Current Research (2014) Newfoundland and Labrador Department of Natural Resources
Geological Survey, Report 14-1, pages 135-154

PRELIMINARY RESULTS FROM BEDROCK MAPPING IN THE SWEET BAY AREA (PARTS OF NTS MAP AREAS 2C/5 AND 2C/12), WESTERN BONAVISTA PENINSULA, NEWFOUNDLAND

A.J. Mills
Regional Geology Section

ABSTRACT

A regional (1:50 000 scale) bedrock-mapping project began in 2013 in the Sweet Bay area of Bonavista Bay (parts of NTS map areas 2C/5E and 2C/12SE), and builds upon previous 1:50 000-scale mapping in the region. The project complements recent bedrock mapping surveys of the Bonavista, Trinity and Random Island 1:50 000 NTS map areas to cover most of the Bonavista Peninsula.

The study area lies within the Avalon Zone of the Newfoundland Appalachians and is underlain by Neoproterozoic, marine-dominated, siliciclastic sedimentary rocks of the Connecting Point Group in the west; red, terrestrial sedimentary and volcanic rocks of the Musgravetown Group in the east; and a shale-dominated Cambrian marine shelf succession in the south-central part of the map area. A new informal lithological unit, the Kate Harbour formation, is used to distinguish the red, arkosic sandstone and minor shale that occur transitionally and locally disconformably above flysch units of the Connecting Point Group. The Kate Harbour formation reflects subaerial exposure of upper parts of the Connecting Point Group. The newly proposed Muddy Pond formation (informal) consists of mainly red pebble conglomerate that overlies the Kate Harbour formation, and is overlain by the Cambrian platformal succession to the south. This unit is broadly contemporaneous with the Musgravetown Group.

Four deformational events are evident in the Sweet Bay area. Precambrian uplift is apparent at Southward Head, where an angular unconformity separates underlying steeply northeast-dipping siliceous sandstones of the upper Connecting Point Group from overlying, shallowly north-dipping Cannings Cove Formation conglomerates and Bull Arm Formation mafic volcanic rocks of the Musgravetown Group. An open, shallowly east-southeast-plunging anticline/syncline pair, apparent in Connecting Point Group rocks west of the Cambrian shelf succession at Ocean Pond, does not appear to carry across into the Cambrian rocks there, and therefore may be a product of Precambrian D_1 deformation. Two regional, post-Cambrian deformation events have affected all rock units in the map area. The first of these, D_2, is characterized by north-northeast-trending, open to tight, asymmetric folds with a 1–2 km wavelength. D_3 is characterized by broad, open, east-southeast-trending F_3 folds that have moderately to steeply southwest-dipping axial planes. Late 045–060°-trending faults offset F_2 and F_3 folds and are herein considered elements of latest D_4 deformation. Regional metamorphic grade and strain state in the study area are low (sub-biotite grade).

A new trilobite locality, located west of southern Ocean Pond, preserves trilobite fragments of Paradoxides davidis *and* Jincella *in an outcrop of black shale capped by a thin, dark-brown-weathering veneer of volcanic ash.* P. davidis *is a distinctive species that defines a Middle Cambrian biostratigraphic subzone indicating that the shale is Drumian (Series 3 of the Cambrian, formerly Middle Cambrian; absolute age range: 504.5–500.5 Ma). These are the youngest rocks in the study area and are correlative with the Manuels River Formation elsewhere in the Avalon Zone.*

INTRODUCTION

A recent initiative to map the Bonavista Peninsula began in 2009 (Normore, 2010) in order to survey the entire peninsula at 1:50 000 scale. Previous regional bedrock mapping had been conducted at a much smaller scale (*e.g.*, Hayes, 1948 at 1:125 000 scale; Christie, 1950 at 1:125 000 scale; Jenness, 1963 at 1:250 000 scale; Younce, 1970 at 1:63 360 scale). No further regional bedrock mapping was conducted until the late 1980s and early 1990s. These surveys focused on areas west of Bonavista Bay and the westernmost Bonavista Peninsula, within 50 km of the Dover Fault (Figure 1) in the Eastport and Sweet Bay areas (O'Brien, 1987, 1992, 1993, 1994; Knight and O'Brien,

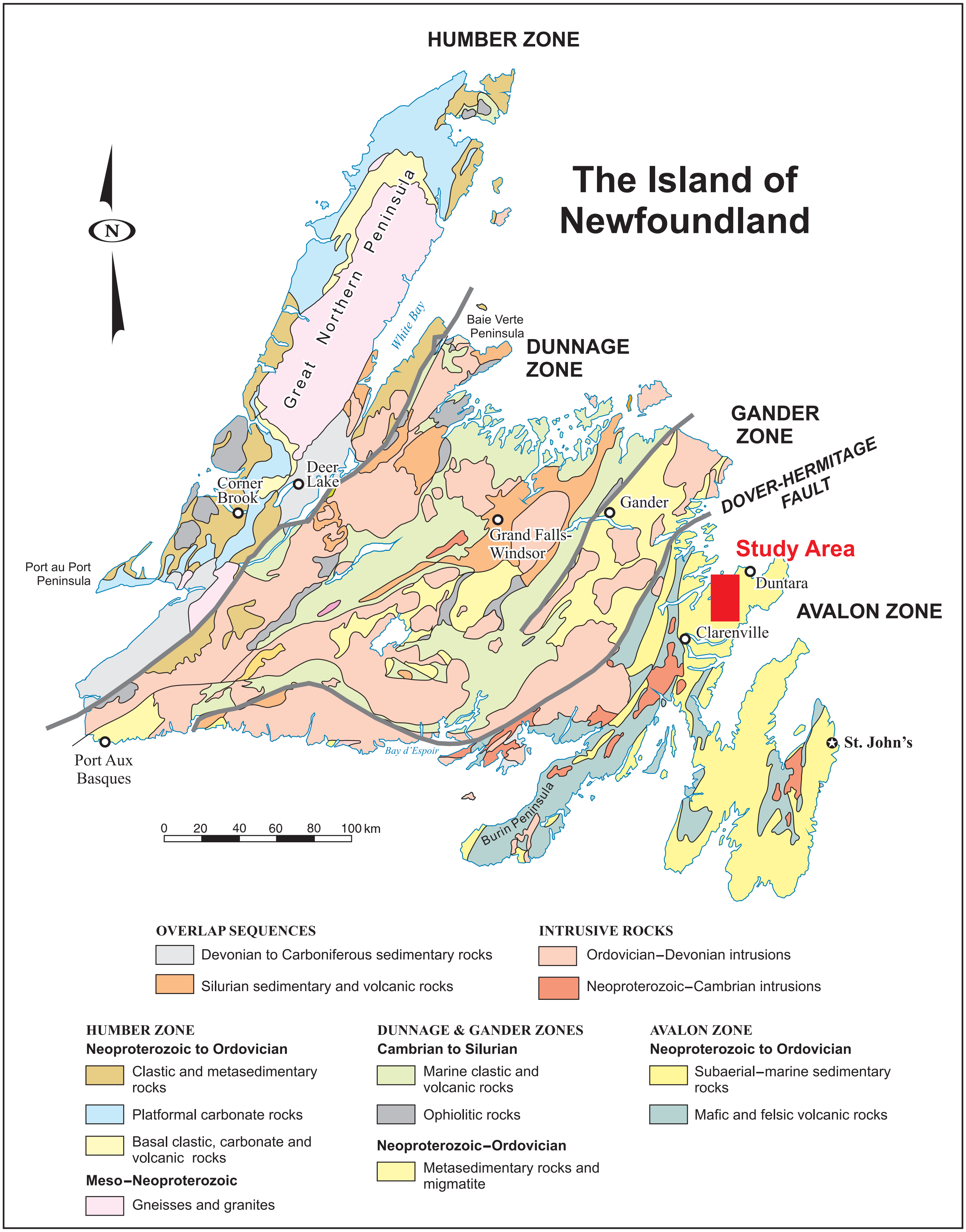

Figure 1. *Simplified geological map of insular Newfoundland showing the study area within the Avalon Zone.*

1988; O'Brien and Knight, 1988). Bedrock mapping of the eastern Bonavista Peninsula in the early 2000s resulted in major changes to the stratigraphic framework due, in part, to recognition of units correlative to the Conception, St. John's and Signal Hill groups, including the fossiliferous Mistaken Point Formation (O'Brien and King, 2002, 2004, 2005).

A 1:50 000-scale regional mapping project began in 2009, and bedrock mapping was completed in the Trinity, Bonavista and Random Island map sheets (Normore, 2010, 2011, 2012). One of the main objectives of the current mapping project is to produce an updated geological map of the Bonavista Peninsula to provide a modern, regional tectonic context.

This report outlines preliminary results of 1:50 000-scale bedrock mapping in the Sweet Bay area of Bonavista Bay (NTS 2C/5E and 2C/12SE; Figures 1 and 2). The project builds upon previous 1:50 000-scale mapping by O'Brien (1994) and that dataset has been digitized to augment the current project.

REGIONAL SETTING

The Sweet Bay map area lies in the Avalon Zone of the Newfoundland Appalachians and is underlain by Neoproterozoic, marine-dominated, siliciclastic sedimentary rocks of the Connecting Point Group (CPG; Hayes, 1948) to the west; red, terrestrial sedimentary and volcanic rocks of the Musgravetown Group (MG; Hayes, 1948) to the east; and a Cambrian shale-dominated shelf succession in the south-central part of the map area (Figure 2). The CPG is the oldest and most areally extensive geological succession. It is exposed as a southward-narrowing siliciclastic sedimentary belt that extends from central Bonavista Bay in the north to Placentia Bay in the south. The >3500-m-thick sequence conformably overlies the volcanic-rock-dominated Love Cove Group (Knight and O'Brien, 1988; Dec *et al.*, 1992; Myrow, 1995), exposed ~15 km to the west, near Clarenville. Geochronological constraints on the CPG include the underlying Love Cove Group, from which a greenschist-facies volcanic rock was dated at 620 ± 2 Ma (O'Brien *et al.*, 1989), and a tuff unit from the middle of the CPG succession, dated at 610 ± 1 Ma (G. Dunning, unpublished data, 1990, *in* Dec *et al.*, 1992). No direct geochronological constraints are currently available for the upper CPG.

Descriptions of upper contacts of the CPG vary regionally, from an angular unconformity with overlying conglomerates of the Cannings Cove Formation at Milner Cove and at Charlottetown on Clode Sound (Hayes, 1948; *see* also O'Brien, 1987, Plate 12) to a conformable or disconformable contact with the volcanic-dominated Bull Arm Formation of the MG at Newman Sound, south and east of the Louil Hills, west of Traytown (Younce, 1970) and also two miles west of Rantem Cove (McCartney, 1967). The MG is a >3000-m-thick, dominantly subaerial succession that consists of a basal conglomerate (Cannings Cove Formation), overlain by a bimodal volcanic formation (Bull Arm Formation), succeeded by a shallow-marine to terrestrial, coarsening-upward clastic sedimentary sequence that comprises the Rocky Harbour and Crown Hill formations (Jenness, 1963; O'Brien *et al*., 1990). The only geochronological age constraint currently available for the MG comes from a rhyolite dated at 570 +5/-3 Ma (O'Brien *et al*., 1989). The base of the dated rhyolite (locality of which lies west of the Bloody Reach Fault on the west side of Bonavista Bay) is unexposed and is interpreted to be from the top of the Bull Arm Formation but could, alternatively, be a rhyolite flow from within the Rocky Harbour Formation (S. O'Brien, personal communication, 2014).

The Random Formation (Walcott, 1900) regionally overlies the MG with significant erosional unconformity (Anderson, 1981), but conformably overlies the Chapel Island Formation at Fortune Head to the south on the Burin Peninsula (Narbonne *et al*., 1987; Myrow and Hiscott, 1993) and the MG at Keels, on the northwest tip of the Bonavista Peninsula (O'Brien and King, 2004). The Random Formation is succeeded by red and green shale, slate and minor limestone of the Adeyton Group (Hutchinson, 1962; Jenness, 1963), which, in turn, are conformably overlain by black shale of the Harcourt Group (Manuels River Formation; Hutchinson, 1962).

LITHOLOGY

CONNECTING POINT GROUP

Knight and O'Brien (1988) divided the CPG rocks of the Eastport area into six lithostratigraphic units interpreted to have been deposited in two turbiditic basin-fill events, separated by an olistostrome that resulted from basin collapse. The lower package comprises upward-coarsening turbidites deposited on a low-efficiency, prograding deep-sea fan typical of a volcaniclastic apron surrounding a volcanic arc. The upper package is characterized by a well-developed, high efficiency, levee–channel sequence consistent with basin enlargement.

Efforts to correlate the CPG rocks with units established by Knight and O'Brien (1988) were hampered by the lack of unambiguous marker horizons, the occurrence of similar lithofacies at various stratigraphic levels, lack of lateral continuity of many lithofacies and abundant brittle faults that commonly offset stratigraphy. Although some of the lithofacies of Knight and O'Brien (1988) occur within the map units designated herein, they cannot be correlated

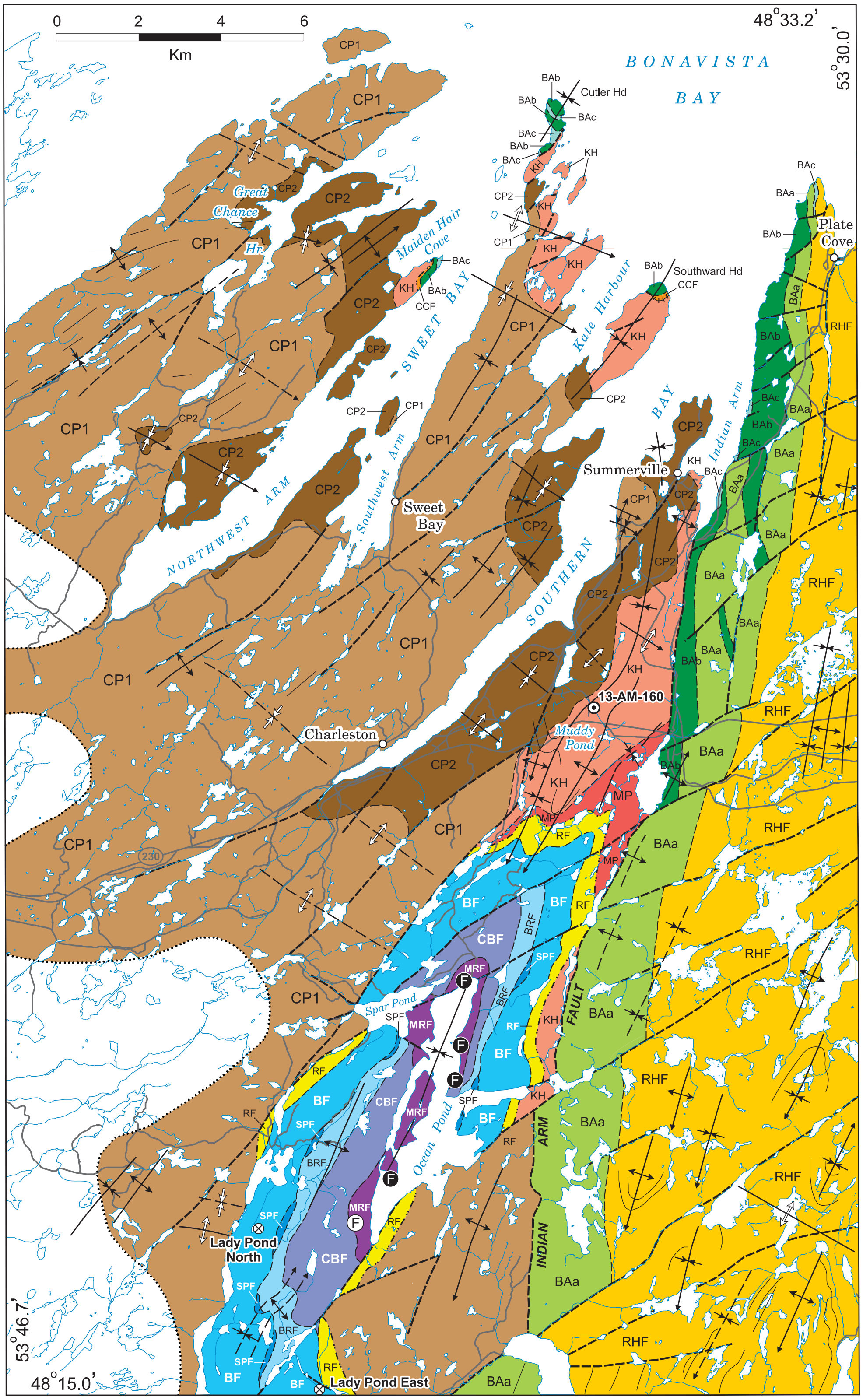

Figure 2. *Simplified geological map of the Sweet Bay–Ocean Pond area.*

LEGEND

CAMBRIAN

Harcourt Group

MRF **Manuels River Formation:** Black shale with minor grey calcareous concretions; locally contains fossil fragments

Adeyton Group

CBF **Chamberlains Brook Formation:** Grey and green shale and slate, commonly Manganese-stained

BRF **Brigus Formation:** Red and green shale and slate with pink limestone nodules, minor grey fossiliferous limestone

SPF **Smith Point Formation:** Fossiliferous, pinkish red, thin to thick bedded nodular limestone; minor interbeds of dark red shale containing pink limestone nodules

BF **Bonavista Formation:** Red and green shale and slate locally containing limestone nodules

Random Formation

RF Thick-bedded, coarse-grained, white quartz arenite, and pebble conglomerate, minor coarse- to medium-grained, grey sandstone

EDIACARAN

Musgravetown Group

RHF **Rocky Harbour Formation:** Red, grey and green, foliated, matrix-supported pebble to cobble conglomerate, medium- to coarse-grained pink to red arkosic sandstone, minor grey sandstone and rare, light grey shale

BAa BAb BAc **Bull Arm Formation:** a) red and maroon, aphyric and banded felsic flows, feldspar-porphyritic flows and tuff, welded breccia, minor volcanogenic sandstone; b) green-grey to black, locally maroon-weathering, aphyric to quartz-, chlorite- and/or epidote-amygdaloidal basalt flows, mafic breccia; c) minor interflow sedimentary rocks including grey-green laminated siltstone and red shale commonly having well-developed ripple marks

CCF **Cannings Cove Formation:** Fining upward red boulder- to cobble conglomerate with a poorly sorted, sandy to pebbly matrix (clasts are subrounded to subangular, predominantly red sandstone, siltstone and felsic volcanic rock, minor cherty, grey-green pebbles), minor red sandstone, shale, and red to yellow-pink feldspar-porphyritic felsic tuff

Post-Connecting Point Group, Broadly Musgravetown Group-Equivalent Rocks

MP **Muddy Pond formation:** Thick-bedded, matrix-supported, red pebble conglomerate that commonly displays normal grading to coarse-grained red sandstone or grit

Connecting Point Group

KH **Kate Harbour formation:** Red to red-green (variegated), medium- to thick-bedded sandstone, minor medium-bedded red siltstone and thinly interbedded sandstone and shale . Locally convolute-bedded with shaley rip-up clasts

CP2 Mainly thin interbeds of orange-brown and white-weathering, grey-green sandstone and dark grey shale, commonly cross-laminated with sharp, scoured bases; minor brown- to buff-weathering volcaniclastic sandstone

CP1 Mainly medium- and parallel-bedded, grey-green siltstone disposed in fining-upward sequences capped by thin black silty laminations; thick-bedded, structureless grey-green to pale grey silicified sandstone; minor black shale and grey-green granule conglomerate

SYMBOLS

Geological contact ....

Fault ....

Disconformity, approximate ....

Unconformity, inferred ....

Unconformity, angular ....

Form lines ....

Fossil locality (2013) .... Ⓕ

Fossil locality (1993) ....

F_2 anticline (approx, inferred) ....

F_2 syncline (approx, inferred) ....

F_3 anticline (approx, inferred) ....

F_3 syncline (approx, inferred) ....

directly for reasons outlined above. However, inferences regarding depositional environment can be tentatively drawn based on the assumption that the same lithofacies are products of the same depositional processes. Subdivision of the CPG stratigraphy broadly follows that of O'Brien (1994) and is expounded upon herein.

The CPG rocks in the study area consist of lithofacies that can be broadly subdivided into two marine sequences, the lower of which is dominated by medium- and parallel-bedded, grey-green cherty siltstone (Plate 1) disposed in fining-upward sequences capped by thin black silty laminations, lesser grey-green silicified sandstone, minor black shale and grey-green granule conglomerate (CP1). The upper sequence consists of thin-bedded, commonly cross-laminated, orange-brown- and white-weathering, grey-green sandstone and dark grey shale (Plate 2), thick-bedded, structureless to internally laminated, siliceous, grey-green sandstone, and minor brown- to buff-weathering tuffaceous sandstone (CP2). Minor volcaniclastic rocks occur throughout the CPG in the study area. Millimetre-thick tuffaceous layers, although rare within the cherty siltstones of CP1, are more common within the thinly interbedded sandstone and shale and in black argillite of CP2.

The medium-bedded, grey-green siltstone of CP1 (Unit 2 of O'Brien, 1994), is lithologically consistent with the distal turbidites of Knight and O'Brien (1988; lithofacies D). Turbidites, coarse-grained sandstone, and granule to pebble conglomerate that occur near the top of CP1, compare, and may be correlative, with lithofacies G of Knight and O'Brien (1988). These are interpreted as proximal turbidites, consistent with shallowing-up progradation of a submarine fan. The thin interbedded sandstone and shale of CP2 are lithologically similar to lithofacies E of Knight and O'Brien (1988), interpreted to reflect deposition in a distal levee or near-channel levee environment. Thickening and coarsening-upward trends first noted by Knight and O'Brien (1988) and O'Brien (1994) were also noted during the present study and are consistent with an overall shallowing-upward prograding submarine sequence. The conformable and transitional relationship between the CPG and the underlying Love Cove Group, as well as the abundance of volcanic detritus in sandstones of the CPG, are consistent with a spatial association between the two groups, possibly in an arc-adjacent setting (Knight and O'Brien, 1988; Dec *et al.*, 1992).

KATE HARBOUR FORMATION (INFORMAL)

The Kate Harbour formation (KHF; Figure 2) consists of red sedimentary rocks that occur within the CPG in the map area, but above the flysch sequence and below the MG. It consists mainly of thick-bedded, coarse-grained, pink to

Plate 1. *Thin- and parallel-bedded, grey-green, normal-graded siltstone with black silty laminations; one of the main lithofacies in CP1 (hammer – 30 cm; beds are upright; shoreline 2 km south of Cutler Head; UTM coordinates: 304622m E, 5374656m N; NAD 27; Zone 22N).*

Plate 2. *Thin, interbedded, orange-brown and white-weathering, grey-green sandstone and dark-grey shale in CP2 at Great Chance Harbour. The sandstone is commonly cross-laminated with sharp, scoured bases. (coin – 2.5 cm; tops are to the south; UTM coordinates: 302456m E, 5377001m N; NAD 27; Zone 22N).*

red sandstone, although medium-bedded siltstone and thinly interbedded sandstone and shale occur locally (west of Kate Harbour, across from Southward Head and the south side of Maiden Hair Cove, respectively). This sandstone-dominated unit occurs at the headlands in spatial association with unconformably overlying MG rocks (Figure 2).

The contact between green, siliceous sandstone of CP2 and red arenite of KHF ranges from sharp to gradational, and a possible basal disconformity was identified along the shoreline in the small cove east of Kate Harbour (Figure 2). There, structureless, medium-bedded, fine-grained, grey-green sandstone is disconformably overlain by laminated, swaley-bedded, medium-grained, grey to pink sandstone (Plate 3). At the southernmost part of Southward Head, thin-bedded, normally graded, fine-grained, grey-green sandstone of the upper CPG exhibits a coarsening- and thickening-upward trend toward medium- to thick-bedded, grey-green to reddish, commonly variegated, sandstone of the KHF. South of Cutler Head, thin- to medium-bedded black siltstone (common to both CP1 and CP2) and normal-graded, grey-green granule conglomerate (more common to CP1 than CP2) are interbedded with variegated coarse-grained sandstone assigned to the KHF, indicating a transitional contact. On the north side of the headland south of Maiden Hair Cove, thin interbedded sandstone and shale (CP1) show a sharp transition along strike to the northeast from green to red (KHF; Plate 3), possibly resulting from redox effects. Toward the top of the KHF here, the thin-bedded facies is variegated and becomes progressively more fractured.

Immediately north of Muddy Pond (Figure 2), a section through CPG and KHF units was newly exposed during Hurricane Igor (as a result of forceful flooding that displaced the culvert beneath Highway 230 and washed out the banks of the river). Here, thick-bedded, red sandstone (KHF) overlies thin-bedded, black argillite and grey-green siltstone of the upper CP2 unit with apparent conformity (Figure 3). The coarse-grained, pink to red sandstone locally contains pinkish siltstone rip-up clasts, well-developed convolute bedding, scoured bedding surfaces and other small-scale thixotropic deformation features (Plate 5).

MUDDY POND FORMATION (INFORMAL)

In the vicinity of Muddy Pond (Figure 2), the red sandstone of the KHF apparently coarsens up-section, as red pebble conglomerate is first noted south of Highway 230 and becomes dominant to the south and east. The conglomerate-dominated unit is distinguished from the underlying arkosic sandstones of the KHF on the basis of lithology and stratigraphic relationships. This informal new unit is herein referred to as the Muddy Pond formation, after the local name for the small pond there (Figure 2). It consists of thick-bedded, matrix-supported, red granule to pebble conglomerate, pink, buff and lesser grey sandstone and minor red to red-grey (variegated) siltstone and shale. Clasts of the red conglomerate include well-rounded to angular, red and green-grey sandstone, red siltstone, minor volcanic rock fragments and quartz pebbles. Beds locally show crudely developed stratification and crossbedding. Like the arkosic sandstone, the matrix to the conglomerate is coarse grained with poorly sorted, angular feldspars and rock fragments indicating limited transport prior to deposition of these immature sediments. The southern part of the Muddy Pond formation dips variably to the south beneath the Random Formation (Figure 2) and is inferred to underlie the Bull Arm Formation to the east.

Plate 3. *Possible disconformity surface (on which hammer head is resting) between siliceous, parallel-bedded, green-grey sandstone of CP2 and overlying swaley bedded, internally laminated, grey to pink sandstone of the Kate Harbour formation at Kate Harbour (view to the east; hammer - 40 cm; UTM coordinates: 308730m E, 5371973m N; NAD 27, Zone 22N).*

Plate 4. *Abrupt along-strike colour change from grey-green (yellow arrow) to red in thinly interbedded sandstone and shale lithofacies of the Kate Harbour formation at Maiden Hair Cove (view to southwest; geologist for scale; UTM coordinates: 304622m E, 5374656m N; NAD 27, Zone 22N).*

THE MUSGRAVETOWN GROUP

The Musgravetown Group (Hayes, 1948) consists of a thick succession of red and green, coarse-grained siliciclastic fluvial and alluvial sedimentary rocks and interbedded terrestrial rhyolite and basalt that overlies the CPG and is overlain by the Random Formation. On the Bonavista Peninsula, Jenness (1963) divided the MG into five conformable lithostratigraphic units, namely, in ascending order, the Cannings Cove Formation, Bull Arm Formation, undifferentiated middle unit, Rocky Harbour Formation and Crown Hill Formation. The Cannings Cove Formation con-

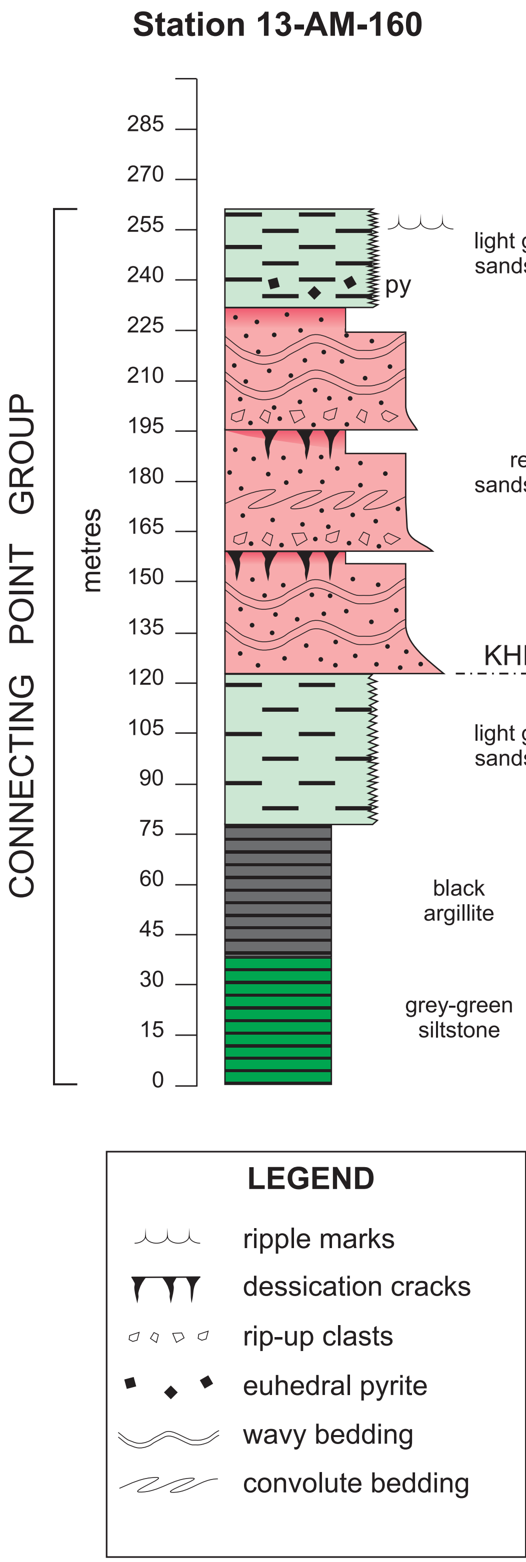

Figure 3. *Schematic stratigraphic column of the upper Connecting Point Group and overlying Kate Head formation (based on stream section exposed north of Muddy Pond at station 13-AM-160; UTM coordinates: 308827m E, 5363396m N; NAD 27; Zone 22N).*

Plate 5. *Coarse-grained, thick-bedded, red sandstone showing well-developed convolute bedding with scoured tops, consistent with deposition on an unstable slope, Kate Harbour formation, stream washout north of Highway 230 at Muddy Pond (hammer - 30 cm; handle points southwest; tops to the southwest; UTM coordinates: approximately 308827m E, 5363396m N; NAD 27, Zone 22N).*

sists of pebble to cobble conglomerate with lesser sandstone, siltstone and shale; although predominantly red, the basal rocks are typically green (Jenness, 1963). The Bull Arm Formation is a bimodal volcanic suite (Jenness, 1963; Malpas, 1971) that sits near the base of the MG. The undifferentiated middle unit consists of grey, green and red sandstone, siltstone and grey to brown pebble conglomerate. The Rocky Harbour Formation (Jenness, 1963) is a succession of yellowish green greywackes. O'Brien and King (2002, 2005) identify six lithostratigraphically distinct facies within the Rocky Harbour Formation on the Bonavista Peninsula, thereby negating use of the former middle undivided unit of Jenness (1963), and propose that each may be elevated to member status. The uppermost Crown Hill Formation (McCartney, 1958) consists chiefly of red pebble conglomerate with lesser red sandstone, siltstone and minor grey to greenish-grey sandstone.

Cannings Cove Formation

Red conglomerate of the Cannings Cove Formation is exposed above the angular unconformity at Southward Head and at the headland south of Maiden Hair Cove. The base of the unit at Southward Head is clast-supported, red, cobble to boulder conglomerate that has a poorly sorted, sandy to pebbly matrix. The subrounded to subangular clasts consist predominantly of red sandstone and siltstone, felsic volcanic rock fragments and minor cherty, grey-green pebbles probably of CPG affinity. The unit becomes finer grained and thinner bedded up-section. Toward the top of the formation, ~1 m below the first mafic volcanic flow, a red to yellow-pink, 3- to 5-m-thick, feldspar porphyritic tuff is interbedded with red cobble conglomerate. The same conglomerate occurs interbedded with mafic volcanic rocks, indicating a transitional upper contact with the Bull Arm Formation, at least locally.

Bull Arm Formation

The Bull Arm Formation comprises predominantly felsic flows, pyroclastic rocks and breccias, with lesser mafic flows and breccias and minor interflow sedimentary rocks dominated by ripple-marked red shale. Mafic flows commonly occur at the base of the formation and are overlain by either red shale (Plate 6), or, less commonly, felsic flows, the base of which contains abundant blocks of entrained basaltic debris. Mafic flows are generally aphyric near the base, quartz ± epidote ± chlorite amygdaloidal toward the top and locally preserve well-developed flow-top breccia. Felsic flows are commonly well banded, but aphyric and weakly feldspar-porphyritic flows also occur and devitrified glass spherules were noted locally (Plate 7). A distinctive columnar-jointed flow (Plate 8) outcrops sporadically along the length of the north-northeast-trending volcanic belt. It is pale grey, locally weakly plagioclase porphyritic (sub-mm scale) and is herein included with the mafic flows, although it may be intermediate in composition. Samples have been collected for lithogeochemical study.

Northwest of the fault near the tip of Cutler Head (Figure 2), rocks of probable MG affinity include thick mafic volcanic flows, breccia, and a variety of interflow sedimentary rocks. Red and green sandstone, red siltstone and shale, and volcaniclastic boulder to cobble conglomerate comprise the main interflow rock types. Most conglomerate is red to brown, matrix-supported and normally graded, but thick-bedded, clast-supported, volcaniclastic boulder conglomerate and a variably thick (30–80 cm) agglomerate bed were also noted. The agglomerate contains mafic and felsic, subrounded, cobble- to boulder-sized bombs (up to 40 cm) in a green, tuffaceous matrix. The mafic bombs commonly have either tear-drop or fusiform morphology, and amygdales are elongate parallel to the long axis of fusiform bombs (Plate 9). Felsic bombs are smaller (6–10 cm diameter) and some exhibit a poorly developed bread-crust exterior.

A roadcut along the east side of Indian Arm, across the bay from Summerville, was investigated in detail because it exposes Bull Arm volcanic rocks, interflow sedimentary rocks and underlying siliciclastic rocks of possible CPG affinity (Figure 4). Felsic and mafic volcanic flows are the dominant rock types. Interflow sedimentary material includes red, and lesser, green cherty mudstone (locally slate), pink, grey-green and light-green, thin-bedded sandstone, yellowish-green, thick-bedded, laminated sandstone and minor maroon coarse-grained sandstone to grit. Grey-green to maroon, clast-supported conglomerate outcrops near the base of the sequence. Clasts are subrounded to subangular and the dominant clast lithology is grey-green cherty siltstone. Hematite staining is pervasive on fracture and clast surfaces. Thin-bedded, grey-green, siliceous siltstone having darker laminations occurs below the conglomerate and may be the source for lithologically similar clasts in the overlying conglomerate. Both the conglomerate and grey-green cherty siltstone are lithologically indistinguishable from, and typical of, CPG rocks.

Plate 6. *A large loose boulder showing flow top breccia of angular amygdaloidal basalt fragments infiltrated by overlying red mudstone (hammer – 65 cm long; UTM coordinates: 313232m E, 5370614m N; NAD 27, Zone 22N).*

Plate 7. *Devitrified glass spherules in a flow-banded rhyolite from the Bull Arm Formation located 2 km east of Muddy Pond (coin – 2.5 cm; UTM coordinates: 310891m E, 5361552m N, NAD 27, Zone 22N).*

Rocky Harbour Formation

Conglomerate and sandstone of the Rocky Harbour Formation (RHF; Jenness, 1963; O'Brien and King, 2002, 2005) are exposed east of the Bull Arm volcanic belt. The unit consists of red to grey polymictic conglomerate, lesser

Plate 8. *Well-developed columnar jointing in mafic to intermediate (?) volcanic flows exposed intermittently along the eastern shore of Indian Arm. Bedding dips steeply to the east; view to the east (geologist for scale; UTM coordinates: 312818m E, 5372079m N; NAD 27, Zone 22N).*

Plate 9. *Agglomerate interbedded with green-grey siltstone and conglomerate near the base of the Bull Arm Formation on the west side of Cutler Head. Note tear-shaped and fusiform morphology of two of the mafic bombs. (hammer – 40 cm; UTM coordinates: 308102m E, 5377711m N; NAD 27, Zone 22N).*

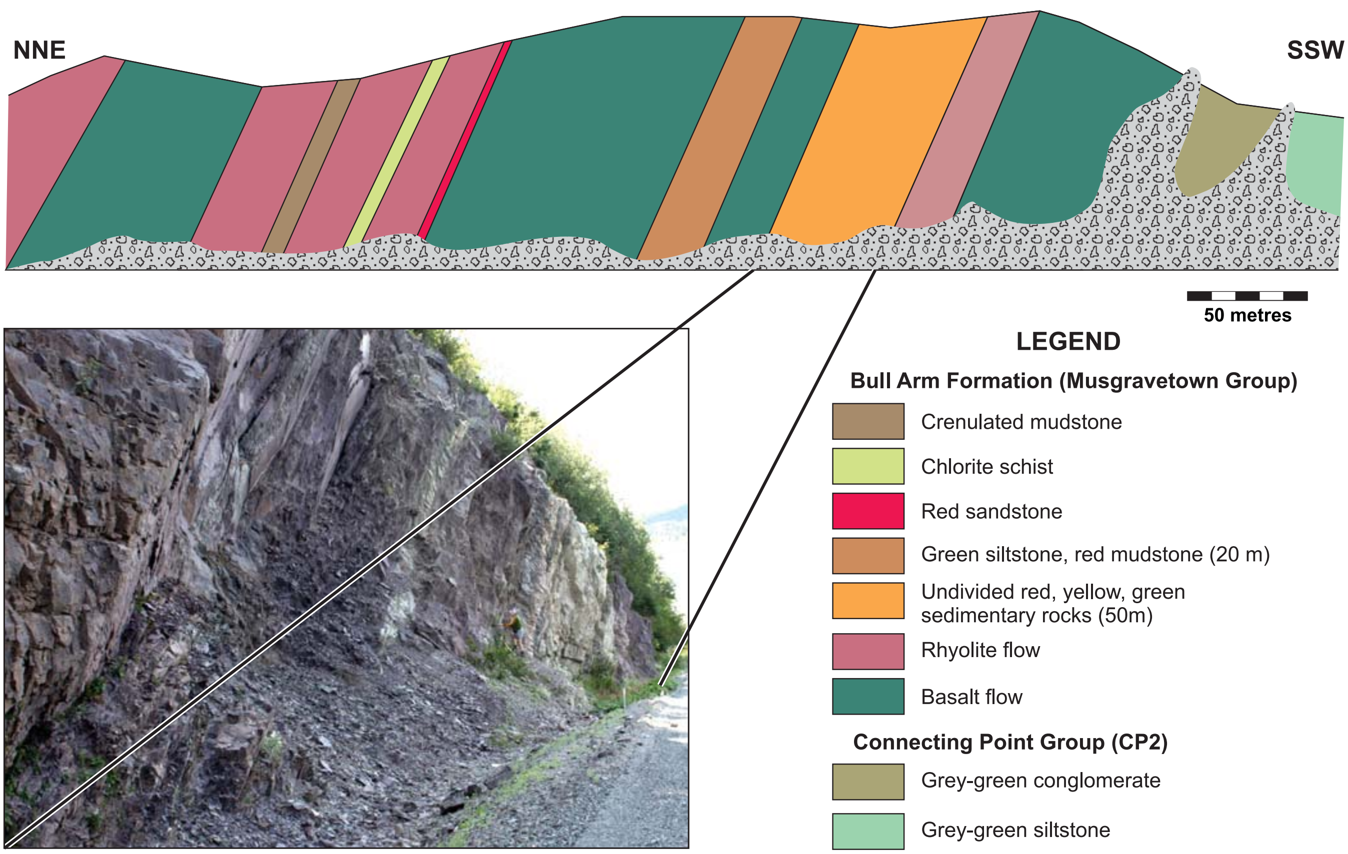

Figure 4. *Simplified cross-section through volcanic and interflow sedimentary rocks of the Bull Arm Formation (roadcut along Highway 235, east of Summerville).*

red arkosic sandstone and siltstone, minor thick-bedded, internally laminated, medium-grained, siliceous grey-green sandstone and grey shale. Conglomerate is red to grey, matrix-supported, and contains pebble- to cobble-size clasts elongate parallel to a well-developed, subvertical penetrative fabric. Clast content ranges from volcanic-rock-dominated to sandstone- and siltstone-dominated containing minor volcanic clasts. Rare quartz and granite clasts were noted locally (Plate 10). Grey siliceous sandstone outcrops along the shoreline near Plate Cove (Figure 2), where it underlies red, reverse-graded granule to cobble conglomerate (Plate 11); it also crops out in a few localities in the southeast corner of the study area. This siliceous sandstone unit may be correlative to the unnamed siliceous facies of O'Brien and King (2004), which occurs at the base of the Rocky Harbour Formation and is intercalated with conglomerate of the Jones Pond facies (O'Brien and King, 2002, 2004). The unit is overall east-facing, with minor west-facing beds due to regional F_2 folding (*see* Preliminary Structural Interpretation, below).

Plate 10. *Rounded granite pebble in deformed, polymictic conglomerate. Other pebbles include red sandstone (yellow arrow) and green-grey siltstone and sandstone. Rocky Harbour Formation of the Musgravetown Group (coin – 2.5 cm; UTM coordinates: 314915m E, 537488m N; NAD 27, Zone 22N).*

CAMBRIAN ROCKS

The lithostratigraphic succession in the vicinity of Ocean Pond is similar to that described for other early Paleozoic successions in Trinity and Conception bays (*e.g.*, Walcott, 1900; Hutchinson, 1962; Jenness, 1963; O'Brien, 1994; Normore, 2010, 2012). Stratigraphic nomenclature of Hutchinson (1962) and Jenness (1963) is herein retained. In ascending stratigraphic order, the map units include: the Random Formation; the Bonavista, Smith Point, Brigus and Chamberlains Brook formations of the Adeyton Group; and the Manuals River Formation of the Harcourt Group. The Adeyton Group was divided into the four formations by Jenness (1963) to resolve difficulties in using the biostratigrahically defined formations for regional mapping purposes. As the Bonavista and Brigus formations are lithologically indistinguishable, their relative position below and above the distinctive limestone stratigraphic marker of the Smith Point Formation, respectively, can be used with confidence to map the group (*e.g.*, O'Brien, 1994).

Plate 11. *Medium-grained, laminated, grey-green sandstone overlain by a thick, inversely graded, granule to pebble conglomerate bed in Rocky Harbour Formation near Plate Cove (view to the north; hammer - 40 cm; UTM coordinates: 314683m E, 5375839m N; NAD 27, Zone 22N).*

Random Formation

The basal contact of the Random Formation has been the subject of controversy since it was first recognized (Walcott, 1900). It is interpreted as conformable in two places: on the west limb of a north-plunging syncline exposed at Keels, northwest Bonavista Peninsula (O'Brien and King, 2004), and at Fortune Head on the Burin Peninsula (Hiscott, 1982). The Random Formation is interpreted to overlie the Precambrian Hodgewater Group at southern Trinity Bay with angular unconformity (Hutchinson, 1953). Fletcher (2006) suggests that the Random Formation rests unconformably on the partially peneplanated surface of a tilted MG sequence on the Cape St. Mary's Peninsula. Anderson (1981) convincingly argues that elsewhere, the marine sedimentary rocks at the base of the Random Formation must overlie continental MG rocks disconformably, despite conformable appearances. Deposition of the Random Formation may have begun with the reworking of poorly consolidated MG sediments, resulting in the apparent continuity of sequence (Anderson, 1981).

The Random Formation consists of quartz arenite, micaceous sandstone and grey siltstone interpreted to have been deposited as subtidal sand ridges or shoals on a broad continental shelf in a coastal embayment of the Avalon Zone during a global transgression in Early Cambrian times (Hiscott, 1982). The Random Formation marks the base of the Cambrian shelf succession and envelopes the synclinorium at Ocean Pond, although its basal contact is not exposed. It overlies grey-green siltstones and black argillites of the CP1 (to the west and southeast; Figure 2) and red pebble conglomerate and sandstone of the Muddy Pond formation (to the north and northeast). It is a distinctive unit of white, coarse-grained quartz sandstone and quartz-pebble conglomerate locally interbedded with coarse- to medium-grained, micaceous, grey sandstone. Both trough and herringbone crossbedding occur locally. The top of the unit is not exposed here, but is interpreted to be disconformable, as well established elsewhere in the Avalon Zone (Hutchinson, 1962; Smith and Hiscott, 1984; Normore, 2012).

Adeyton Group

The formations of the Adeyton Group have been well-described for the Ocean Pond area (O'Brien, 1994) and elsewhere (Hutchinson, 1962; Jenness, 1963; Normore, 2012). The base of the Adeyton Group consists of red and green shale and slate of the Bonavista Formation, which overlies white quartz sandstone of the Random Formation. Green shale and slate occur at the base of the Bonavista Formation, succeeded by red shale, with which green shale is commonly interbedded. Pinkish calcareous nodules are common toward the top of the formation, and locally define bedding. Pink to red fossiliferous limestone and minor dark-red shale of the Smith Point Formation overlie the Bonavista Formation, and is an excellent marker horizon, where exposed. The best Smith Point Formation exposures outcrop along the eastern shore of Ocean Pond, where the unit is estimated to be 3–4 m thick. The presence of hyalithids, fragments of inarticulate brachiopods, and possible trilobite fragments were previously noted in the area (O'Brien, 1994). The contact between the Smith Point Formation and underlying Bonavista Formation is exposed at the southern point of the east arm of Ocean Pond (Figure 2), where it is subhorizontal and appears to be conformable. Grey-green shale and slate of the Brigus Formation overlie the Smith Point Formation with apparent conformity. Red shale is less common within the Brigus Formation relative to the Bonavista Formation, and calcareous concretions were noted only locally. Grey to green shale of the Chamberlains Brook Formation overlie, and is lithologically similar to, the Brigus Formation, except that blackish iridescent Mn-staining is more common in the former unit. As noted by O'Brien (1994), interformational contacts are approximate and can only be more precisely pinned through the use of biostratigraphy.

Harcourt Group

The Manuels River Formation (Hutchinson, 1962) of the Harcourt Group overlies the Adeyton Group with apparent conformity and forms the core of the synclinorium at Ocean Pond (Figure 2). Therein, the dark-grey to black shale is typically well cleaved with two distinct cleavages. The shale contains minor grey calcareous concretions and rare round pyrite nodules up to 1 cm in diameter. Trilobite fragments are locally present; O'Brien (1994) noted four fossil localities in the Ocean Pond area. An additional locality was discovered in 2013 (Figure 2) and details are given in a subsequent section of this report (*see* Biostratigraphy, below). The basal contact with underlying Chamberlains Brook Formation is not exposed in the study area but is presumed to be conformable as described elsewhere on the Bonavista Peninsula (see Hutchinson, 1962).

NEOPROTEROZOIC STRATIGRAPHIC RELATIONS

Contact relations of the CPG and overlying MG vary regionally from an angular unconformity with the overlying Cannings Cove Formation (Younce, 1970; Hussey, 1979; O'Brien, 1987) to conformable with Bull Arm Formation (McCartney, 1967; Younce, 1970). Within the study area, the CPG–MG contact occurs in four geographic areas: 1) Southward Head, 2) Cutler Head, 3) Maiden Hair Cove and 4) along the Indian Arm Fault. The first three occur at prominent headlands in the area, whereas the fourth occurs along the north-northeast-trending shoreline of an ocean inlet. Relationships exposed at the headlands are described first and discussed collectively. Exposures along Indian Arm are described and discussed separately.

THE HEADLANDS

Southward Head

Near the tip of Southward Head (Figure 2), a pronounced angular unconformity (Plate 12) separates grey-green to pinkish, medium-bedded sandstone (KHF) from overlying cobble conglomerate, interbedded felsic tuff (Cannings Cove Formation of MG) and mafic flows (Bull Arm Formation of MG). Erosional discordance is readily apparent, as the unconformity surface is sharp but irregular and shows strong structural discordance across the interface. The underlying sandstone (KHF) dips steeply (75º) to the northeast whereas the overlying conglomerate (MG) dips shallowly to the north (~30º), parallel to the unconformity surface. This clearly indicates that sub-unconformity strata were tilted prior to deposition of the basal conglomerate and interbedded volcanic rocks.

Cutler Head

At Cutler Head, a northeast-trending, subvertical fault juxtaposes MG rocks to the northwest with CPG rocks to the southeast (Figure 2). Shallowly northeast-dipping mafic volcanic flows and interbedded green and red sandstone to shale are herein assigned to the Bull Arm Formation of the

Plate 12. *Red conglomerate of the Cannings Cove Formation (basal MG) overlies steeply dipping, siliceous sandstones of the Kate Harbour formation (uppermost CPG) with angular discordance (arrow) at Southward Head; view to the northwest (UTM coordinates: 310798m E, 5373684m N; NAD 27, Zone 22N).*

MG. The mafic volcanic rocks here are indistinguishable (based on field evidence alone) from those exposed at Southward Head and along Indian Arm. Steeply southeast-dipping, grey-green to grey-red (variegated) turbiditic sandstone and granule conglomerate (KHF) occur southeast of the fault. The sense and magnitude of displacement on the fault are unknown.

South Maiden Hair Cove Headland

At the tip of the southern headland of Maiden Hair Cove (Figure 2), green and red, pebble to cobble conglomerate, herein assigned to the Cannings Cove Formation, is interbedded with mafic volcanic rocks (Bull Arm Formation) although the two are locally in fault contact. On the north side of the headland, the contact between the MG rocks and underlying thin-bedded, variegated sandstone (KHF) is covered by a 3-m section of unconsolidated beach debris, but discrepancies between the bedding orientations of KHF (steeply northwest-dipping) and MG rocks (steeply north-dipping) allow the possibility of an angular unconformity, similar to that exposed at Southward Head. Local pervasive quartz veining in both KHF and MG rocks, a narrow zone of fault breccia, and minor macroscopic brittle offsets, are, however, features most consistent with a faulted contact, which may be a tectonized unconformity.

Indian Arm Fault

The Indian Arm Fault (O'Brien, 1994) is a north-north-east-trending structure, marked by brittle offset that juxtaposes various levels of the CPG with the MG. Slivers of thin-bedded, ripple-marked, grey-green sandstone, laminated siltstone, and rare colour-banded chert commonly underlie Bull Arm volcanic rocks along the east side of Indian Arm. Rocks of possible CPG affinity dip steeply beneath the Bull Arm volcanic rocks along the shore of Indian Arm. The Indian Arm Fault likely extends through Indian Arm and thence south-southwesterly along the western margin of the Bull Arm volcanic belt (Figure 2), coincident with a prominent lineament evident on aerial photographs. Discrete narrow zones of fault breccia occur sporadically along Indian Arm, some of which correspond to the numerous northeast-trending cross faults that cut the stratigraphy. The sense and magnitude of displacement along the Indian Arm Fault is, however, not clear.

IMPLICATIONS OF STRATIGRAPHIC RELATIONS

The Kate Harbour formation represents the uppermost formation of the CPG in the study area and may be correlative to red siltstones and grewackes of the upper CPG mapped elsewhere in the Avalon Zone (*e.g.*, the southwestern tip of the peninsula south of Little Southern Harbour; McCartney, 1967). The redbeds of the KHF are interpreted to indicate that upper parts of the CPG basin not only thicken and coarsen upward (Knight and O'Brien, 1988; O'Brien, 1994), but become emergent. The angular unconformity separating CPG from overlying MG rocks is evident solely at Southward Head. Despite no clear evidence of angular discordance along the Indian Arm Fault, the fault is herein interpreted to represent a faulted unconformity at the margin of the CPG basin, similar to relations described and interpreted for Maiden Hair Cove.

The basal contact of MP, although not exposed, is apparently conformable, based on consistency of MP bedding trends with those of the underlying KHF. Further, the contact may well be gradational, for in the vicinity of Muddy Pond (Figure 2) the red sandstone of KHF apparently coarsens up-section, as red pebble conglomerate (MP) overlies red sandstone of the KHF and becomes dominant to the south and east. The MP conglomerate is clearly Precambrian, as it is overlain by shallow-marine Cambrian rocks at Ocean Pond to the south (Figure 2). The upper contact of MP is not exposed but is interpreted to be an unconformity (Figure 5), as established for the base of the Random Formation elsewhere in the Avalon Zone (Anderson, 1981). Contact relations between MP and Bull Arm volcanic rocks to the east are also not exposed, but the position of MP above KH (uppermost CPG) and below the Cambrian Random Formation imply that MP must be broadly contemporaneous with the MG.

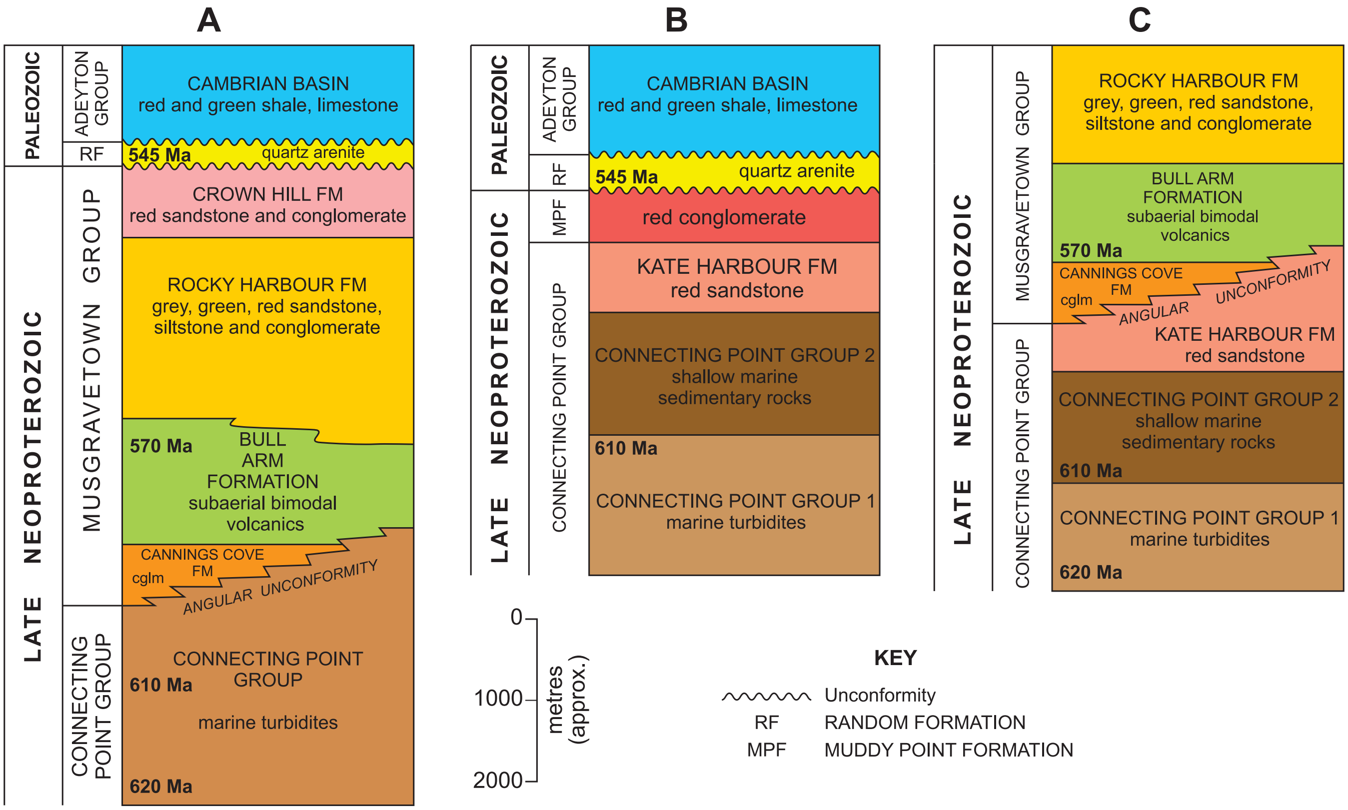

Figure 5. *Schematic stratigraphic profiles: A) composite section from Bonavista Bay (after O'Brien and King, 2002); B) schematic profile of section north to south from Summerville headland to Ocean Pond area (modified after O'Brien and King, 2002); C) section through study area, west to east from Summerville headland across Indian Arm to area south of Plate Cove (modified after O'Brien and King, 2002).*

DYKES WITHIN THE CONNECTING POINT GROUP

Mafic dykes occur commonly within the CPG and their prevalence has been noted previously as a characteristic, almost diagnostic feature, of the CPG (Jenness, 1963). Most are fine-grained diabase dykes that commonly contain fine-grained, disseminated pyrite. The fine-grained diabase dykes crosscut bedding, are generally subvertical to steeply dipping, and broadly trend northeast, although a small subset trends north-northwest. Chill margins, flow-layering, and bayonet-like apophases are locally well preserved. Some dykes exhibit cuspate margins, reminiscent of magma co-mingling textures, indicating that emplacement likely occurred during compaction, lithification and induration of the sediments (Plate 13). O'Brien and Knight (1988) suggest synsedimentary emplacement of a swarm of dykes spatially associated with CPG in the Eastport area and is also inferred for many of the diabase dykes in the Sweet Bay area.

Other dykes found within the study area include: 1) one porphyritic olivine–gabbro dyke that has chilled margins crosscuts rocks of the CPG ~2 km south of Sweet Bay; 2) two hornblende(?)-bearing dykes occur 400 m and 4.5 km southwest of Spar Pond, respectively (Figure 2); 3) two north-trending dykes containing trace sulphides, magnetite and black polycrystalline pseudomorphs (after relict clinopyroxene?) were noted one and three kilometres north of Charleston; 4) north- to north-northeast trending, plagioclase porphyritic dykes occur locally. One of these, which outcrops along a roadcut in Charleston, displays a distinct ophitic texture with 2-cm, radially arranged plagioclase phenocrysts comprising about 20% of the rock.

BIOSTRATIGRAPHY

A new fossil locality discovered in 2013 west of the southern tip of Ocean Pond (Figure 2), within the Manuels River Formation, consists of scattered fragmentary trilobites in an outcrop of black shale that is capped by a thin, dark-brown-weathering veneer of volcanic ash. The trilobite fragments identified (from photographs) include the thorax of *Paradoxides davidis* and the cranidium and thorax of *Jincella* (Plates 14 and 15; D. Boyce, personal communication, 2013). *Paradoxides davidis* was first described by Salter (1863) and defines a Middle Cambrian biostratigraphic sub-

Plate 13. *Mafic dyke crosscuts thick-bedded white to pink-weathering sandstones of the Kate Harbour formation at stream washout north of Highway 230 near Muddy Pond. Note the cuspate exterior dyke margins, whereas the interior margins of the apparently bifurcating dyke range from sharp to gradational, consistent with synsedimentary dyke emplacement (divisions on notebook in centimetres; UTM coordinates: 308827m E, 5363396m N; NAD 27, Zone 22N).*

zone, *P. davidis*, established in Newfoundland and the UK (Howell, 1925; Hutchinson, 1962; Fletcher, 2006). This globally correlative biostratigraphic subzone is consistent with a Drumian age (D. Boyce, personal communication, 2013; Series 3 of the Cambrian, formerly Middle Cambrian), which has an absolute age range of 504.5–500.5 Ma (Peng *et al.*, 2012).

Plate 14. *Cranidium of the trilobite* Jincella *(right arrow) and thorax of possibly* Jincella *(left arrow) in black shale of the Manuals River Formation west of southern Ocean Pond. Identification by W.D. Boyce. (UTM coordinates: 302346m E, 5351569m N; NAD 27, Zone 22).*

Plate 15. *Thorax of* Paradoxides davidis *in black shale of the Manuals River Formation. Same locality as Plate 14. Identification by W.D. Boyce.*

PRELIMINARY STRUCTURAL INTERPRETATION

Precambrian orogenesis in the Avalon Zone remains contentious (Dallmeyer *et al*., 1983; Nance *et al*., 2002) but evidence for late Precambrian deformation is well documented in several disparate parts of the Avalon Zone in Newfoundland (*e.g.*, O'Brien, 1987, 2002; Calon, 2001). Evidence of Precambrian deformation in the study area is cryptic. Bedding reversals in CP1 rocks, west of Ocean Pond, define a syncline–anticline pair that is not clearly evident in the adjacent Cambrian rocks to the east (Figure 2). However, the south-of-east trend of this fold pair is similar to that of folds interpreted to be generated by the second post-Cambrian deformation event affecting all rock units in the Sweet Bay area (*see* below). If the orientations of regional D_1 and D_3 structures are about the same, then alternate criteria must be used to clearly distinguish between artifacts of the two events.

Two post-Cambrian regional deformation events affected all map units in the study area, as the youngest rocks in the study area (Middle Cambrian Manuels River Formation) are Drumian (D. Boyce, personal communication, 2013). The first of these events, D_2, is characterized by a subvertical, axial-planar cleavage to north-northeast-trending, open to tight, asymmetric folds that have 1–2 km wavelengths and doubly plunging fold axes (Figure 2). The Cambrian succession at Ocean Pond is tightly folded by F_2 folds and its overall geometry defines a doubly plunging, north-northeast-trending synclinorium (Figure 2; O'Brien, 1994). The second post-Cambrian regional event, D_3, is characterized by broad, open, southeast- to east-southeast-trending, possibly east-southeast-plunging F_3 folds. Faults are ubiquitous across the study area, and the 045–060º-trending fault set (Figure 2) may represent a late, brittle D_4 event, as these faults appear to offset F_2 and F_3 folds in the area.

A subvertical cleavage, axial planar to F_2 folds, is well developed in Cambrian rocks at Ocean Pond and within conglomerate of the RHF, but varies from slatey to a weakly developed fracture cleavage in CPG rocks. Unlike the other map units in the area, CPG rocks commonly exhibit faulted fold hinges and cm-scale to larger offsets along joints. In contrast, rocks of the RHF display well-developed, tight, north-northeast-trending, doubly plunging folds and the traces of some of these fold closures are evident on aerial photographs. The different styles of deformation reflect competency contrast: many of the rock types of the CPG are highly indurated and siliceous, and are rheologically competent relative to Cambrian shales and arkosic rocks of the RHF.

One of the most prominent structural features in the Sweet Bay area is the north-northeast-trending Indian Arm Fault (O'Brien, 1994). Although nowhere exposed in the Sweet Bay area, this significant structure separates the western terrain of shoaling-upward marine CPG rocks from subaerial MG rocks to the east. The Indian Arm Fault is likely a reworked unconformity at the margin of the older CPG basin. O'Brien (1994) describes a sericite-defined fabric in Bull Arm volcanic rocks and asymmetric clast rotation in overlying MG conglomerate that are both consistent with east-side-down–west-side-up displacement. It follows, then, that the adjacent Indian Arm Fault represents the east-bounding fault of the CPG horst, as proposed by McCartney (1967) for CPG-bounding, high-angle faults on the Isthmus of Avalon. Displacement must have occurred after MG volcanism and before development of the 045–060º-trending fault set (Figure 2). Subsequent (or coeval?) regional D_2 deformation produced the north-northeast-trending folds that dominate the map pattern and basal MG rocks are exposed as synclinal slivers at the headlands in the Sweet Bay area. The D_3 caused an undulatory warping of stratigraphy and modification of F_2 fold axes and axial planes. The 045–060º-trending D_4 faults are associated with dextral offset and appear to be the youngest structural elements in the study area.

ECONOMIC POTENTIAL

Sedimentary-hosted 'stratiform' copper (SSC) mineralization was discovered in the MG elsewhere on the Bonavista Peninsula but is more prevalent in reduced parts of the Crown Hill Formation, particularly within the Blue Point facies, near Duntara, ~20 km northeast of the study area (O'Brien and King, 2002). Regional potential for SSC mineralization in rocks of the Rocky Harbour and Crown Hill formations of the MG is discussed in detail by Hinchey (2010). Malachite was noted in felsic tuffaceous rocks and breccias of the Bull Arm Formation, east of the Indian Arm Fault (O'Brien, 1994). Subrounded malachite blebs with bleached haloes, locally up to 1 cm in diameter, occur in felsic tuff that is interbedded with red pebble to cobble conglomerate above the angular unconformity at Southward Head (Plate 16). The main heavy mineral in the final Frantz separates of a sample from the tuff is native Cu, which occurs as matted plates and wire-like pieces (G. Dunning, personal communication, 2013). North of the Cambrian basin, dilational quartz veins display well-developed comb texture and minor malachite (Plate 17). Examples of copper mineralization in rocks of the RHF include the Fifields Pit, Trinity and Trinity Pond occurrences (Hinchey, 2010) and correlative rocks of the RHF occur east of the Bull Arm volcanic belt in the study area (Figure 2) and are therefore considered to have SSC potential.

The online Mineral Occurrence Database, available through the Department of Natural Resources' Geoscience Online Resource Atlas, records two copper occurrences in Cambrian rocks of the study area (Lady Pond East and Lady Pond North; Figure 2). Soil sampling completed by Noranda in 2002 yielded anomalous copper values and follow-up work located minor malachite and chalcocite associated with calcareous nodules in locally bleached red shales of the Adeyton Group (Graves, 2003).

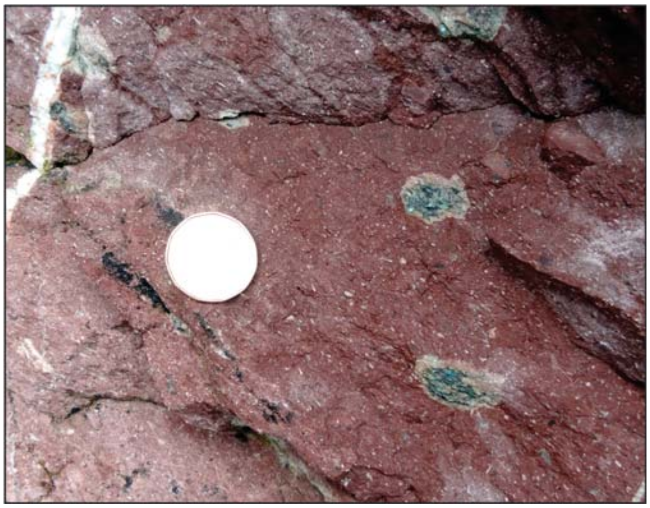

Plate 16. *Subrounded blebs of malachite showing bleached haloes in felsic tuff interbedded with red pebble to cobble conglomerate above the angular unconformity at Southward Head (coin – 2.5 cm; UTM coordinates: 310798 E, 5373684 N; NAD 27, Zone 22N).*

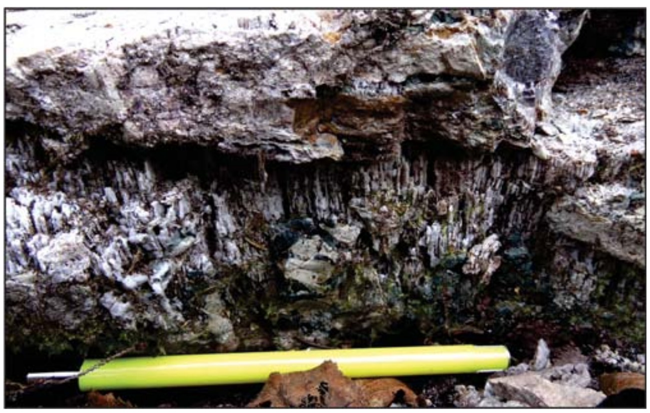

Plate 17. *Dilational quartz veins displaying well-developed comb texture and minor malachite (?) crosscut red siltstone of the Kate Harbour formation, 2 km west of Muddy Pond (Pen magnet – 10 cm; UTM coordinates: 306766m E, 5362395m N; NAD 27, Zone 22N).*

The Avalon Zone has long been recognized for its potential to host epithermal-style systems (*e.g.*, O'Brien *et al.*, 1998, 1999). Recent exploration at the Big Easy prospect in the Thorburn Lake area identified low-sulphidation gold and silver mineralization hosted within the RHF (Silver Spruce Resources Inc., press release, 2013), and demonstrates that the sedimentary succession immediately overlying Bull Arm Formation volcanic rocks is also prospective for gold (Sparkes, 2012).

Gabbro dykes, apparently spatially restricted to the CPG, commonly contain disseminated pyrite that locally

Plate 18. *Euhedral pyrite cubes up to 1 cm in grey-green sandstone of the Kate Harbour formation. Same location as Plates 10 and 13. Tip of pen magnet – 1.7 cm.*

comprises up to two modal %. Euhedral pyrite cubes of up to 1 cm were noted at two localities in siltstone of the upper CPG (Plate 18). O'Brien (1994) describes pyrite along fractures in shales of the CPG. Pervasive, as well as irregular and patchy hydrothermal alteration, ranging from pistachio green to salmon pink, was noted at several localities in sandstones of the CPG.

Cambrian slate of the Adeyton Group has a history of commercial building-stone production in Newfoundland (*e.g.*, Random Island, Keels; Tuach, 1993). Red to green slate exposed near Ocean Pond may also have potential as a slate resource. Manganese staining has been noted locally in shale and slate of the Chamberlains Brook Formation (O'Brien, 1994).

ACKNOWLEDGMENTS

The author acknowledges the enthusiastic and reliable assistance provided by Zoe Goodyear throughout the field season. Hamish Sandeman and Kendra Power helped to make the most of limited helicopter support. Horace Newell provided sound guidance as our boatman; Judy Newell graciously extended wonderful hospitality. Thanks go to Dave White, Dave Moss and Gerry Rose for their help and kindness throughout the summer, most notably when difficulties with our moored boat were encountered. Sean O'Brien kindly provided the author with his 1993 field data. Doug Boyce generously examined photographs of trilobite fragments, resulting in their identification. Tony Paltanavage provided excellent support in drafting figures. Larry Nolan, Alana Hinchey and Robin Constantine provided much needed technical support. Gerry Hickey provided help with field logistics and safety issues. Thoughtful discussions with Art

King, Hamish Sandeman and Brian O'Brien were most beneficial. Critical reviews by Alana Hinchey and Ian Knight helped to improve the manuscript.

REFERENCES

Anderson, M.M.
1981: The Random Formation of southeastern Newfoundland: a discussion aimed at establishing its age and relationship to bounding formations. American Journal of Science, Volume 281, pages 807-830.

Calon, T.
2001: Late Precambrian sedimentation and related orogenesis of the Avalon Peninsula, eastern Avalon Zone, Newfoundland. Geological Association of Canada, St. John's 2001 Field Trip Guidebook, Field Trip A9/B8, 32 pages.

Christie, A.M.
1950: Geology of Bonavista map-area, Newfoundland (summary account). Department of Mines and Technical Surveys. Geological Survey of Canada, Paper 50-7, 50 pages and map (Map 50-7A).

Dallmeyer, R.D., Hussey, E.M., O'Brien, S.J. and O'Driscoll, C.F.
1983: Chronology of tectonothermal activity in the western Avalon Zone of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 20, pages 355-363.

Dec, T., O'Brien, S.J. and Knight, I.
1992: Late Precambrian volcaniclastic deposits of the Avalonian Eastport basin (Newfoundland Appalachians): petrofacies, detrital clinopyroxene and paleotectonic implications. Precambrian Research, Volume 59, pages 243-262.

Fletcher, T.P.
2006: Bedrock geology of the Cape St. Mary's Peninsula, southwest Avalon Peninsula, Newfoundland, (includes parts of NTS map sheets 1M/1, 1N/4, 1L/16 and 1K/13). Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 06-02, 137 pages [NFLD/2948].

Graves, G.
2003: Noranda Incorporated and Cornerstone Resources Incorporated; First year, first year supplementary, second, third, and fourth year assessment report on geological, geochemical and diamond drilling exploration for licence 6363M-6364M, 7821M, 7867M-7869M, 7939M, 7941M-7945M, 7948M, 8023M-8024M, 8069M-8099M, 8101M, 8329M, 8457M-8468M, AND 8810M-8812M on claims in the Duntara to Deer Harbour area, eastern Newfoundland, 2 reports.

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.

Hiscott, R.N.
1982: Tidal deposits of the Lower Cambrian Random Formation, eastern Newfoundland: facies and paleoenvironments. Canadian Journal of Earth Sciences, Volume 19, pages 2028-2042.

Hinchey, J.G.
2010: Neoproterozoic sedimentary-hosted 'stratiform' copper mineralization – Bonavista Peninsula, Avalon Zone, Newfoundland: Initial field and petrographic observations. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survery, Report 10-1, pages 1-21.

Howell, B.F.
1925: The faunas of the Cambrian paradoxides beds at Manuels, Newfoundland. Bulletins of American Paleontology, Volume 11, Number 43, pages 1-140.

Hussey, E.M.
1979: Geology of the Clode Sound area, Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, 312 pages.

Hutchinson, R.D.
1953: Geology of Harbour Grace map-area, Newfoundland. Geological Survey of Canada, Memoir 275, 43 pages [001N/11/0038].

1962: Cambrian stratigraphy and trilobite faunas of southeastern Newfoundland. Geological Survey of Canada, Bulletin 88, 156 pages.

Jenness, S.E.
1963: Terra Nova and Bonavista map-areas, Newfoundland (2D E ½ and 2C). Geological Survey of Canada, Memoir 327, 184 pages.

Knight, I. and O'Brien, S.J.
1988: Stratigraphy and sedimentology of the Connecting Point Group and related rocks, Bonavista Bay, Newfoundland: an example of a Late Precambrian Avalonian basin. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 207-228.

Malpas, J.G.
1971: The petrochemistry of the Bull Arm Formation near Rantem Station, southeast Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, 126 pages.

McCartney, W.D.
1958: Geology of Sunnyside map area, Newfoundland. Geological Survey of Canada, Paper 58-8.

1967: Whitbourne map area, Newfoundland, Geological Survey of Canada, Memoir 341, 135 pages.

Myrow, P.M.
1995: Neoproterozoic rocks of the Newfoundland Avalone Zone. Precambrian Research, Volume 73, pages 123-136.

Myrow, P.M. and Hiscott, R.N.
1993: Depositional history and sequence stratigraphy of the Precambrian – Cambrian boundary stratotype section, Chapel Island Formation, southeast Newfoundland. *In* Event Makers in Earth History. *Edited by* H. Geldzetser and G. Nowlan. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 104, pages 13-35.

Nance, R.D., Murphy, J.B. and Keppie, J.D.
2002: A Cordilleran model for the evolution of Avalonia. Tectonophysics, Volume 352, pages 11-31.

Narbonne, G.M., Myrow, P.M., Landing, E. and Anderson, M.M.
1987: A candidate stratotype for the Precambrian-Cambrian boundary, Fortune Head, Burin Peninsula, southeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1277-1293.

Normore, L.S.
2010: Geology of the Bonavista map area (NTS 2C/11), Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 10-1, pages 281-301.

2011: Preliminary findings on the geology of the Trinity map area (NTS 2C/06), Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 11-1, pages 273-293.

2012: Geology of the Random Island map area (NTS 2C/04), Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survery, Report 12-1, pages 121-145.

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, Geological Survey Branch, Report 87-1, pages 257-270.

1992: Geological development of the Avalon Zone, the easternmost Gander Zone, and the ductile Dover Fault in the Glovertown (NTS 2D/9, East half) map area, eastern Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 171-184.

1993: A preliminary account of geological investigations in the Clode Sound – Goose Bay region, Bonavista Bay, Newfoundland (NTS 2C/5 NW and 2D/8 NE). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 293-309.

1994: 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). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 94-1, pages 187-199.

2002: A note on Neoproterozoic gold, early Paleozoic copper and basement-cover relationships on the margins of the Holyrood Horst, southeastern Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 02-1, pages 219-227.

O'Brien, S.J., Dubé, B., O'Driscoll, C.F. and Mills, J.
1998: Geological setting of gold mineralization and related hydrothermal alteration in late Neoproterozoic [post-640 Ma] Avalonian rocks of Newfoundland, with a review of coeval gold deposits elsewhere in the Appalachian Avalonian belt. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 98-1, pages 93-124.

O'Brien, S. J., Dubé, B. and O'Driscoll, C. F.
1999: High-sulphidation, epithermal-style hydrothermal systems in late Neoproterozoic Avalonian rocks on the Burin Peninsula, Newfoundland: implications for gold exploration. *In* Current Research. Newfoundland and Labrador Department of Mines and Energy, Geological Survey, Report 99-1, pages 275-296.

O'Brien, S.J., Dunning, G.R., Knight, I. and Dec, T.
1989: Late Precambrian geology of the north shore of Bonavista Bay (Clode Sound to Lockers Bay). *In*

Report of Activities. Geological Survey Branch, Department of Mines and Energy, pages 49-50.

O'Brien, S.J. and King, A.F.
2002: Neoproterozoic stratigraphy of the Bonavista Peninsula: preliminary results, regional correlations and implications for sediment-hosted stratiform copper exploration in the Newfoundland Avalon Zone. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 02-1, pages 229-244.

2004: Late Neoproterozoic to earliest Paleozoic stratigraphy of the Avalon Zone in the Bonavista Peninsula, Newfoundland: an update. *In* Current Research. Newfoundland. Department of Mines and Energy, Geological Survey, Report 04-1, pages 213-224.

2005: Late Neoproterozoic (Ediacaran) stratigraphy of Avalon Zone sedimentary rocks, Bonavista Peninsula, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 05-1, pages 101-113.

O'Brien, S.J. and Knight, I.
1988: The Avalonian geology of southwest Bonavista Bay: portions of the St. Brendan's (2C/13) and Eastport (2C/12) map areas. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 193-205.

O'Brien, S.J., Strong, D.F. and King, A.F.
1990: The Avalon Zone type area: southeastern Newfoundland Appalachians. *In* Avalonian and Cadomian Geology of the North Atlantic. *Edited by* R.A. Strachan and G.K. Taylor. Blackies and Son Ltd., Glasgow, pages 166-194.

Peng, S., Babcock, L.E. and Cooper, R.A.
2012: The Cambrian Period, Chapter 19. *In* The Geologic Time Scale 2012. *Edited by* F. Gradstein, J. Ogg, M. Schmitz and G. Ogg. Elsevier, 1176 pages.

Salter, J.W.
1863: On the discovery of Paradoxides in Britain. Quarterly Journal of the Geological Society, Volume 19, pages 274-277.

Smith, S.A. and Hiscott, R.N.
1984: Latest Precambrian to Early Cambrian basin evolution, Fortune Bay, Newfoundland: fault-bounded basin to platform. Canadian Journal of Earth Sciences, Volume 21, pages 1379-1392.

Silver Spruce Resources Inc.
2013: News Release, September 26, 2013. http://www.silverspruceresources.com/s/NewsReleases.asp?ReportID=605285&_Type=News&_Title=Silver-Spruce-Reports-on-Independent-Assessment-of-its-Big-Easy-Epithermal-...

Sparkes, G.W.
2012: New developments concerning epithermal alteration and related mineralization along the western margin of the Avalon Zone, Newfoundland. *In* Current Research. Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 12-1, pages 103-120.

Tuach, J.
1993: The Random Island slate deposit, NTS 2C/04, Newfoundland. *In* Ore Horizons. *Compiled by* A. Hogan and H. S. Swinden. Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Ore Horizons, Volume 2, pages 37-48.

Walcott, C.D.
1900: Random – Precambrian Upper Algonkian Terrance. Bulletin of the Geological Society of America, Volume 11, pages 3-5.

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.