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ON THE GEOLOGICAL DEVELOPMENT OF THE AVALON ZONE IN THE AREA BETWEEN OCEAN POND AND LONG ISLANDS, BONAVISTA BAY (PARTS OF NTS 2C/5 AND NTS 2C/12)

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ABSTRACT

The dominantly marine, siliciclastic Connecting Point Group is the oldest stratigraphic unit in the area and is of late Precambrian age. Its strata are affected by northwest- to northeast-trending, open, upright folds, many of which are cleavageless. On a regional scale, progressively higher stratigraphic levels of the group are encountered southeastward across the map area. Red conglomerate, assigned by previous workers to the Musgravetown Group, unconformably overlies a sequence of redbeds, here included in the Musgravetown Group, on Southward Head. Elsewhere, thin-bedded, shallow-marine to terrestrial sandstones, assigned here to the Musgravetown Group, lie above Connecting Point turbidites, without obvious discordance. The Musgravetown Group succession east of Indian Arm differs from that to the west, and includes a bimodal volcanic unit correlated with the Bull Arm Formation. Basal Cambrian quartz arenites (Random Formation) are infolded, in a series of northeast-trending anticlines and synclines, with uppermost red sandstone and conglomerate units of the Musgravetown Group. These folds are associated with a strong, axial-planar, slate-like cleavage. The quartz arenites, which appear to be conformable on underlying strata, represent the basal division of an internally concordant, shale-dominated platformal succession (Adeyton and Harcourt groups). The age of the cover sequence on Southward Head and its equivalents elsewhere are unknown but a post-Cambrian age for those rocks cannot be discounted.

INTRODUCTION

This report presents the preliminary results of recent 1:50 000-scale bedrock geological mapping carried out in the eastern half of the Sweet Bay map area (NTS 2C/5) and in the adjacent southeastern corner of the Eastport map area (NTS 2C/12), Bonavista Bay. The survey augments mapping in the Sweet Bay area by the Geological Survey Branch in 1992 (O'Brien, 1992, 1993), and supplements earlier systematic mapping and related sedimentological studies in the Eastport area (O'Brien, 1986, 1987; O'Brien and Knight, 1988).

Previous geological mapping in this area was carried out by the Geological Survey of Newfoundland, as part of a regional survey around Bonavista and Trinity bays (Hayes, 1948). Following Newfoundland's confederation with Canada in 1949, the Geological Survey of Canada (GSC) began remapping the same region at the scale of 1:125 000; results of some initial aspects of this work are presented by Christie (1950). The most recent published geological map of the study area is the GSC 1:250 000-scale Bonavista (NTS 2C) sheet (in Jenness, 1963). This map is based, in part, on reconnaissance mapping by Jenness over a 10-week-period in 1957, carried out in an attempt to consolidate Christie's earlier work, much of which had been unpublished.

REGIONAL SETTING AND STRATIGRAPHIC FRAMEWORK

The area studied is centred on Sweet Bay, in southeastern Bonavista Bay, on the east coast of the Island of Newfoundland. The area is part of the much larger Avalon Zone of the Newfoundland Appalachians (Williams, 1979), and its geology exemplifies the distinctive tectonostratigraphic nature of that zone in a number of ways. The first is the occurrence of thick and regionally homogeneous sequences of deep- to shallow-marine sedimentary rocks of late Precambrian age. The second is the presence of a younger terrestrial clastic succession, also of late Precambrian age, containing bimodal volcanic rocks near its base. Another feature is the presence of a platformal Cambrian cover, composed mainly of fine-grained clastic sedimentary rocks, containing Acado-Baltic trilobite fauna. The last, and more disputable, is possible evidence for weak and inhomogeneous deformation related to the enigmatic Avalonian Orogeny of Lilly (1966), a series of late Precambrian orogenic events, viewed as emblematic of the Avalon Zone throughout the Appalachians (e.g., Rodgers, 1970, 1972).

The late Precambrian *Connecting Point Group* (Hayes, 1948), is the oldest and most extensive of the major geological divisions within the study area (Figure 1). This sequence of marine, siliciclastic sedimentary rocks is divided into three

principal lithostratigraphic components. Progressively higher stratigraphic levels of the group are encountered, on a regional scale, southeastward across the map area. The second and younger of the major Precambrian units in the area, the *Musgravetown Group* (Hayes, 1948), contrasts starkly with the Connecting Point Group in terms of lithology, and is characterized by fluvial and alluvial facies redbeds interlayered with terrestrial rhyolites and basalts. The Musgravetown Group has been separated into several units, two of which can be readily assigned to the *Bull Arm* and *Crown Hill formations* of Jenness (1963).

Shallow-marine to terrestrial sandstones, indistinguishable from parts of the Musgravetown Group in other parts of Bonavista Bay, lie above green Connecting Point strata, without obvious angular discordance. These redbeds were included in the Musgravetown Group by Hayes (1948) and Christie (1950), but subsequently reassigned to the Connecting Point Group by Jenness (1963). Elsewhere, an angular unconformity separates Jenness's Connecting Point Group from overlying red terrestrial clastic and volcanic rocks, assigned by all earlier workers to the Musgravetown Group. The true significance of this unconformity and the age and stratigraphic designation of rocks adjacent to it remain unproven (see below).

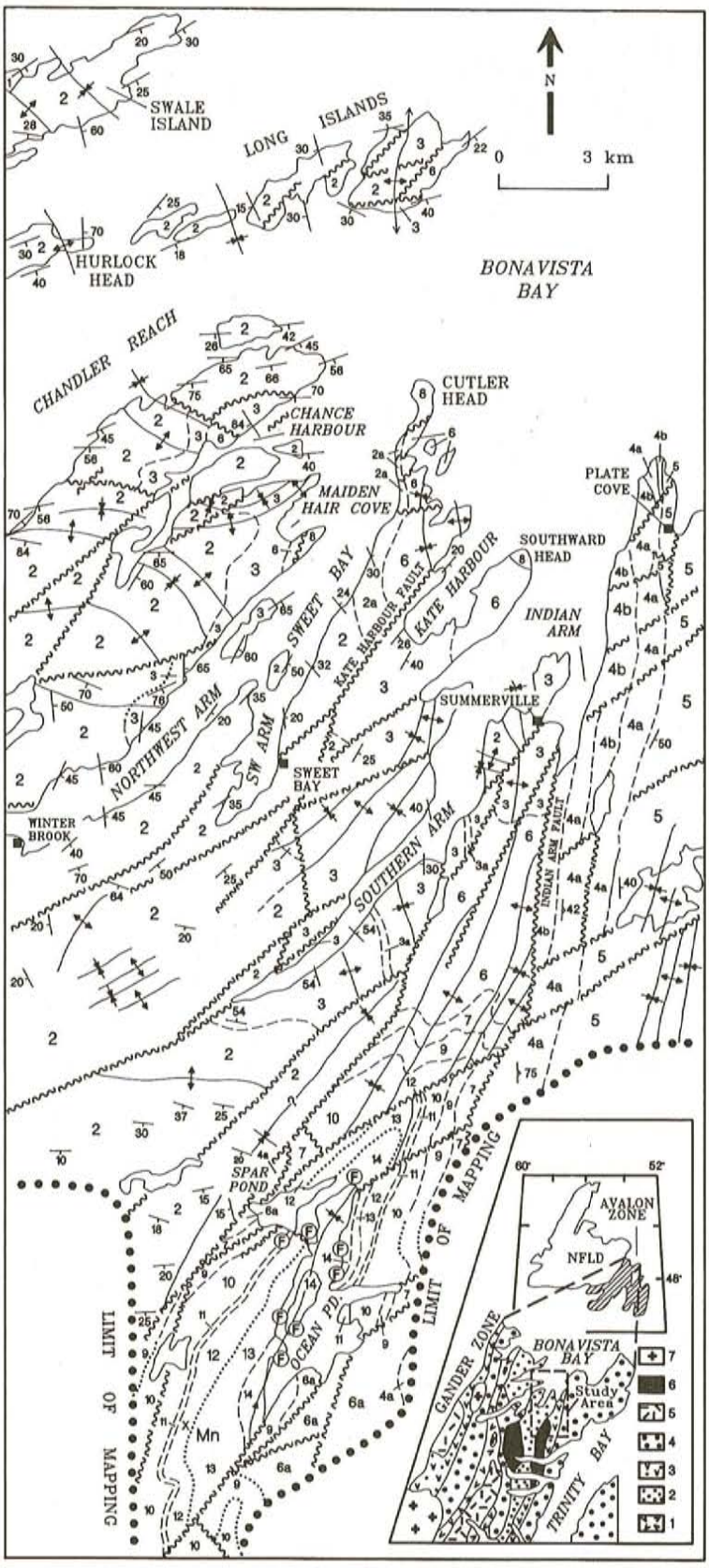
Cambrian sedimentary rocks comprise the final major stratigraphic component of the study area. Quartz arenites of the basal Cambrian *Random Formation* (Walcott, 1900; Christie, 1950) overlie uppermost red sandstone and conglomerate units of the Musgravetown Group in the southern part of the map area. The Cambrian strata are infolded with the underlying rocks and no angular discordance at the Precambrian–Cambrian boundary is apparent. The quartz arenites lie at the base of an internally conformable, shale-dominated platformal succession that comprises the *Adeyton* and *Harcourt groups* (Jenness, 1963). The original stratigraphic relationship of Cambrian rocks and the Connecting Point Group is obscured by faults.

CONNECTING POINT GROUP

The Connecting Point Group is subdivided into three lithostratigraphic components, with a combined thickness of between 2 and 2.5 km. Based on correlations with similar rocks elsewhere in Bonavista Bay, it can be assumed that the lowest part of the succession in the study area lies at least 2 km above the base of the Connecting Point Group.

UNIT 1

Deepest stratigraphic levels of the group occur in the northwest part of the area, on Swale Island,



LEGEND

MIDDLE CAMBRIAN

HARCOURT GROUP

MANUELS RIVER FORMATION

14 *Fossiliferous black shale with grey calcareous concretions; thin grey limestone beds*

ADEYTON GROUP (Units 10 to 13)

CHAMBERLAINS BROOK FORMATION

13 *Green slate, manganiferous grey shale and red, variably manganiferous, slate and shale*

EARLY CAMBRIAN

BRIGUS FORMATION

12 *Grey and grey-green shale and slate; red slate with pink limestone nodules*

SMITH POINT FORMATION

11 *Fossiliferous, pink and bright-red, nodular and oncolitic limestone; minor red and grey shale with limestone nodules*

BONAVISTA FORMATION

10 *Light-green and grey slate and shale; red shale and slate, locally with calcareous nodules*

RANDOM FORMATION

9 *White quartz arenite; white and grey granule to pebble conglomerate; minor micaceous sandstone*

LATE PRECAMBRIAN OR SILURO-DEVONIAN?

8 *Red boulder to pebble conglomerate; basaltic flows and breccia; minor fine-grained, volcanogenic sedimentary rocks*

LATE PRECAMBRIAN

MUSGRAVETOWN GROUP

West of the Indian Arm Fault

Crown Hill Formation

7 *Red pebble conglomerate with minor red sandstone; rare quartz pebble conglomerate and pink quartz arenite*

6 *Red, purple and maroon siltstone and fine- to coarse-grained red sandstone, and more rarely, pebble conglomerate. Minor buff and green siltstones and pale-green, siliceous sandstone;* **6a,** *green, thin-bedded sandstone*

East of the Indian Arm Fault

5 *Grey, green, and locally pale-red, cobble- to fine-grained boulder conglomerate; grey, feldspar-rich, pebbly sandstone and variegated volcanogenic granule conglomerate*

Bull Arm Formation

4 **4a,** *red and maroon, massive to finely banded aphyric and feldsparphyric, rheomorphic ash-flow tuff; fine-grained pyroclastic flows and welded breccia; minor massive to banded lava flows and autobreccia; minor variegated, volcanogenic sandstone;* **4b,** *grey-green vesicular to aphyric basalt flows; minor mafic breccia and unseparated sedimentary rocks*

CONNECTING POINT GROUP (Units 1 to 3)

3 *Thin- and regularly-bedded dark-grey siltstone and fine-grained sandstone, containing thin black silty laminae, internal cross-laminae and ripple-drift structures. Minor red and purple siltstone and coarse-grained grey sandstone;* **3a,** *mafic tuff and tuff-breccia*

2 *Mainly regularly bedded, grey-green to buff-weathering, medium- to thin-bedded silicified sandstone with unseparated, thick beds of buff, amalgamated sandstone; minor dark-grey thin-bedded siltstone;* **2a,** *grey to pale-pink sandstone and granule conglomerate*

1 *olistostrome; minor slumped and planar-bedded grey shale and siltstone*

SYMBOLS

Geological boundary (defined, approximate, assumed)

Bedding, tops known, inclined

Flow banding

Syncline

Anticline

Fossil locality

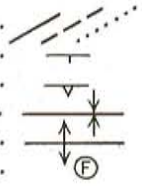


Figure 1. *Simplified geological map of the study area. Inset shows the area's regional setting and location; numbers in inset legend correspond to: Love Cove Group (1), Connecting Point Group (2), Musgravetown Group—mainly volcanic rocks (3), Musgravetown Group—mainly terrestrial sedimentary rocks (4), Precambrian granite (5), Cambrian sedimentary rocks (6), and Devonian granite (7).*

where olistostromes (Unit 1) are exposed. These chaotic slump deposits, which are spectacularly and extensively developed farther north in the Eastport (NTS 2C/12) area, overlie a shale-rich part of the Connecting Point succession (O'Brien and Knight, 1988; Knight and O'Brien, 1988). The olistostromes—or mixtites—are coarse-grained, unsorted or poorly sorted rocks containing metre- to centimetre-scale sedimentary olistoliths in a shaly or variably tuffaceous matrix. The olistoliths are thinly layered, slump-folded or massive. The base of the olistostrome unit has scoured into underlying shales. Fine-grained, syn-sedimentary diabase dykes are emplaced into both the mixtite and the slump-folded, in-situ shaly rocks associated with it.

UNIT 2

Chandler Reach Sections

On Swale Island, Unit 1 olistostromes are succeeded by regularly bedded, thin- to medium-bedded[1] green and grey turbidites. Rocks of similar facies underlie much of the nearby Long Islands and the Hurlock Head promontory (Figure 1). The affect of broad periclinal folds notwithstanding, the overall younging direction is toward the south, from Swale Island to Long Islands, across Chandler Reach, and thence onto the mainland. There, similar rocks form most of the bedrock exposures west and south of Sweet Bay. These turbidite facies rocks, the most extensive of the Connecting Point Group, are collectively designated as Unit 2 on the accompanying map.

The succession on Swale Island, which represents the lower 900 m of the unit, is characterized by regularly bedded, grey-green to buff-weathering, medium- to thin-bedded silicified sandstones (Plate 1). These are locally disposed in thinning- and fining-upward cycles but, in general, the succession appears to be coarser grained and thicker bedded in its upper parts. Beds are graded, internally cross- and planar-laminated, shale-capped, and locally display sole markings; clearly, they have been deposited by turbidity currents. Pale-grey to buff, thick to very thick, amalgamated sandstone beds occur in the thin-bedded sequence at several intervals. The beds have gritty or pebbly bases and are amalgamated and internally convoluted. A distinctive 2-m-thick unit of thin-bedded, bright-green sandstone lies near the mid-point of the succession on Swale Island.

At least 500 m of Unit 2 rocks are exposed on the peninsula between Sweet Bay and Chandler Reach, north of Chance Harbour. It is assumed that these strata lie above those on Swale Island, although it is possible that the sections overlap, or that an intervening section exists underwater in Chandler Reach. The succession here is mainly thin-bedded, siliceous green sandstone, locally disposed, together with medium and, rarely, thick beds of sandstone, in coarsening-upwards cycles. The thin-bedded rocks are rippled, locally slumped, regularly bedded and weather buff or pale brown. On the northwest shore of Chance Harbour, a monotonous succession of thin-bedded rocks, many tens of metres thick, is overlain by regularly layered, medium to thick beds of sandstone and quartzofeldspathic grit. These pass into thin- and medium-bedded sandstones, capped by a distinctive pebbly bed, above which thin-bedded, dark-grey, fine-grained sandstone predominates.

Plate 1. *Medium-bedded sandstone turbidites, Unit 2 of the Connecting Point Group.*

Sweet Bay Sections

A well-exposed cross-section through more than 800 m of the upper part of Unit 2 can be seen along the northwest and southwest arms of Sweet Bay. The lower half of this section, best seen in Northwest Arm, is mainly thin- to medium-bedded, dark-grey sandstones, containing amalgamated, fine-grained, green sandstone beds. The latter vary from about 20 cm up to 2 m in thickness; many of the thicker beds scour into the underlying strata. Locally, the thick beds contain pebbly layers at their base. Graded bases, cross-stratified tops and shaly caps are preserved in the thinner, regularly bedded facies. These pass upward into several tens of metres of medium- to thick-bedded, siliceous, pale-green sandstones that contain very little interlayered shale.

The stratigraphic section of Unit 2, exposed on the east shore of Sweet Bay, between the community of Sweet Bay and Cutler Head, dip and young northeastward, away from the southeast-facing section described above, but are separated from it by a number of exposure gaps. The section begins with thin- to medium-bedded dark-grey to black, fine-grained distal turbidites. These rhythmically bedded rocks contain rare 10- to 15-cm-thick buff sandy beds, which increase in proportion upward (over ca. 20 m) until they are the prevalent

[1] bedding thickness terminology follows that of Ingram (1954).

rock type. This section is capped by thin-bedded, dark-grey siltstone. Similar cycles are repeated several times up-section, interrupted locally by very thick, down-cutting, amalgamated sheet sands.

Between approximately 350 and 400 m above the base of this section, green, medium- to thick-bedded sandstones are predominant, and thin-bedded sandstone–siltstone interlayers are present only at widely spaced intervals. These rocks are succeeded by dark-grey sandstones, which pass up into a thickening- and coarsening-upward sequence capped by massive amalgamated sandstone. At this stratigraphic level, the sandstones are siliceous and in many cases have a very pale-pink hue. Generally, only the thickest beds are pink. From that point upward, Unit 2 contains increasing amount of coarse-grained sandstone, disposed in thickening-and coarsening-upward cycles; these rocks are designated *subunit 2a* on the accompanying map. These sandstones locally exhibit ripple-drift cross-laminae. Near the top of subunit 2a, thick to very thick and massive green sandstones occur, within which are central zones marked by outsized pebbles and, rarely, cobbles. From that point northward, the section is disrupted by cross faults, but continues to dip and young to the northeast or east. The stratigraphically highest part of subunit 2a contains a large proportion of poorly sorted green and khaki grit and granule- to small-pebble conglomerate. In one locality, the conglomerate is red. The rocks of subunit 2a may be time equivalents of parts or all of Unit 3 (see below).

UNIT 3

Unit 3 includes the mainly thin-bedded marine sedimentary rocks that lie at or near the top of the Connecting Point Group throughout much of this area. These rocks are best exposed along the shores of Southern Bay, where they attain a minimum thickness of between 400 to 500 m, approximately.

The most diagnostic rock types are thin- and regularly-bedded dark-grey siltstone and fine-grained sandstone, containing thin black silty laminae (Plate 2). Beds are between 2 and 4 cm thick; bedding surfaces may be subplanar or wavy; internal cross-laminae and ripple-drift structures are common. In some cases, the beds weather brown and white and contain recessive-weathering calcareous zones. Thin, red laminae occur in the upper stratigraphic levels of the unit, where the rocks have a purplish or red cast. A thin mafic tuff and tuff-breccia flow, designated subunit 3a on the accompanying map, occurs in the upper part of Unit 3 on the east side of Southern Bay (Plate 3). Although the unit is marked by thin-bedded, fine-grained rocks, coarser and thicker sandy beds are locally present.

A coarser grained variant of these rocks may occur in what is mapped as subunit 2a on the east side of Sweet Bay. A conformable and gradational contact between Unit 3 rocks with overlying red beds, here assigned to the Musgravetown Group, is seen in several areas (see below). The contact with underlying turbidites appears to be gradational, although in a number of areas it is either unexposed or has been tectonized.

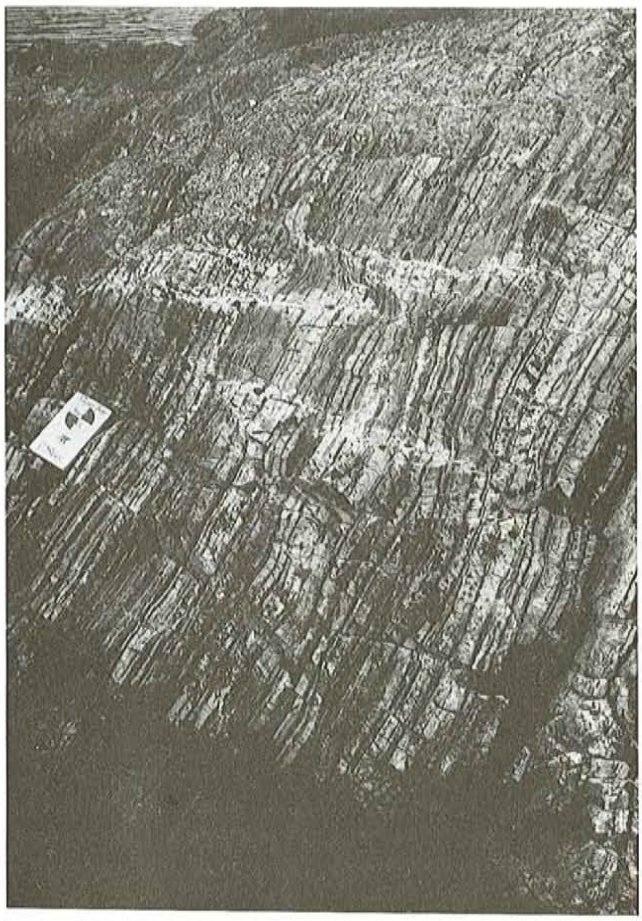


Plate 2. *Thin-bedded sandstone facies, Unit 3 of the Connecting Point Group.*

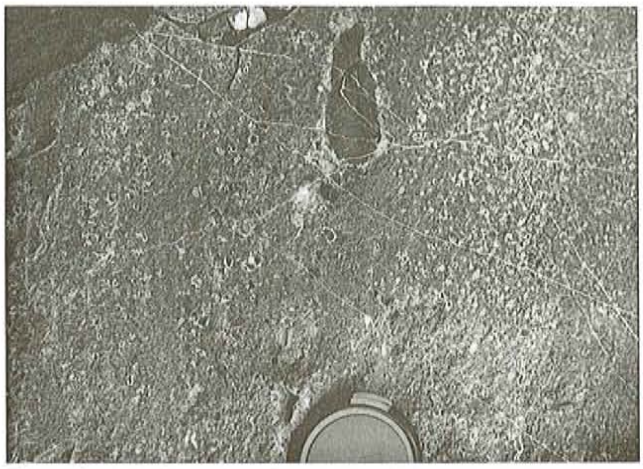


Plate 3. *Mafic tuff, subunit 3a of the Connecting Point Group.*

MUSGRAVETOWN GROUP

An accurate account of Musgravetown Group stratigraphy is best facilitated by describing two separate sections, east

and west of the Indian Arm Fault (Figure 1). Rocks in both sections pass upward into Cambrian strata: at Ocean Pond, in this map area, and farther east, at Keels (Jenness, 1963). Thus, their Musgravetown Group affiliation is clear.

Rocks above the unconformity at Southward Head (Figure 1), and correlative strata at Cutler Head and Maiden Hair Cove were previously included in the Musgravetown Group, at its base (cf. Jenness, 1963). This section, however, records no relationship with Cambrian strata. Independent and unequivocal tests of the age of the succession above the Southward Head unconformity are presently lacking, and the possibility remains that these strata are of mid-Paleozoic rather than late Precambrian age. Because of the uncertainty in stratigraphic designation, these rocks are described in a separate section below (see ROCKS ABOVE THE SOUTHWARD HEAD UNCONFORMITY).

MUSGRAVETOWN GROUP EAST OF THE INDIAN ARM FAULT

Volcanic and sedimentary rocks, assigned here to the Bull Arm Formation (Unit 4), form the lower part of the Musgravetown belt exposed east of the Indian Arm Fault. These are overlain by a sequence of grey and green tuffaceous conglomerate and grit (Unit 5). On a regional scale, the stratigraphic section here becomes younger toward the east, however, folding produces local reversals in this trend.

Bull Arm Formation

Like its equivalents elsewhere in the Bonavista Bay region, the Bull Arm Formation can be best characterized as a bimodal (rhyolite-basalt) volcanic suite, deposited in mainly subaerial conditions. Although interlayering on outcrop-scale does occur, the mafic and felsic rocks more commonly form broad, north–south-trending units, hundreds of metres in width. The most widely developed felsic rock type is massive to finely banded aphyric and feldsparphyric, rheomorphic ash-flow tuff. These red and maroon rocks are associated with fine-grained pyroclastic flows and welded breccia, and in places, all are interlayered with lesser amounts of variegated, volcanogenic sandstone. Less extensively developed are massive to banded lava flows and related autobreccia, which locally exhibit columnar joints (Plate 4).

The mafic volcanic rocks are chiefly grey and grey-green vesicular basaltic flows in which chlorite, hematite and epidote are common secondary phases. Fine-grained, green, aphyric rocks are less extensively developed. Hematite alteration is common and liesegang bands are developed in many areas. Flows up to 10 m in thickness occur; some thicker flows exhibit crude columnar joints. On the east shore of Indian Arm, basaltic flows are interlayered with massive to crudely layered mafic breccia. Sedimentary rocks represent an aerially significant proportion of the Bull Arm Formation exposed along Indian Arm. Thinly laminated, green, yellow-green and reddish-green sandstone siltstone and grit, and lesser amounts of red sandstone and yellow-brown siltstone occur through the lower and middle parts of the succession,

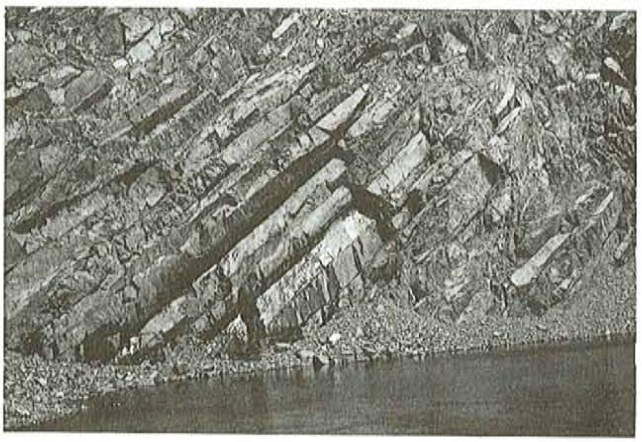


Plate 4. *Columnar jointed lava flow in the Musgravetown Group.*

where they are associated with basaltic flows. Red, pebble and cobble conglomerate and trough-crossbedded red sandstone is interbedded with basalt near the top of this sequence.

Unnamed Conglomerate

The basal part of Unit 5 consists of several tens of metres of grey, green, and locally pale-red, cobble- to fine-grained boulder conglomerate. These are rich in basalt and rhyolite clasts derived from the underlying Bull Arm Formation, and also contain intrabasinal clastic detritus, in addition to red chert, red granite and white vein quartz. The coarser grained rocks are matrix-supported and moderately to well-rounded, although significant tectonic flattening has occurred. Farther south, the conglomerates tend to be either red or purple, rather than grey and green.

The coarse-grained conglomerates pass upward into tectonically flattened, grey, feldspar-rich and tuffaceous, pebbly sandstone and variegated volcanogenic granule conglomerate. Together, these comprise the most extensive facies within the unit. Locally interlayered with these rocks are fine-grained, yellow-green tuffaceous sandstones, containing red and purple laminae. Trough crossbeds are preserved in a few localities. Generally, the rocks are moderately to poorly sorted, although some primary features may be obliterated by the pervasive tectonic fabric.

Basal Contact and Correlation

The base of Unit 5 is exposed on Plate Cove Head, where it conformably overlies a thin basalt flow at the top of the Bull Arm Formation in that area. In the remainder of the map area, the thin basalt flow is not developed and the same conglomerate lies directly on Bull Arm rhyolite and rheoignimbrite. This unit occupies a similar stratigraphic position as the Rocky Harbour Formation of Jenness (1963), and may represent a coarse-grained facies variant of it.

MUSGRAVETOWN GROUP WEST OF THE INDIAN ARM FAULT

Unnamed Red Beds

Extensive successions of interbedded red and, to a lesser extent, green, fine- to coarse-grained clastic sedimentary rocks (Unit 6) conformably and gradationally overlie the Connecting Point Group in at least six areas: south of Summerville, south of Cutler Head, at Maiden Hair Cove and Chance Harbour, below the unconformity at Southward Head, and on the easternmost of the Long Islands (Figure 1). The most extensive area of red beds occurs south of Summerville, where they pass upward, without angular discordance, through the Crown Hill Formation, into the Random Formation.

Unit 6 is characterized by red, purple and maroon siltstone and fine- to coarse-grained sandstone, and more rarely, pebble conglomerate. They are typically thin-bedded, and interlayered on various scales with buff and green siltstones. In areas, the green beds have a mottled, secondary red coloration. Elsewhere, minor pale-green, siliceous sandy beds are present. In exposures on the west shore of Southward Head, the beds become progressively thicker upward, over approximately 400 m of section.

Basal Contact and Correlation

Jenness (1963) assigned the predominantly red sedimentary successions northwest of Southern Bay to the Connecting Point Group, contesting the views of earlier workers (Hayes, 1948; Christie, 1950), who had included at least some of the same rocks with the Musgravetown Group. Jenness's conclusion was based on the assumption that the base of the Musgravetown Group was drawn at the unconformity at Southward Head. However, the red beds in question—below the unconformity—share the same basal relationship (i.e., conformable on Unit 3 of the Connecting Point Group) with lithologically similar rocks south of Summerville (Figure 1), that pass upward, without apparent angular discordance, into the basal Cambrian Random Formation. To include these red beds in the (lithologically dissimilar) Connecting Point Group, (cf. Jenness, *op. cit.*) necessitates separating them from similar red beds (e.g., Musgravetown Group south of Summerville) in the same position, conformably above the Connecting Point Group. A simpler solution—and the one tentatively adopted here—is to assign the red beds in question to the Musgravetown Group.

Crown Hill Formation

The upper part of the Musgravetown Group in this area consists of between 50 and 100 m of conglomerate that underlie the Random Formation, northeast of Ocean Pond (Unit 7; Figure 1). These rocks consist primarily of well-cleaved, poorly sorted, massive to crudely layered, red pebble conglomerate, rich in volcanic and sedimentary detritus. In one area, a distinctive bed of quartz-pebble conglomerate was noted. The red conglomerates are locally interlayered with red gritty sandstone, and near the top of the formation, pink quartz arenite occurs as thin interlayers.

Basal Contact and Correlation

This unit conformably overlies thin-bedded red sandstone and siltstone at the top of Unit 6; the base of the formation is drawn where pebble conglomerate becomes prominent in the succession. On the basis of their lithology and stratigraphic position beneath the Random Formation, these conglomerates are here assigned to the Crown Hill Formation of McCartney (1958).

ROCKS ABOVE THE SOUTHWARD HEAD UNCONFORMITY

On the north end of Southward Head, a well-exposed angular unconformity separates red terrestrial sedimentary and volcanic rocks from underlying Precambrian strata. A corresponding succession of lavas and clastic rocks is exposed at Maiden Hair Cove and Cutler Head, where the unconformity has been in the first case, partly, or in the second case, completely tectonized. These rocks are designated as Unit 8 on the accompanying map.

SOUTHWARD HEAD

Here, the base of the sequence is a moderately to well-stratified red pebble to boulder conglomerate, containing minor sandy material (Plate 5). The basal conglomerate becomes finer grained and thinner bedded in its upper few metres. The basal unit is succeeded by 2 to 3 m of pink felsic lithic tuff and tuffaceous sandstone, overlain by dark-grey to green, vesicular basalt. The section is capped by more red conglomerate.

MAIDEN HAIR COVE

On the point east of Maiden Hair Cove, approximately 3 m of basalt overlies thin-bedded red and green sandstone of Unit 6. The contact has been affected by minor brittle displacements. The basal lava flow is overlain by cobble to boulder conglomerate containing interbeds of purple sandstone. These pass up into several tens of metres of vesicular basalt flows, overlain by mafic breccia. These are succeeded by more interbedded red conglomerate and basalt flows that pass up into buff, yellow and purple sandstones. The top of this succession is marked by red, cobble to fine-grained boulder conglomerate. The latter is well-stratified, matrix-supported and contains many clasts that contain pre-incorporation foliations.

CUTLER HEAD

The thickest section of Unit 8 is exposed at Cutler Head. There, lowermost red sandstone and grey and green, pebbly sandstone and conglomerate are down-faulted against the Connecting Point Group and the overlying Musgravetown Group. The basal beds give way upward to a reddening- and

Plate 5. *Boulder conglomerate immediately above the unconformity surface at Southward Head.*

fining-upward unit of boulder- to pebble-conglomerate, approximately 10 m thick. This conglomerate is succeeded by aphyric, and then vesicular, subaerial basalt flows (Plate 6). These pass up into a red tuff-breccia, capped by red sandstone and conglomerate, which is, in turn all overlain by 6 to 7 m of vesiculated tuff and tuff-breecia. This second tuff unit is overlain by buff, pale-green, and red, variegated sandstones, which pass upward though a coarse-grained, mafic volcanic breccia (Plate 7) into the first of two basalt flows, separated by red sandstone and conglomerate. The upper levels of the section on Cutler Head consist of three massive to vesicular hematite-rich basalt flows, several tens of metres thick. The upper two flows are separated by a 50-cm-thick red sandstone layer.

Basal Contact and Correlation

The basal relationship of this succession is best preserved on the west side of Southward Head, where bedding in the underlying strata, assigned here to the Musgravetown Group, is clearly truncated by an erosion surface, above which, gently dipping, well-stratified, boulder to cobble conglomerate occurs (Plate 8). Rocks, above and below the unconformity, host a single, weakly developed cleavage.

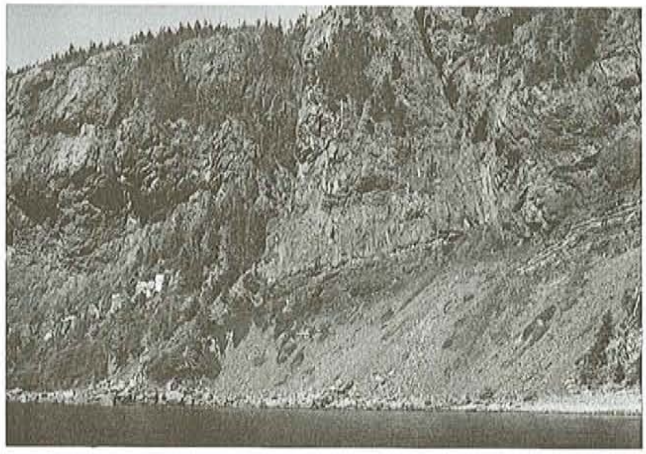


Plate 6. *Basalt flows overlying sedimentary rocks at Cutler Head.*

Plate 7. *Mafic breccia, Cutler Head.*

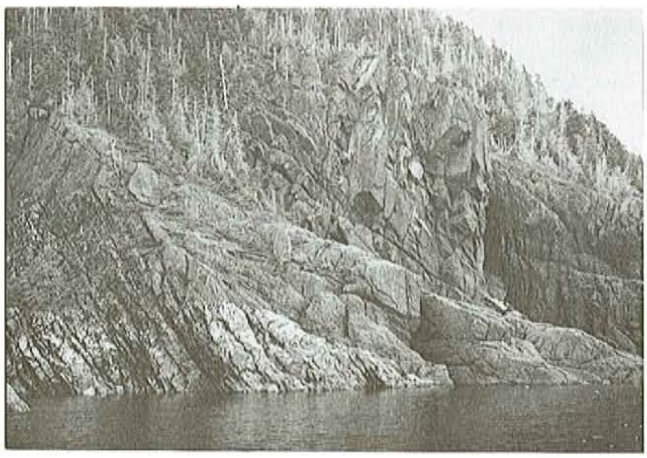


Plate 8. *Unconformity at Southward Head.*

These strata were viewed as the basal parts of the Musgravetown Group by Jenness (1963), who assigned the lavas to the Bull Arm Formation and the red conglomerates to the underlying Cannings Cove Formation. This view is inconsistent, at least in part, with the presence of

Musgravetown Group rocks at deeper stratigraphic levels in the same succession, which locally pass upward, without angular discordance, into fossiliferous Cambrian strata (see above). It remains unclear if the lavas and associated sedimentary rocks at Cutler Head belong to the Musgravetown Group or represent a younger, post-Cambrian cover sequence.

CAMBRIAN ROCKS

Early to Middle Cambrian, fine-grained platformal sedimentary rocks overlie the Musgravetown Group and are infolded with those Precambrian strata in a major north–northeast-trending synclinorium at Ocean Pond. The lithostratigraphic succession in this outlier is similar to the classical early Paleozoic sections around Trinity and Conception bays (e.g., Walcott, 1900 and others), and the stratigraphic nomenclature used by Hutchinson (1962) and Jenness (1963) for those areas is adopted here. In ascending stratigraphic order, these divisions are: the Random Formation; the Bonavista, Smith Point, Brigus and Chamberlains Brook formations of the Adeyton Group; and the Manuels River Formation of the Harcourt Group. During the course of this study, the Cambrian rocks were surveyed in a reconnaissance fashion, and further mapping and paleontological study may result in changes to the boundaries shown on Figure 1.

RANDOM FORMATION

Approximately 4 km northeast of Ocean Pond, a quartz-arenite-rich unit, assigned to the basal Cambrian Random Formation (Unit 9), overlies red pebble to cobble conglomerate of the Crown Hill Formation of the Musgravetown Group. In this area, as is the case elsewhere in the Bonavista Peninsula and Trinity Bay, the Random Formation consists mainly of white quartzite or quartz arenite. These exhibit metre-scale planar- and trough-crossbeds and locally, well-developed, smaller scale herringbone crossbeds. Much less extensively developed in the Random Formation are quartz granule and quartz pebble conglomerate. Southwest of Spar Pond, the formation consists of micaceous grey sandstone interbedded with a small proportion of quartz arenite.

There is no single, well-exposed section through the formation in the Ocean Pond outlier. A roughly 30-m-wide zone of quartz arenite is exposed on Ocean Pond. On the basis of its map pattern, however, the formation could be at least 50 m thick in this area.

Basal Contact

Although the Musgravetown Group and the Random Formation lie in very close proximity, no outcrop of the contact was seen. No angular discordance on map scale was noted. In addition, the presence of pink, quartz-rich sandstone and purer quartz arenite as interlayers near the top of the Musgravetown Group is consistent with the lack of a significant break at this boundary. It is conceivable, however, that the boundary is disconformable, as is the case farther to the northeast, at Keels, and to the south, at Random Island and Smith Sound (Anderson, 1981).

ADEYTON GROUP

Bonavista Formation

Quartz arenite of the Random Formation is succeeded by well-cleaved, red and green shale and slate, here assigned to the Early Cambrian Bonavista Formation (Unit 10). This unit is extensively exposed throughout much of the outlier. The best section through the formation can be seen along the eastern arm of Ocean Pond, where upwards to 150 m of section may be preserved. There, light-green slate and shale are succeeded by red shale, which contains up to 10 percent, interbedded, pale-grey and pale-green shale and slate. The top of the sequence there consists of red shale that is rich in calcareous nodules. These red rocks locally contain 1- to 5-cm-thick, green, shaly interbeds.

Basal Contact

The base of the Bonavista Formation is not exposed in the Ocean Pond outlier. Elsewhere, in Bonavista and Trinity bays, its contact with the underlying Random Formation is a minor disconformity (Hutchinson, 1962).

Smith Point Formation

Pink and red limestone, here assigned to the Early Cambrian Smith Point Formation (Unit 11), occurs as a thin but continuous unit within the Cambrian outlier. The best exposures of the unit were seen at Ocean Pond, where it is between 2 and 3 m thick. The Smith Point Formation in this area consists of well-cleaved, pink and bright red, nodular, oncolitic limestone. The limestone beds have thin shaly partings, and contain thin beds of red shale, rich in red and pink limestone nodules. The limestone is fossiliferous in all exposures. Hyalithids, fragments of inarticulate brachiopods, and possible fragments of trilobites were noted. Hutchinson (1962) reports the presence of *Callavia*-zone trilobites in the upper part of the Smith Point Formation elsewhere in the Avalon Zone.

Basal Contact

The Smith Point Formation conformably overlies red shales assigned to the Bonavista Formation. Although thin limestone layers occur at lower stratigraphic levels, this formation represents the only massive limestone unit of substantial thickness in the Cambrian succession. Thus, its basal boundary is readily identifiable above the uppermost shale of the Bonavista Formation.

Brigus Formation

Those Early Cambrian, shales and slates that occupy a stratigraphic position above the Smith Point Formation and beneath Middle Cambrian black shales in the Ocean Pond

outlier are assigned to the Brigus Formation (Unit 12; Hutchinson, 1962). No reliable estimate of its thickness in this area can be made. The section on Ocean Pond consists primarily of grey and grey-green shale and slate. Similar rocks are also predominant in exposures of this unit farther south in this area. Red slates are less extensive; these locally contain pink limestone nodules.

Basal Contact

The base of the Brigus Formation is not exposed in this area. In Trinity Bay, this formation lies with apparent conformity on the Smith Point Formation, but in other areas (e.g., Conception Bay), the base of the Brigus Formation is a profound unconformity developed on various Precambrian units (e.g., Hutchinson, 1962).

Chamberlains Brook Formation

Red shale and slate of the Brigus Formation is succeeded upward by well-cleaved green slate, manganiferous grey shale and red, variably manganiferous, slate and shale. These rocks are assigned to the early Middle Cambrian Chamberlains Brook Formation (Unit 13). The shales near the north end of Ocean Pond locally contain deformed fragments of very large trilobites, which may be *Paradoxides bennetti.*

Basal Contact

The Chamberlains Brook Formation and the underlying Brigus Formation share a number of lithological characteristics, and the position of their mutual boundary as drawn on Figure 1 is thus approximate and, in some areas, perhaps significantly inaccurate. More precise definition of this boundary awaits more detailed mapping aided by paleontological studies.

HARCOURT GROUP

Manuels River Formation

Green shale and slate of the Chamberlains Brook Formation are succeeded by black shale assigned to the Middle Cambrian Manuels River Formation (Unit 14). Black, cleaved, sulphurous shale is the most distinctive and diagnostic rock type in this formation. The shales contain grey calcareous concretions and thin grey limestone beds. Variably deformed trilobites and trilobite fragments in cleaved black shales were found in several areas (Figure 1). Fauna from at least three of these localities are readily identifiable as *Paradoxides davidus.*

Basal Contact

The basal contact of the Manuels River Formation was not seen, but, it is assumed that the formation lies conformably above the Chamberlains Brook Formation. This is the case farther south in the Trinity Bay area (Hutchinson, 1962).

STRUCTURAL HISTORY

MAJOR STRUCTURAL FEATURES

Throughout much of the map area, the regional strain and metamorphic grade is low, with the distribution of rock units, particularly those of the Connecting Point Group, controlled primarily by broad open anticlines and synclines. These folds display various wavelengths and amplitudes and in places are periclinal; many are cleavageless. The strike of axial surfaces is variable, despite their generally steep nature. The amount and direction of plunge can vary significantly along the trace of these structures. As a general observation, the axial trace of folds affecting Connecting Point strata appear to rotate progressively from northwest–southeast, to northeast–southwest, with increasing proximity to the main band of the Musgravetown Group rocks in the eastern edge of the map area.

Strain in both the Precambrian and Cambrian rocks is higher in the region southeast of Southern Bay. Most Cambrian rocks in this area have a strong vertical to subvertical cleavage. This is characteristically a closely spaced, slate-like cleavage that is axial planar to moderately south-plunging, locally periclinal, synclines and anticlines. These are parasitic on a larger (4 to 5 km wavelength) synclinorium, in which the Cambrian outlier at Ocean Pond is preserved. The same single cleavage is developed in both Precambrian and Cambrian strata. In the Precambrian strata, this fabric varies from an intense slate-like cleavage to a weak, open, fracture cleavage.

The increased strain in this area may be in part due to the buttressing affects of the adjacent Musgravetown Group volcanic belt. Another factor is primary lithological character of rocks in this area, namely: the shale-rich nature of the Cambrian rocks and thin-bedded and fine-grained character of the Precambrian rocks. The Cambrian rocks, like those of Precambrian age both here and elsewhere in the map area, are greenschist grade or lower.

East of the Indian Arm Fault, a subvertical to vertical flattening fabric with a steep, down-dip lineation is pervasive in conglomerates of the Musgravetown Group. This fabric is in many places a penetrative chlorite-grade schistosity. Assymetric clast rotation in several exposures of conglomerate is consistent with east-side-down–west-side-up sense of displacement. A fabric of similar intensity, defined by sericite, is only locally developed in the more massive volcanic rocks of the underlying Bull Arm Formation.

Faults have had a varying affect on the distribution of rock units within the area. The most significant structure, in this respect, is the Indian Arm Fault, a north–northeast-trending structure, now marked mainly by brittle offset, that juxtaposes various levels of the Musgravetown Group with each other and with Cambrian strata. Facies variations seen in the Musgravetown Group across this stucture imply that the Indian Arm Fault had a significant displacement history prior to the Cambrian. A similarly oriented structure

separates or is inferred to separate Cambrian rocks and Connecting Point strata. Another of these structures is the Kate Harbour Fault, a major vertical brittle structure, downthrown to the northwest, and marked by a several-metre-wide zone of brecciation. The fault juxtaposes Connecting Point and Musgravetown strata at Kate Harbour, and farther southwest, juxtaposes Units 2 and 3 of the Connecting Point Group. A series of slightly curved to straight, northeast-trending brittle faults have the most pronounced topographic expression of the faults in the area, and locally offset units dextrally. For the most part, however, these latest structures effect little significant displacement of rock units.

Perhaps the single most profound structural feature in the area is the unconformity exposed on the east side of Southward Head. The surface of the unconformity is planar to slightly undulating over a distance of several metres. Northwest-striking, steeply dipping beds beneath are truncated by gently dipping red conglomerate that, at the contact, locally strike northeast. At the unconformity, a single very open-spaced cleavage is developed, albeit poorly, in the cover; strata immediately below are tilted and fractured but essentially uncleaved. However, basement rocks elsewhere on Southward Head do exhibit a single weak cleavage. At Southward Head and Maiden Hair Cove, bedding in the basement, which over large areas is subhorizontal, is steeper (and locally overturned) within about 1 km of the unconformity. The potential significance of the Southward Head unconformity, and possible explanations of its formation are described below.

THE PROBLEM OF THE TIMING OF DEFORMATION

In the absence of clear evidence to the contrary, it is assumed that the same regional cleavage, which is of varying intensity, is shared by both the Musgravetown Group and the overlying Cambrian rocks. Critical to this assumption is the apparently conformable relationship of the Crown Hill and Random formations, described above. The age of this fabric is unknown, but must be younger than Early Ordovician. This is the age of the youngest rocks in similar, internally conformable early Paleozoic outliers along strike to the south in Trinity Bay (Jenness, 1963).

The nature and timing of deformation events affecting the Connecting Point Group is contentious. It can be argued that the apparent conformity between red sandstones, here tentatively assigned to the Musgravetown Group, and Connecting Point strata requires that much or all tectonism affecting Connecting Point rocks is of post-Cambrian age. This argument is dependent on correlation of the red beds in question (which are the basement at the Southward Head) with those conformable into the Random Formation 10 km farther south. This scenario also implies that the cover sequence at Southward Head should be post-Cambrian in age.

An alternate possibility, however, is that the red clastic rocks under the unconformity—despite their resemblance to Musgravetown Group—are part of the Connecting Point Group. An analogous unit might be the Mistaken Point Formation of the Conception Group on the Avalon Peninsula (Williams and King, 1979). This would allow the cover sequence to be part of the Musgravetown Group, but would require revision of the stratigraphy of the late Precambrian rocks below the Random Formation. It could be maintained that some Precambrian deformation was associated with synsedimentary faulting at or near the margins of the basin in which the Connecting Point Group accumulated. This would allow for gradation from marine to terrestrial deposition in some areas, and discordance elsewhere. Such a scenario would not only permit the observed unconformity, but also some degree of stratigraphic variation beneath the Musgravetown Group. A similar model has been invoked to explain relationships amongst late Precambrian units on the Avalon Peninsula (King, 1990).

Testing the above models hinges on ascertaining the age and thus regional stratigraphic designation of the cover—as yet unknown. Continued mapping coupled with isotopic investigations may resolve this problem. In light of present data, a distinct possibility remains: namely, that the cover at Southern Head is of post-Cambrian age. Devonian rocks that are lithologically indistinguishable from those above the Southward Head unconformity were deposited over large parts of the southwestern Avalon Zone (see Widmer, 1950). If the cover rocks in the present area were of similar age, then at least some of the tectonism in the basement could be post-Early Ordovician and pre-Devonian in age, possibly related to Silurian tectonism such as that chronicled along the western margin of the Avalon Zone (O'Brien and Holdsworth, 1992; Holdsworth and O'Brien, 1993).

ECONOMIC POTENTIAL

No significant mineralization in the Precambrian rocks was noted during the course of mapping. Malachite-stained fractures were noted in tuffaceous sediment and related rhyolites of the Musgravetown Group near the Indian Arm fault. In a number of areas within the Connecting Point Group, pyrite occurs as locally extensive disseminations in diabase dykes and along fractures in host shales.

The Early and Middle Cambrian outlier includes an assortment of variegated, very fine-grained sedimentary rocks, which in many exposures, host a pronounced slatey cleavage. Some of these rocks may have significant potential as a slate resource. Exposures of green and grey-green slate occur immediately north of Spar Pond. Although the principal structure is a broad synclinorium, with a wavelength between 3 and 4 km, tighter parasitic structures do occur and may be significant in terms of slate formation. Manganese is common in some of the red and green shales of the Chamberlains Brook Formation. The most extensive occurrence is shown on Figure 1.

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