

LATE NEOPROTEROZOIC TO EARLIEST PALEOZOIC STRATIGRAPHY OF THE AVALON ZONE IN THE BONAVISTA PENINSULA, NEWFOUNDLAND: AN UPDATE

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Regional Mapping Section

ABSTRACT

Recent regional mapping and stratigraphic studies of the eastern Bonavista Peninsula, together with the discovery of a diverse suite of Ediacaran fossils near Catalina, have confirmed the correlation of the Late Proterozoic succession east of the newly defined Spillars Cove–English Harbour fault zone with parts of the Conception, St. John's and Signal Hill groups. This regional tectonic boundary delimits the western extent of these three groups in the Avalon Zone and the eastern extent of the Musgravetown Group on the Bonavista Peninsula. Despite some differences in facies development, there is pronounced similarity between late Neoproterozoic lithostratigraphy and biostratigraphy of the Bonavista Peninsula east of the Spillars Cove–English Harbour fault zone and that of the western Conception Bay and southern shore regions of the Avalon Peninsula. Mapping in the area west of the fault zone has corroborated and further refined the authors' previously published facies subdivision of the Musgravetown Group, and has necessitated expansion of that group to include a distinctive, siliceous sedimentary facies previously considered as possible Conception Group. Work on fossiliferous Cambrian and adjacent latest Neoproterozoic rocks in the northwestern Bonavista Peninsula has demonstrated the conformable and broadly gradational nature of the Random Formation–upper Musgravetown Group contact, the lack of angular discordance at the base of the overlying fossiliferous Cambrian shale succession, and the existence of similar styles of sediment-hosted stratiform copper mineralization in Early Cambrian and late Neoproterozoic rocks above and below the Random Formation.

INTRODUCTION

The 2003 field work in the Bonavista Peninsula, described in this report, is the continuation of a larger investigation aimed at developing a regionally unified stratigraphic framework for the late Neoproterozoic sedimentary basins of the Appalachian Avalon Zone and the syngenetic base-metal mineralization therein. Preliminary results of the authors' earlier work in the Bonavista Peninsula, with a review of previous geological studies, have been presented elsewhere (O'Brien and King, 2002).

The authors' 2003 studies focused primarily on the eastern Bonavista Peninsula and included detailed mapping and stratigraphic analysis of the lithostratigraphically contrasting, yet broadly coeval, late Neoproterozoic sedimentary successions juxtaposed along the Spillars Cove–English Harbour fault zone (Figures 1 and 2). In the northwest Bonavista Peninsula, additional mapping has been carried out in the fossiliferous Cambrian shale-rich succession, and

also in the underlying quartz arenite-rich Random Formation and adjacent copper-bearing units of the upper Musgravetown Group succession. The following is a brief account of some principal results, including the first discovery of late Neoproterozoic Ediacaran fossils on the Bonavista Peninsula. Descriptions of this diverse assemblage of exceptionally well-preserved biota and their regional correlation are included in a companion paper by the authors, elsewhere in this volume.

LATE NEOPROTEROZOIC ROCKS

The newly defined Spillars Cove–English Harbour fault zone demarcates the boundary of two lithologically and stratigraphically contrasting, broadly coeval, siliciclastic domains of late Neoproterozoic age on the Bonavista Peninsula (Figure 2). Sedimentary rocks west of this south–south-east-trending brittle structural zone are part of the Musgravetown Group (Hayes, 1948; O'Brien and King, 2002), a major volcano-sedimentary succession that crops out over

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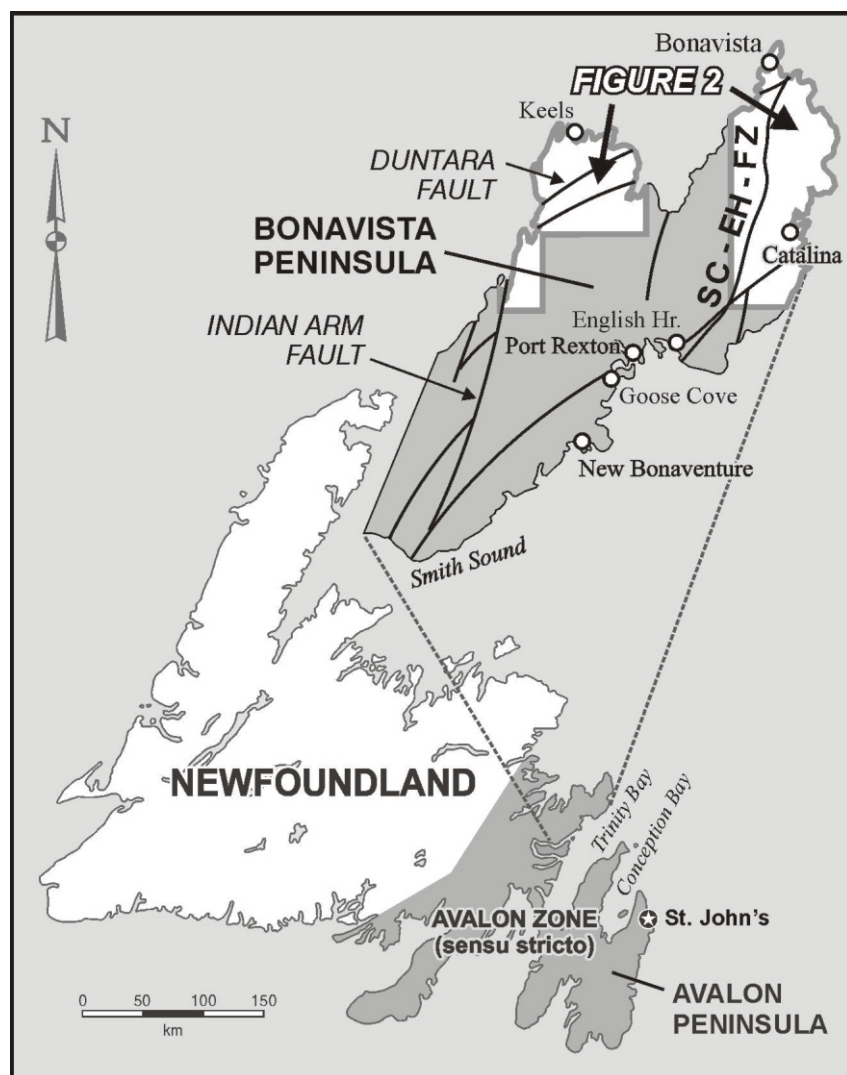


Figure 1. Location of the study area. SC-EH-FZ = Spillars Cove–English Harbour fault zone.

large parts of the northwest Avalon Zone in Newfoundland. Sedimentary strata east of the fault zone include rocks that are lithostratigraphic equivalents of parts of the principal late Neoproterozoic, post-590-Ma stratified units of the Avalon Zone on the eastern Avalon Peninsula: viz. (in ascending stratigraphic order) the upper Conception, St. John's and lower Signal Hill groups. The biostratigraphic correlation of eastern Bonavista Peninsula rocks with these groups is now corroborated by the newly discovered occurrence within those strata of late Neoproterozoic Ediacaran fossils of both Mistaken Point and Fermeuse assemblages (*cf.* Narbonne *et al.*, 2001).

The Spillars Cove–English Harbour fault zone is a broad feature that comprises a number of steep north-northeast- and linked, northeast-trending structures that are developed primarily in shale-rich facies of the St. John's Group.

The fault zone has been mapped southward from the area between Lance Cove and Spillars Cove, near Bonavista (where it is offset by one of an equally prominent set of regional east-northeast-trending structures), to the Champney's–English Harbour region. Its southern extension beyond English Harbour has not been identified, although the zone may merge, in the offshore, with a series of north-trending, sub-vertical faults through Port Rexton, and with a pronounced northeast-trending structure through Goose Cove. Reconnaissance mapping in northwest Trinity Bay, south of Port Rexton, has not identified a stratigraphic succession comparable with the Conception, St. John's and Signal Hill groups. This could indicate the fault zone continues south of the Bonavista Peninsula in the offshore, proximal and parallel to the west shore of Trinity Bay. It is noteworthy that McCartney (unpublished data, 1955), in his preliminary field maps of the Sunnyside map area (GSC archives), noted possible Conception-like beds along parts of the southwest shore of Trinity Bay, south of Random Sound.

CONCEPTION GROUP

The distribution of the Conception Group on the Bonavista Peninsula is restricted to the region east of the newly defined Spillars Cove–English Harbour fault zone, reduced significantly from that shown in the authors' earlier interpretations (*see* O'Brien and King, 2002). For reasons outlined below (*see* Musgravetown Group), siliceous clastic rocks immediately west of this structure, previously equated with the Conception Group, now have been reassigned to the Musgravetown Group. The base of the Conception Group on the Bonavista Peninsula is unexposed; it is transitional upward into interbedded pale grey-green mudstone, siltstone and sandstone of the Trepassey Formation (St. John's Group). The Conception Group facies in the study area are comparable with and herein correlated with the Mistaken Point Formation of the Avalon Peninsula (Williams and King, 1979; King, 1988; Figure 3).

Three conformable lithofacies are recognized in the newly outlined Conception Group of the eastern Bonavista Peninsula. The lowermost exposed facies in the stratigraphic succession occupies the core of a periclinal fold, herein named the Catalina dome, centred on the town of Catalina.

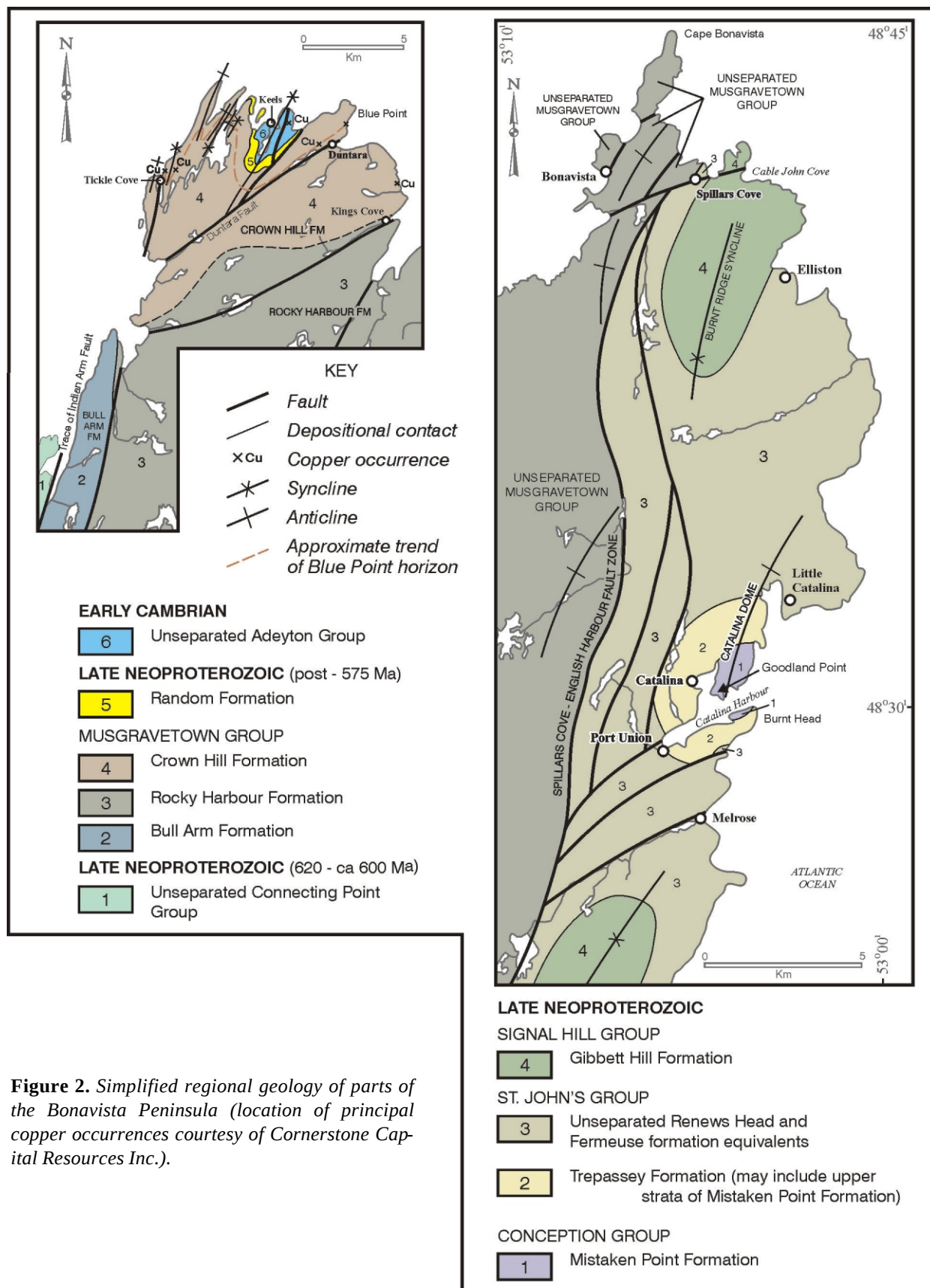


Figure 2. Simplified regional geology of parts of the Bonavista Peninsula (location of principal copper occurrences courtesy of Cornerstone Capital Resources Inc.).

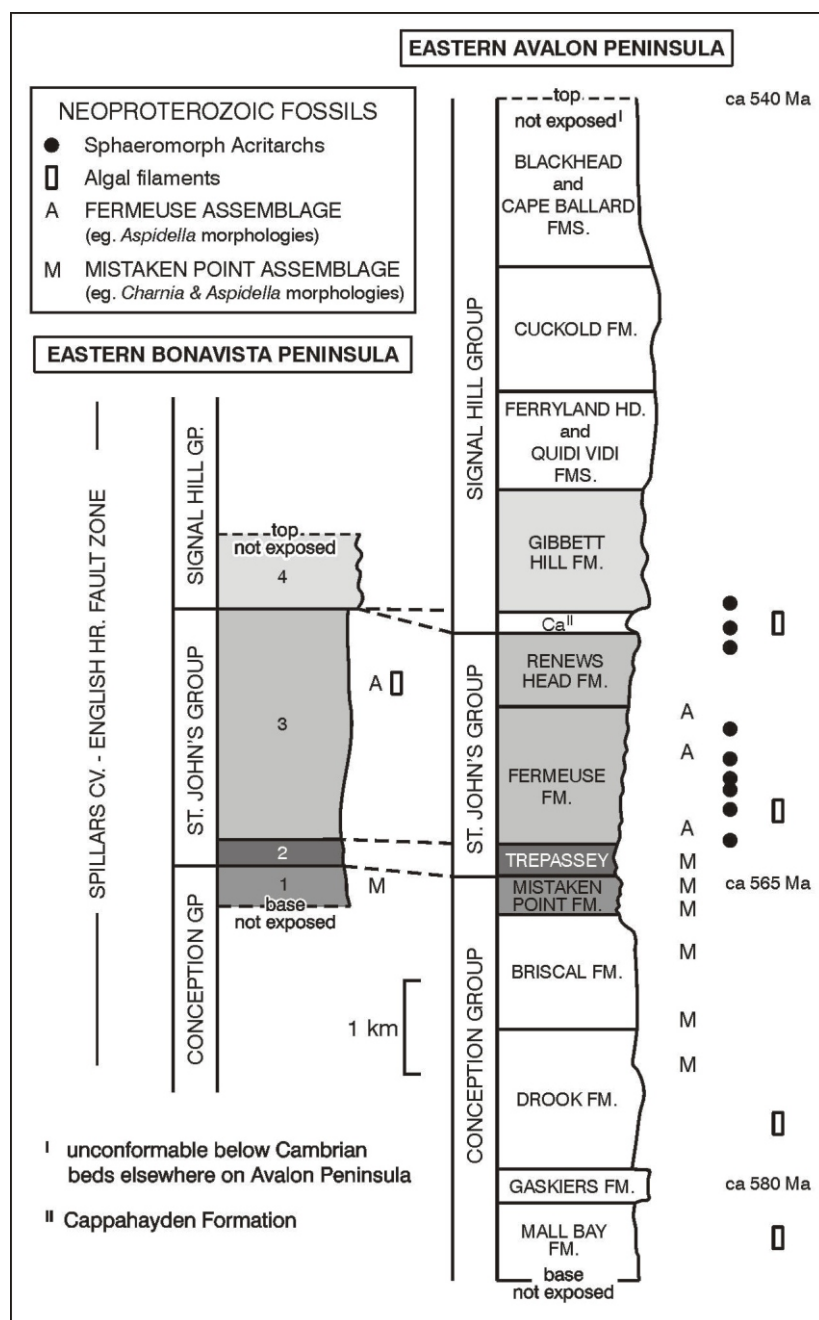


Figure 3. Stratigraphic profile and correlation between the eastern Bonavista and Avalon peninsulas.

It is characterized by units of fine-grained siliceous sandstone and siltstone having continuous, well-developed parallel lamination, accentuated by laminae and thin laminar beds of grey, green and black mudstone and siltstone; locally slumped and wavy laminated beds occur within this facies. This part of the Conception Group is comparable with T_{DE} and $T(B)_{CDE}$ turbidite facies of the Mistaken Point Formation that are developed in the Bareneed area of western Conception Bay (King, 1988).

The laminated facies passes upward into an intermediate unit of buff to pale yellow-weathering, thin- to medium-bedded, grey siliceous sandstone and convoluted cherty beds. This part of the $T(B)_{CDE}$ turbidite succession is well exposed at Goodland Point in Catalina (Figure 2). The siliceous sandstones have a distinctive, albeit weak, reddish colouration and contain variably preserved red siliceous laminae, as well as locally developed calcareous concretions. This facies also includes very pale red and green, parallel-laminated and scoured sandstone beds, and thin-bedded, fine-grained graded grey sandstone and siltstone.

An upper, non-siliceous facies of the Conception Group is well exposed around Port Union, including the south side of Catalina Harbour, and on the coastline between Catalina and Little Catalina. It is composed of green-grey and locally purple-grey, medium-bedded, non-siliceous sandstone; beds are internally laminated and graded, and have sharp bases and parallel sides. Laminae and beds (<1 cm to 20 cm thick) of light green to buff sandstone having a probable tuffaceous origin component, occur throughout the succession. These rocks pass gradationally upward into primarily distal turbidites (T_{DE} beds) consisting of grey, very thin- to medium-bedded siltstones, sandstones and mudstones beds, at the base of the overlying Trepassey Formation of the St. John's Group. This upper, non-siliceous facies is comparable with the Hibbs Cove Member of the Mistaken Point Formation (King, 1990) present in the St. John's and western Conception Bay areas of the Avalon Peninsula.

Correlation of the clastic succession east of the Spillars Cove–English Harbour fault zone with the upper Conception Group is further supported by the discovery of late Neoproterozoic fossils in the Catalina–Port Union area during the 2003 field season (see O'Brien and King, *this volume*). The Ediacaran fauna occur mainly at the boundary of siliceous and non-siliceous rocks in the upper facies of the Conception Group, below the contact with the Trepassey Formation of the St. John's Group. Well-preserved Ediacaran spindle-, discoidal- and frond-like biota occur together. Discoidal holdfasts include *Spriggia* and *Ediacaria* morphological variants of *Aspidella* (cf. Gehling *et al.*, 2000); some individual fronds are attached by a stalk to the disc (Plate 1). The fossils are exposed on the south



Plate 1. Late Neoproterozoic Ediacaran fossils from the Mistaken Point Formation in the Catalina–Port Union area.

shore of Catalina Harbour in a sequence of dark green sandstone containing thin, light green-grey, fine-grained sandy layers of probable tuffaceous character (Plate 2). The principal fossil occurrence is on the top surface of a 45-cm-thick bed of dark green-grey sandstone, which is in turn overlain by light green-grey, argillaceous sandstone and mudstone, all with tuffaceous aspect.

In the Catalina–Port Union area, several morphological variants of *Aspidella* occur in a number of stratigraphic horizons in the Mistaken Point Formation along a ca. 1-km strike-section on the south side of Catalina Harbour. Discoidal forms showing *Spriggia* preservation (cf. Gehling *et al.*, 2000) are most common and can occur on the same bedding surface with fronds, discoidal forms and tentaculate discs. Both *Aspidella*-type preservation and *Ediacaria* preservation (cf. Gehling *et al.*, 2000) also occur. *Aspidella* have been noted from stratigraphically higher parts of the succession, in black shale containing laminae and thin lenticular beds of sandstone, in the St. John's Group section east of English Harbour. A detailed description of these Ediacaran fossils is presented in an accompanying paper by the authors (O'Brien and King, *this volume*). Further investigations are in progress and additional studies in and around the area of this new fossil discovery are planned for the 2004 field season.

Although the absolute age of the Neoproterozoic section east of the Spillars Cove–English Harbour fault zone is undetermined locally, correlation with the precisely dated and fossiliferous Mistaken Point Formation on the southwestern Avalon Peninsula implies deposition about 565 Ma ago. The age is that of zircon separated from a thin tuff layer immediately above the Ediacaran fossil horizon at the top of the Mistaken Point Formation on the southern Avalon (565 ± 3 Ma U–Pb age by G.R. Dunning, as reported in Benus, 1988).



Plate 2. Fossiliferous late Neoproterozoic marine sandstones of the Mistaken Point Formation, Conception Group, near Catalina.

ST. JOHN'S GROUP

A thick and areally extensive sedimentary succession characterized by variably cleaved, dark grey to black shales having interbedded sandstone, here assigned to the St. John's Group, overlies the Conception Group. The St. John's Group, which has an approximate thickness of 2 to 2.5 km, is bounded to the west by the Spillars Cove–English Harbour fault zone. Reconnaissance mapping in north-west Trinity Bay has yet to identify St. John's Group rocks in the well-exposed, thick, and presumably complete, late Neoproterozoic to Early Cambrian stratigraphic section between Port Rexton and Random Sound.

Trepassey Formation

The lower part of the St. John's Group crops out around the core of the Catalina dome and is well exposed in Port Union and Catalina and along the west side of Little Catalina Harbour. This lithologically distinctive basal division is

characterized by medium to thick, tabular beds of very fine-grained, pale green to green-grey argillaceous mudstone, siltstone and sandstone. These light-yellow to grey-weathering beds gradationally overlie the variegated fossiliferous beds of the uppermost Conception Group, and are correlated on the basis of both their facies and stratigraphic position with the Trepassey Formation of the St. John's Group of the southern Avalon Peninsula (Williams and King, 1979; see O'Brien and King, 2002; Figure 3). These rocks are non-siliceous and are characterized by well-developed, parallel-sided, graded beds that display partial Bouma sequences T_{CDE} and T_{DE} . Locally, medium-bedded, crosslaminated sandstones are interstratified with planar units of very thick, pale grey-green silty mudstone with graded, amalgamated bases. The thickness of these sand-mud units varies from a few tens of centimetres to about 3 m. Also present in parts of the Trepassey succession are metre-scale slump folds and rare pebbly layers, typically less than a few centimetres thick.

In a number of areas, the Trepassey Formation contains bright-yellow diagenetic pyrite euhedra, up to 5 cm on a side. These crystals are well preserved in outcrops around Catalina and Port Union (Plate 3), and are known historically as "Catalina-stone"; they were first noted by early English explorers, who mistakenly identified the pyrite as gold (see review in O'Brien and King, 2002). These Trepassey Formation rocks differ from similar pyrite-bearing beds in grey-green reduced units in the uppermost Musgravetown Group of the western Bonavista Peninsula in that they are apparently devoid of the significant cupriferous replacement that is commonplace in the latter (see O'Brien and King, 2002 and below). Small galena-bearing quartz-carbonate veins occur in similar rocks (albeit without coarse pyrite) on the west shore of Little Catalina Harbour.

At the top of the Trepassey Formation, a unit, several tens of metres thick, consists of dark grey shales with laminae and thin lenticular beds of sandstone, interbedded with parallel-sided beds of pale green sandstone; the latter also occur as blocks in brecciated and slumped shale beds. These facies together represent a transition zone with the overlying pyritic shale and typically slumped beds of the middle and upper St. John's Group.

Unseparated Dark Grey Shale-Sandstone Facies

The authors' earlier mapping in the eastern Bonavista Peninsula (O'Brien and King, 2002) identified facies characteristic of the uppermost two divisions of the St. John's Group, namely, the Fermeuse and overlying Renew's Head formations (cf. Williams and King, 1979). Recent detailed mapping around Melrose and the coastal exposures between Elliston and Catalina, however, has demonstrated that facies

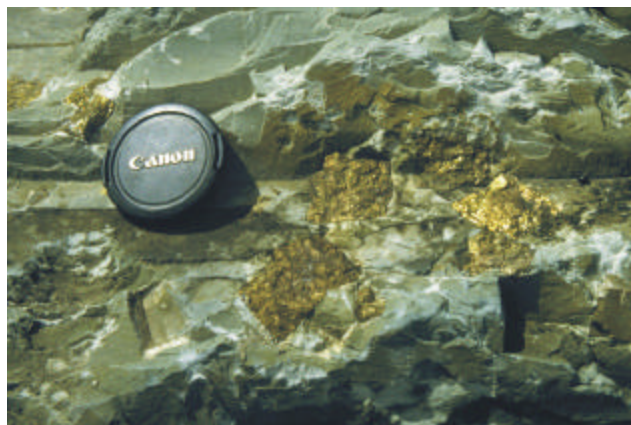


Plate 3. Coarse-grained euhedral pyrite (known colloquially as "Catalina-stone"), Trepassey Formation, Catalina.

characteristic of both these formations are interdigitated throughout this near-complete section of St. John's Group. No mappable distinct separation into lower shale-rich (cf. Fermeuse Formation) and upper sand-rich (cf. Renew's Head) formations, like that in the easternmost Avalon Zone, is obvious in these eastern Bonavista Peninsula sections. Placement of a boundary would be arbitrary and difficult to define, particularly in poorly exposed inland areas.

Although the formational names Fermeuse and Renew's Head are not applicable in the eastern Bonavista Peninsula mapped thus far, similar facies do occur in similar stratigraphic positions in both areas. The most notable is in the lowest parts of the succession above the Trepassey Formation, where slumped sandstone-shale beds and shale-rich units comparable with those present in the Fermeuse Formation of the Avalon Peninsula are well developed (see King, 1988, 1990; Williams and King, 1979). Individual soft-sediment folds vary in scale from a few centimetres to about 10 metres, and in a number of instances, slumping has produced a chaotic, mixtite deposit with remnants of disaggregated folded and planar sandstone beds "floating" as isolated blocks in a matrix of shale and pebbly mudstone. The shales are characteristically pyritic, and in several instances, two or more morphologies of diagenetic pyrite are present. This part of the section also includes rhythmically bedded to ribbon-laminated dark grey shale and crosslaminated sandstone.

A variety of sandy facies occur throughout the St. John's Group on the eastern Bonavista Peninsula. They typically occur as white to rusty-weathering units, with thin, lenticular-bedded to wispy laminated dark and light grey sandstone in dark grey shale and siltstone. The shales locally contain laminated sandy concretions. Sandstone can account for up to 50 percent of an outcrop. The shales typically weather light grey or white, whereas sandy layers

weather brown. In the upper part of the group (e.g., near Elliston), the sand-rich units are locally associated with thin discontinuous layers of granule to fine pebble conglomerate, containing clasts of intrabasinal sediments. The sandstones, which in places are weakly calcareous, show various styles of bedding structures, including cross-, wavy-, streaky- and parallel-lamination. Similar facies occur near the top of the St. John's Group in the section between English Harbour and Horse Chops. In that same section, dark grey, variably slumped shale with sandy laminae contain *Aspidella* (O'Brien and King, *this volume*).

SIGNAL HILL GROUP

Dark grey pyritic shales of the upper St. John's Group at Elliston pass conformably and gradationally upward into massive grey sandstones with granule and pebble beds correlated with the Gibbett Hill Formation of the Signal Hill Group (King, 1990; *see also* O'Brien and King, 2002; Figure 2). The latter beds have been mapped in an open, gently plunging fold – here named the Burnt Ridge Syncline – located between Elliston and Spillars Cove, south of a east-northeast-trending fault through Cable John Cove (Figure 2); up to 400 m of Gibbett Hill section are exposed in this region. Similar rocks are interpreted to occupy the core of a south-plunging syncline centred several kilometres south of Melrose (O'Brien and King, 2002).

The base of the Signal Hill Group can be drawn where thick tabular beds of coarse-grained sandstone become prominent in the section above the uppermost sandstone and interbedded shale facies of the St. John's Group in the Elliston area. Typical examples exposed in the lower part of the Signal Hill Group at Burnt Ridge and Green Ridge are pale brown- to pale grey- and white-weathering. Inland exposures are characteristically massive in appearance. However, the sandstones locally show amalgamated bedding, weakly defined parallel laminations, channel cut-and-fill structures and dewatering features. Some channel-fill deposits and basal parts of thick-bedded sandstones contain planar and trough crossbedded sandstone intermixed with well-rounded pebble conglomerate. In summary, facies development in this succession is similar to that seen in the Gibbett Hill Formation of the Signal Hill Group on the Bay de Verde Peninsula (e.g., Heart's Content–Carbonear Road).

The highest exposed part of the Signal Hill Group in the area occurs at the topographically highest part of the Green Ridge, where the thick-bedded Gibbett Hill facies rocks have a distinctive and ubiquitous, very pale purple to pale red colour.

A fault-bounded section immediately west of Spillars Cove, and north of the aforementioned fault through Cable

John Cove, includes Gibbett Hill facies sandstone interstratified with diagenetically altered, yellowish-green, locally crossbedded sandstones similar to those in the Rocky Harbour Formation (Cape Bonavista facies of O'Brien and King, 2002) of the Musgravetown Group. These rocks are in fault contact with extensively brecciated hematitic and limonitic dark grey shales, with probable St. John's Group affinity.

MUSGRAVETOWN GROUP

The sedimentary rocks of the Musgravetown Group on the Bonavista Peninsula comprise two principal divisions: viz., the areally extensive and stratigraphically lower, mainly shallow-marine, Rocky Harbour Formation and the overlying, terrestrial Crown Hill Formation (*see* Jenness, 1963; Figure 4). Mapping on both detailed and reconnaissance scales shows that these formations exhibit widespread vertical and lateral stratigraphic variation, and are characterized by numerous facies, many which have thicknesses in the

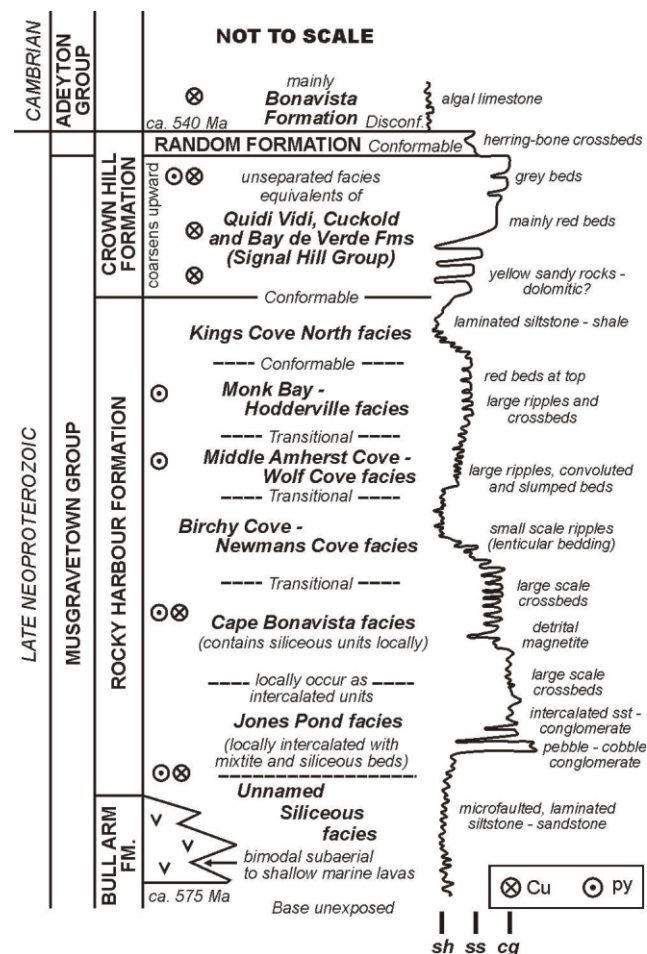


Figure 4. Schematic composite section of parts of the north-western Bonavista Peninsula, showing lithofacies and selected copper occurrences. Facies relationships are generalized; not to scale.

order of tens to a few hundreds of metres. Within the Rocky Harbour Formation on the north coast of the peninsula, varied rock types can be grouped into six broad, albeit distinct facies of potential member status (see O'Brien and King, 2002; Figure 4). Recent mapping has added at least one major new facies division to a significantly expanded Rocky Harbour Formation. A decision on assigning this new facies to a separate formational status within the Musgravetown Group awaits further regional mapping in the south-central parts of the peninsula.

The absolute age of the Musgravetown Group remains unconstrained in this area. A comparable succession of Rocky Harbour and Crown Hill rocks is developed on the west side of Bonavista Bay, where rhyolite flows at the base of the Rocky Harbour Formation have yielded a zircon age of 570 ± 3 Ma (O'Brien *et al.*, 1989).

Lower Rocky Harbour Formation: Unnamed Siliceous Sandstone Facies

Coarse-grained, well-rounded, variegated conglomerate and coarse-grained sandstone, including beds assigned to the Jones Pond facies (O'Brien and King, 2002) of the Rocky Harbour Formation, forms an important marker unit in the Musgravetown Group on the eastern half of the Bonavista Peninsula. It separates a lower division (the base of which is unexposed in the area studied), characterized by silicified, laminated, micro-fractured and variably pyritic, fine-grained sandstone from an overlying division composed of crossbedded sandstone of the Cape Bonavista facies and younger strata of the Rocky Harbour Formation (see O'Brien and King, 2002; Figure 4).

The fine-grained siliceous rocks are disposed in a regional anticlinorium, sited between Bonavista and World Pond, north of Port Rexton, and immediately west of the Spillars Cove–English Harbour fault zone. Neither the conglomerate nor the lower siliceous beds occur east of that structure. The lower siliceous facies is typically poorly exposed; the most complete section through the unit can be seen in widely spaced roadcuts along the Catalina to Amherst Cove highway. The authors had previously included the lower siliceous unit with the Conception Group (O'Brien and King, 2002) but further mapping has shown the siliceous rocks are clearly interbedded at several stratigraphic levels with minor units of pink arkosic sandstone and orange-pebble conglomerate facies, diagnostic of the higher levels of Musgravetown Group in this area. Typically the beds are either massive in appearance or very finely laminated, micro-faulted and silicified; in several areas the silicic beds are finely pyritic.

The siliceous beds pass upward into Jones Pond conglomerate and overlying, crossbedded and streaky laminated sandstone facies of the upper Rocky Harbour Formation; this succession is unlike the Ediacaran-bearing upper Conception Group, which is overlain by well-bedded non-siliceous turbidites of the Trepassey Formation and dark grey shale-rich St. John's Group. Unlike the Conception Group, these beds locally contain disseminated chalcocite mineralization, such as that in the Fifield's Pit prospect of Cornerstone Resources Inc., near Port Rexton (T. Froude, Cornerstone Capital Resources Inc., personal communication, 2003).

Broadly similar fine-grained, grey siliceous sandstone occurs within and above crossbedded sandstone of the Cape Bonavista facies and is disposed around a domal structure within the Rocky Harbour Formation near Bonavista. These stratigraphically separate siliceous units around Bonavista are much thinner and less extensive than the unnamed siliceous facies described above.

Upper Rocky Harbour Formation

A gently dipping and broadly homoclinal section through the upper Rocky Harbour Formation is well exposed on the north coast of northern Bonavista Peninsula, between Bonavista and Keels. It is divisible into six informal, stratigraphically unique facies (*viz.*, Cape Bonavista, Jones Pond, Birchy Cove–Newmans Cove, Middle Amherst Cove–Wolf Cove, Monk Bay–Hodderville and Kings Cove North facies; O'Brien and King, 2002).

New mapping by the authors in this and other sections through the Musgravetown Group in the Bonavista Peninsula has confirmed (with some revision) the overall nature of these facies and the stratigraphic order, as previously described. The Birchy Cove–Newmans Cove facies is more extensive and lithologically variable than previously noted and the Middle Amherst Cove–Wolf Cove facies significantly less so. Several distinctive marker units have been mapped within the upper Rocky Harbour Formation, including coarse-grained pink conglomerate interbedded with splotchy textured (epidote–sericite–chlorite-altered) sandstone near the base of the Monk Cove–Hodderville facies and black ironstone and black conglomerate (both magnetite-bearing) in the Cape Bonavista facies; these have potential value in regional correlation with unmapped sections farther southwest. Mottling due to late chlorite–sericite alteration is most typical of the Cape Bonavista facies, and it increases in intensity with proximity to east-northeast- and northeast-trending faults. This style of alteration is not restricted to this stratigraphic level of the Rocky Harbour

Group. Pyritic beds are more widespread in both the upper and lower Rocky Harbour Formation, than previously noted, although cupriferous replacement of the pyrite was not observed in the sections studied.

New work on that part of the Rocky Harbour Formation below the Birchy Cove–Newmans Cove facies has shown that fine-grained siliceous sedimentary rocks are more widespread than previously thought. This is, in part, because large tracts of fine-grained siliciclastic rocks, previously assigned to the Conception Group, are now included with Rocky Harbour Formation (*see below*). New mapping of the coastal and inland sections between Bonavista and Kings Cove indicates that thick units of interbedded siltstone and thick, massive sandstone sheets, not encountered in previous reconnaissance, are integral aspects of the Birchy Cove–Newmans Cove facies.

Mapping of sections in the southern and southwestern parts of the peninsula (e.g., around Trinity Pond, and between Port Rexton and New Bonaventure) has revealed the widespread distribution of facies that can be equated with each of the Cape Bonavista, Jones Pond and Birchy Cove–Newmans Cove facies. Reconnaissance farther south in the west Trinity Bay area has identified similar facies recognizable as far south as Random Sound.

Crown Hill Formation

The Crown Hill Formation between Keels and Kings Cove is a coarsening-upward redbed succession characterized by mudstone, sandstone and conglomerate facies like those in the Signal Hill Group on the Bay de Verde and Avalon peninsulas (e.g., Quidi Vidi, Cuckold and Bay de Verde formations; King, 1988, 1990; *also see* O'Brien and King, 2002). Beginning at the basal contact with underlying Kings Cove facies of the Rocky Harbour Formation, the lower part of the section contains several distinctive units of yellow (dolomitic?) sandstones (Plate 4) having algal-like laminations, and traces of copper. The redbed section above this level contains traces of malachite in several areas and includes at least two variably reduced grey sandstone units, one of which hosts sediment-hosted stratiform copper (SSC) mineralization at Cornerstone Resources Blue Point prospect (O'Brien and King, 2002; Plate 5). On-strike, about 9 km to the west-southwest at Tickle Cove, at least two reduced beds occur near the top of the folded redbed section. The grey-green to red colour boundary is parallel to bedding, and developed in rock of uniform lithology – fine-grained sandstone with cm-scale discontinuous layers of coarser grained sandstone. Water escape structures, including small-scale sand volcanoes, are well preserved. The upper reduced bed is lithologically comparable with that at the Blue Point mineralized zone, and contains a stratabound,



Plate 4. *Crown Hill Formation laminated yellow sandstones, near Kings Cove.*

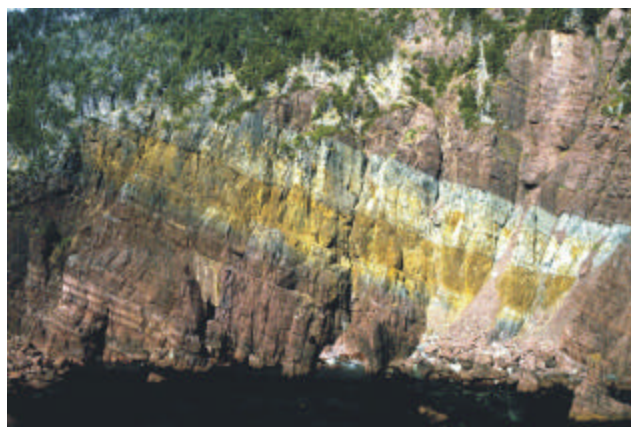


Plate 5. *Main mineralized zone (ca. 25 m thick) at Blue Point, Crown Hill Formation, Musgravetown Group.*

central rusty zone, approximately 10 m thick, in which laminated dark grey fine-grained sandstone and siltstone, contain fine-grained, disseminated syngenetic pyrite. Unlike Blue Point, most if not all of the chalcocite in the Tickle

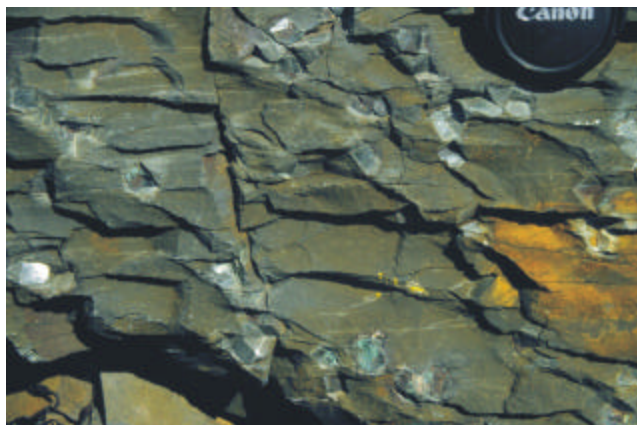


Plate 6. Coarse-grained pyrite euhedra replaced by chalcocite (and malachite), in reduced grey-green sandstone beds of the upper Crown Hill Formation (Musgravetown Group) redbed succession, Tickle Cove.

Cove locality appears to be associated with coarse-grained pyrite euhedra (Plate 6).

The mineralized grey beds in the west are conformably overlain by red pebble to cobble conglomerate. The conglomerate is comparable overall with the Cape Spear member of the upper Signal Hill Group (King, 1990) and passes conformably upwards into interbedded quartz arenite, grey sandstone and red conglomerate of the Random Formation (*see below*).

Reconnaissance work in several parts of northwest Trinity Bay between the Avalon Isthmus and Random Sound indicates that the Crown Hill Formation is substantially thicker and more widespread in the region south of the Bonavista Peninsula than noted by earlier workers (e.g., Jenness, 1963). Extensive areas of rocks assigned by various mappers to other Musgravetown Group formations (e.g., Trinny Cove, Rocky Harbour) contain several facies identical to those seen in the Crown Hill Formation succession as exposed between King's Cove and Keels to the north. Significant areas of flat-lying to subhorizontal, reduced grey units occur within the Crown Hill Formation occur in the northwest Trinity Bay region; at least some of these appear to have been assigned to the Neoproterozoic Connecting Point Group by earlier workers.

LATEST NEOPROTEROZOIC AND EARLY CAMBRIAN ROCKS

In the northwestern Bonavista Peninsula, the Musgravetown Group is overlain by a tightly folded succession of uppermost Neoproterozoic to lowermost Cambrian ("Eocambrian") quartz arenites, succeeded by Lower Cambrian fossiliferous red and green shales and nodular limestone beds (Figure 2). This post-Musgravetown stratigraphic

succession is comparable with that in the lower half of a similarly folded Eocambrian-to-Middle Cambrian basin located immediately west of the nearby Indian Arm fault (O'Brien, 1994). It is noteworthy that similarities (in terms of both lithology and thickness) in Cambrian successions across this structure, are not apparent in juxtaposed Neoproterozoic sedimentary successions below the Cambrian (*see* O'Brien, 1994).

Random Formation

Coarse-grained redbeds of the upper Crown Hill Formation of the Musgravetown Group are overlain by shallow-marine, grey to white quartz arenites and quartz granule to pebble conglomerate of the Random Formation (Walcott, 1900; Christie, 1950) at the community of Keels, northwest Bonavista Peninsula. There, the conformable and gradational nature of the Musgravetown Group–Random Formation contact is revealed on the well-exposed west limb of a north-plunging syncline. This structure is one of a series of tight regional folds of Neoproterozoic and lower Paleozoic rocks that are preferentially developed (and spectacularly exposed) northwest of the east-northeast-trending Duntara fault. On the east limb of the same fold, the nature of the Musgravetown–Random boundary relationships is obscure because of faulting. Jenness (1963) reported a total thickness of approximately 100 m for the Random Formation in this area, based on unpublished data from A. Christie (*also see* Christie, 1950).

The Random Formation in the Keels region can be divided into three principal facies, all of which are exposed on the shore of Castle Cove (immediately west of Keels) and on the islands offshore of that community. The lowermost is composed primarily of white to light-grey quartz arenite and quartz-granule to quartz-pebble conglomerate, all of which display prominent crossbedding (Plate 7). Beds of red, pebbly sandstone locally occur within these quartz arenites. The middle facies is composed of white and grey quartz arenite interbedded with medium to dark grey-green sandstone, containing detrital muscovite; both are associated with minor grey shale. The sandstones are variably rusty and pyritic; associated quartz arenites are reduced and reddish hematite has been replaced by pyrite. The upper facies consists of red, pink and light grey quartz arenite, quartz granule conglomerate, and red sandstone and conglomerate comparable with those at the top of the underlying Crown Hill Formation.

Adeyton Group

The Random Formation is overlain by green mudstone and shale of the Early Cambrian Bonavista Formation (Van Ingen, 1914; Hutchinson, 1962), the basal division of the



Plate 7. *Crossbedding in Random Formation quartz arenite near Keels.*

Early Cambrian Adeyton Group (Jenness, 1963). The Cambrian stratigraphic nomenclature of Hutchinson (1962) and earlier authors has precedence over subsequent usages and is thus employed here; the reader is referred to Landing (1996) for a review of alternative nomenclature denoting Cambrian strata in southeastern Newfoundland.

The base of the Bonavista Formation at Keels is marked by a disconformity surface within a 2-m-thick unit, comprising a 10-cm-thick, flat-pebble conglomerate that is bounded above and below by laminated green-grey siltstone and sandstone (Plate 8). There is slight erosion and down-cutting of the conglomerate bed into underlying sandstone; however, the contact of the lower sandstone with underlying quartz arenite is concordant. The conglomerate has intra-basinal sedimentary detritus (ca. 0.1 to 2.0 cm clasts); clasts of the underlying quartz arenite are uncommon. The lack of angular discordance at the base of the Cambrian shale succession indicates folds and cleavage in the Musgravetown Group northwest of the Duntara fault are post-Early Cambrian in age.

The lower part of the Cambrian succession at Keels is characterized by grey-green shales, mudstones and slates. A 3-m-thick, fossiliferous algal limestone overlies the green beds, separating them from a younger succession of red and green shales and mudstones, containing pink, and reduced grey nodular limestone beds. An overlying unit of pink and green, manganiferous limestone containing thin, discontinuous red shale layers contains stromatolites, oncolites and shelly fossils, including hyalithids, and is comparable with the Smith Point Formation of the Adeyton Group (Hutchinson, 1962). If such a comparison is correct, then the presence of that unit implies that the Cambrian section at Keels, which has previously been equated in its entirety with the Bonavista Formation (e.g., Hutchinson, 1962), also includes younger Early Cambrian strata belonging to the Brigus For-



Plate 8. *Flat-pebble conglomerate at the base of the Lower Cambrian Bonavista Formation, Adeyton Group.*

mation (Van Ingen, 1914; Hutchinson, 1962). Hutchinson (1962) cautions that thin limestone beds elsewhere in the Early Cambrian succession can be mistaken for the Smith Point Formation. The thickness of the limestone at Keels, however, is similar to that of less equivocal Smith Point limestone in the Cambrian succession at Ocean Pond (immediately west of the Indian Arm fault), which is continuous from the Random Formation through the complete Adeyton Group (Brigus, Smith Point and Bonavista formations) into the younger Harcourt Group.

The variegated Cambrian shales display prominent redox fronts having highly variable discordance to bedding. Both the shales and the limestones contain traces of malachite and chalcocite in widely separate areas. The presence of pre-cleavage stratiform sedimentary copper mineralization in these Cambrian rocks and in underlying Crown Hill Formation reduced beds, coupled with lack of significant discordance at the boundary, could indicate that the copper in both cases is coeval and of Early Cambrian (or younger) age. The presence of copper in reduced units above and below the Random Formation points to the possibility of copper mineralization in reduced and/or suitably porous units in that formation.

The Cambrian rocks at Keels have a penetrative slaty cleavage that is axial planar to the north-plunging structures described above. Recent attempts have been made by private interests to identify and develop potential slate resources in this area.

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