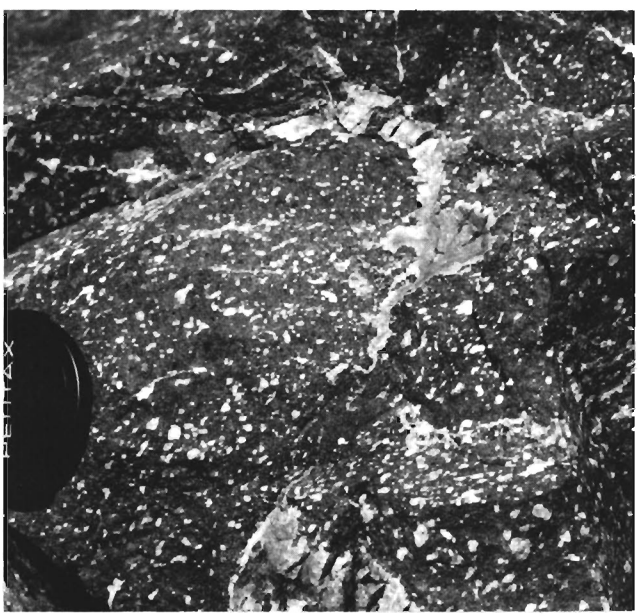

Plate 5. *Vesicular basalt with quartz–carbonate veinlets (Unit 11); Musgravetown Group, west shore of Bloody Reach.*

The rhyolite breccia is conformably overlain by approximately 225 m of basaltic volcanic rocks (Unit 11). The diagnostic lithology is amygdule-rich, variably oxidized basalt (Plate 5). The basalt is generally massive, although flow tops are recognized locally. Mafic tuff and thin beds of red sandstone are intercalated with the basalt in several places. The top of the unit is marked by a zone of flow-top breccia overlain by a coarse grained, epiclastic volcanic breccia containing subangular, rounded and tabular clasts of the basalt and underlying rhyolite.

The basalt unit is succeeded by approximately 50 m of thin-bedded to laminated, dark-green, locally tuffaceous sandstone (Unit 12). The basal contact of the sandstone is gradational over 2 to 3 m.

Unit 12 grades upward, over a few metres, into a coarsening-upward, 400-m-thick succession of dominantly red, coarse grained, clastic sedimentary rocks (Unit 13). Locally, a green–yellow, metre-thick, tuffaceous sandstone is present at the base of the succession. Above this sandstone, the lower part of the unit consists of graded and rippled, generally poorly bedded to amalgamated red sandstone containing thinly interstratified red shale. These rocks are succeeded by red, poorly sorted pebble conglomerate containing sandstone interlayers, which pass upward through interbedded red, pebble conglomerate, sandstone and rare shale into cleaved, pebble conglomerate. The latter rock is rich in rhyolitic volcanic detritus and persists to the top of the succession.

Plate 6. *Lithic tuff of Unit 10 overlying basalt–boulder conglomerate, Tumbler Island.*

The base of the Musgravetown Group east of the Bloody Reach fault is exposed on the west shore of Tumbler Island. There, a thin unit of lithic tuff, overlain by rhyolite, is unconformable on mafic volcanic rocks of the Love Cove Group. The two groups are separated by a 1- to 2-m oligomict, boulder conglomerate–breccia containing rounded blocks of the underlying mafic rocks (Plate 6).

Western Belt. The extensive Musgravetown Group succession west of the Bloody Reach fault is divided into four formations, which from oldest to youngest are: Bull Arm, Rocky Harbour and Crown Hill (Jenness, 1963) and Deer End (Younce, 1970).

The Bull Arm Formation (Unit 14) is composed of dominantly felsic volcanic and lesser tuffaceous sedimentary and mafic volcanic rocks that are exposed in a series of periclinal folds, mainly in the eastern half of the outcrop belt. Its diagnostic rocks are rhyolite flows and ash flows, both of which are flow layered. The rhyolite flows, like those in the Musgravetown Group to the east of the Bloody Reach fault, are characterized by their intricate flow patterns. Minor amounts of felsic volcanic breccia are associated with the flows. A sequence of green and grey, mafic tuffaceous sedimentary rocks (subunit 14a), containing several subaerial basalt flows, minor rhyolite flows and a distinctive mafic agglomerate (subunit 14b), underlies the main rhyolite unit in an anticlinal core located north of Rocky Bay and east of Great Content Cove (Figure 2).

Plate 7. *Wispy-bedded sandstone; Rocky Harbour Formation, Musgravetown Group.*

The stratigraphically highest rhyolite of the Bull Arm Formation is overlain by a pebble to cobble conglomerate unit that marks the base of the overlying and structurally concordant Rocky Harbour Formation (Unit 15). This formation is between 1- and 1.5-km thick in the map area and is divided into sedimentary and volcanic lithofacies. The most widespread rock type within the formation is green, thin-bedded to laminated, fine- and medium-grained sandstone, displaying a characteristic, wispy stratification (Plate 7). This rock is associated with planar-stratified and cross-stratified, locally quartzose, green, buff and pale-yellow sandstone, and minor pebble conglomerate. At least four separate rhyolite flows or sills (subunit 15a) are interstratified with the upper part of the sequence. These are either fine grained and originally glassy (now devitrified), very finely porphyritic or flow banded; all are buff to pale yellow-green.

The top of the Rocky Harbour Formation is drawn at the first appearance of purple and red sandstone interbeds of the overlying Crown Hill Formation (Unit 16). This formation consists of mainly red sandstone and pebble to boulder conglomerate and is separated into four informal lithostratigraphic units (Unit 16 and subunits 16a, 16b and 16c). The Crown Hill Formation is exposed in a broad open syncline on the east shore of Content Reach, and to the north, in open folds on Deer Island and nearby islands. All subunits are not necessarily exposed or deposited in a single area.

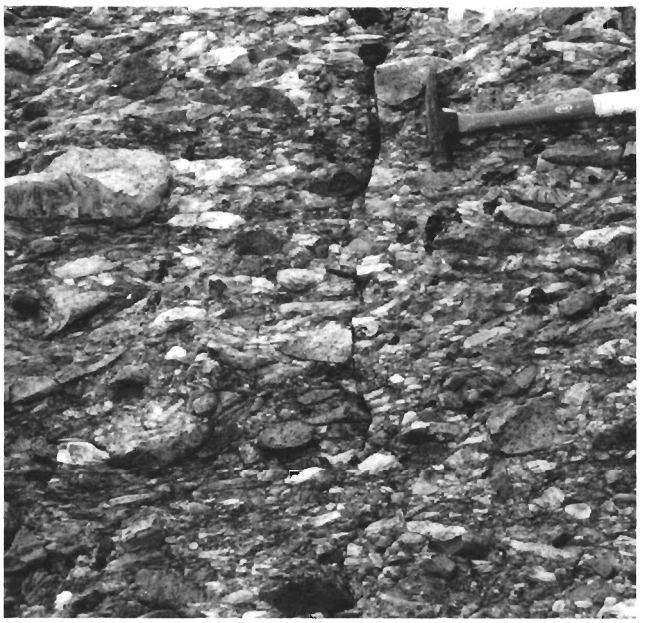

Plate 8. *Pebble conglomerate; Crown Hill Formation, Musgravetown Group from core of the syncline at Content Reach.*

At Deer Island, the base of the Crown Hill Formation is marked by red sandstone and granule conglomerate (Unit 16). In the syncline at Content Reach, red, purple and green sandstone, granule sandstone and granule to pebble conglomerate (subunit 16b) form the lowest part of the Crown Hill Formation. This is overlain by a fining-upward boulder to pebble conglomerate succession (subunit 16a; Plate 8). Clasts in these conglomerates are well-rounded, poorly sorted and derived from underlying Musgravetown Group rocks, particularly the Bull Arm Formation. The conglomerates fine rapidly along strike across the core of the syncline, and are succeeded by red sandstone and granule conglomerate, equivalent to the oldest part of the Crown Hill succession at Deer Island (Unit 16). At Deer Island, the uppermost subunit (16c) of the Crown Hill Formation is exposed. It consists of green sandstone, overlain by mainly red and also variegated sandstone that contains thin beds of granule conglomerate and quartzose sandstone.

At Deer Island, the Crown Hill Formation is overlain conformably by the Deer End formation (Unit 17; Younce,

1970), a unit consisting of approximately 900 m of green and grey sandstone, quartzite, quartz sandstone, grey shale and calcareous sandstone. A similar sequence occurs along strike to the southwest at Lockers Flat Island. That portion of the succession on Deer Island above the highest quartzitic sandstone was included in the Deer End formation by Younce (1970). Younce's original definition is here expanded to include that part of the succession below the quartzite to the top of the underlying Crown Hill Formation. The Deer End formation has not yielded body fossils, but it is lithologically similar to lowermost Cambrian rocks in Fortune Bay (e.g., Chapel Island Formation) that conformably underlie the Random Formation quartzites. The authors do not concur with Younce's assignment of the quartzitic portion of this succession to the Random Formation.

The basal unit of the Deer End formation consists of a thin succession of variegated sandstone and siltstone (exposed only on Deer Island), overlain by green and grey, thin- to medium-bedded sandstone and laminated siltstone containing S-shaped worm burrows. The green and grey rocks are interbedded with quartzose sandstone and grey siltstone, the latter being rich in detrital muscovite. These rocks are, in part, interstratified with, but also overlain by white, quartzofeldspathic sandstone and quartz arenite containing a minor amount of variegated sandstone. The top of the formation, exposed only on the west end of Deer Island, consists of green and grey sandstone with calcareous nodules, grey shale and calcareous sandstone. Younce (1970) measured this unit's total thickness at approximately 525 m.

An exact correlation between Musgravetown Group units on either side of the Bloody Reach Fault cannot be made without the results of chemical and precise geochronological studies, some of which are still in progress. The sequence east of the fault may represent: 1) a condensed version of the entire succession to the west, or 2) equivalents of the Bull Arm Formation only. The first scenario requires a thinning of the Rocky Harbour Formation from 1500 m in the west to 50 m in the east. The latter possibility is presently favoured.

Plutonic Rocks within the Musgravetown Group

Dykes and sills of mainly gabbroic composition intrude the Musgravetown Group. These are designated as Unit 18 on Figure 2. Many are demonstrably pretectonic. Several gabbros intruding into the lower portion of the group are exposed along the coastline between Content Reach and Bloody Reach and on Pitt Sound Island. Typically, a core of coarse- to medium-grained, patchy-textured, equigranular to subporphyritic gabbro fines outward into fine grained plagioclase-porphyritic diabase. Locally, the gabbro contains patches of quartz diorite. At Little Content Cove, cordierite-bearing, wispy-bedded sandstone is cut by chloritized, fine grained, porphyritic to subporphyritic hornblende–biotite granodiorite (subunit 18a), the contacts of which can be traced parallel to the strike of the sandstone. Many cleaved to massive diabase dykes, generally less than 1-m wide, intrude the Bull Arm and Rocky Harbour formations. Diabase dykes that intrude into higher levels of the succession are not common.

An orange-red granite porphyry sill or dyke (subunit 18b), containing zoned and hematitized feldspar phenocrysts up to 2-cm long, intrudes the upper part of the Rocky Harbour Formation at the east end of Rocky Bay. A dyke of similar composition and texture intrudes similar rocks on the west shore of Content Reach.

STRUCTURE

The map area is crossed by several major northeast- to north-northeast-trending, high-angle faults that define lithologically and structurally distinct regions. In the west, the Dover Fault separates the western belt of the Love Cove Group from mylonitic Dover Fault granite (Blackwood, 1976, 1977). In the western belt, the Love Cove Group carries a regionally penetrative, vertical to subvertical, northeast-trending foliation, which intensifies adjacent to the Dover Fault. Within the steep to vertical fault zone, tuffs are mylonitic. The Dover Fault has a protracted history of movement (Blackwood, 1976, 1977), although the mylonitic fabric developed within the fault zone is considered to be Acadian (Dallmeyer *et al.*, 1981). The main and perhaps latest movements are considered generally to be strike slip (Blackwood, 1977, 1985; Caron, 1986). These observations are supported by deep seismic data (Keen *et al.*, 1986), which indicate the structure is a vertical fault that offsets the Moho. A detailed description of the fault can be found in Blackwood (1976, 1977) and Dallmeyer *et al.*, (1981). Its kinematic history has been discussed by Caron (1986).

The Howses Cove fault (Younce, 1970) is a high-angle structure that separates the Love Cove Group from adjacent Musgravetown Group rocks to the east. The fault, unexposed in the map area, strikes north-northeast from Howses Cove in the adjacent Gambo (2D/16) map area under Content Reach. It juxtaposes highly strained, sericitized and chloritized, volcanic rock and openly folded, little-deformed rocks of the upper parts of the Musgravetown Group (Plate 9).

The folded Musgravetown Group to the west of the Bloody Reach Fault is cut by numerous northeast- and

Plate 9. *Moderately dipping sandstone, typifying structural style in Musgravetown Group near trace of Howses Cove Fault; Dover Fault and Gander Zone are in background skyline.*

northeast-trending, high-angle faults and by east-southeast-trending cross faults. A major fault zone trending north-northeastward through Pitt Sound Island is marked by zones of sericite schist, brecciation and quartz veining.

The Bloody Reach fault is unexposed in the map area, but its trace underlies Bloody Reach; the geology of small islets within the reach (not shown on Figure 2) constrain the position of the fault to within 1 km of the eastern shore. On land to the southeast (outside the map area), the structure comprises a ductile fault zone in which strain is relatively high. The fault zone separates the Love Cove Group from the western belt of the Musgravetown Group (O'Brien, 1987).

The Musgravetown Group to the east of the Bloody Reach fault is offset sinistrally by cross faults that trend east-northeast, east and east-southeast.

The Love Cove Group and the lower parts of the Connecting Point Group are exposed on the common inverted limb of a major anticline–syncline pair, the axes of which trend northeastward through Hail Island and Willis Reach, respectively. Typically, the Connecting Point Group strata are steeply inverted or vertical and upright. On the east side of Cottel and Tumbler islands, however, inverted beds of Connecting Point Group having dips as shallow as 45 degrees are exposed. Within and to the east of the Willis Reach syncline, the Connecting Point Group is predominated by cleaved shaly rocks that are disposed in a series of small-scale, fold pairs with east-dipping axial planes. The stratigraphically higher levels of the group exposed east of Willis Island are disposed in broad, open, locally periclinal folds with partly curvilinear fold hinges. Farther south and east, on the Salvage Peninsula, the highest levels of the group form an east-dipping homocline.

The distribution of the lower portion of the Musgravetown Group, including much of the Bull Arm Formation and the lower half of the Rocky Harbour Formation, is controlled by several north-northeast-trending periclinal folds. A major open, south-plunging anticline controls the outcrop pattern of the lower part of the Bull Arm Formation. The regional disposition of the upper part of the Rocky Harbour Formation and the overlying Crown Hill and Deer End formations of the Musgravetown Group is controlled by a major, open, north-plunging syncline, the axis of which passes immediately west of Lockers Flat Island and Deer Island. Parasitic on the major regional fold are an open, gently north-plunging anticline to its west, and several open, south-plunging syncline–anticline pairs to its east.

The Musgravetown Group to the east of the Bloody Reach fault is disposed in a moderately (40 to 60 degrees) west-dipping homocline offset by cross faults. On the south end of Cottel Island, the succession is folded into a steeply plunging, periclinal anticline.

METAMORPHISM

All rocks within the map area contain mineral assemblages typical of low-grade, regional metamorphism. Whereas there is evidence for some synvolcanic metamorphism in the form of epidote–quartz blocks in intraflow basalt breccia, most of the chlorite-grade assemblages formed during the main episode of deformation. Typical macroscopic assemblages are quartz–sericite–epidote and chlorite–epidote–albite.

Pretectonic cordierite hornfels occur in the aureole of small intrusions in the Musgravetown and Connecting Point groups. Intrusion of the granodiorites into the Love Cove Group has resulted in local silicification, sericitization and epidotization.

ECONOMIC GEOLOGY

In the central portion of the map area, the Love Cove Group contains numerous occurrences of silicified and pyritized, locally sericitized volcanic rocks. Many of these showings have yielded elevated gold contents. The occurrences in the central St. Brendans map area form the northeast continuation of a narrow (1 to 2 km) band of variably altered, locally auriferous rocks within the Love Cove Group, extending along strike for over 30 km. All but three of the samples listed in Table 1 are assays of chip and grab samples collected within this zone.

In the St. Brendan's map area, altered volcanic rocks containing pyrite, sericite and secondary quartz, with or without gold, are exposed on Hail Island, Coal Island, the northeast end of Broad Island and several of the small islets adjacent to these islands, as well as on Tumbler Island and Cottel Island (see Figure 2). On the latter two islands, a several-hundred-metre-wide zone of pyritic alteration is developed within intermediate tuffs of the Love Cove Group. Mineralization is found in each of the three subunits of the Love Cove Group, and in several areas the mineralization and alteration is spatially associated with mafic dykes. These alteration zones are also spatially associated with fault zones and in some cases with exposed granitoid intrusions. The age of mineralization is unknown, although similar mineralization in the same rocks along strike on the Burin Peninsula is considered to be Precambrian (Huard and O'Driscoll, 1986).

The protolith of the altered rocks include vitric tuff, lithic tuff, quartz-phyric rhyolite, felsic agglomerate, mafic tuff and metabasic flows. Gold contents up to 575 ppb (1 m chip sample collected from a quartz vein in silicified rhyolite) were obtained during the course of mapping (Table 1). A typical silicified rock from the Coal Island–Hail Island area contains crosscutting, grey and black quartz veinlets and sweats (both mm- and cm-scale), as well as pervasive fine grained silica. The degree of pyritization of these rocks is variable. Individual occurrences may contain between 0.1 and 2 percent disseminated sulphide or cm-scale zones of massive pyrite. The degree of sericitic alteration varies from a fine dusting on cleavage planes to sericite schist composed almost entirely of fine grained mica.

The Musgravetown Group hosts minor mineral occurrences in several localities. On the north shore of a cove on the northwest corner of Pitt Sound Island, chalcopyrite,

Table 1. Gold assay results (greater or equal to 10 ppb) from the Love Cove Group in the St. Brendan's and Eastport map areas

Sample number	N.T.S.	Lithology	Au (ppb)	UTM easting,northing
1941383	2C/12	felsic tuff	32	287750,5394100
1941384	2C/12	felsic tuff	22	287750,5394100
1941389	2C/12	rhyolite	87	281675,5400750
1941402	2C/12	silicified tuff	21	288650,5398600
1941404	2C/12	silicified breccia	51	289250,5399375
1941405	2C/12	silicified tuff	80	289150,5399350
1941409	2C/12	silicified breccia	111	289200,5399350
1941415	2C/12	pyritic sericite schist	10	290900,5402700
1941416	2C/12	pyritic sericite schist	14	290900,5402700
1941556	2C/13	intermediate tuff	30	294500,5407200
1941561	2C/13	quartz veinlets	65	294500,5407000
1941562	2C/13	silicified tuff	10	294400,5406900
1941563	2C/13	silicified tuff	75	294360,5406780
1941572	2C/13	rhyolite	15	294380,5405010
1941575	2C/13	silicified tuff	10	295000,5406370
1941578	2C/13	silicified tuff	25	294650,5405880
1941583	2C/13	quartz vein	575	294610,5406000
1941619	2C/13	felsic dyke	45	286850,5405200
1941681	2C/13	quartz vein	510	308310,5417800
1941682	2C/13	quartz vein	65	308310,5417800

together with minor chalcocite and bornite, in quartz veins, occurs near the contact of a diorite–gabbro intrusion. At the showing, veinlets of granodiorite and felsite, presumably late-stage phases of the larger intrusion, crosscut a metabasalt that is part of a succession of interbedded basalt and tuffaceous sedimentary rocks within the Bull Arm Formation (subunit 14a). The showing consists of two quartz–carbonate–chlorite–epidote veins, approximately 10 cm wide, that trend north and dip between 70 degrees east and vertical. In the midnineteenth century, a small adit was driven into the vein for a distance of several metres (Plate 10). Massive veins and stringers of quartz, locally containing specular hematite and pyrite, cut the Musgravetown Group elsewhere on Pitt Sound Island as well as at The Beaches and Lakeman's Island. On the south shore of Rocky Bay, rusty, silicified zones cut by quartz–chlorite–epidote–specular hematite veins are present in the basal part of the Rocky Harbour Formation.

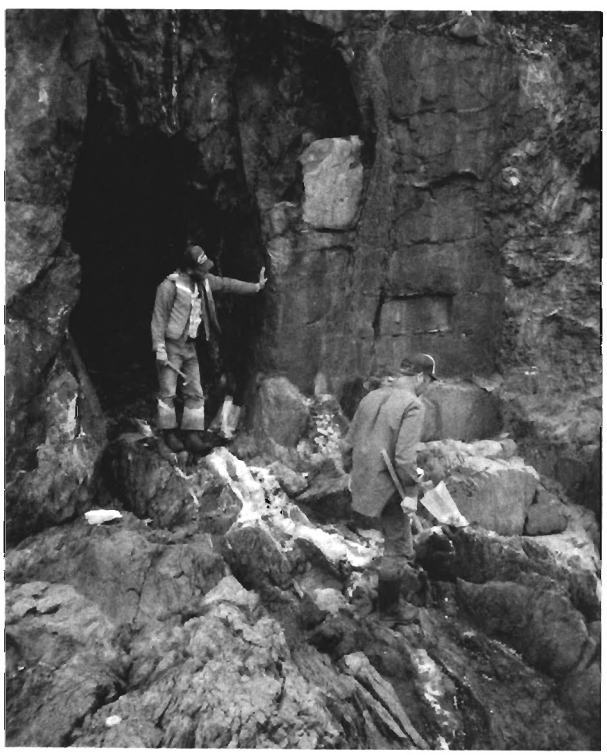

Plate 10. *Adit along chalcopyrite–bornite–calcite vein, Pitt Sound Island.*

The Connecting Point Group is cut by quartz–carbonate veins adjacent to the mafic plugs in the northeast part of the map area. On the southernmost of the three Inner Gooseberry Islands, a 70-m by 1- to 30-cm-crosscutting quartz vein occurring at the diorite–shale contact, yielded an assay of 510 ppb gold. Murray and Howley (1881) describe argentiferous quartz–asenopyrite–specularite–pyrite veinlets from the same area.

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REFERENCES

Blackwood, R.F.
1976: The relationship between the Gander and Avalon Zones in the Bonavista Bay Region, Newfoundland. Unpublished M.Sc Thesis, Memorial University of Newfoundland, St. John's, 156 pages.

1977: Geology of the east half of the Gambo (2D/16) map area and the northwest portion of the St. Brendan's (2C/13) map area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-5, 20 pages.

1985: Geology of the Facheux Bay area (11P/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-4, 56 pages.

Blackwood, R.F. and Kennedy, M.J.
1975: The Dover Fault: western boundary of the Avalon Zone in northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 12, pages 320-325.

Caron, A.
1986: Microstructural study of the Dover Fault, northeastern Newfoundland. *In* Program with Abstracts, Volume 11. Geological Association of Canada, Mineralogical Association of Canada and Canadian Geophysical Union, Joint Annual Meeting, Ottawa, page 52.

Christie, A.M.
1950: Geology of the Bonavista map area, Newfoundland. Geological Survey of Canada, Paper 50-7, 40 pages.

Dalbello, A.E.
1977: Stratigraphic position and petrochemistry of the Love Cove Group, Glovertown–Traytown map area, Bonavista Bay, Newfoundland, Canada. Unpublished M.Sc Thesis, Memorial University of Newfoundland, St. John's, 155 pages.

Dallmeyer, R.D., Blackwood, R.F. and Odom, A.L.
1981: Age and origin of the Dover Fault: tectonic boundary between the Gander and Avalon Zones of the northeast Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 18, pages 1431-1442.

Dallmeyer, R.D., Odom, A.L., O'Driscoll, C.F. and Hussey, E.M.
1981a: Geochronology of the Swift Current granite and host volcanic rocks of the Love Cove Group, southwestern Avalon Zone, Newfoundland: evidence of a late Proterozoic volcanic–subvolcanic association. Canadian Journal of Earth Sciences, Volume 18, pages 699-707.

Hayes, A.O.
1948: Geology of the area between Bonavista and Trinity Bays, eastern Newfoundland. Geological Survey of Newfoundland. Bulletin 32, Part 1, pages 1-37.

Huard, A. and O'Driscoll, C.F.
1986: Epithermal gold mineralization in late Precambrian volcanic rocks on the Burin Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 65-78.

Jenness, S.E.
1963: Terra Nova and Bonavista map areas, Newfoundland. Geological Survey of Canada, Memoir 327, 184 pages.

Keen, C.E., Keen, M.J., Nichols, B., Reid, I., Stockmal, G.S., Colman-Sadd, S.P., O'Brien, S.J., Miller, H., Quinlan, G., Williams, H. and Wright, J.
1986: A deep seismic reflection profile across the northern Appalachians. Geology, Volume 14, pages 141-145.

Knight, I. and O'Brien, S.J.
This volume: Stratigraphic and sedimentological studies of the Connecting Point Group, portions of the Eastport (2C/12) and St. Brendan's (2C/13) map areas, Bonavista Bay, Newfoundland.

Murray, A. and Howley, J.P.
1881: Geological Summary of Newfoundland (Reports for 1864 through 1880). Edward Stanford, London, 536 pages.

O'Brien, S.J.
1987: Geology of the Eastport (west half) map area, Bonavista Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 257-270.

O'Brien, S.J. and Blackwood, R.F.
1987: St. Brendan's (2C/13), Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Map 87-55.

O'Brien, S.J., Strong, P.G. and Evans, J.
1977: The geology of the Grand Bank (1M/4) and Lamaline (1L/13) map areas, Burin Peninsula, Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-1, pages 35-42.

Widmer, K.
1949: Unpublished map and incomplete report on the Glovertown–Clode Sound area. Geological Survey of Newfoundland. [2D9/65]

Williams, H.
1976: Tectonostratigraphic subdivision of the Appalachian orogen. *In* Abstracts with Programs, Volume 8, Number 2. Geological Society of America, Northeast Section Annual Meeting, page 200.

Williams, H. and Hatcher, R.D. Jr.
1983: Appalachian suspect terranes. *In* Contributions to the tectonics and geophysics of mountain chains. *Edited by* R.D. Hatcher, Jr., H. Williams and I. Zeitz. Geological Society of America, Memoir 158, pages 33-53.

Younce, G.B.
1970: Structural geology and stratigraphy of the Bonavista Bay region, Newfoundland. Unpublished Ph.D. thesis, Cornell University, Ithaca, New York, 188 pages.

Note: Mineral Development Division file numbers are included in square brackets.