

LATE NEOPROTEROZOIC (EDIACARAN) STRATIGRAPHY OF AVALON ZONE SEDIMENTARY ROCKS, BONAVISTA PENINSULA, NEWFOUNDLAND

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Regional Mapping Section

ABSTRACT

New mapping has resulted in a detailed and revised stratigraphic subdivision of the late Neoproterozoic (Ediacaran Period) marine sedimentary succession in the eastern Bonavista Peninsula. The oldest exposed unit, assigned to the Drook Formation of the Conception Group, is the Shepherd Point member, characterized by mainly parallel-laminated, siliceous siltstones, mudstones and fine-grained sandstones. The overlying, fossiliferous Mistaken Point Formation (upper Conception Group) is divided into a lower, siliceous and variegated tuffaceous, silt- to fine-sand-rich Goodland Point member and an upper, grey to red, argillaceous Murphy's Cove member. The conformably overlying Trepassey Formation (lower St. John's Group) is divided into a lower, grey-green argillaceous Catalina member and an upper, sand-rich Port Union member. The upper Trepassey Formation rocks are overlain conformably by thin- to medium-bedded, dark grey shales and disrupted or slumped units of sandstone and shales of the lower Fermeuse Formation, designated Back Cove member. Laminae and thin beds of ash tuffs are a prolific and diagnostic part of the rock record of the eastern Bonavista Peninsula. The tuffaceous volcanicity is recorded at multiple stratigraphic levels throughout the marine section; fossiliferous beds are everywhere associated with thin tuff units.

The known lateral and vertical extent of Ediacaran biota in the eastern Bonavista Peninsula has been extended significantly. More than twenty separate fossil localities from multiple stratigraphic levels throughout the late Neoproterozoic marine succession have been identified. The vertical range of Charnia-related discs and associated frond-like forms, spindle-shaped fossils, bush-like fossils and radial forms in the Bonavista Peninsula succession is now known to extend throughout the Mistaken Point Formation, upward through the Trepassey Formation and into the Fermeuse Formation. Morphological variants of Aspidella occur throughout the same stratigraphic range, but extend higher into the upper St. John's Group than the other Ediacaran forms.

New mapping of the upper Rocky Harbour and overlying Crown Hill formations of the Musgravetown Group in the western Bonavista Peninsula has established locally developed to regionally extensive facies subdivisions of potential member status within the thick, shallow-marine to terrestrial succession. Some units may correlate with significant parts of the Signal Hill Group, 150 km farther east, thus highlighting the large dimensions of the late Neoproterozoic basin. The basin fill is characterized by pronounced east-to-west facies variations related in part to syn-sedimentary faulting. The development of laterally consistent, reduced, sulphide-bearing (and variably cupriferous) grey beds within the thick redbed succession was an important aspect of basin evolution.

INTRODUCTION

The Geological Survey's program of mapping and related stratigraphic and paleontological studies of late Neoproterozoic (Ediacaran Period), marine, deltaic and terrestrial sedimentary facies in the Bonavista Peninsula continued

during the 2004 field season (Figure 1). The mapping and stratigraphic work described builds upon data previously reported in O'Brien and King (2002, 2004a,b), and allows a detailed and revised stratigraphic subdivision of the Conception and St. John's groups in the eastern Bonavista Peninsula. Additional mapping in the northwestern Bona-

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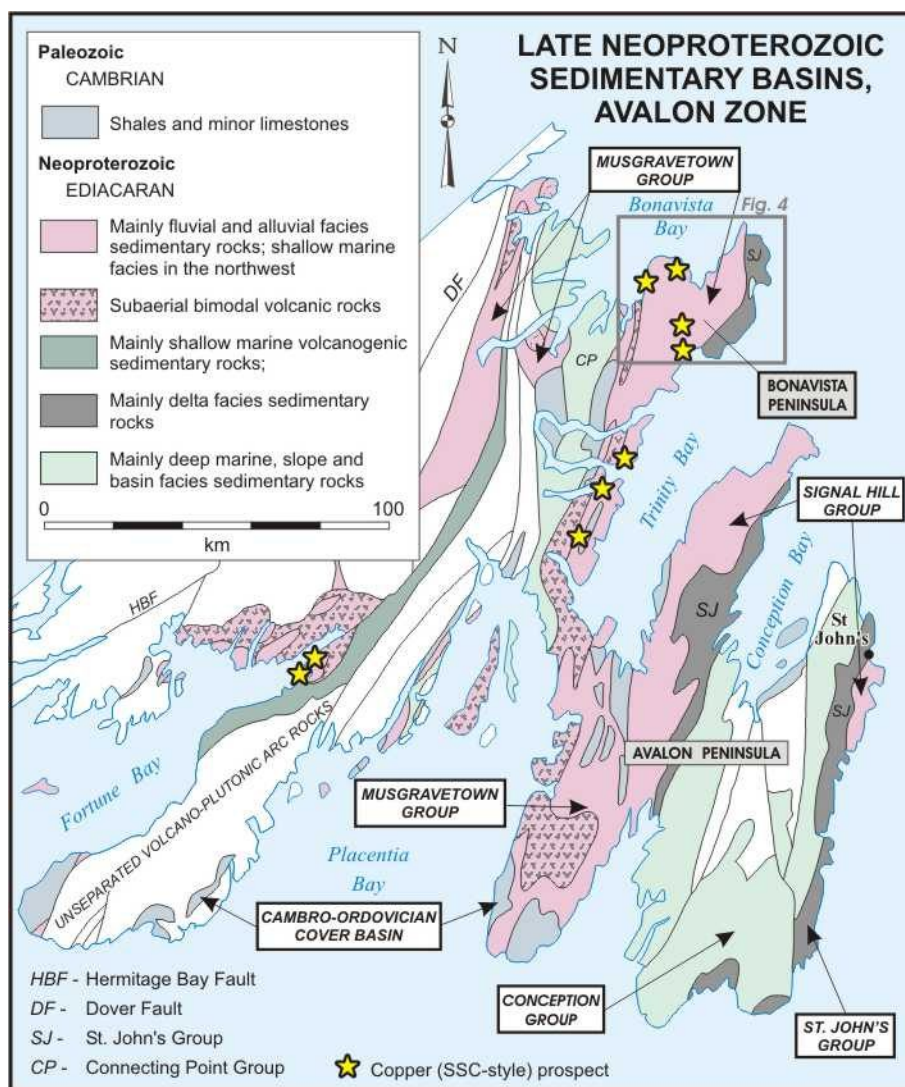


Figure 1. Regional distribution of principal sedimentary facies in the late Neoproterozoic of the Avalon Zone, showing the location of the areas studied.

vista Peninsula, carried out in conjunction with work by Cornerstone Resources, has led to further subdivision of the Rocky Harbour and Crown Hill formations of the Musgravetown Group in that area. The Bonavista Peninsula study is part of a larger, continuing investigation aimed at developing a unified regional stratigraphic framework for the late Neoproterozoic basins of the Appalachian Avalon Zone of Newfoundland, to serve as a guide to exploration for sediment-hosted stratiform copper deposits.

NEOPROTEROZOIC MARINE STRATA, EASTERN BONAVISTA PENINSULA: CONCEPTION AND ST. JOHN'S GROUPS

Earlier mapping of the late Neoproterozoic succession east of the Spillars Cove–English Harbour fault zone con-

firmed the correlation of marine siliciclastic rocks there with parts of the Conception, St. John's and Signal Hill groups of the Avalon Peninsula, eastern Newfoundland (O'Brien and King, 2002, 2004a,b). New detailed mapping of the Conception and lower St. John's groups allows a detailed and revised stratigraphic subdivision of the late Neoproterozoic rocks in that part of the Bonavista Peninsula. New distinctive units having regional extent have now been identified and new member names are proposed (Figures 2 and 3).

Significant new discoveries of Ediacaran Period (ca. 630 to 542 Ma) fossils in this marine succession were made during the 2004 field season. Detailed paleontological work on these sites is ongoing. A detailed and systematic paleontological study of these and other recently discovered sites in the region (see O'Brien and King, 2004a) was initiated in 2004, and is being carried out by H. Hofmann (McGill University), in conjunction with the authors. Over 100 latex moulds and a large number of high-resolution digital photographs were made in the field and are currently being studied; the results of this ongoing work will be reported elsewhere.

New mapping has identified laminae to thin beds of ash–tuff at numerous stratigraphic levels throughout the Conception and St. John's groups in the eastern Bonavista Peninsula. Several samples of tuff were collected during the 2004 field season as part of a geochronological study with G.R. Dunning (Memorial University of Newfoundland). This work is designed to determine: i) the ages of contrasting terrestrial and fossiliferous marine facies of the Neoproterozoic basin in this region, ii) the depositional rates within the basin, and iii) the absolute age of Neoproterozoic fossils contained therein. Samples of tuff have been collected from several parts of the profusely fossiliferous Mistaken Point Formation (Conception Group), and from fossil beds in the overlying Trepassy Formation (St. John's Group).

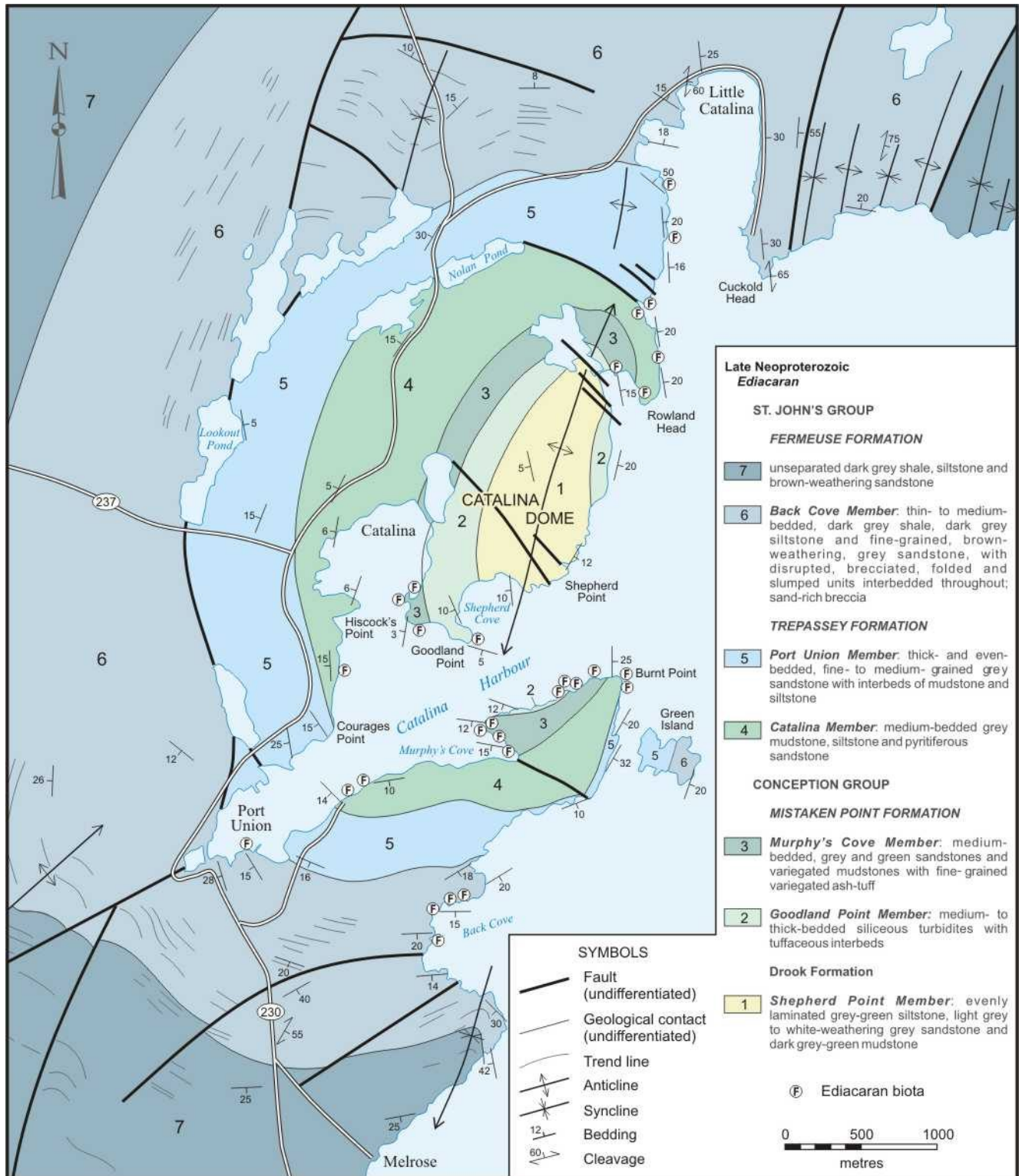


Figure 2. Geology of the Conception and St. John's groups in the Catalina region.

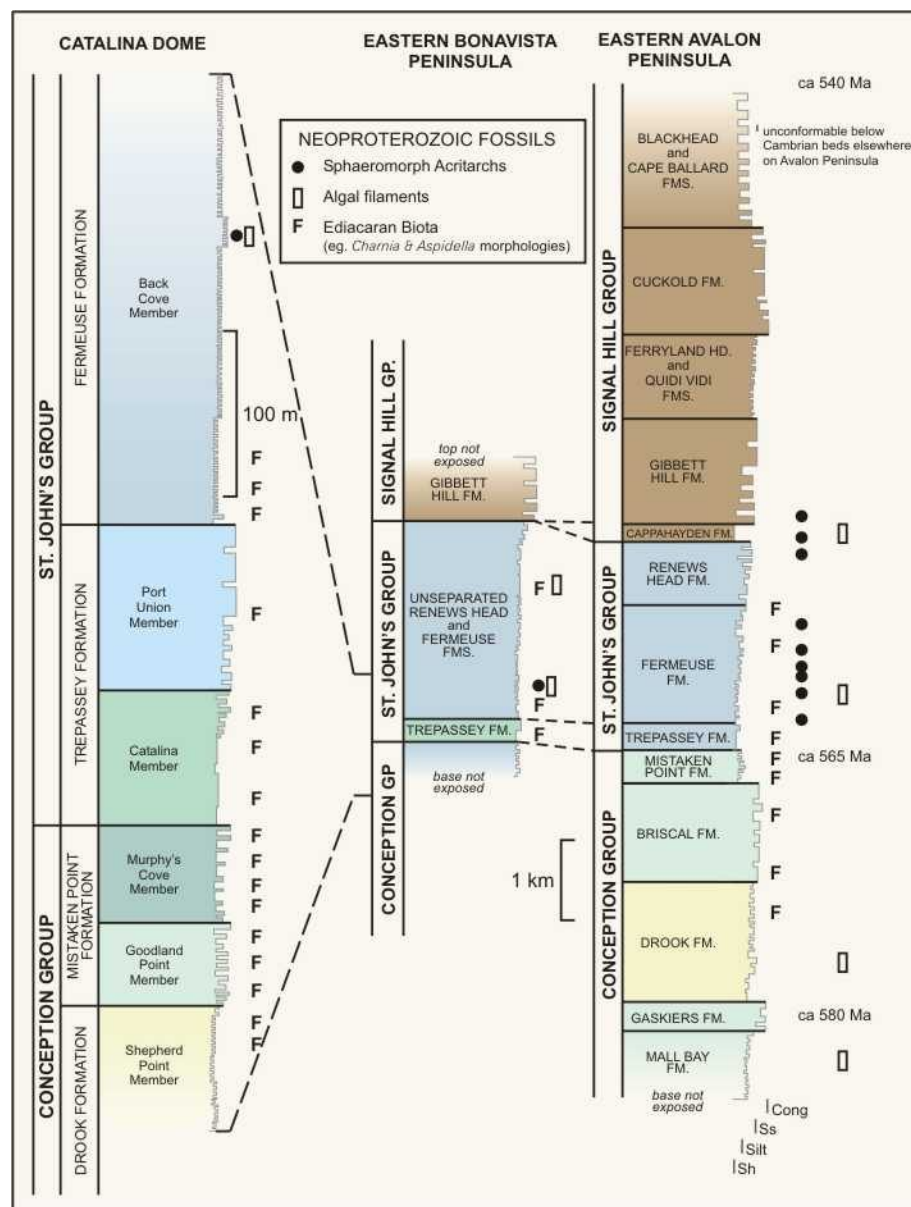


Figure 3. Stratigraphic profiles of the Conception and St. John's groups in the eastern Bonavista Peninsula, showing a comparison with similar rocks in the Avalon Peninsula.

STRATIGRAPHY AND NEW NOMENCLATURE

Conception Group

The *Shepherd Point member*, the oldest exposed unit of the Drook Formation (Williams and King, 1979) in the Conception Group of the Catalina area, forms the core of the Catalina Dome (O'Brien and King, 2004b; Figure 2). The type section is along the coast between Shepherd Cove and Shepherd Point (Figure 2), where it has an exposed stratigraphic thickness of about 60 m; the base of the member is unexposed within the Catalina Dome. The member is characterized by evenly laminated grey-green siltstone, white-

grey sandstone and dark grey-green to black mudstone. The bedding is composed of alternating parallel layers, typically 1 to 3 mm thick, of laminated silt, sand and mud. Individual sets of fine sand, silt and mud may be followed along strike for several metres where they pinch out or are terminated by slightly irregular, very low-angle erosional discontinuities (Plate 1). Scouring features are commonly developed, as are small-scale syn-sedimentary slump folds and faults, and mud rip-up clasts. Interspersed throughout the succession are coarsely interlayered, thin to medium beds of parallel-laminated sand that alternate with thin, parallel-laminated layers of silt and mud. Crosslaminated units of sandstone, 2 to 10 cm thick, are locally preserved but are rare; sandstone laminae and beds typically have sharp bases. Similar and comparable facies occur in the Drook Formation, in the Bareneed area (west Conception Bay) of the Avalon Peninsula (cf. King, 1988) and in the 750-m-thick Torbay Member, Drook Formation in the St. John's area (King, 1990; Figure 3).

The overlying, fossiliferous Mistaken Point Formation (upper Conception Group) has been subdivided into a lower, siliceous *Goodland Point member* and an upper, argillaceous *Murphy's Cove member*; both members are well exposed within the Catalina Dome (Figure 2). The type section of the Goodland Point member is centred around Goodland Point, Catalina, where it has an estimated stratigraphic thickness of about 50 m. The Goodland Point member is a medium- to thick-bedded siliceous turbidite sequence composed of silt, fine sand and tuff, representing T_{BCDE} Bouma divisions. Large-scale slump folds are locally preserved. This member resembles and may correlate with the 100-m-thick Middle Cove member, Mistaken Point Formation, St. John's area (King, 1990). During the 2003 field season, Ediacaran fossils were discovered below tuff beds in this siliceous succession of the Goodland Point member, at



Plate 1. Parallel-laminated siltstone and sandstone and dark grey-green mudstone showing low-angle erosional discontinuities; *Shepherd Point member, Drook Formation, Conception Group*.

the overlying boundary between siliceous and non-siliceous parts of the turbidite succession, and in overlying argillaceous rocks. The latter argillite unit is here designated Murphy's Cove member.

The type section of the Murphy's Cove member is on the east side of Murphy's Cove (Figure 2), where it has a stratigraphic thickness of about 60 m. The geographic name Murphy's Cove is the preferred local usage, equivalent to Southeast Cove, as shown on Bonavista map area (NTS 2C/11 and 2C/10). The member is dominated by medium-bedded, grey and green sandstones and variegated structureless and laminated mudstones, which resemble and may correlate with the 135-m-thick Hibbs Cove Member, uppermost Mistaken Point Formation, at its type locality on the Avalon Peninsula (King, 1990). Fine-grained ash-tuff forms thin beds and laminae throughout the member; tuffs are typically white or grey, more rarely brown, and in at least one instance, red (Plate 2).

St. John's Group

The conformably overlying Trepassey Formation, the basal unit of the St. John's Group, is divided into a lower, grey-green argillaceous *Catalina member* and an upper, sand-rich *Port Union member*. The latter is overlain conformably by mainly dark grey shales of the lower Fermeuse Formation (Williams and King, 1979), which are herein designated as the *Back Cove member*.

The type locality of the Catalina member is well exposed around Catalina Harbour, between Courages Point and the shore north of Hiscocks Point, as well as the coastal section west of Murphy's Cove (Figure 2). It forms an estimated 80-m-thick monotonous succession of grey, thin to medium-bedded mudstone, siltstone and pyritiferous sand-



Plate 2. Thin-bedded fossiliferous sandstones with abundant tuff layers (buff and pale red), *Murphy's Cove member, Mistaken Point Formation, Conception Group*.



Plate 3. Light-brown tuff preserving Ediacaran biota (oblate spindle-like forms) in the *Trepassey Formation, St. John's Group*.

stone (mainly T_{DE} beds). Laminae and thin beds of ash-tuff are common throughout the member. During the 2004 field season, well-preserved Ediacaran fossils were discovered below distinctive brown ash layers at several stratigraphic levels in the upper part of the Catalina member (Plate 3). The Catalina member correlates with most of the 100- to 125-m-thick Trepassey Formation at its type locality in the southern Avalon Peninsula. This member is also characterized by prominent diagenetic pyrite cubes, and is known both historically and locally as Catalina stone (see O'Brien and King, 2002). The upper part of the Catalina member coarsens and thickens upward.

The Catalina member passes transitionally into the Port Union member. The type locality of the Port Union member is well exposed around Port Union, particularly in shoreline exposures southwest of Courages Point. Its estimated stratigraphic thickness is about 100 m. Thick and even beds of fine- to medium-grained grey sandstone and interbeds of

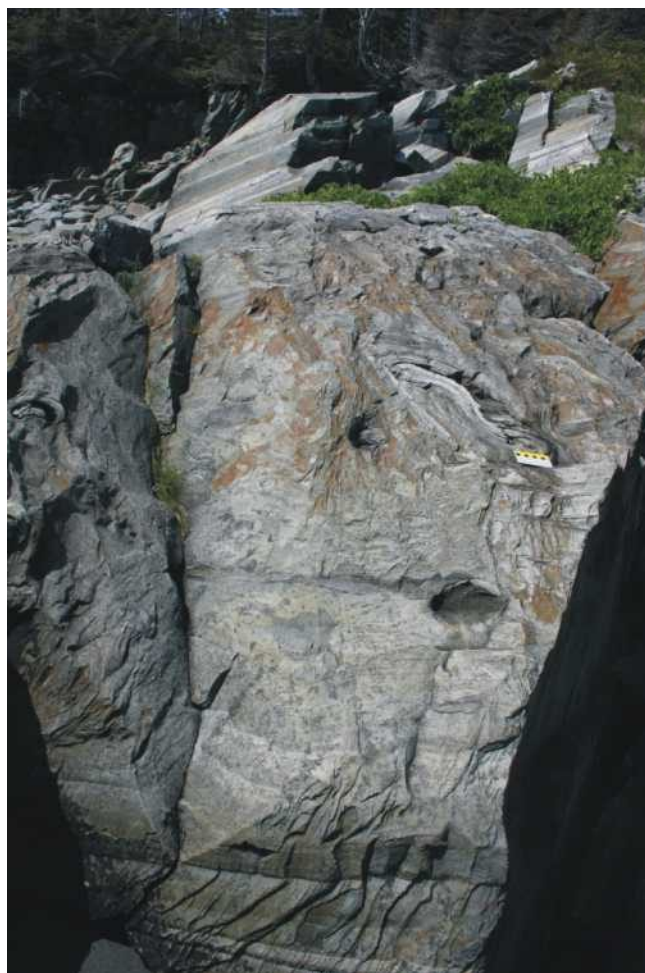


Plate 4. *Disrupted, brecciated, folded and slumped units bounded above and below by dark grey and black shale beds; Back Cove member, Fermeuse Formation, St. John's Group.*



Plate 5. *Sand-rich sedimentary breccia capping slump unit, overlain by shale; Back Cove member, Fermeuse Formation, St. John's Group.*

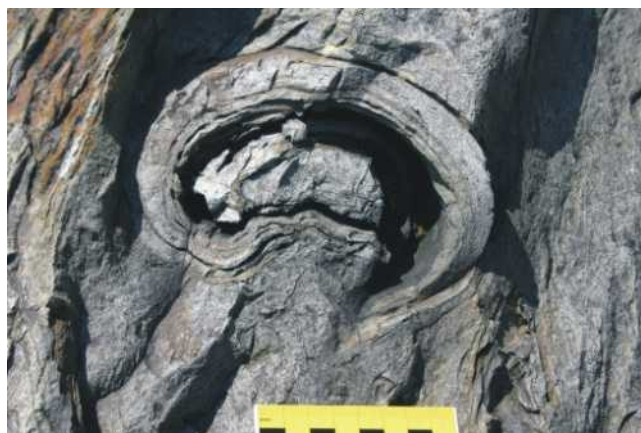


Plate 6. *Syn-sedimentary fold of disrupted bed in a slump unit within the Back Cove member, Fermeuse Formation, St. John's Group.*

mudstone, siltstone and tuff together characterize the member. The distinctive, highly feldspathic sandstones (lithic arkose) are fine to medium grained with a moderately well-sorted mixture of subangular to subrounded grains of mainly plagioclase feldspar, microcline, quartz and minor lithic fragments. The Port Union member is presumed to correlate with a relatively minor sandstone unit at the top of the coarsening-upward Trepassy Formation, in the southern Avalon Peninsula (King, 1988; Wood *et al.*, 2003).

The type locality of the Back Cove member, Fermeuse Formation, is well exposed in the coastal section about one kilometre east of Port Union. Stratigraphic studies of its extent throughout the Melrose area to the south are incomplete; a preliminary estimate of the stratigraphic thickness of the member is about 350 m. The Back Cove member consists of thin to medium, even and parallel beds of dark grey mudstone, shale, dark grey siltstone and fine-grained, brownish-weathering grey sandstone. Disrupted, brecciated, folded and slumped units are prominent throughout the shale succession, and are particularly well exposed around Back Cove (east of Port Union) and at Little Catalina Harbour. These widespread slump deposits, which are locally capped by sand-rich breccia, are up to several metres thick and bounded above and below by shales (Plates 4 and 5). They show a variety of sedimentary structures ranging from simple upright folds to complex décollement-like folds and associated syn-sedimentary thrust faults. Other coarse deposits are varied in composition and texture; examples include tabular-bedded sandstone fragments having minimal mud matrix, rolled beds of sandstone fragments surrounded entirely by mudstone (Plate 6), and coarse, poorly sorted breccias of mixed clastic composition. These deposits, which are interpreted as debris-flows, typically grade upward from coarse breccia into finer, clast-rich sediments

that are sharply overlain by turbidites. Ediacaran biota, including several morphological variants of *Aspidella*, were discovered at several stratigraphic levels within the basal 200 m of the Back Cove member during the 2004 field season. This member correlates with the basal Fermeuse Formation, Avalon Peninsula (King, 1988, 1990; Narbonne *et al.*, 2001).

STRATIGRAPHIC RANGE OF EDIACARAN BIOTA

The known lateral and vertical extent of Ediacaran Period (ca. 630 to 542 Ma) fossils in the marine succession of the eastern Bonavista Peninsula has been extended significantly (Figures 2 and 3). To date, Ediacaran biota have been discovered in over 20 separate sites in the well-exposed coastal section through the late Neoproterozoic rocks between Little Catalina and Melrose, Trinity Bay. The vertical stratigraphic range of *Charnia*-related discs and frond-like forms (e.g., *Charniodiscus*), spindle-shaped fossils, bush-like fossils (e.g., *Bradgatia*) and radial forms (e.g., *Hiemalora*), as described in O'Brien and King (2004a), now extends throughout the Mistaken Point Formation (fossils in both Goodland Point and Murphy's Cove members), upward through the Trepassy Formation (fossils in both Catalina and Port Union members) and into the Fermeuse Formation (Back Cove member). The fossiliferous Mistaken Point Formation is not only a distinctive and widespread lithostratigraphic unit throughout the Avalon Zone of eastern Newfoundland but also a biostratigraphic and possible chronostratigraphic one as well. *Aspidella* occurs throughout the same stratigraphic range, but extends higher into the upper St. John's Group. *Aspidella terranova* Billings, 1872 has now been found in several parts of the St. John's Group, as far south as English Harbour.

DEPOSITIONAL ENVIRONMENTS

Preliminary sedimentological studies in the eastern Bonavista Peninsula suggest that the Mistaken Point Formation, like its correlative in the southern Avalon Peninsula, formed in a deep-water basin and slope environment (cf. Wood *et al.*, 2003). Turbidity currents, bottom-contour currents, gravity flows and pelagic deposition of mud and silt appear to be important processes in this stage of the evolution of the volcanic-arc-adjacent basin. Frondose fossils were buried without destruction under thin layers of volcanic ash and show preferred depositional orientation indicating weak but persistent bottom currents. The Trepassy Formation in this area clearly shows a coarsening- and thickening-upward succession; the proportion of sand (and tuff) is much greater in the Bonavista Peninsula than in the Avalon Peninsula (e.g., Williams and King, 1979; King, 1988, 1990; Narbonne *et al.*, 2001, p. 87). Abundant large-scale slumps and a major upward influx of laminated, fine-

grained sands, indicate high-energy downslope processes and may represent shoaling of the basin or sea-level changes. The overlying lower Fermeuse Formation shows an abrupt change to clay and silt deposition, probably under pro-deltaic conditions. Huge masses of sand, mud and coarse clastic debris were transported as submarine slumps, debris, and other mass flows into deeper parts of a submarine slope and basin. Ediacaran organisms were still present in the basin at this time, and are preserved by volcanic ash. The upper part of the St. John's Group records another coarsening- and thickening-upward succession. This represents a second cycle, but one of prograding deltaic sedimentation that passes upward and laterally (above the deep basin and slope) into terrestrial conditions represented by the Signal Group, which is exposed in major regional synclines north and south of the Catalina Dome (see O'Brien and King, 2002, 2004b).

NEOPROTEROZOIC TERRESTRIAL AND SHALLOW-MARINE STRATA, WESTERN BONAVISTA PENIN- SULA: UPPER MUSGRAVETOWN GROUP

New mapping of the late Neoproterozoic Musgravetown Group in the western Bonavista Peninsula has established, i) regionally mappable facies subdivisions of potential member status within the Crown Hill Formation and ii) an additional facies in the underlying, previously subdivided (O'Brien and King, 2002) Rocky Harbour Formation. A composite and schematic profile of these facies is shown in Figure 4; the location of the reference sections is shown in Figure 5. All are described in terms of a new, informal nomenclature presented below. The reader is also referred to additional data on these successions presented previously in O'Brien and King (2004a).

The new mapping shows that the Crown Hill Formation (cf. Christie, 1950; Jenness, 1963) represents the redbed-dominated part of a thick, coarsening-upward, shallow-marine to mainly terrestrial succession that includes the Monks Cove–Hodderville facies of the upper Rocky Harbour Formation (O'Brien and King, 2002). The overall succession is characterized by distinctive and rapid, east- to west-facies variations, and the local, albeit important development of reduced grey beds that are laterally consistent, sulphide-bearing and variably cupriferous. Rocks of similar facies to several of those in the Crown Hill Formation (including sulphide-rich reduced beds) locally occur in stratigraphically lower parts of the Musgravetown Group elsewhere on the Bonavista Peninsula. The principal facies of the Crown Hill Formation in this region correlate with stratigraphically equivalent rocks in the Signal Hill Group, located 150 km farther east on the eastern Avalon Peninsula.

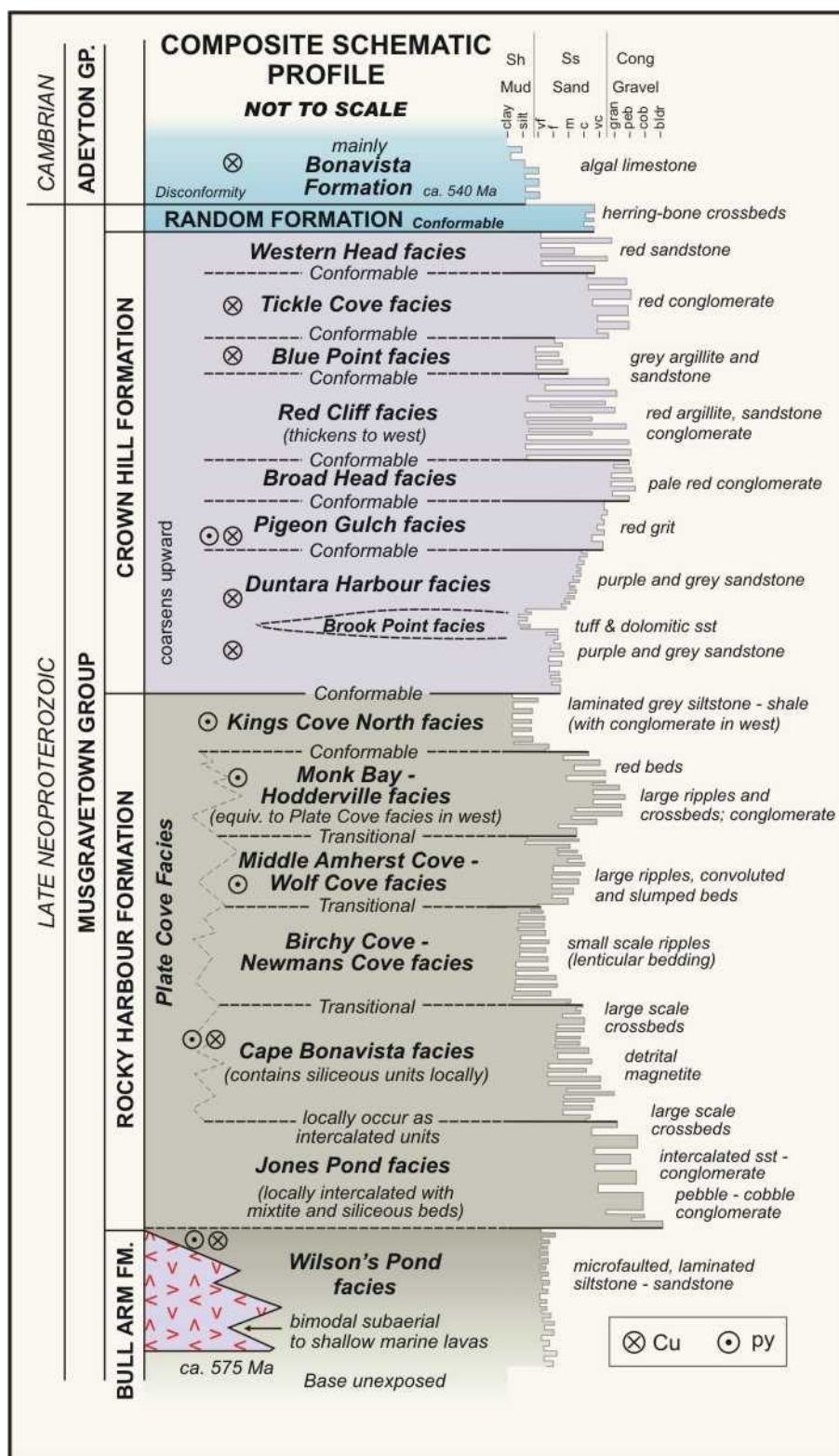


Figure 4. Composite stratigraphic profile through the Rocky Harbour and Crown Hill formations of the Musgravetown Group in the northwestern Bonavista Peninsula.

la, highlighting the large dimensions of late Neoproterozoic sedimentary basins in the Avalon Zone.

UPPER ROCKY HARBOUR FORMATION

Grey and green, primarily argillaceous rocks define the uppermost Rocky Harbour Formation in the northwestern Bonavista Peninsula and have been designated *Kings Cove North* facies by O'Brien and King (2002). This unit gradually passes from mud into sand upwards. The unit thickens westward where it is more pyritic and intercalated with purple-grey, granule to cobble conglomerate. In the Plate Cove area (Figure 5), the *Kings Cove North* facies passes conformably down into a succession of cobble and locally, boulder conglomerate, here included in the newly named *Plate Cove facies*. This conglomerate is a distinctive purple-grey due to the predominance of similarly coloured volcanic detritus contained within. The *Plate Cove facies* is dominant throughout the entire Rocky Harbour succession in the northwestern and western Bonavista Peninsula (proximal to the Indian Arm Fault). There, it is stratigraphically underlain by volcanic rocks of the Bull Arm Formation, Musgravetown Group. *Plate Cove* conglomerates locally resemble those assigned to the *Jones Pond facies* in the Bonavista area (O'Brien and King, 2002). They are flattened along a penetrative cleavage (Plate 7) that is developed in a broad, north-south belt adjacent to the Bull Arm Formation in the western Trinity Pond-Plate Cove region (O'Brien, 1993, 1994; Figure 3).

In the Blackhead Bay section (Figure 5), however, argillites of the *Kings Cove North* facies pass down-section into rippled and trough cross-bedded, pale red to buff sandstone, with less extensive units of pink to red, granule to small pebble conglomerate.

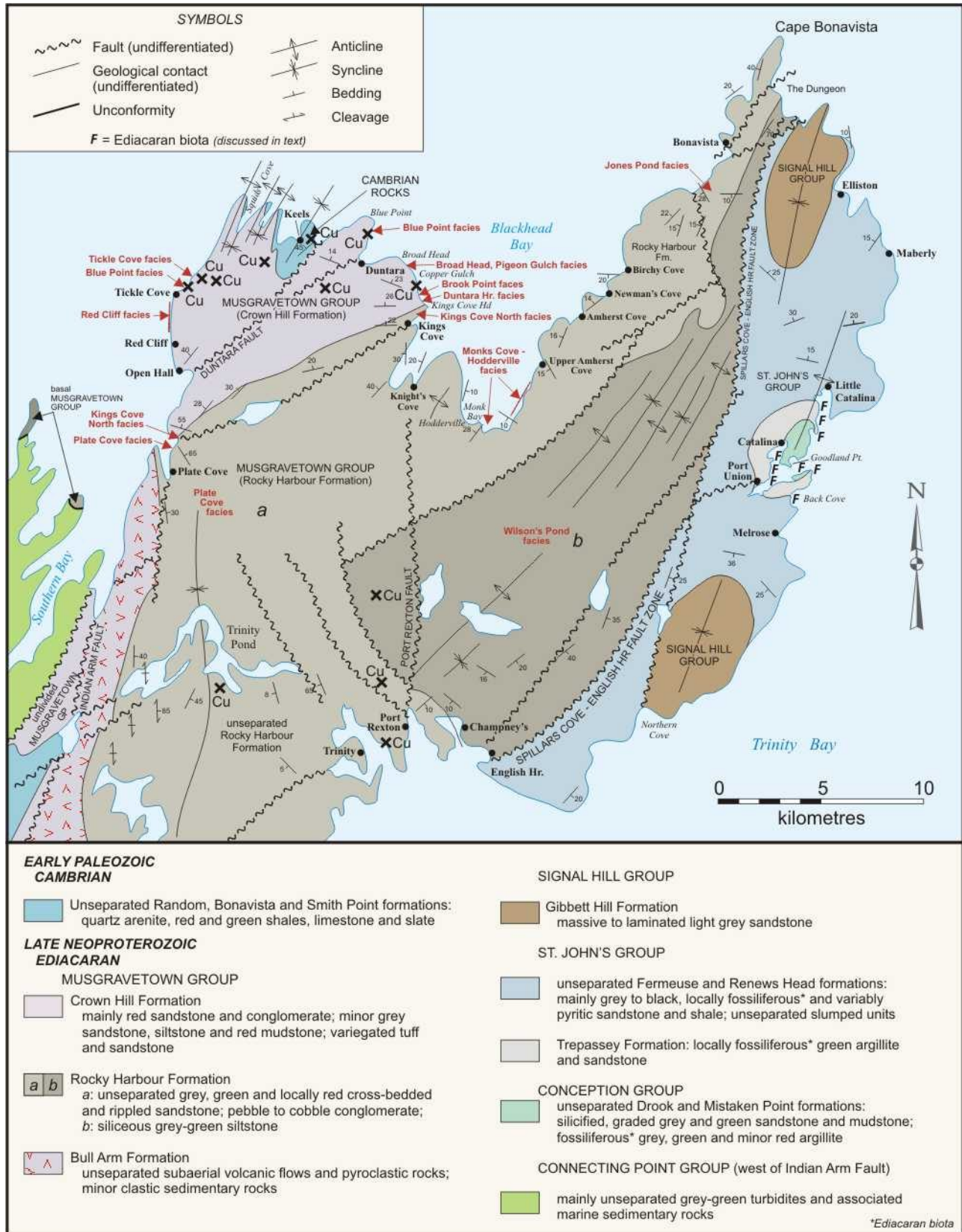


Figure 5. Simplified map showing regional geological elements of the Bonavista Peninsula and the location of reference sections for principal facies in the Musgravetown Group described in the text (modified from O'Brien and King, 2002).



Plate 7. Penetrative cleavage development in conglomerate of the Plate Cove facies, Crown Hill Formation, Musgravetown Group.

erate, which together form the upper part of the previously named *Monks Cove–Hodderville facies* (O’Brien and King, 2002). Gently dipping to subhorizontal strata of this facies, including thick distinctive units of well-rounded pink-pebble conglomerate, are exposed almost as far east as Upper Amherst Cove (Figure 5). The abundance of fine-grained diagenetic pyrite in several parts of this succession and the occurrence of splotchy chlorite–sericite deuterite alteration near the base of the facies, further highlights the potential prospectivity of the upper Rocky Harbour Formation for stratiform sediment-hosted style copper mineralization. This facies and stratigraphically lower units of the Rocky Harbour Formation are described in O’Brien and King (2002) and are not discussed further. Generally, broad northwest- to southeast-facies variations within the Rocky Harbour Formation in the study area appear to coincide with proximity to the Indian Arm Fault and the original western margin of the Musgravetown basin.

CROWN HILL FORMATION

Rocks assigned to the Crown Hill Formation in the northwestern Bonavista Peninsula form the upper, redbed-predominant part of a thick and stratigraphically complex, primarily terrestrial succession that includes the Monks Cove–Hodderville facies of the upper Rocky Harbour Formation (O’Brien and King, 2002). The base of the Crown Hill Formation lies in regionally concordant, slightly erosive contact with upper Rocky Harbour Formation. The boundary is drawn at the top of the uppermost grey argillite and sandstone beds in the Kings Cove North facies of the Rocky Harbour Formation, and is well exposed at Kings Cove Head. A preliminary new facies subdivision of the Crown Hill Formation is outlined below.

Much of the lower part of the Crown Hill Formation is a thick, homogeneous succession of thin to medium irregular beds of purple and grey sandstones and thin interbeds of red mudstone, herein named *Duntara Harbour facies* (Plate 8). This facies is well exposed on the coast east of Duntara, near Open Hall, and northward from Kings Cove Head, and is comparable (in terms of lithology) to the thin- to medium-bedded elements of the Maddox Cove Member of the Blackhead Formation, Signal Hill Group (King, 1990). Minor chalcocite mineralization is spatially associated with narrow, discontinuous reduced zones in sandy beds within this facies but is primarily sited in late fractures; such is the case at Copper Gulch (Figure 5).

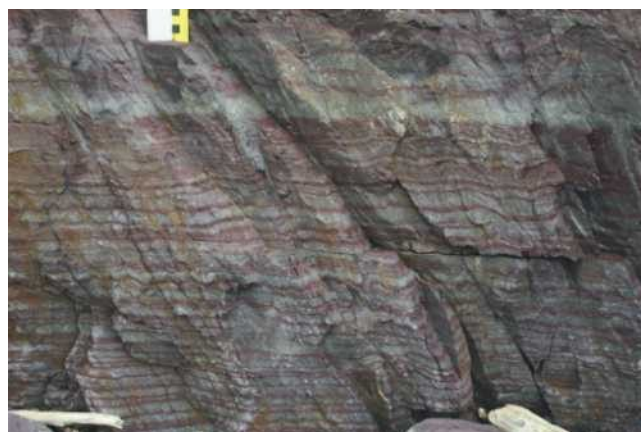


Plate 8. Cleaved, red and grey sandstones of the Duntara Harbour facies, Crown Hill Formation, Musgravetown Group.

Units of tuffaceous volcanoclastic rocks and buff, siliceous beds occur within the Duntara Harbour facies, and become a prominent feature about 100 m above the base of the Crown Hill Formation. A distinctive unit, having buff to yellow, variably siliceous and locally tuffaceous sandy beds,



Plate 9. Buff, pale yellow and red sandstones and tuffaceous beds, *Brook Point facies*, *Crown Hill Formation*, at *Brook Point*, *Blackhead Bay*.

is about 90 m thick, and is here named *Brook Point facies*. It is developed primarily in the eastern portion of *Crown Hill Formation*, and is best exposed in spectacular coastal outcrops, such as those ca. 500 m north of the *Kings Cove* lighthouse (Plate 9). Here, variegated beds include thin, possibly dolomitic, algal-like laminations (see O'Brien and King, 2004a; Cornerstone Resources, unpublished data). The facies appears to pinch out westward, as it is not apparent in the equivalent section exposed on the west shore of the peninsula between *Plate Cove* and *Tickle Cove*. Variegated and siliceous beds of the *Brook Point facies* are succeeded by a further 300 m of *Duntara Harbour facies* sandstones. The top of the *Duntara Harbour facies* coarsens upward into a localized succession of crossbedded, thick units of red sandstone and grit that are here designated as the *Pigeon Gulch facies*. In the area of *Broad Head*, *Blackhead Bay*, the sandy beds pass gradationally upward into a distinctive unit composed of thick, amalgamated beds of pale red to grey conglomerate. These rocks, referred to as the *Broad Head facies*, occupy the stratigraphically highest part of the *Crown Hill* succession south of the *Duntara Fault* (Figure 5).

Coarse-grained rocks similar to those of the *Broad Head facies* occur in the westernmost *Bonavista Peninsula*, north of the *Duntara Fault*, near *Open Hall* (Figure 5). There they pass gradationally upward into red argillite, sandstone and pebble conglomerate, denoted as the *Red Cliff facies*; these beds are comparable with the *Quidi Vidi Formation* of the *Signal Hill Group*, eastern *Avalon Peninsula* (King, 1990). Coarse-grained sandstones at the top of the facies pass up into thick reduced beds of laminated grey argillite and fine-grained sandstone of the *Blue Point facies*. These reduced units, unlike the rest of the *Crown Hill Formation*, exhibit little east–west-facies variation and extend laterally across the northwestern *Bonavista Peninsula*. This unit locally hosts significant disseminated and fracture-controlled chalcocite mineralization, which is apparently most

extensive and best exposed at *Blue Point*, on the north shore of *Duntara Harbour*, where the unit is about 25 m thick (Plate 10; see O'Brien and King, 2002). The same unit is exposed on the west coast of the peninsula at *Tickle Cove*, where chalcocite occurs mainly as a partial replacement of coarse-grained diagenetic pyrite.

The mineralized grey beds of the *Blue Point* member are everywhere overlain by a succession of bright red to maroon, trough-crossbedded granule, pebble and cobble conglomerate, red sandstone and rare red argillite (*Tickle Cove facies*). Conglomerates of the *Tickle Cove facies* may be distinguished from those of the stratigraphically lower *Broad Head facies* on the basis of the formers' greater thickness (>130 m), brighter red colour and coarser grain size. The *Tickle Cove facies* is comparable with the *Cuckold Formation* of the *Signal Hill Group*, eastern *Avalon Peninsula* (King, 1990).

In the western *Bonavista Peninsula*, between *Keels* and *Tickle Cove*, the uppermost coarse-grained conglomerate of the *Tickle Cove facies* is overlain by a 30-m-thick unit of red sandstone, argillite and minor granule conglomerate. This unit, named *Western Head facies*, defines the top of the *Crown Hill Formation*. It records the transition from coarse-grained alluvial environments into tidal deposits represented by well-sorted quartz arenites of the conformably overlying (Cambrian) *Random Formation* (see descriptions in O'Brien and King, 2002). The base of the *Random Formation* in this section between *Tickle Cove* and *Squids Cove* (Figure 5) is sharp, conformable, and drawn at the first appearance in the section of thick beds of quartz arenite. The *Random Formation* and its boundary with the underlying *Crown Hill Formation* is well exposed on several of the prominent headlands between *Tickle Cove* and *Squids Cove*, and in the vicinity of *Keels* (Figure 5; O'Brien and King, 2002).



Plate 10. *Chalcocite-bearing pyritic, reduced, grey beds in the Blue Point facies, Crown Hill Formation, Blue Point prospect.*

SUMMARY AND CONCLUSIONS

- 1) New mapping of the late Neoproterozoic rocks east of the Spillars Cove–English Harbour fault zone confirms previous correlation of the eastern Bonavista Peninsula succession with the principal stratified units of the Avalon Peninsula. This work has resulted in a detailed and revised stratigraphic subdivision for much of the eastern Bonavista Peninsula succession.
- 2) Parallel-laminated, siliceous grey siltstones and fine-grained sandstones of the Shepherd Point member (Drook Formation, Conception Group) occupy the core of the Catalina Dome and are the oldest rocks yet recognized in the eastern Bonavista Peninsula. Their temporal and original spatial relationships with broadly similar, siliceous facies of the lower Musgravetown Group, west of the Spillars Cove–English Harbour fault zone, remain equivocal.
- 3) The Mistaken Point Formation (upper Conception Group) overlies the Shepherd Point member and is divided into a lower, siliceous Goodland Point member and an upper, argillaceous Murphy's Cove member. Both units contain a wide range of well-preserved Ediacaran biota. Turbidity currents, bottom-contour currents, gravity flows and pelagic deposition of mud and silt are important processes in this stage of the evolution of the basin.
- 4) The conformably overlying Trepassey Formation (basal St. John's Group) is divided into a lower grey-green argillaceous Catalina member and an upper, sand-rich Port Union member. This upward- coarsening and upward-thickening succession contains a much greater proportion of sand and tuff than in the equivalent succession on the Avalon Peninsula.
- 5) Dark grey shales and slumped units of sandstone and shale overlie the Catalina member and are assigned to the Back Cove member, lower Fermeuse Formation. The abundance of large-scale slump units, debris-flows and the upward influx of laminated, fine-grained sands in the succession above the Catalina member, indicate high-energy downslope processes, related to basin shoaling or sea-level changes. Subsequent clay and silt deposition in the mid- to upper Fermeuse Formation likely occurred under pro-deltaic conditions.
- 6) The known lateral and vertical extent of Ediacaran biota in the eastern Bonavista Peninsula has been extended significantly. More than twenty separate fossil localities from multiple stratigraphic levels throughout the late Neoproterozoic marine succession have been identified. *Charnia*-related discs, frond-, spindle-, bush-like fossils occur throughout the Mistaken Point Formation, through the Trepassey Formation and at least 100 m into the Fermeuse Formation.
- 7) Laminae and thin beds of ash tuffs are newly recognized as a prolific and diagnostic part of the rock record of the eastern Bonavista Peninsula. A project to date these tuff units has been initiated to establish the absolute age of the wide range of Ediacaran fossils and calibrate an important part of the newly proposed Ediacaran Period.
- 8) New mapping in the western Bonavista Peninsula has established locally developed to regionally extensive facies subdivisions of potential member status within the thick, late Neoproterozoic shallow-marine to terrestrial succession of the upper Rocky Harbour and overlying Crown Hill formations of the Musgravetown Group. The principal facies of the Crown Hill Formation may be correlated with similar-aged rocks, the Signal Hill Group, located 150 km farther east on the eastern Avalon Peninsula, with implications for large basin dimensions.
- 9) Much of the upper Rocky Harbour–Crown Hill formation's succession is characterized by distinctive and rapid, east- to west-facies variations. In general, facies variations appear to reflect proximity to the western margin of the Musgravetown basin and the volcanic ranges (Bull Arm Formation) exposed adjacent to the Indian Arm Fault.

- 10) The development of laterally consistent, reduced, sulphide-bearing (and variably cupriferous) grey beds within the thick shoaling-upward upper Rocky Harbour–Crown Hill succession was an important aspect of basin evolution. Available data highlight the potential prospectivity of not only the Crown Hill Formation, but also the upper Rocky Harbour Formation for stratiform sediment-hosted style copper mineralization.

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