



GEOLOGICAL ASSOCIATION OF CANADA
NEWFOUNDLAND AND LABRADOR SECTION

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BONAVISTA !

Guidebook compiled by Andrew Kerr

Technical Material from Sean O'Brien, Hans Hofmann,
Art King, Tom Lane, Andrew Kerr and Paul Dean

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NEWFOUNDLAND and LABRADOR SECTION**

2008 FALL FIELD TRIP

BONAVISTA !

**STRATIGRAPHY, PALEONTOLOGY, AND ECONOMIC
GEOLOGY ALONG THE HISTORIC DISCOVERY TRAIL**

Compilation and Editing: Andrew Kerr¹

Technical Information:

Sean O'Brien¹, Hans Hofmann³, Art King⁴, Tom Lane², Andrew Kerr¹ and Paul Dean⁵

¹ Geological Survey of Newfoundland and Labrador,
Department of Natural Resources
PO Box 8700, St. John's, NL, A1B 4J6

² Research Director, CAMIRO, PO Box 70684,
2938 Dundas Street, Toronto, ON, M6P 1Y0

³ Department of Earth and Planetary Sciences,
McGill University, Montreal, QC, H3A 2A7

⁴ Department of Earth Sciences, Memorial University,
St. John's, NL, A1B 3X5

⁵ Johnson GEO CENTRE, 175 Signal Hill Road,
St. John's, NL, A1A 1B2

Front Cover: Images from the Bonavista Peninsula, all photos by Andrew Kerr

Top Row: "Charnia" fossil - Cape Bonavista lighthouse - The famous Arch Hole at Tickle Cove

Middle Row: Seastacks, Skerwink Trail - slump folds in Rocky Harbour Formation - "Heimalora" fossil

Lower Row: Surf at Cape Bonavista - "Catalina Stone" pyrite cubes - Red beds of the Crown Hill Formation.

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SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the Geological Association of Canada to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. GAC recommends steel-toed safety boots when working around road cuts, cliffs, or other locations where there is a potential hazard from falling objects. GAC will not supply safety boots to participants. Some field trip stops require sturdy hiking boots for safety. Field trip leaders are responsible for identifying any such stops, making participants aware well in advance that such footwear is required for the stop, and ensuring that participants do not go into areas for which their footwear is inadequate for safety. Field trip leaders should notify participants if some stops will require waterproof footwear.

Field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary (when recommended by the field trip leader or upon personal identification of a hazard requiring PPE use). It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

Specific Hazards

Many of the stops on this field trip are in coastal localities. Access to the coastal sections normally requires short hikes, in some cases over rough, stony or wet terrain. This field trip involves some moderate hikes, of which the longest is about 5 km. Participants should be in good physical condition and accustomed to exercise. The coastal sections contain saltwater pools, seaweed, mud and other wet areas; in some cases it may be necessary to cross brooks or rivers. There is a strong possibility that participants will get their feet wet, and we recommend waterproof footwear. We also recommend footwear that provides sturdy ankle support, as localities may also involve traversing across beach boulders or uneven rock surfaces. On some of the coastal sections that have bouldery or weed-covered sections, participants may find a hiking stick a useful aid in walking safely.

Coastal localities present some specific hazards, and participants **MUST** behave appropriately for the safety of all. High sea cliffs, such as those at Cape Bonavista and the Kings Cove lighthouse, are extremely dangerous, and falls at these localities would almost certainly be fatal. Participants must stay clear of the cliff edges at all times, stay with the field trip group, and follow instructions from leaders. Coastal sections elsewhere may lie below cliff faces, and participants must be aware of the constant danger from falling debris. Please stay away from any overhanging cliffs or steep faces, and do not hammer any locations immediately beneath the cliffs. In all coastal localities, participants must keep a safe distance from the ocean, and be

aware of the magnitude and reach of ocean waves. Participants should be aware that unusually large “freak” waves present a very real hazard in some areas. If you are swept off the rocks into the ocean, your chances of survival are negligible. If possible, stay on dry sections of outcrops that lack any seaweed or algal deposits, and stay well back from the open water. Remember that wave-washed surfaces may be slippery and treacherous, and avoid any area where there is even a slight possibility of falling into the water. If it is necessary to ascend from the shoreline, avoid unconsolidated material, and be aware that other participants may be below you. Take care descending to the shoreline from above.

A small number of field trip stops are located on or adjacent to roads. In these areas, participants should make sure that they stay off the roads, and pay careful attention to traffic, which may be distracted by the field trip group. Roadcut outcrops present hazards from loose material, and should be treated with the same caution as coastal cliffs.

Weather is unpredictable in this area and participants should be prepared for a wide range of temperatures and conditions. Always take suitable clothing. A rain suit, sweater, sturdy footwear are essential at almost any time of the year.

The hammering of rock outcrops, which is in most cases completely unnecessary, represents a significant “flying debris” hazard to the perpetrator and other participants. For this reason, we ask that outcrops not be assaulted in this way; if you have a genuine reason to collect a sample, inform the leaders, and then make sure that you do so safely and with concern for others. In this context, all participants should note that the fossil localities visited on this excursion are protected by Provincial legislation, and any damage or attempts at sampling or collecting material are against the law. Our preference is that you leave hammers at home or in the field trip vans.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, the introductions for specific localities make note of specific safety concerns such as traffic, water, cliffs or loose ground. Field trip participants should read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

INTRODUCTION

The Bonavista Peninsula is well known as an historic and scenic region of eastern Newfoundland, and it attracts growing numbers of visitors and seasonal residents. The first and most famous Transatlantic visitor was Giovanni Caboto, or John Cabot, who reputedly landed in 1497 near Cape Bonavista. Legend has it that his first words upon seeing this new world rise above the horizon were “*Buena Vista !*” (beautiful sight). Today, tourists are drawn by the beauty of landscapes and seascapes, by historic communities such as Bonavista, Trinity and King’s Cove, outdoor activities such as hiking and kayaking, and by a growing summertime cultural scene involving theatre and music. From a geological viewpoint, the peninsula has always been poorly known compared to the neighbouring Avalon Peninsula, and the only systematic mapping prior to 2002 was by the Geological Survey of Canada in the 1950s, who assigned virtually the entire area to a single unit (Jenness, 1963). Over the years, mineral exploration largely bypassed the region, aside from some small-scale industrial minerals operations. There was a general perception that the region held little mineral potential, and this provided a disincentive for the more systematic geological investigation enjoyed by some other parts of eastern Newfoundland.

This situation began to change with the new millenium. Regional mapping initiated by the Geological Survey of Newfoundland and Labrador (GSNL) showed that the sedimentary rocks of the area were more varied than previously supposed, including at least two areas with distinct stratigraphy and structure (O’Brien and King, 2002; 2004a, b; 2005; O’Brien et al., 2006). A fledgling junior exploration company, later to become Cornerstone Resources, became interested in the potential of certain units for stratiform sediment-hosted copper (SSC) deposits. Their prospecting efforts located several new showings and occurrences, which eventually led to a joint venture with Noranda Mining, and some limited drilling (e.g., Graves, 2002; Seymour et al., 2005). Although these mineral discoveries were not of economic grades or dimensions, they sparked a wider interest in the copper potential of Late Precambrian sedimentary rocks in eastern Newfoundland and led to exploration elsewhere in the Avalon Zone . In 2003, well-preserved soft-bodied fossils of the latest Precambrian *Ediacaran biota* were discovered in the Catalina area, confirming that host rocks were correlatives of the famous Mistaken Point Formation (O’Brien and King, 2004b). Subsequent detailed investigations showed that Ediacaran fossils are widely distributed, and over 40 sites are currently known. These fascinating organisms (including four new genera) are now thoroughly documented by a recent paper (Hofmann et al., 2008). Clearly, there is much more to the Bonavista Peninsula than early mapping had indicated, and the new work from several sources now provides a framework for an interesting field excursion. GAC-NL has been interested in the idea of a Bonavista field trip since 2004, and we are pleased that it has now finally come to fruition. The preparation of this intermediate-level guidebook is an important part of this initiative, and we hope it will prove useful for future trips designed both for specialist audiences and perhaps the general public.

The field trip is broken into three parts. The Day 1 afternoon drive to the Trinity-Port Rexton area includes some brief stops that illustrate rock types in the area and allow a brief visit to copper occurrences hosted by mafic volcanic rocks. It will conclude with a visit to some interesting coastal outcrops at Port Rexton. Day 2 focuses on the stratigraphy, structure and paleontology of the region between Trinity and Cape Bonavista, including some of the more

accessible Ediacaran fossil localities. It will end at spectacular Cape Bonavista, the site of John Cabot's landfall in 1497. Day 3 of the trip will focus on possible stratiform sediment-hosted copper (SSC) mineralization and its host rocks in the Port Rexton area, and on the scenic peninsula between King's Cove and Plate Cove, where we will also visit a slate deposit. In addition to aspects related to bedrock geology, the field trip will also highlight several interesting aspects of coastal geomorphology that illustrate the active processes that work to create dramatic scenery throughout the peninsula.

Revisions to the ordering of stops, and perhaps complete reversals of Days 2 and 3, may be necessitated by weather conditions and/or tidal schedules. Some of the fossil localities require a hike of about 4.5 km, for which good weather is naturally preferred, and they are better appreciated when the sun is low in the sky, to better accentuate the low relief of specimens. The Brook Point coastal section near King's Cove requires a round trip hike of some 2.5 km, and some negotiation of coastal outcrop faces.

The material in this guidebook is drawn from and simplified after several recently published sources, notably O'Brien and King (2002; 2004a, b; 2005) and Hofmann et al. (2008). It also incorporates material derived from unpublished mineral exploration assessment reports that are now in the public domain, notably by Lane (2004) and Thorsen (2004), both of which are included in the assessment report of Seymour et al. (2005). Several figures were drawn directly from these sources, with some minor modification to suit our purposes. Although this guidebook was written and assembled by the compiler, who takes full responsibility for any errors or omissions, the underlying geological information should always be attributed to the original sources listed above. Additional references relevant to specific units and topics are given in the appropriate sections that follow. The stop descriptions in the second part of the guidebook were developed from observations by the compiler, coupled with information from P. L. Dean, H. J. Hofmann, T. E. Lane, A. F. King and S. J. O'Brien as needed. Development of this guidebook would not have been possible without the interest and assistance of those individuals who have conducted work in this area since 2000, and they are sincerely thanked for their input to this project.

REGIONAL GEOLOGICAL SETTING

The Bonavista Peninsula is located on the northwest side of Trinity Bay and the southeast side of Bonavista Bay, and lies entirely within the Avalon Zone of the Appalachian Orogen in Newfoundland (Figure 1). The Avalon Zone is dominated by a complex assemblage of Neoproterozoic sedimentary, volcanic and plutonic rocks developed between 760 Ma and 540 Ma ago; these are overlain by Cambrian and locally Ordovician sedimentary rocks of shallow-water setting (e.g., O'Brien et al., 1996; Figure 1). The rocks of the Avalon Zone (*sensu stricto*) were unaffected by the Ordovician and Silurian orogenic events that formed the Appalachian Orogen, but they were probably eventually "accreted" to Laurentia during the Devonian, prior to emplacement of ca. 380 to 375 Ma granites. The later Paleozoic history of the type Avalon Zone is expressed by regional folding and the emplacement of these granites, notably along its western boundary (Figure 1). Several small areas of Neoproterozoic rocks occur within the central portion of the Newfoundland Appalachians, representing either extensions of Avalonian crust or a separate block, now generally termed *Ganderia* (e.g., van Staal, 2005). The wider context of Avalonia and Ganderia within the tectonic evolution of the Appalachians is beyond the scope of this guidebook, but they are generally considered to be (a) microcontinental block(s) representing part of the Gondwanan margin of the Early Paleozoic Iapetus Ocean, along with similar rocks in Europe, north Africa and South America. On a wider scale, they are part of the so-called "Pan African" orogenic belts, which weld older cratonic nuclei throughout the southern continents. The Pan-African Orogeny was essentially the event that assembled the supercontinent of Gondwanaland, which would later be joined with other continental blocks at the end of the Paleozoic to form Pangaea.

The regional stratigraphy and structure of the Avalon Zone in Newfoundland is an intricate topic, not easily summarized in a paragraph, but there is a widely accepted general framework from the mapping and compilation of King (1988), adapted from earlier work by the GSC. The evolution of the Avalon Zone is reviewed by O'Brien et al. (1996), and the regional correlations of units within it are indicated in Figure 2. Note that the stratigraphic terminology for time-equivalent volcanic and sedimentary rocks varies from east to west, across the Paradise Sound Fault and related structures, and also within the area east of these. The early development of the entire region is dominated by volcanism and plutonism considered to be of broadly arc-related character. The assembly of these individual arcs into a composite terrane was followed by the development of sedimentary basins during the time period now termed the Ediacaran (~ 635 Ma to 542 Ma). In a general sense, Ediacaran sedimentary rocks of the Connecting Point and Musgravetown groups (western Avalon zone) and the Conception, St. John's and Signal Hill groups (easternmost Avalon zone) constitute shallowing-upward sequences that progress from deep marine to shallow water and then to terrestrial and alluvial environments. However, the western and eastern sequences differ in lithology and depositional environments. At the top of these sequences, a marine transgression indicates a return to marine conditions in "Eocambrian" (i.e., latest Ediacaran) times, and there is a local disconformity with respect to the older Precambrian rocks. The Ediacaran in the western Avalon Zone was also marked by extensive bimodal volcanism in the form of the Bull Arm Formation, which sits near the base of the Musgravetown Group (Figure 2). For further discussion of the complex Precambrian history of the region, readers are referred to O'Brien et al. (1996) and the relevant chapters in the DNAG volume (Williams, 1995), and to the abundant references therein.

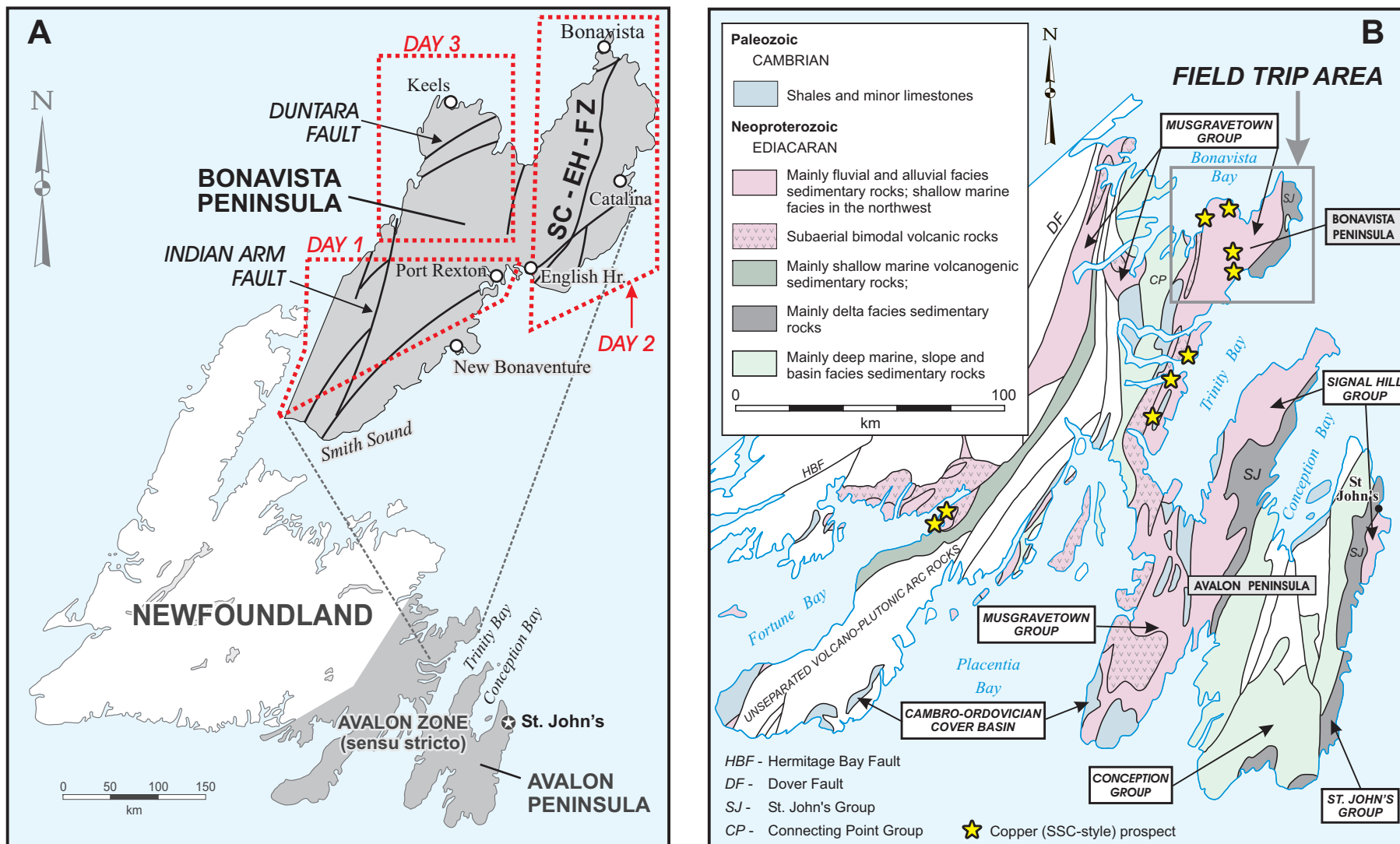


Figure 1. The geographic and geological context of the field-trip area. A: Location of the Bonavista Peninsula, and the approximate outlines of areas to be visited. B: Simplified geology of the Avalon Zone, showing the field-trip area, and locations of copper mineralization explored since the late 1990s. Both maps modified slightly from O'Brien and King (2005).

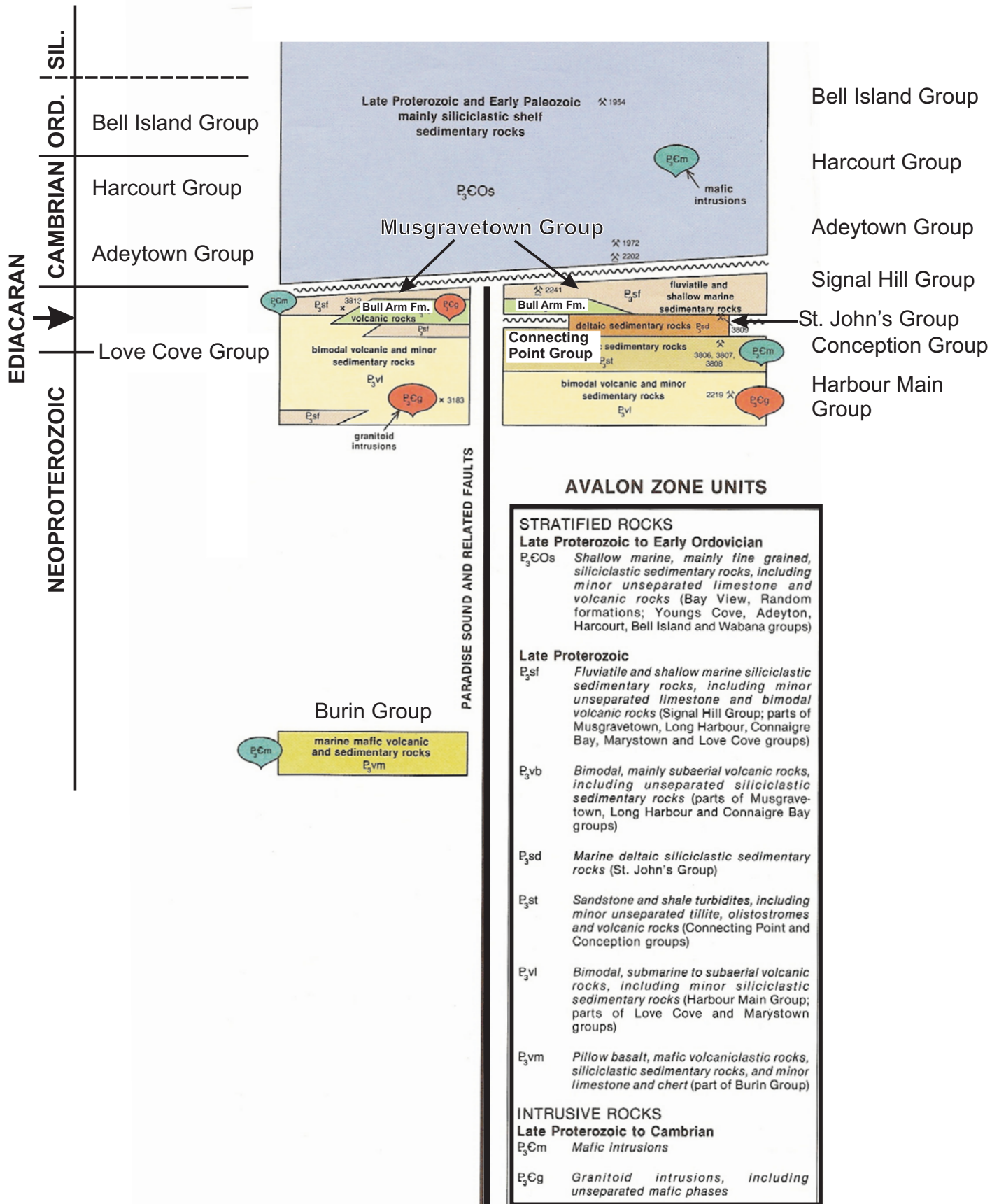


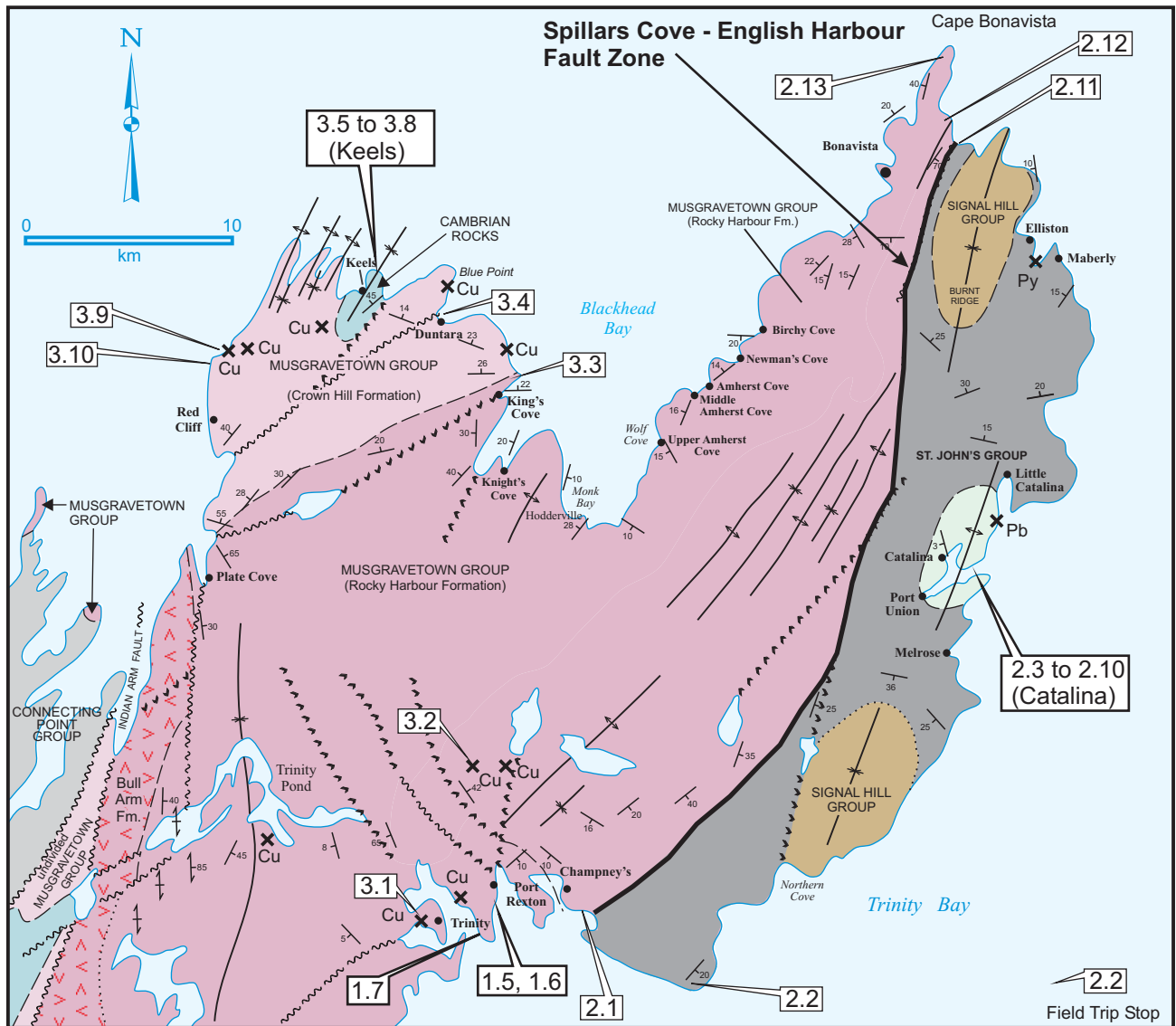
Figure 2. Stratigraphic nomenclature and correlations across the Avalon Zone in Newfoundland. Based on the legend for the 1:1 million scale map of Newfoundland (Colman-Sadd et al., 1991), with some minor modifications.

The Bonavista Peninsula forms part of a region dominated by Ediacaran sedimentary rocks that is juxtaposed with older volcanic and plutonic rocks to the west by the Paradise Sound Fault and related structures. Volcanic rocks of the Bull Arm Formation occur in the western and central parts of the peninsula, and Cambrian rocks are preserved as synclinal outliers in three main areas (Figure 1). The sedimentary rocks of the peninsula were traditionally assigned in their entirety to the Musgravetown Group (e.g., Jenness, 1963). Recent mapping (discussed below) confirms this conclusion for most of the region, although it is now apparent that the extent of truly terrestrial sedimentary rocks in the group is less than previously assumed. Also, the northwestern extremity of the peninsula, which is demarcated by an important fault zone, is now correlated with time-equivalent sequences of the Conception, St. John's and Signal Hill groups, for which the type areas are in the easternmost Avalon Peninsula (Williams and King, 1979; O'Brien and King, 2004a, 2005; O'Brien et al., 2006). Initial reconnaissance work suggested that Conception Group rocks might occur elsewhere on the Bonavista peninsula, but later examination suggested that these were instead part of a lower marine sequence within the Musgravetown Group (O'Brien and King, 2004a). The Bonavista Peninsula thus preserves portions of two discrete sedimentary basins that overlap in time, but perhaps not in their original spatial relationships.

GEOLOGY

The area visited on this field trip mostly corresponds to the portion of the Bonavista Peninsula east of a series of faults that cross it near Summerville, which collectively mark the eastern boundary of the Connecting Point Group (Figure 3). Recent regional mapping (O'Brien and King, 2002; 2004a, 2005) and detailed mapping connected to mineral exploration (e.g., Lane, 2004) now covers much of this area, and the following summary is derived from these sources. Some stops on the first day of the field trip are located on the peninsula between Goose Bay and Clode Sound, north of Musgravetown (Figure 3), where the geology is described by Hutchings (1998) and Froude (2002) and references therein.

Field work by A. F. King in the 1980s in the area between Trinity and Bonavista suggested that some of these rocks resembled those of the eastern Avalon Peninsula (St. John's area) rather than the typical strata of the Musgravetown Group. Mapping by O'Brien and King (2002; 2004a, 2005) confirmed this correlation and identified an important regional structure that defines the western limit of these rocks. This is termed the *Spillars Cove - English Harbour fault zone*, and it divides the field trip area into two contrasting halves (Figure 3). Although initial work (O'Brien and King, 2002) suggested that the Conception Group occurred to the west of this structure, it is now believed that it is restricted to a small area in the vicinity of Catalina (Figure 3). The sedimentary rocks across the entire region are all affected by Paleozoic folding, but in general the intensity of such effects is greater to the west of the Spillars Cove - English Harbour fault zone. However, the lithological monotony of parts of the Musgravetown Group impedes detailed analysis of the structure. Cambrian rocks in the Keels area are restricted to a regional tight synclinal structure, which is flanked by numerous minor structures in the underlying Precambrian rocks. Subvertical rocks in the immediate Trinity area contrast with gently-dipping rocks elsewhere, and indicate structural complications related to regional folding and/or block faulting. In contrast, to the east of the Spillars Cove - English Harbour fault zone, Ediacaran



THE DUNGEON

EARLY PALEOZOIC

CAMBRIAN

Unseparated Random, Bonavista and Smith Point formations: quartz arenite, red and green shales, limestone and slate

LATE NEOPROTEROZOIC

MUSGRAVETOWN GROUP

Crown Hill Formation
mainly red sandstone and conglomerate, minor grey sandstone and red mudstone

Rocky Harbour Formation
unseparated grey and green cross-bedded and rippled sandstone and pebble to cobble conglomerate

Bull Arm Formation
unseparated subaerial volcanic flows and pyroclastic rocks; minor clastic sedimentary rocks

SIGNAL HILL GROUP

Gibbett Hill Formation
massive to laminated light grey sandstone

ST. JOHN'S GROUP

unseparated Trepassey, Fermeuse and Renew's Head formations
mainly grey to black, locally pyritic sandstone and shale

CONCEPTION GROUP

mainly silicified, graded grey and green sandstone and mudstone; minor red argillite (may include unseparated areas of Musgravetown Group in south)

CONNECTING POINT GROUP (west of Indian Arm Fault)

unseparated grey-green turbidites and associated marine sedimentary rocks

Figure 3. Simplified geology of the northeastern Bonavista Peninsula including most of the field-trip area. For the detailed locations of field trip stops in the Catalina and Keels areas, see figures 4 and 6 respectively. Modified from O'Brien and King (2002, 2004a, 2005).

strata of the St. John's and Signal Hill groups dip gently around open dome-and-basin structures, and the Conception Group occurs in the core of a broad domal culmination. The regional pattern is attributed to Devonian folding, and a Paleozoic age is clearly indicated by the involvement of the Cambrian rocks.

The sedimentary rocks on either side of the Spillars Cove - English Harbour fault zone are in part time-equivalent, but differ markedly in terms of lithology and depositional setting, suggesting that it is a structure of regional importance (O'Brien and King, 2004a, 2005). However, the exact nature of and the magnitude of movements across the structure remain an open question, as does the course of its continuation offshore in the Trinity Bay region (O'Brien and King, 2002).

PRECAMBRIAN (EDIACARAN) ROCKS BETWEEN TRINITY AND BONAVIDA

Conception Group

The oldest rocks in the area are assigned to the Conception Group, and occur only in a small area around Catalina and Port Union, where they are exposed in the core of a gentle doubly-plunging anticlinal structure, termed the "Catalina Dome" (Figure 3, Figure 4; O'Brien et al., 2004a, 2005). The base of the Conception Group is nowhere seen on the Bonavista Peninsula, and the sequence in the Catalina Dome represents the upper part of the group, namely the Drook Formation and the Mistaken Point Formation (Figure 4). The Conception Group on the Bonavista Peninsula represents a deep-water marine environment, as in its type area, and most of the rocks represent turbidites, separated by thin intervals of pelagic sedimentation. O'Brien and King (2005) provide detailed information on these rocks and their contained sedimentary structures, which is summarized below.

Drook Formation: The Drook Formation is dominated by laminated siltstones and sandstones, typically grey-green, interbedded with subordinate mudstones. Essentially all are of turbiditic origin. The base of the formation is not seen in the Catalina area, where its constituent rocks are named the Shepherd Point Member (O'Brien and King, 2005).

Mistaken Point Formation: The Mistaken Point formation consists of a lower sequence of siltstones and sandstones, and an upper sequence of more argillaceous character, including mudstones and shales. These are termed the Goodland Point and Murphy's Cove members, respectively (O'Brien and King, 2005), and are also dominated by turbidites. The Mistaken Point formation also includes numerous thin units of pale yellow-green siliceous material interpreted to be of volcanic origin, i.e., fine-grained aquagene tuff from distant explosive eruptions. These tuffaceous intervals are critically important in the context of Ediacaran fossil preservation. The Murphy's Cove Member is the most prolific in terms of fossil localities.

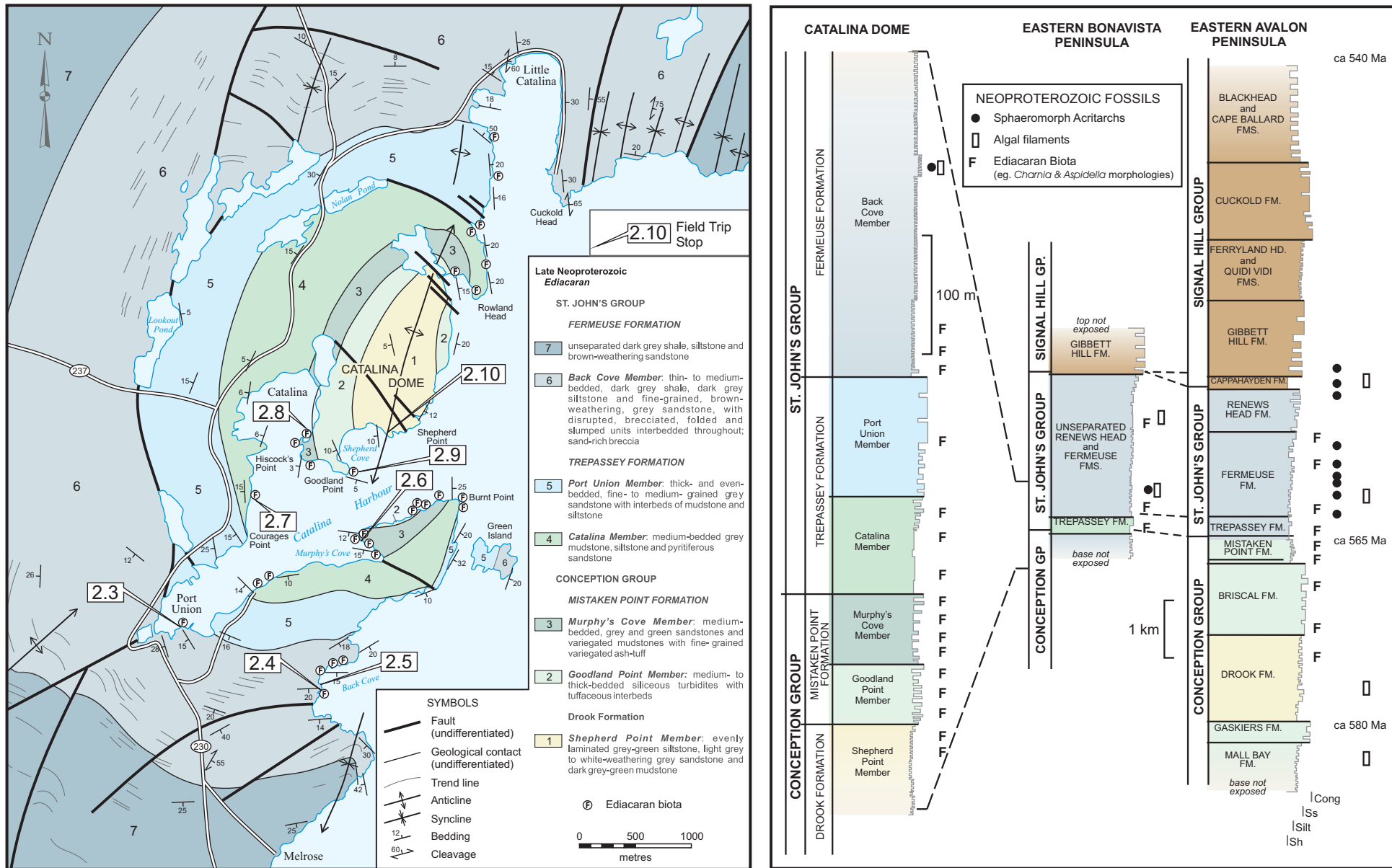


Figure 4. Geological map of the Catalina - Port Union area, showing member-level subdivisions of the Conception and St. John's groups, coupled with their wider stratigraphic context. The map shows most, but not all, fossil localities, and also the sites visited by this field trip. Modified and adapted from O'Brien and King (2005).

St. John's Group

Around the Catalina Dome, the rocks of the Conception Group pass conformably into those of the St. John's Group, which occupy much of the area east of the Spillars Cove - English Harbour fault zone (Figure 3). In its type area, the St. John's Group is divided into the Trepassey, Fermeuse and Renew's Head formations (Williams and King, 1979) and all three divisions are recognized in the field-trip area, although the total thickness of the group is considerably less than in its type area (Figure 4). The rocks of the St. John's Group are well exposed along the coastal section northeast of English Harbour (Figure 3), where they are described in considerable detail by O'Brien and King (2005), and summarized below.

Trepassey Formation: The Trepassey Formation includes a lower sequence dominated by siltstones and mudstones, and an upper sequence of more thickly-bedded sandstones; these are termed the Catalina and Port Union members, respectively (O'Brien and King, 2005). As a whole, the formation represents a coarsening-upwards and thickening-upwards cycle. The Catalina Member includes some thin tuffaceous units, associated with Ediacaran fossils. The Trepassey Formation also includes spectacular slumped units that attest to periodic sediment instability.

Fermeuse Formation: The Fermeuse Formation consists mostly of dark shales, with lesser mudstones, siltstones and sandstones, marking a return to deeper-water conditions. Like the underlying Trepassey Formation, it contains slumped units, and thin tuff units that are associated with Ediacaran fossils.

Renew's Head Formation: The Renew's Head Formation is a coarsening-upward and thickening-upward sequence of siltstones, sandstones and granule conglomerates that preserves sedimentary structures indicative of a gradual transition from basinal into deltaic conditions. It contains very few Ediacaran fossils of note.

Signal Hill Group

The youngest rocks in the area east of the Spillars Cove - English Harbour fault zone are assigned to the Signal Hill Group, specifically the lowermost Gibbet Hill Formation (Williams and King, 1979). These rocks are preserved in the cores of two gentle synclinal structures that complement the anticlinal culmination of the Catalina Dome (Figure 3). In the field trip area, the Gibbet Hill Formation consists mostly of thick-bedded sandstones interpreted to be of largely deltaic origin (O'Brien and King, 2005). Higher formations of the Signal Hill Group are not exposed on the Bonavista Peninsula.

PRECAMBRIAN (EDIACARAN) ROCKS ELSEWHERE IN THE AREA

Musgravetown Group

All Precambrian rocks in the field-trip area west of the Spillars Cove - English Harbour fault zone are assigned to the Musgravetown Group (Jenness, 1958; O'Brien and King, 2002; 2004a; 2005). The most abundant subdivision is the Rocky Harbour Formation, dominated by marine siltstones and sandstones, punctuated by conglomerate marker units. The formation is not formally subdivided, as its internal stratigraphy is not well-known, and likely has lateral facies variations. The overlying Crown Hill Formation is a very different sequence dominated by red beds and terrestrial sedimentary rocks, and occurs only in the area around Duntara and Tickle Cove, where it hosts copper mineralization (Figure 3). Volcanic rocks of the Bull Arm Formation occur along the western edge of the field trip area, and are likely lateral facies equivalents of parts of the Rocky Harbour Formation. Overall, the Musgravetown Group exhibits considerable lateral facies variations, described in detail by O'Brien and King (2004a, 2005), and the correlation of individual sequences to define member-level subdivisions is not an easy matter. The present stratigraphic framework for the group in the field trip area is shown in Figure 5, simplified after O'Brien and King (2005). For simplicity, the various "facies" proposed as potential members by these authors are not named below.

Bull Arm Formation: The Bull Arm Formation occurs at or near the base of the Musgravetown Group and is best known in the area of the isthmus of Avalon (Figure 1). The formation is more than 2 km thick, and is lithologically variable, but essentially bimodal in composition. The dominant rock types are subaerial basalts, mafic pyroclastic rocks, rhyolites, felsic ash-flow tuffs, and assorted pyroclastic breccias. The felsic rocks locally have alkaline to peralkaline compositions (O'Brien et al., 1990, Williams, 1995).

Cannings Cove Formation: The Cannings Cove Formation is a conglomeratic unit that overlies the Connecting Point Group, with an angular unconformity, in the area north of Musgravetown visited on Day 1 of the excursion. It is considered to be the basal unit of the group, although its lateral relationship to the Bull Arm Formation is not clear.

Rocky Harbour Formation: O'Brien and King (2002; 2004a, 2005) divide the Rocky Harbour Formation into two broad sequences, interpreted to represent its lower and upper subdivisions, separated by a distinctive marker unit of well-sorted conglomerates. This latter sequence is superbly exposed in the area around Port Rexton. The lower subdivision is found mostly in the area between Bonavista and Trinity, immediately west of the Spillars Cove - English Harbour fault zone, whereas the upper subdivision extends from Cape Bonavista to the area around Kings Cove and Plate Cove (Figure 3). The lower subdivision is dominated by fine-grained siliciclastic rocks of generally monotonous character. Locally, these resemble some of the turbiditic rocks typical of the Conception Group, and were initially correlated with the strata exposed around Catalina (O'Brien and King, 2002). However, thin arkosic units, which are very atypical of the Conception Group, were subsequently recognized by O'Brien and King (2004a), suggesting that this area should remain within the Musgravetown Group. The upper subdivision of the Rocky Harbour Formation is dominated by cross-bedded sandstones and conglomerates; O'Brien and King (2004a, 2005) define several facies that appear to have broad stratigraphic continuity and

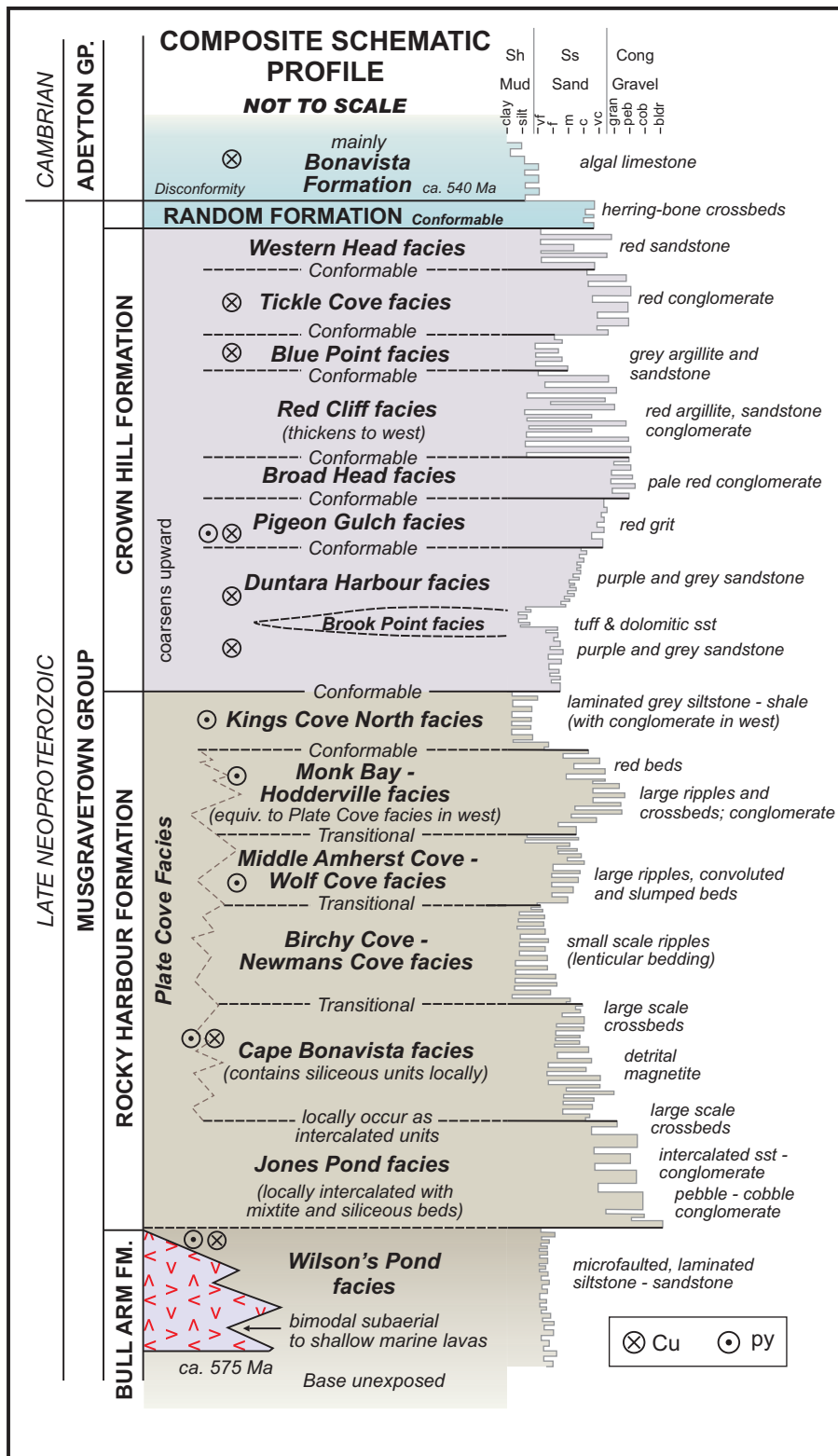


Figure 5. Generalized schematic stratigraphic column for the Musgravetown Group, showing informal facies that have potential member status. From O'Brien and King (2005).

may thus form a basis for member-level subdivision. Some of the units in this part of the formation have a red or orange cast, but they are not red beds in the sense of the overlying Crown Hill Formation (see below). The uppermost rocks of the Rocky Harbour Formation (Kings Cove North facies, O'Brien and King, 2005) are grey shales and siltstones, which pass abruptly but conformably into red beds of the Crown Hill Formation. In the west of the field trip area, a thick sequence of conglomerates marks the general boundary region between sedimentary rocks of the Musgravetown Group and the underlying (or laterally equivalent ?) Bull Arm Formation; these conglomerates resemble the Cannings Cove Formation.

Sedimentary rocks of the Rocky Harbour Formation are pyritiferous in many areas, and locally contain disseminated copper mineralization, notably around Trinity and Port Rexton (Seymour et al., 2005; Figure 3).

Crown Hill Formation: The Crown Hill Formation includes the youngest Precambrian rocks in the area and, broadly-speaking, is considered to be a time-equivalent of the upper part of the Signal Hill Group in the eastern Avalon Peninsula (i.e., the Quidi Vidi, Cuckold and Bay de Verde formations). These latter units have presumably been removed by erosion in the area east of the Spillars Cove - English Harbour fault zone (Figure 3). The Crown Hill Formation is a spectacular sequence dominated by red and purple sandstones and conglomerates, that exhibit a wide range of sedimentary structures, coupled with evidence of algal activity and perhaps bioturbation. In the lower section of the formation, distinctive yellow-green units have been interpreted as tuffs (O'Brien and King, 2005) or as possible dolomitic sandstones representing an evaporitic tidal-flat setting, i.e., a "sabhka" (Lane, 2004; Thorsen, 2004). The stratigraphy is summarized in Figure 5, after O'Brien and King (2005), and Lane (2004). Although the bulk of the Crown Hill Formation is red and oxidized, there are intermittent but stratigraphically persistent "grey beds" that represent a transient return to reducing conditions. Some of these grey silty units are important as hosts to disseminated copper mineralization (Figure 3, Figure 6). They are described in detail by Lane (2004), who mapped their distribution and divided the Crown Hill Formation into several map units that appear to have stratigraphic continuity. These subdivisions are shown in the detailed map of Figure 6, with more detailed stratigraphic columns for the Crown Hill Formation that indicate contrasts from east to west.

LATEST EDIACARAN AND CAMBRIAN ROCKS

Random Formation

The Random Formation is a laterally persistent marker in the Avalon Zone that represents the latest Neoproterozoic to earliest Cambrian ("Eocambrian") marine transgression that marks the beginning of the Paleozoic Era. In the field trip area, it is exposed only in the Keels area, where it surrounds the synclinal structure of the Cambrian Inlier (Figure 3, Figure 6). The Random Formation is only about 100 m thick, and consists of quartz arenite and quartz-pebble conglomerates, typically showing excellent cross-bedding. The boundary between the Musgravetown Group and the Random Formation is interpreted to be a conformable transition, although it is locally complicated by faulting. These rocks and their contact relationships are described by O'Brien and King (2004a, 2005).

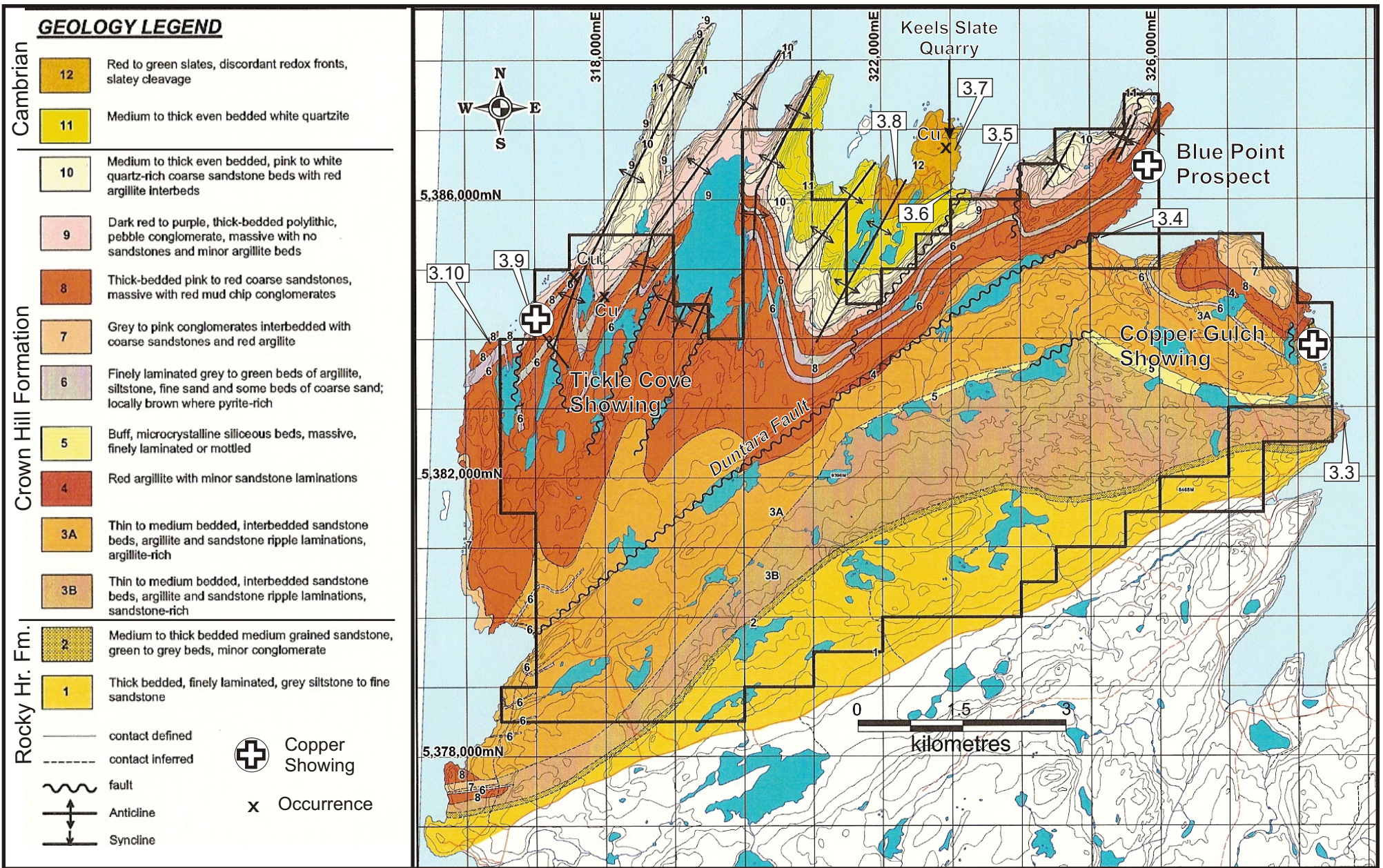


Figure 6. Geological map of the Red Cliff copper property, representing mostly the Crown Hill Formation. Locations of field trip stops for Day 3 are shown. Note that map units do not correspond exactly to facies suggested in Figure 5, although there is a general relationship between them. Adapted from Lane (2004).

Adeytown Group

Green and red mudstones and shales of Cambrian age overly the Random Formation in the Keels area (Figure 3, Figure 6). O'Brien and King (2004a, 2005) assign these mostly to the Bonavista Formation (Hutchison, 1962), and also recognize the distinctive pink algal limestones characteristic of the Smith Point Formation, although they recognized the possibility that these might represent other carbonate units lower in the sequence. Thus, the presence of other Cambrian formations that normally underly the Smith Point marker unit cannot be established with certainty. The Cambrian rocks exhibit wide colour variation due to differential oxidation and reduction, which transgresses bedding and is clearly of late timing. They are well-cleaved in the central part of the synclinal structure, where they are true slates, locally of high quality and with attractive colour variations. Minor copper mineralization is reported in Cambrian rocks of the Keels area, and also in the area around Ocean Pond, south of Summerville (Lane, 2004; Seymour et al., 2005).

REGIONAL STRATIGRAPHIC RELATIONSHIPS

Figure 7 (modified after Lane, 2004) is a schematic cross-section across the Avalon Zone indicating the inferred stratigraphic architecture of the basin(s) that contain the rocks described above, prior to later folding, faulting and plutonic activity. The oldest sedimentary rocks are those of the Connecting Point and Conception Groups, which sit upon an older "basement" developed through earlier plutonism and volcanism. The St. John's Group is thickest in the east, whereas the sequence exposed by faulting in the easternmost Bonavista Peninsula represents its condensed equivalent. It is inferred to be absent in the westernmost part of the area, where the conglomerates of the basal Musgravetown Group sit unconformably upon the Connecting Point Group. The regional stratigraphy of the Musgravetown Group remains poorly known, other than that it contains lateral facies variations, and the exact relationship between the Rocky Harbour Formation of the Bonavista Peninsula and the more lithologically varied sequence defined by King (1988) in the Trinity Bay area remains to be established. They are indicated in Figure 7 as partial lateral equivalents. However, the predominantly continental red bed sequence of the Crown Hill Formation is present at the top of the Musgravetown Group across the western Avalon Zone, and is considered to be the equivalent of the Signal Hill Group in the immediate St. John's area. The Eocambrian to Ordovician sequence forms the uppermost part of the sequence, and its regional stratigraphy appears to be consistent over wide areas. The Random Formation is conformable or disconformable upon the Crown Hill Formation, and presumably has a similar relationship to the Signal Hill Group, although the two are not known to be in contact on land. Figure 7 represents a possible regional configuration linking all these discrete sequences, but it is by no means the only interpretation.

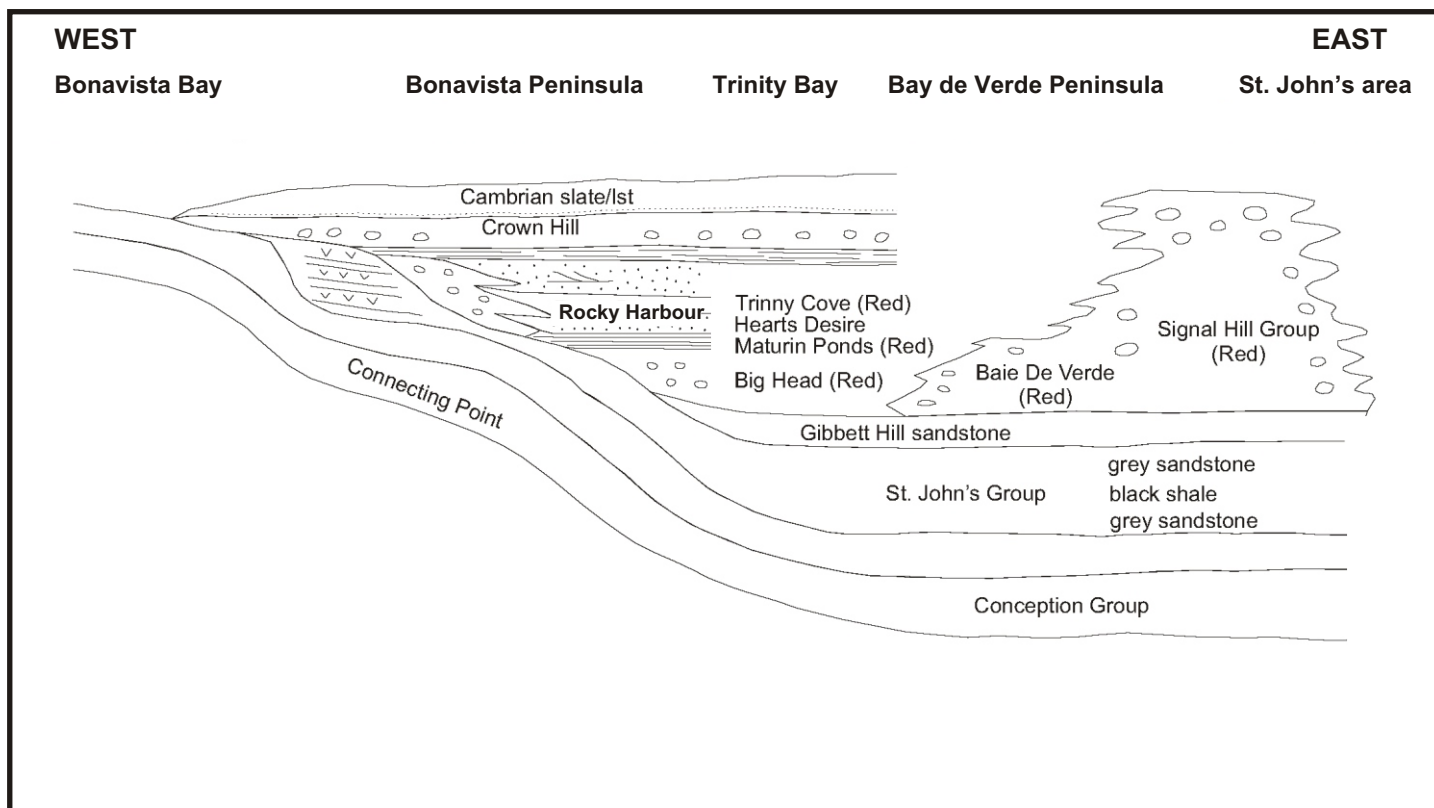


Figure 7. Schematic illustration of possible regional stratigraphic relationships across the Avalon Zone within the Ediacaran to early Paleozoic basin(s). Modified after Lane (2004). See text for further description and interpretation.

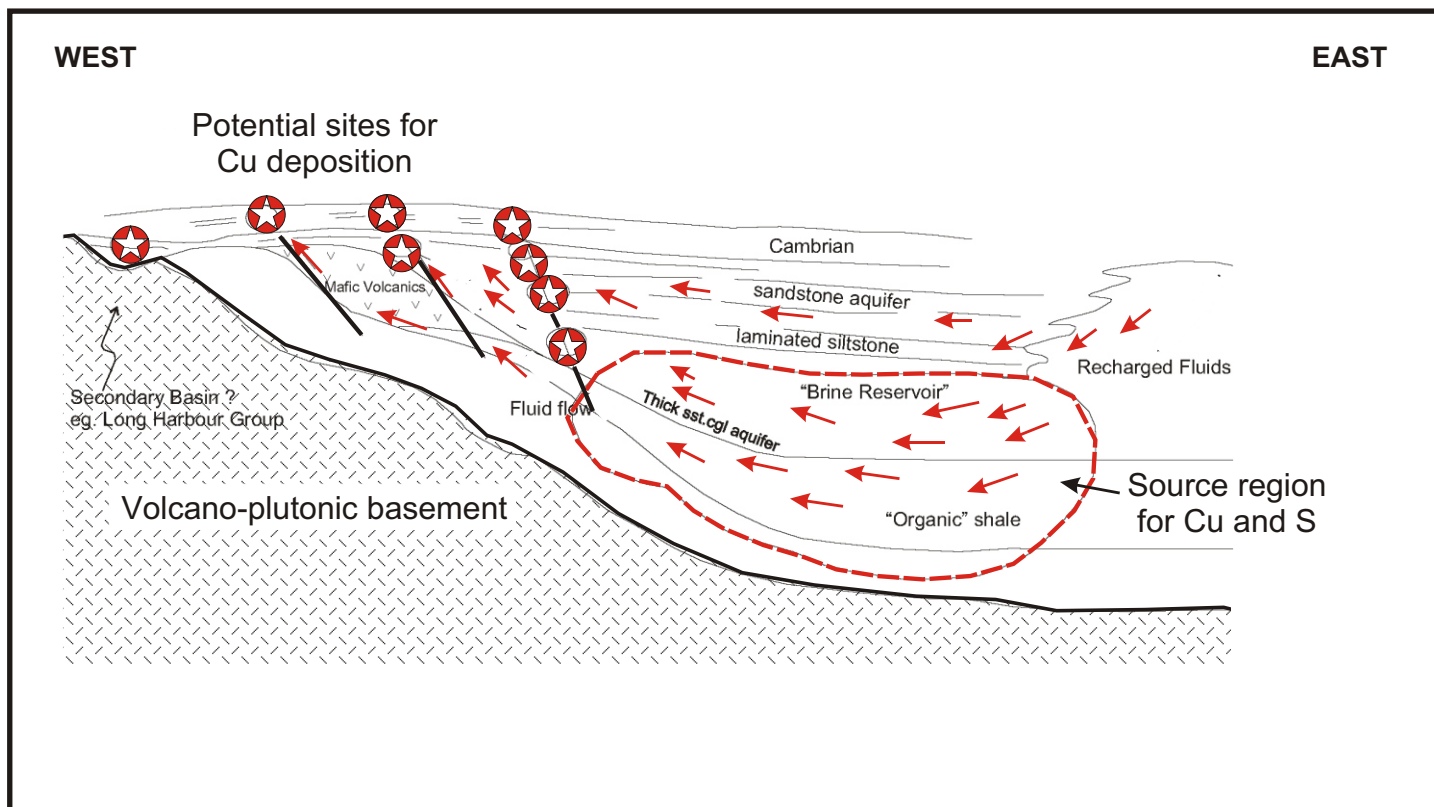


Figure 8. Generalized model for the formation of stratiform sediment-hosted copper deposits within the Ediacaran to early Paleozoic sedimentary basins across the Avalon Zone

ECONOMIC GEOLOGY

GENERAL INFORMATION

The Avalon Zone has a diverse metallogeny, including gold mineralization (mostly epithermal in character), lead and zinc (typically vein-hosted, but locally of VMS affinity), several styles of copper mineralization, stratabound iron ore and manganese, barite, fluorite, molybdenite and a wide range of industrial minerals commodities including slate, building stone and pyrophyllite. Although some deposit types are demonstrably linked to mid-Paleozoic granites, and others are interpreted to be so linked, many examples of mineralization are connected to the Precambrian and earliest Paleozoic history of the region.

The Bonavista Peninsula is historically very significant in the context of economic minerals in Newfoundland, because it gave rise to the first suggestions of mineral potential in the nascent colony. Sir Martin Frobisher's expeditions of the late 1500s documented coarse grained "gold and copper" in the "slates" of the Catalina area, and these sites were also visited by Sir Humphrey Gilbert, who collected samples and took them back across the ocean for identification and assay. Neither Frobisher or Gilbert possessed geological knowledge, and were perhaps disappointed when the "gold and copper" turned out to be large cubes of common pyrites. Despite its lack of value, diagenetic pyrite cubes are spectacular in their own right, and will be visited as part of the field trip; they are locally termed "Catalina stone".

The Bonavista Peninsula contained very few known mineral occurrences prior to 2000, and it still remains poorly-endowed compared to other parts of Newfoundland. The area saw little or no systematic exploration during the 20th century. However, interesting copper mineralization has been documented by exploration since the late 1990s, and these form part of the focus for this field trip. This section contains a brief summary of copper mineralization and potential host environments. There has to date been limited public-domain information on this mineralization deposits, although some general descriptive information is present in regional geology reports (e.g., O'Brien and King, 2005). Assessment reports, mostly prepared for Cornerstone Resources and/or Noranda (e.g., Graves et al., 2002; Seymour et al., 2005), are now in large part public domain documents, and these provide significantly more information, which in part provides sources for the descriptions below. The report by Lane (2004) is perhaps the most comprehensive and readable account, and contains several useful maps and sections. Figure 8 shows the model proposed for copper mineralization in the field trip area.

AN OVERVIEW OF STRATIFORM SEDIMENT-HOSTED COPPER (SSC) DEPOSITS

Over the last few years, mineral exploration in the Bonavista area has been focused on the search for sediment-hosted stratiform copper (SSC) deposits within the Musgravetown Group. This section provides some general information about SSC deposits, drawn in large part from reviews by Brown (1998) and Hitzman et al. (2005). Details of copper mineralization in the area are summarized in the following section;

SSC deposits of major economic significance are rare, but this group includes some of the world's largest copper deposits, and is second only to porphyry deposits as a global copper

source, accounting for almost 25% of world Cu production. The best-known examples are the Kupferschiefer deposits of central Europe, the Central African copperbelt of Congo and Zambia, and the White Pine deposits in Michigan. Other SSC deposits occur in central Asia and Australia, although not all of these are currently exploited. In addition to copper, deposits of this clan are significant sources of cobalt, silver, and locally gold, uranium and rare-earth elements (Brown, 1998, Hitzman et al., 2005). Some of these deposit clusters are enormous; for example, the reserves and resources in central Africa are estimated at close to 5 billion tonnes at 3.4% Cu (165 Mt of metal). Many such deposits have high grades and exhibit remarkable stratigraphic continuity, making them very attractive mining targets. Others have relatively low grades (<1% Cu) but their large tonnages and ease of mining grant them economic viability, particularly where deeply weathered and oxidized.

SSC deposits are viewed as concentrations of diagenetic to epigenetic timing linked to the basin-scale movement of low temperature, metal-bearing hydrothermal solutions through the host sedimentary sequences. Like all ore deposit types, they require sources for metals, sources for fluids, thermal and hydraulic processes to drive fluid flows and - above all - an effective mechanism for precipitation of metals (Hitzman et al., 2005). The host sequences to these deposits commonly include reduced (i.e., grey or green) sedimentary units within sequences dominated by rocks of oxidized, terrestrial character (i.e., redbeds). The immediate reduced host units are in some cases stratigraphic members representing marine transgressions, or the local development of anoxic conditions in restricted basins; However, they may also be discordant reduced zones that themselves result from post-depositional but pre-mineralization processes (Brown, 1998). The reduced units, which commonly contain abundant syngenetic or diagenetic pyrite on a regional scale, likely formed chemical traps for metalliferous brines, reflecting the low solubility of copper under reducing conditions compared to its high solubility in oxidized fluids. SSC deposits are typically located above thick footwall redbed sequences, which are viewed as permeable aquifers, and also as the most likely sources of the copper, originally held in Fe-oxides and hydroxides. The interface between these oxidized footwall units and the reduced host unit, also known as the *redoxcline* (Brown, 1998) is commonly regionally enriched in copper (and other metals) and forms the most obvious exploration target, once it is identified. The sulphur associated with the metals could have a variety of sources including marine or lacustrine evaporites, HS-bearing organic matter, or reduced seawater. Hitzman et al. (2005) emphasize the potential importance of evaporites in generating high-salinity fluids, but note that they may in some cases exist only in relict form within the host sequences. The metalliferous fluids were focused at depositional sites controlled by the basin architecture, and possibly also by syndepositional faults associated with basin development. Precipitation of metals was likely a function of reduction, through syngenetic sulphides and/or organic matter in the host “grey bed” units (Brown, 1998; Hitzman et al., 2005). Mineralization consists of copper sulphides (chalcocite, chalcopyrite, digenite and bornite), other base-metal sulphides (e.g., galena and sphalerite), and native copper and silver may also be present. The deposits are commonly zoned, with chalcocite and digenite closest to the redoxcline, and chalcopyrite and bornite in more distal settings; such zonation reflects differing solubilities of these sulphides as the oxidized solutions become progressively reduced. Other base-metal sulphides also tend to be located “downstream” of the redoxcline, because they have higher solubilities than the copper sulphides (Figure 9).

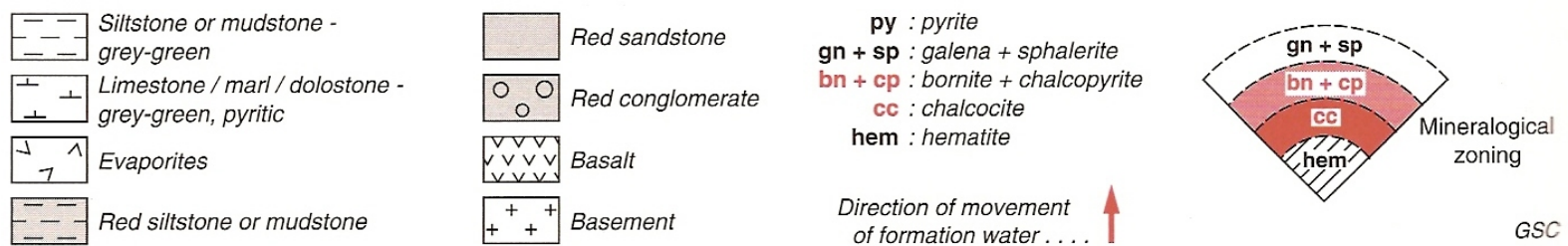
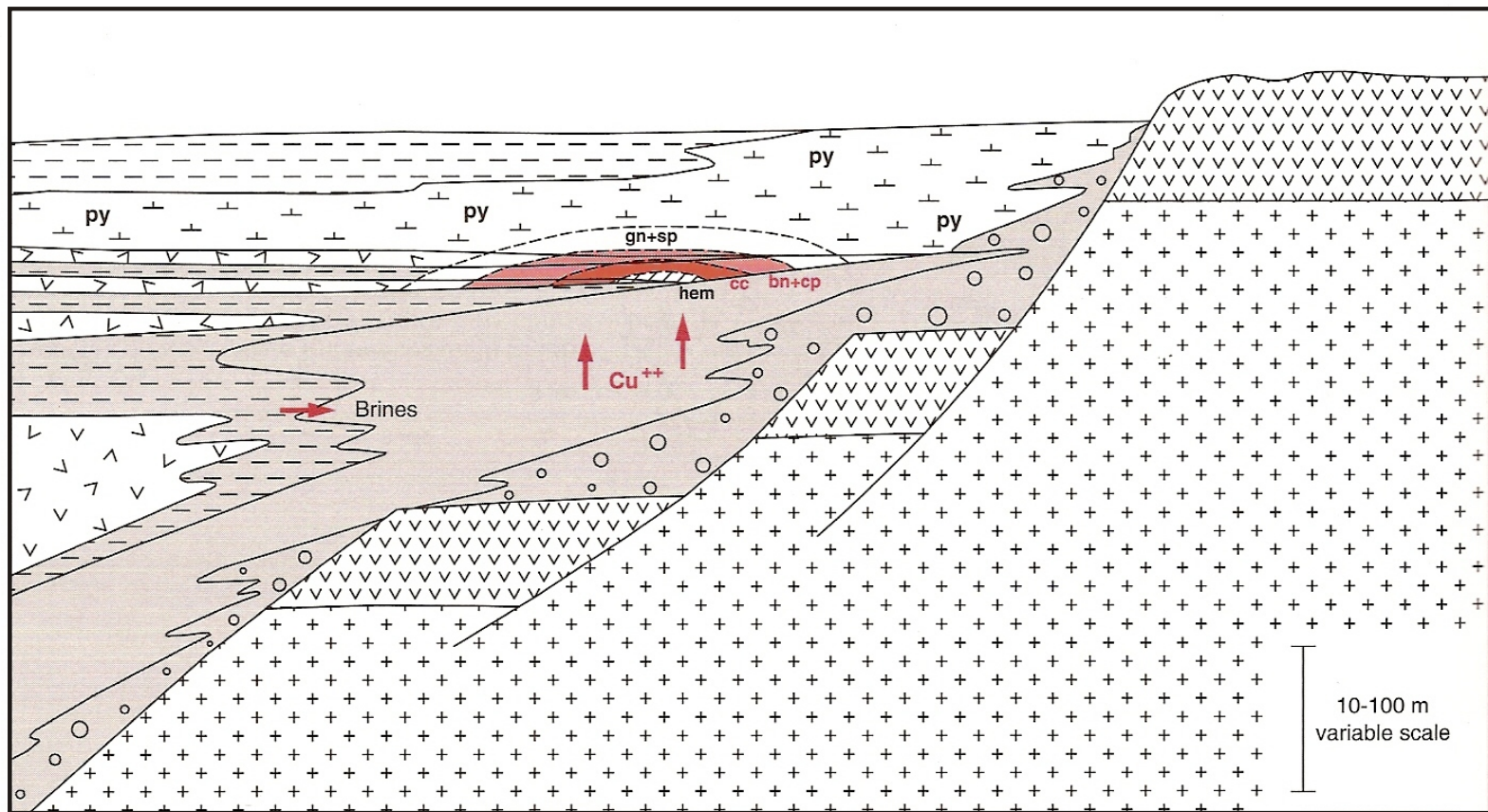


Figure 9. Generalized model for sediment-hosted stratiform (SSC) copper deposits developed in rift-type basins with thick rebed sequences overlain by marine sedimentary rocks. The copper is interpreted to be leached from the rebed sequences, and transported in oxidized solutions, and then precipitated via redox effects when brines encounter reduced, sulphide-bearing units or zones higher in the stratigraphy, or as lateral equivalents of the rebeds. Taken from Kirhkam (1995).

The stratiform character of these deposits, and their commonly bedded appearance, has led to considerable discussion as to their origins. Early models suggested magmatic-hydrothermal models in which the host sediments were “replaced”, but these ideas were replaced between the 1940s and 1960s by syngenetic concepts. These models held that copper and other metals were deposited with their host rocks in sedimentary environments where metal-rich waters discharged into anoxic basins. However, this model encountered problems in explaining the transport of metals in fresh waters that lacked suitable complexing agents such as chloride. The most widely accepted model today calls upon diagenetic or epigenetic processes that are related to basin development and dewatering, without the requirement for magmatic involvement. However, the fact that many SSC deposits are in rift-type basins may indicate that there is also a role for elevated heat flow in driving hydrothermal solutions. The sources of the metals are considered to be the footwall redbed sequences and/or deeper marine sedimentary rocks, and the fluids are believed to be focused along fault systems around the margins of developing basins, which were likely active during sedimentation. In some cases, fluids also flowed laterally along permeable units. The timing of mineralization is epigenetic, but in some cases metals may have been deposited prior to complete consolidation and lithification of their host strata. Replacement of early syngenetic or diagenetic pyrite by copper sulphides suggests that this represents an important control on the formation of such deposits. Hitzman et al. (2005) suggest that deposits of this type can form at several stages in basin evolution, ranging from early diagenesis to much later deformation and metamorphism linked to basin inversion. Thus, the temperatures of fluids involved may vary significantly, and the characteristics of the deposits so formed are variable, rather than unique. This is supported by the differences in metal associations and depositional controls reported between major SSC deposit provinces such as the North American midcontinent, central Europe, south-central Africa and Siberia.

COPPER MINERALIZATION ON THE BONA VISTA PENINSULA

This section provides a brief review of copper mineralization known on the Bonavista Peninsula, including sites that will be visited on this field trip. It is based to a large extent of assessment reports submitted by exploration companies that are now in the public domain (notably Graves et al., 2002; Seymour et al., 2005, and Lane, 2004), coupled with more general observations provided by the Geological Survey (e.g., O’Brien and King, 2002; 2005). Figure 8 (after Lane, 2004) summarizes the model for copper mineralization in the area.

Prior to the late 1990s, the only exploration in this area was by Cominco, who followed up Pb and Zn anomalies in regional lake sediment data, and by Radex Minerals, who conducted a regional reconnaissance for uranium in the sedimentary sequences. In the late 1990s, prospectors working with Cornerstone Resources discovered copper mineralization as chalcocite, malachite and native copper in basalts and rhyolites near Musgravetown (the Princess Property and Stag Brook showings). Continued exploration resulted in the discovery of a chalcocite-bearing unit in steep cliffs of the Crown Hill Formation, on the coast northeast of Duntara (the Blue Point prospect). Similar mineralization was discovered in the Tickle Cove area. These discoveries prompted a systematic investigation of the Crown Hill Formation as a potential host to SSC mineralization, through a joint venture with Noranda, and a wider reconnaissance of equivalent rocks elsewhere in the Avalon Zone. Several other copper showings were discovered in the Crown Hill Formation within the field-trip area.

Cornerstone Resources explored the Peninsula northeast of Musgravetown (the Princess property) for several years. Mineralization in this area is hosted by mafic volcanic rocks of the Bull Arm Formation, and also by quartz-carbonate vein systems in Musgravetown Group sedimentary rocks. Stratigraphic controls on mineralization documented in the Duntara-Tickle Cove area (see below) are less evident near Musgravetown (Hutchings, 1998; Froude, 2002), and the style of mineralization in the latter area was compared broadly to “Volcanic Redbed Copper” (VRC) as defined by Kirkham (1996). Hitzman et al. (2005) consider VRC mineralization to be broadly similar to SSC mineralization in that it is driven by similar fluid migration and redox precipitation mechanisms; in many provinces, the two are associated together, and perhaps both indirectly linked to high heat flow expressed by the associated volcanism. Drilling results in this area, at the Stag Brook prospect, indicated that mineralization was discontinuous and low in grade, and no recent work has occurred. The Princess Property will be visited briefly on the first day of the field trip.

In the Duntara area, work suggested that there was a strong stratigraphic control on the location of mineralization. Systematic sampling of the Blue Point prospect (not an easy task in view of its precipitous location) indicated 0.93% Cu over a 13.5 m channel, mostly in the form of finely disseminated and fracture-hosted chalcocite and bornite, associated with abundant disseminated pyrite. The characteristics of the mineralization broadly fit the SSC model, with precipitation of copper within a reduced, pyritiferous unit within a thick oxidized redbed sequence (cf., Brown, 1998; Hitzman et al., 2005). A drilling program in 2001 tested the continuity of the host unit away from the coastal exposures, and proved that it extends for a distance of at least 600 metres. The best results were similar to those of the initial discovery, with intersections of 0.8% Cu over 9.7 m and 1.0% Cu over 14.25 m (Graves et al., 2002; Seymour et al., 2005). The highest grade interval returned about 2% Cu over 6.2 m. The further extensions of the prospective horizon are presently less well-defined, although the dip of the strata limit the area available for exploration for large tonnage, open-pit targets (Seymour et al., 2005). Work elsewhere on the peninsula identified both surficial and bedrock copper enrichment, and some systematic work was completed in the Rocky Harbour Formation in the Port Rexton area, where drilling was completed on low-grade disseminated mineralization at the Fifield’s Pit and World Pond showings. The results from work in this area were not as encouraging as those from Duntara. The applicability of the SSC model in this area is not as obvious, although the host rocks do form part of a generally reduced sequence in which there is local red oxidation.

The Joint Venture with Noranda expired in 2003, and Cornerstone initiated some regional geological studies through a consultant, Jon Thorsen, and some systematic mapping and evaluation under the direction of Tom Lane. The results of this work are reported by Thorsen (2004) and Lane (2004), although some of the data and synthesis in the former source remains preliminary in nature. Work on the Bonavista Peninsula and elsewhere in the Avalon Zone identified low-grade Cu mineralization and potential SSC environments in several areas, but there has subsequently been little in the way of systematic investigation.

OTHER TYPES OF MINERALIZATION

There has long been an interest in the potential of the Cambrian rocks for slate production, driven in part by the attractive red, purple and green colours of this material, which yield better prices in the slate market than the dull greys generally associated with the stone. Slates developed on the east side of the synclinal structure at Keels contain a well-developed cleavage, and a small quarry was developed here in the 1990s. However, this did not prove to be economically viable.

Other indications of mineralization include laterally extensive pyritiferous zones of stratiform aspect in the sedimentary rocks of the St. John's Group, notably at Sandy Cove, between Elliston and Maberly. Although these are not known to contain interesting or anomalous metal contents, they indicate the possibility for sediment-hosted base metal mineralization. Equivalent rocks in the Heart's Content - Carbonear area do contain some Pb and Zn mineralization, and both areas are associated with Pb enrichment in lake sediments. The Pb-enriched area in the northeastern Bonavista Peninsula is bounded to the west by the trace of the Spillars Cove - English Harbour fault zone, independently supporting conclusions drawn on the basis of regional geology and paleontology (O'Brien and King, 2002; 2005). A small galena showing was reported in the Little Catalina area by Jenness (1963) but this occurrence has not been visited by the authors.

PALEONTOLOGY

THE DISCOVERY OF EDIACARAN FOSSILS

Prior to 2003, the only fossils known on the Bonavista Peninsula were some of Cambrian age recovered from the Keels area, and poorly-preserved acritarchs and filamentous structures in the Catalina area (Hofmann et al., 1979). Acritarchs were also known from Random Island (Parsons, 19xx). However, the recognition that the axial portion of the Catalina Dome included rocks of the Mistaken Point Formation suggested that the area had potential for well-preserved Ediacaran fossils akin to those at the famous type locality of this unit. Ediacaran fossils are also known from parts of the St. John's Group, although they are rarely as spectacular as those of the Mistaken Point Formation.

Well-preserved body fossils of Ediacaran animals were discovered in the Murphy's Cove Member of the Mistaken Point Formation (Figure 4) in 2003, and have subsequently been discovered at many other sites in this unit and the overlying Trepassey and Fermeuse formations of the St. John's Group (O'Brien and King, 2004b, Hofmann et al., 2008). Although the numbers of preserved organisms pale in comparison to the famous Mistaken Point sites, their preservation is exceptional, and the associations between different forms and species lend new insight into the nature of the Ediacaran biota and its ecosystem (Hofmann et al., 2008; see below). This section of the guide is divided into two sections. The first provides some general information about Ediacaran fossils and organisms, drawn from various published sources. The second provides a simplified account of the Ediacaran fossils described in the Catalina area, summarized from Hofmann et al. (2008).

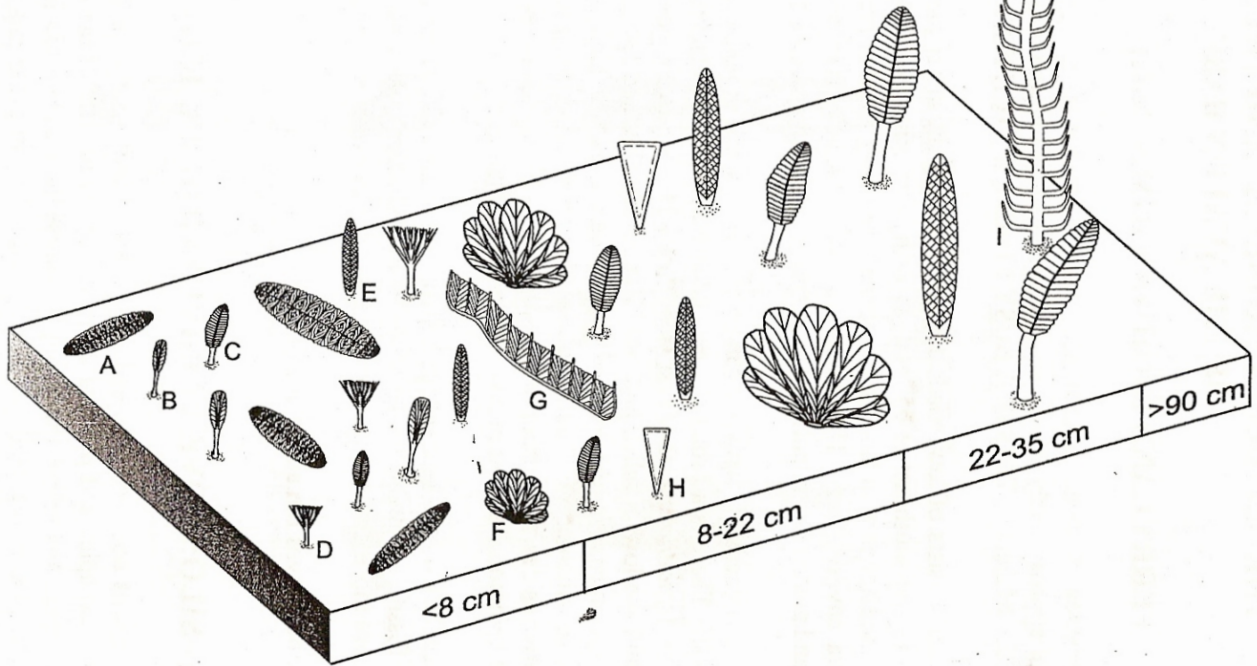
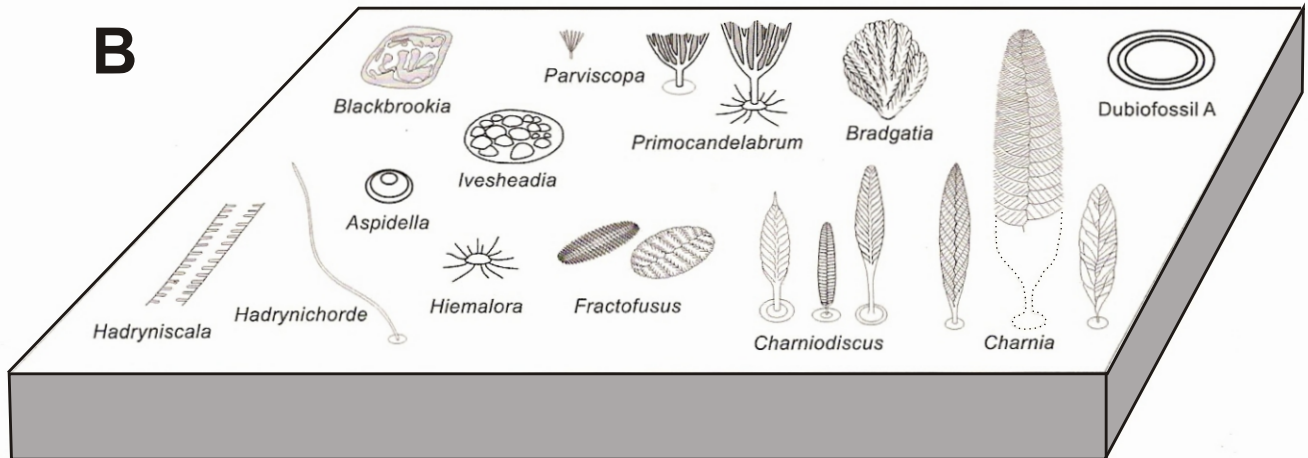
THE EDIACARAN BIOTA AND ITS SIGNIFICANCE

Narbonne (1998) provides a short and readable article that outlines the history of Ediacaran fossil research and the significance of these forms to paleontologists. There are many more detailed accounts in the paleontological literature, which are not referenced here for the sake of brevity. However, the introduction to the recent paper by Hofmann et al. (2008) provides a thorough review of work that is relevant specifically to Newfoundland examples, and Narbonne (2005) provides a wider detailed discussion of the what is known about Ediacaran biology and what is intensely debated. The following is drawn from these sources.

The extremely rare fossils of soft-bodied Neoproterozoic life forms known as the Ediacaran biota offer a tantalising window into the origins of the earliest complex, multicellular organisms on our planet. The Ediacaran is the newest time period to be added to the accepted International Geological Time Scale, and it is partly defined by these creatures. These rare fossils occur in scattered locations around the globe, and eastern Newfoundland contains some of the best-known occurrences, including the famous site at Mistaken Point, first described by Misra (1969). Newfoundland was actually the first place where fossils of this age range were described, as the fossil *Aspidella terranovica* occurs commonly in and around downtown St. John's. It was first described by Elkanah Billings from behind the original post office on Water Street, and Boyce and Reynolds (2008) present a more recent inventory of urban *Aspidella* occurrences. This curious, disk-like fossil spent many years demoted to a mere pseudofossil, but its biological origins were recently restored with the recognition that it is probably a component of frond-like fossils termed *Charnia* and *Charniodiscus*, first described from Charnwood Forest in England. Gehling et al., (2000) suggest that *Aspidella* represents the "holdfast" that tethered the frond-like organism safely to its substrate. It was evidently not the most effective attachment, for *Aspidella* is more commonly preserved than the fronds themselves in Newfoundland, where it seems that the latter were more often swept away to their doom by turbidity currents. The Ediacaran fossils occur on all continents except Antarctica, and there are presently over 100 species known, most of which are visibly more complex than lowly *Aspidella*. Most of the occurrences are in sedimentary rocks of shallow-water character, but the sites in Newfoundland and England are of special interest, because they are hosted by deep-water turbidites. This is of particular importance, because it implies that these organisms lived in a lightless environment, indicating that they did not survive by photosynthesis, and were probably the earliest animals to develop on Earth. Ediacaran fossils in Newfoundland are also unique in that they essentially represent localized extinctions of entire ecosystems; the organisms were killed by ash from distant eruptions, which buried and protected them until they were preserved as epireliefs when the underlying sediments were lithified. This means that statistical studies of such assemblages provide insight into the ecosystem of which they were a part; for example, there is evidence of "size-tiering" at Mistaken Point that is analogous to modern marine ecosystems in which each organism has a distinct niche appropriate to its height above the substrate (Clapham and Narbonne, 2002).

A

Faunal tiering of organisms deduced from studies of the Mistaken Point assemblage

**B**

Reconstructions of the organisms identified in the Bonavista Peninsula assemblage

Figure 10. Reconstructions of Ediacaran organisms. A: Diorama showing the suggested forms, sizes and ecological “tiering” of organisms at Mistaken Point, taken from Clapham and Narbonne (2002). B: Diorama showing the suggested forms of organisms in the Catalina area, including the new genera, taken from Hofmann et al. (2008)

The biological affinities of the Ediacaran organisms are a topic of fierce debate, although most researchers agree that they have little in common with the familiar animal phyla that dominate the Phanerozoic. It has even been suggested that they represent an entirely distinct kingdom that was neither plant nor animal in the true sense of the word, and which has been termed *Vendozoa* or *Vendobionta* (Seilacher, 1989; 1992). Affinities to fungi have also been proposed, and other still maintain that they were early plants or colonial organisms. The abrupt disappearance of the Ediacaran organisms from the geological record has been attributed to the development of predation; these sessile, defenseless organisms are perhaps a remnant of an Earth that was very different to that of today. Predation is believed to have been the driving force of the “evolutionary arms race” that led to the development of defensive exoskeletons and increasingly more complex organisms in the Cambrian. The famous soft-bodied fossils of the Burgess Shale in British Columbia attest to the enormous diversity of early multicellular life. It remains possible that a few Ediacaran organisms were actually the source of the first predatory organisms, which eventually gave rise to modern life forms, but these progenitors have yet to be identified with any confidence (e.g., Narbonne, 2005).

EDIACARAN FOSSILS IN THE FIELD TRIP AREA

Much has been written about the famous fossil site at Mistaken Point (e.g., Narbonne et al., 2001), and much of this is equally applicable to the sites of the Bonavista Peninsula. The mode of preservation appears to be identical, and many of the species described from Mistaken Point also occur around Catalina. Figure 10, adapted from Clapham and Narbonne (2001) and Hofmann et al. (2008), illustrates the interpreted form of Ediacaran organisms preserved in the Mistaken Point and Bonavista areas. Many Ediacaran fossils lacked formal names for many years, and were known by fanciful comparisons such as “spindles”, “pizza disks” and “christmas trees”. The preservation of Ediacaran fossils in Newfoundland is exceptional, because the sedimentary rocks in which they occur are fine-grained. However, they are mostly very low-relief positive impressions (epireliefs) and they can be exceptionally difficult to locate if the light conditions are less than ideal. Some sites in the Bonavista area appear completely barren when the sun is high, and only come to life (so to speak) when low-incidence light accentuates the shadows and reveals their richness. Compared to Mistaken Point, the bedding planes in most areas are sparsely and sporadically fossiliferous, and it is very easy to miss the fossils completely in walking the sedimentary sections.

The fossils known in the Catalina area were described initially by O’Brien and King (2004b) with tentative identifications at a generic level, and are formally described and documented by Hofmann et al. (2008). For detailed description and discussion of examples, readers should consult the latter source. In this guidebook, the formal species names are avoided as much as possible in the text, but they are listed in Figure 10b. Note that two of these genera, namely *Hadryniscalia* and *Hadrynichorde*, are new genera that are presently endemic to the Bonavista occurrences (Hofmann et al., 2008). Their names are derived from the time period “Hadrynian”, which was part of the original Precambrian time-scale developed for the Canadian Shield by C. H. Stockwell in 1964. Although these terms are no longer commonly used, it is appropriate that they be recognized formally in this manner. *Parviscopa* and *Primocandelabrum* are also new species genera by Hofmann et al. (2008).

The Bonavista Peninsula sites are notable for their exceptional preservation of an organism termed *Hiemalora* (Figure 10b), which is less common at Mistaken Point. The morphology of this fossil resembles that of a modern jellyfish, and many researchers have thought of it as an early colenterate-like animal that could have been mobile. At several sites there is an association between this fossil and a newly-recognized bush-like fossil (*Primocandelabrum* in Figure 10b), and in rare cases it appears that the two are intimately attached, with the disk-like portion acting as a holdfast. Thus, *Hiemalora* may be more akin to the humble *Aspidella*, and the “tentacles” might have been more like roots that provided greater security of attachment. The evidence for such a relationship, and various views on the affinities of these creatures, are detailed by Hofmann et al. (2008). The Bonavista fossils also reveal several other inferences about Ediacaran ecology, including an indication that many species extend to higher stratigraphic levels than previously supposed within the St. John’s Group. Previous distinctions between the “Mistaken Point assemblage” and “Fermeuse assemblage” are less evident in the Bonavista area than in the eastern Avalon Peninsula. For further details, readers are referred to Hofmann et al. (2008). Near Mistaken Point, the oldest fossils lie within the Drook Formation, but no localities are presently known in this unit on the Bonavista Peninsula. However, the basal portion of the Mistaken Point Formation (Goodland Point Member; O’Brien and King, 2005) contains a curious *dubiofossil* (i.e., a structure of uncertain but potential biological origin) that might represent a large holdfast to a potentially huge organism that has yet to be documented (Hofmann et al., 2008). The new species *Hadryniscalia* and *Hadrynichorde* are also interesting, because they superficially resemble trace fossils from younger rocks; if this is the case, it implies mobility, which has never been convincingly demonstrated for Ediacaran organisms. However, on consideration of all the evidence, Hofmann et al. (2008) retain an interpretation as body fossils, likely strands attached to the substrate. An interesting possibility is that the string-like *Hadrynichorde* could be associated with the curious fossil *Ivesheadia* (alias the “pizza disk”), which is reported to be attached to a tether of some kind near Mistaken Point (Narbonne et al., 2001).

The absolute age of the fossil horizons on the Bonavista Peninsula remains unknown, but the association of these faunas with tuffaceous units indicates potential for U-Pb zircon dating. The main fossil-bearing plane at Mistaken Point was previously dated by G. R. Dunning (MUN) at 565 +/- 3 Ma (unpublished, reported by Benus, 1988). Tuffs in the sequence at Catalina have been sampled with a view to obtaining similar geochronological data. Compared to Mistaken Point, there has to date been little study of the Bonavista Peninsula sites, and much remains to be learnt, as noted in the conclusions of Hofmann et al. (2008). Given the difficulty of spotting these elusive but beautiful survivors of a bygone age, it is entirely possible that new and prolific localities remain to be discovered, perhaps in unexpected stratigraphic places.

FIELD TRIP STOP DESCRIPTIONS

Field trip stop descriptions are located below using kilometerage distances measurable by vehicle odometer, description of local landmarks, and (for selected stops) by GPS coordinates. We have elected not to provide the latter for potentially sensitive sites where Ediacaran fossils exist. In using the locational information provided, readers should be aware that vehicle odometers vary in accuracy by as much as +/- 5% to 10%, and we recommend calibration against information in this guide - you may have to correct for your vehicle. To minimize this source of confusion, the kilometerage quoted is measured from the nearest possible reference point. It is also possible that landmarks may have changed (e.g., houses may have been repainted), and road conditions may have altered from those described here - sometimes for the better, but more commonly for the worst.

DAY ONE - MUSGRAVETOWN AREA, and PORT REXTON AREA

Stop 1.1: Bull Arm Formation mafic volcanic rocks and copper mineralization at Stag Brook

From St. John's (or wherever you start from) take the TCH to Georges Pond, about 10 km west of Clarenville, and then turn onto on the Discovery Trail (Route 230) signposted for Trinity and Bonavista. After about 22 km, take the turning for Bloomfield and Musgravetown (Route 233), crossing the bridge into the latter community. At the junction in the town, swing left as signposted for Port Blandford. A short distance along this road, just at the edge of the community, there is a prominent communications tower; at a distance of approximately 0.6 km beyond the tower, there are two gravel roads on the right hand side of the road. Turn right on the second road. The road is good for the first 200 m, but becomes narrow and rough just past the baseball field. Passenger cars are best parked at the ballfield, but trucks and other vehicles for which owners are unconcerned by surface scratches on paintwork can proceed for another 0.7 km to a parking area. The outcrops form a large cleared rocky area about 200 m farther along the road, on the left. It takes approximately 10 minutes to walk here from the baseball field parking area.

The following description is adapted from assessment reports and the MODS file (2C/05/Cu001), supplemented by observations in 2008. This large outcrop consists dominantly of subaerial basaltic volcanic rocks, cut by numerous quartz and quartz-carbonate veins; it represents the largest of several copper showings in the area of Stag Brook. The mineralization was discovered by Ken Stead in 1997, and was subsequently explored by Cornerstone Resources between 1998 and 2002. Mineralization consists of chalcocite and malachite (the latter is most obvious) associated with the cross-cutting veins, although disseminated pyrite is present in the outcrops. Some of the disseminated mineralization has anomalous gold contents. The mafic volcanic rocks are cut by red, hematitic zones (perhaps veinlets or dykes of felsic composition) that predate the quartz-carbonate veining. The Stag Brook showing was tested by drilling in 2001, but results did not indicate any economic mineralization. The best result was 0.30% Cu over 0.8 m in a carbonate-rich vein breccia that carried chalcocite and bornite, and 0.34% Cu over 1 m in a faulted zone. This is, however, not the only example of Cu mineralization in the mafic volcanic unit, as traces of Cu occur over a strike length of some 3.2 km. The

mineralization at Stag Brook is considered to be of the volcanic-red bed (VRC) type; although not visible in the outcrops, interbedded red and green siltstones and sandstones were intersected in some of the drill holes.

Stop 1.2: Conglomerates of the Musgravetown Group (Cannings Cove Formation) and copper mineralization in Cannings Cove.

From Stop 1.1, return to Musgravetown, and turn left down the hill signposted for Cannings Cove, passing the “Old Barracks” gift shop and tea room. Turn left at the bottom of the hill and drive through Musgravetown, which occupies several kilometres of this road. Beyond the community, there is a sharp left-hand bend. Continue for about 1.1 km past this bend, and park where the old gravel road diverges on the left; at the time of writing there was a locked gate here. Walk a short distance up this road and you will see the sequence of outcrops forming the stop in and adjacent to the roadbed (GPS 288040E 5368150N).

These outcrops expose conglomerates of the Cannings Cove Formation (Musgravetown Group), which are here cut by quartz and quartz-carbonate veins that contain minor pyrite and chalcopyrite. The veins are locally photogenic, but generally narrow and discontinuous. The veining is considered to be related to a nearby fault (Hutchings, 1998; MODS file 2C/05/Cu012). The best result from grab sampling was 1.45% Cu, accompanied by 15 g/t Ag and 0.75 g/t Au; however, it is now difficult to locate sulphide mineralization.

Stop 1.3: Conglomerates of the Cannings Cove Formation

From Stop 1.2, return to the vehicles and drive about 0.3 km towards Cannings Cove. The stop is the long roadcut outcrop on both sides of the road; the south side offers the better exposures.

Be attentive for traffic, even if the road is quiet, and do not approach the steeper parts of the exposure closely in case of slope instability.

This long roadcut outcrop provides excellent exposures of the Cannings Cove Formation, which forms the basal section of the Musgravetown Group in this area. The conglomerates contain a wide variety of clast types, many of which resemble rock types of the Bull Arm Formation. These polymictic conglomerates are significant in that they provide information on the basement to and source areas of the Musgravetown Group.

Stop 1.4: Connecting Point Group at Cannings Cove Beach

From the roadcut outcrops at Stop 1.3, continue eastward on the road, down the steep hill into Cannings Cove. There are excellent views of Clode Sound along this road. Park at the end of the road, by the wharf, and walk northwards on the gravelly beach; there are several outcrops easily visible.

The outcrops on the beach are grey sandstones and fine-grained gritty conglomerates assigned to the Connecting Point Group, which is the approximate time-equivalent of the

Conception Group sedimentary rocks to be visited on Day 2. The outcrops, which dip steeply southeast at this locality, contain a variety of sedimentary structures.

Stop 1.5: Devil's Cove Section, Port Rexton

From Stop 1.4, return to the Discovery Trail (Route 230) south of Musgravetown, and continue to the Trinity area. Take the road signposted for Port Rexton and Trinity East for about 1 km, and then turn left on to Station Road. The junction is just south of the Sherwood Suites Motel. Turn right where Station Road joins the road along the shore, and drive past the small fishing harbour, then turn left. Continue along this road until it reaches Bailey's Road, and then turn right; this narrow dirt road leads south to Devil's Cove beach. There is only limited space for parking at this locality. Stop 1.5 is also accessible via a short walk from Sherwood Suites, by following a side road down the hill past the Fisher's Loft Inn and joining the abandoned railway bed, from which you can cross the pastures towards Devil's Cove.

This is a very interesting coastal section through steeply-dipping rocks of the Rocky Harbour Formation, which here includes the distinctive marker units that subdivide the formation into contrasting lower and upper sections. The steep dip of the rocks, and prominent northwest-southeast strike throughout this area, are atypical of the peninsula, and brittle deformation is locally intense, indicating the presence of major faults. The spectacular seastacks and coastal features that abound on the Skerwink Trail are in part due to this distinctive structural pattern. The stop is divided into three parts, as described below.

This is a sheltered and safe coastal location, but the rocks may be slippery and wet !

At the south end of Devil's Cove beach, there are good outcrops of dominantly grey-green, well-laminated siltstones, with a few pale-weathering sandier units of possible tuffaceous origin. Graded beds and load casts suggest that the rocks face north. The northern portion of this outcrop is distinctly red, but the lithology is identical. The colour contrast is broadly conformable with bedding, but in detail it can be seen as transgressive, likely reflecting localized diagenetic or epigenetic oxidation of predominantly reduced marine sedimentary rocks. In the middle of the beach, there is a very different sequence of yellowish to pale brown and pink arenites of arkosic origin, which locally display well-developed cross-bedding. The strike of the beds is almost east-west here, and they dip steeply north, beneath the conglomerates at the north end of the beach. The most spectacular part of the stop is at the north end of the beach, where there is a sequence of interbedded sandstones, arkoses and pebble to cobble conglomerates. These display cross-bedding, and also marked lateral variations along individual beds indicating the presence of fossil channels. The beds appear to young northwards, although some individual conglomerate units display coarsening-upward patterns. The conglomerates are locally very well-sorted, and contain a clast population that is dominated by rocks of felsic volcanic aspect. However, there are also some interesting angular, slab-like cobbles of bedded red- and green siltstones that bear an uncanny resemblance to the outcrops at the south end of the beach. There is also at least one unusual clast of possible mixed volcanic and sedimentary material that resembles the unusual rock featured at the next stop (see below).

The area around the conglomerate outcrops consist of a boulder beach, which contains many boulders of conglomerate (these are popular as garden ornaments in and around Port Rexton and Trinity). In some future geological era, these will become ancient conglomerate clasts within another conglomerate! To complicate matters further, there is also a well-developed raised beach deposit exposed behind the modern beach, which is an unlithified pebble to cobble conglomerate. The entire area is essentially a complex Pleistocene to modern unconformity in the process of formation, and the unusual clasts noted above hint at the possibility that a late Precambrian unconformity (or at least a disconformity) may sit beneath it.

Stop 1.6: Skiff Cove, Port Rexton

From Stop 1.5, walk along the dirt road to the south, and then turn onto a rougher track that leads across the pasture to the next beach, known as Skiff Cove. Walk along the trail above the beach to the south end, where it is possible to descend along some gravelly scree to the beach. Once on the beach, walk south past the first rocky outcrop, and you will see the unusual pink- and grey mottled rock that represents this stop.

This is a sheltered and safe coastal location, but the rocks may be slippery and wet !

The outcrops consist of steeply dipping sandstones, arkoses and granule conglomerates that bear some similarity to those seen at Stop 1.5; these pass southward into siltstones. The unit of interest is, however, very different in appearance. It contains rounded masses of pink material that appears to be felsite or rhyolite, most of which is fine-grained and aphanitic. However, white flecks seen locally may be feldspar phenocrysts. The bulbous pink masses are surrounded by featureless dark grey to black material, and both are set in a matrix of grey fine-grained material that is locally laminated and likely of sedimentary origin. In places, the pink and black material appear to be interlayered and contorted. This curious unit is bounded to the south by a bedding-parallel (?) fracture zone that resembles a fault, but there is no indication that the northern (upper ?) contact is tectonic. A bed of clearly sedimentary origin in this contains what appears to a clast of the pink material.

The origins of this strange rock type are unclear, but it appears to have an igneous component. It is possibly a “peperite”, i.e., a mixed rock developed where a felsic extrusion or near-surface intrusion has interacted with unconsolidated, wet, sediment. In such an interpretation, the dark glassy material could represent quickly chilled material, and the lack of vesiculation would indicate significant water depth. An alternative explanation is that it is a heterogeneous dyke of some kind, which is much younger than the sedimentary rocks. It may represent a possible geochronological target, and is certainly a good student project.

It is very difficult to climb back up the scree slope at this stop, so the best return route is to walk along the beach to the north end, where there is an easy trail. The outcrops en route display strong fracturing and are locally gossaned, suggesting that there may be several faults through Skiff Cove. The final outcrop is a grey siltstone that resembles the first part of Stop 1.5.

Stop 1.7: Optional Excursion: The Skerwink Trail

In a province that contains many fine hiking trails, the Skerwink Trail stands out because it is a relative short loop (some 5 km) that is exceptionally rich in spectacular views and pastoral landscapes. The trail contains little of geological interest, but it does include some fine coastal seastacks. These slab-like offshore stacks are in part a function of the steeply-dipping rocks of the Rocky Harbour Formation, and also owe their origins to the major fault zone that trends along this coast. Looking across towards Fox Head, the contrast in dips of the sedimentary rocks from west to east is very clear. The western section of the trail is mostly along clifftops, and culminates at Skerwink Head. The eastern section provides lovely views across to Fort Point and the historic town of Trinity, and then returns to Port Rexton through peaceful meadows. The complete loop takes from 1.5 to 2 hours to walk, allowing time to enjoy views and take photographs.

The trail can be accessed from Stop 1.6, where a foot trail ascends from the top of the south end of the beach; however, it is difficult to climb the gravelly scree slope at this spot, and it may be necessary to walk northward on the beach and then loop back. Alternatively, return to Port Rexton and then to Trinity East, where there is a parking area and a marked entrance where the abandoned railway track crosses the road.

DAY TWO : TRINITY - CATALINA - BONA VISTA AREA

Stop 2.1: English Harbour - Sandstones and redox features in siltstones of the Musgravetown Group (Rocky Harbour Formation).

From Port Rexton, drive to Route 230 and continue eastward slightly more than 2 km, crossing the Salmon Cove River. Turn right on the road signposted for Champneys and English Harbour. Drive through Champneys and English Harbour, to a point about 3.5 km from the junction. Park by the side of the road, just beyond some painted boulders with lighthouse scenes that provide a useful marker. Descend to the shoreline and traverse to the prominent red and green outcrops.

This is a sheltered and safe coastal location, but the rocks may be slippery and wet !

The outcrops consist of well-bedded and cleaved siltstones and sandstones, typical of the lower section of the Rocky Harbour Formation. The outcrop also contains some thin white calcareous units, and the coarser-grained sedimentary rocks locally display cross-bedding. Finer-grained sedimentary rocks show soft-sediment deformation features suggestive of slumping.

The main feature of interest at this site are the contrasting red and green colours of the outcrop. It is clear that the colour variations here do not correspond to individual beds, but cut across bedding at high angles. This indicates that these are post-depositional “redox fronts”, and the boundaries between red (oxidized) areas and green (reduced) areas are actually gradational, even though they are abrupt. Note that the calcareous unit mentioned above is continuous through the Redox front. The changes in oxidation state are caused by the effects of percolating solutions, but the timing is more difficult to assign; such processes could be diagenetic or epigenetic. The Rocky Harbour Formation seems to consist mostly of grey-green sedimentary rocks, at least in this region, so this outcrop likely represents localized oxidation, similar to that seen at Stop 1.5.

Stop 2.2: English Harbour Lighthouse - Sandstones of the St. John’s Group

Continue for another 0.8 km until the pavement ends. Continue on this well-maintained gravel road to the lighthouse, located about 5.2 km beyond the end of pavement and about 9.5 km from Route 230. This is a spectacular road on the clifftops, with expansive sea views across Trinity Bay, and some impressive cliff faces. Shortly before the end of the pavement, the road crosses the trace of the Spillars Cove - English Harbour fault zone. If the weather is not clear, there is very little point in going all the way to the lighthouse; bedded rocks of the St. John’s can be seen (but not examined closely) at the first viewpoint, about 1 km beyond the end of the pavement. This reveals some spectacular bedded cliffs.

Note that there is no guard rail on this road, and the road comes close to the cliff edge, so drive with caution ! Watch for blind hills and a sharp double-bend about 1 km from English Harbour. Note also that the final few hundred metres to the lighthouse is a steep hill, rough in places, that may not be suitable for all vehicles. Parts of the road may not be suitable for

low-clearance vehicles, as it is graded infrequently. The lighthouse is surrounded by steep cliffs, and the views are spectacular, but stay well away from the cliff edges !

At the lighthouse, walk to the left adjacent to the raised wooden helicopter pad to see interbedded fissile slates and interbedded thick sandstone units. The latter are the dominant rocks at this site and can be seen in many of the outcrops in and around the lighthouse. These are amongst the youngest rocks exposed in the area east of the Spillars Cove - English Harbour fault Zone, aside from two small outliers assigned to the basal part of the Signal Hill Group (Figure 3; Figure 4)

Stops 2.3 to 2.6: Port Union - Murphy's Cove - Back Cove Area

This group of stops starts in Port Union, and concludes with a hike of about 4.5 km that includes prominent Ediacaran fossil localities in the Mistaken Point and Trepassey formations, and several other features of geological interest. Most of the hiking route is on a well-marked trail, on which the surface is generally good; however, some parts, notably on hills, may be steep and/or rough. Proper footwear with ankle support is recommended. The approximate stratigraphic locations of the stops listed below, and the Ediacaran genera and species that each contains, are indicated in Figure 11 (modified after Hofmann et al., 2008). From Stop 2.2, return to Route 230, and drive northward to Port Union, passing by the community of Melrose. Turn into the town, passing into its historic district, and park by the Coaker Centre. There is a boardwalk on the seafront immediately below the building.

Stop 2.3: Coaker Centre Museum Boardwalk and Outcrops

These outcrops are located on the shoreline below the Coaker Centre Museum, where the wooden steps lead down to the beach. They consist of siltstones to sandstones assigned to the Port Union Member of the Trepassey Formation of the St. John's Group (O'Brien and King, 2005). This locality contains rare but exceptionally complete frond-like fossils, preserved with their holdfast structures. The square gap visible in the outcrop represents the location of one specimen that was disrupted by winter storm activity and collected for preservation. The outcrops of this same surface are well-exposed at low tide and contain several types of Ediacaran fossils, notable *Bradgatia* and *Charnia*. However, they are not easy to find ! If time permits, it may be possible to examine the specimen that was removed for display in the museum.

Stop 2.4: Back Cove (sedimentological and paleontological interest)

From Stop 2.3, continue eastward, and take the right turn that leads to the trailhead parking area for the Back Cove - Murphy's Cove trail system. From here, hike down the trail to Back Cove, a distance of just over 1 km (about 20 minutes). When the trail reaches the coast, take a right turn on a side trail, which quickly leads to the top of a large bedding plane. Descend this bedding plane with care, and enter the small slot-like cove to the south. The fossiliferous surface is located beneath the cliffs on the far side of this cove. The slumped unit lies below the prominent bedding plane at the end of the access trail.

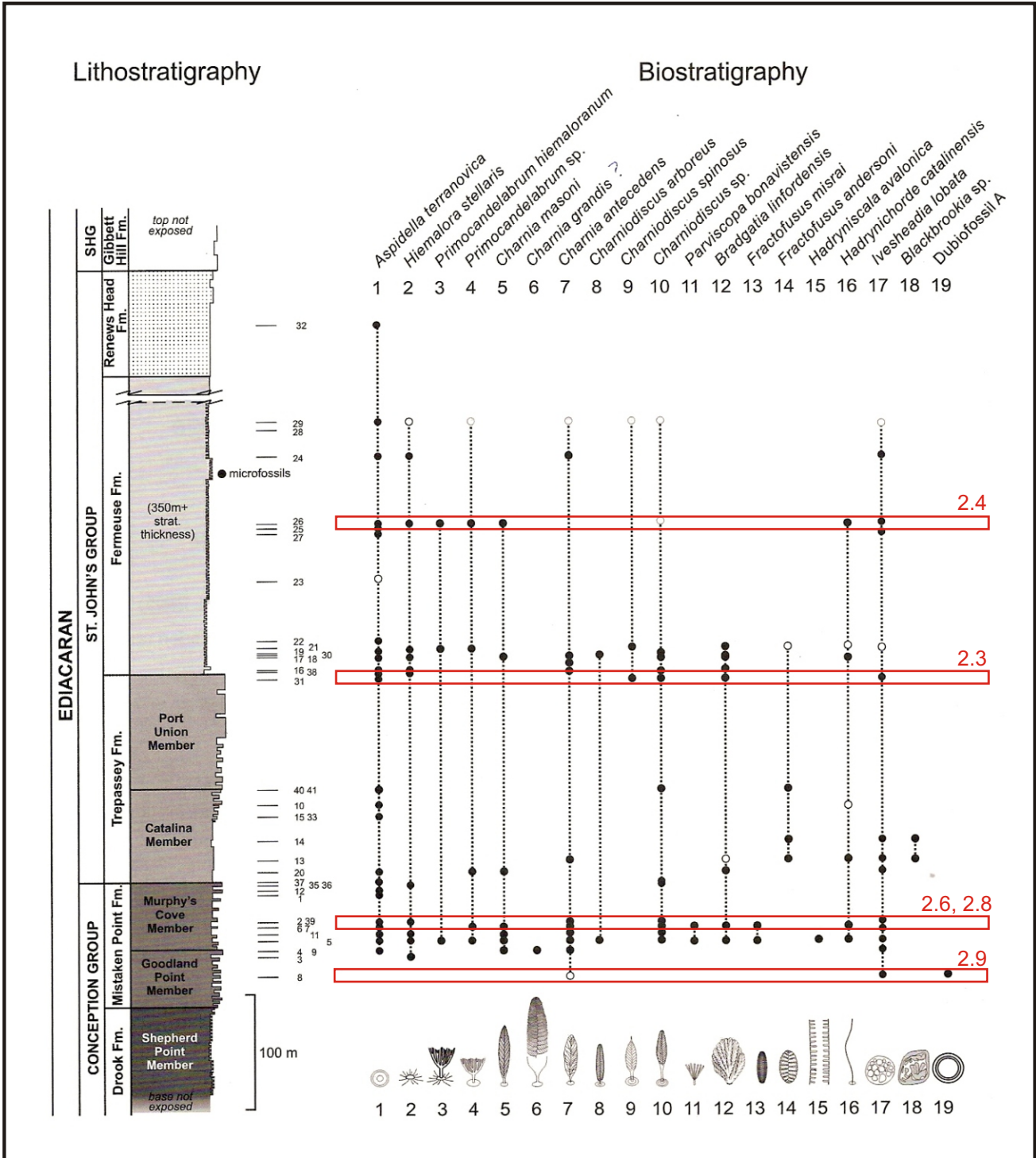


Figure 11. Chart showing distribution of Ediacaran fossils relative to stratigraphy in the Catalina area, and the stratigraphic context of the sites visited on the field trip. Modified slightly from Hoffman et al. (2008).

Note that the cliffs here are steep and in places form overhangs. Loose material could fall from here, and head protection is strongly advised. The fossils are protected by legislation and it is illegal to damage them or attempt any collection. No hammering is permitted !

The Back Cove locality contains two sections of interest. The lowest part of the stratigraphy is marked by a spectacular siltstone unit that exhibits superb soft-sediment slumping structures marked by tight, chaotic folds and numerous broken beds derived from slightly more competent sandy units. Not surprisingly, this unit does not contain any Ediacaran fossils ! However, a bed higher in the section, just below the steep cliff at the south side of Back Cove, contains several well-preserved fossils, including the mysterious “pizza disk” forms known as *Ivesheadia* (Hofmann et al., 2008). These localities are some of the youngest Ediacaran sites in the area, but not the youngest; there are also some examples further upsection, towards Melrose (Hofmann et al., 2008; Figure 3). Interestingly, the “pizza disk” forms are also some of the earliest Ediacaran forms known, as they occur in the Drook Formation in the Mistaken Point area (Narbonne et al., 2002). These organisms appear to be one of the most persistent and long-lived amongst the Ediacaran biota. Back Cove also contains examples of the new genus *Primocandelabrum* (Hofmann et al., 2008), which is closely associated with the jellyfish-like *Hiemalora*, suggesting that the latter might actually form a holdfast attachment for this frond-like organism.

Stop 2.5: “The Squirter”

From Stop 2.4, return to the trail and walk northward. The “Squirter” is signposted, and is worth a quick visit if there is significant wave activity. It is an erosional feature developed along a prominent fracture, which acts as a waterspout when large waves enter the underlying sea cave. The spout is projected back over the ocean, so there is little danger of getting squirted. *But if you approach the ocean too closely, there is a definite danger of falling in, so stay back !*

Stop 2.6: Murphy’s Cove (also known as Southeast Cove)

From Stop 2.5, continue northward on the trail, past Grassy Cove, until the trail reaches a junction with a signpost for the short cut to Murphy’s Cove. The junction is located near to “Johnny House’s Garden”, about 30 minutes walk from Back Cove. This trail crosses a small hill and then joins a more prominent trail. Turn right for Murphy’s Cove and continue for about 10 minutes to the cove. The fossiliferous horizon is located on the point north of the cove, and continues on some outcrops that are only accessible at low tide.

Note that the tidewashed outcrops are very smooth and may be slippery. The fossils are protected by legislation and it is illegal to damage them or attempt any collection. No hammering is permitted !

The outcrops here are siltstones and mudstones assigned to the Murphy’s Cove Member of the Mistaken Point Formation, which underlies the sparsely fossiliferous Catalina Member of the Trepassey Formation. The Murphy’s Cove locality contains several types of Ediacaran fossils, but it is most notable for several superb specimens of the genus *Hiemalora*, which resembles a jellyfish, but is perhaps instead a holdfast attachment for a much rarer frond-like

creature, as seen at Back Cove (Stop 2.4; Hofmann et al., 2008). The most prolific surface is the one closest to the water's edge, but these are very low-relief impressions that are best seen under low-angle light conditions. There are also numerous specimens of *Aspidella* here.

The original discovery site for Ediacaran fossils in this area is located several hundred metres to the east of here, across the gentle anticlinal dome that exposes the Conception Group. This remains the most prolific and diverse of all of the fossil localities in the area (Figure 11), and features prominently in the discussion of Hofmann et al. (2008). However, the surfaces are mostly narrow ledges in a steep cliff, and some are only accessible with the assistance of ropes. The site contains several discrete fossil surfaces, and contains examples of the newly-defined genera. Unfortunately, it is not feasible or safe to visit this site with a field trip group.

From Stop 2.6, retrace the trail to the junction, but instead of turning, continue along the old road back to Port Union (about 30 minutes walk). Take the first left turn in the town to return quickly to the trailhead and the vehicles.

Stop 2.7: “Catalina Stone” locality

From Port Union, return to Route 230 and drive north into Catalina, a distance of less than 1 km. Turn right into the town, passing the fish plant, and continue for almost 1 km to a parking area between two steel guard rails; a picnic bench serves as a useful landmark. Descend to the outcrops just below the bench, which form a well-cleaved but gently-dipping bedding plane.

There are poorly-preserved Ediacaran fossils around here, but the main feature of interest are the large pyrite cubes in the outcrop, some of which are up to 10 cm across. Square cavities in the outcrop indicate where pyrite cubes have weathered out, or have been removed by visitors. As outlined earlier, these were the first indications of economic minerals in the New Founde Lande to be reported and collected by Europeans, who were sorely disappointed when they turned out to have no value. It is interesting to speculate that some of the cavities in this outcrop represent the sites of this enthusiastic sampling in the 16th century by Sir Humphrey Gilbert's expedition.

Stop 2.8: Sandy Point Fossil Locality

From Stop 2.7, continue through the town of Catalina, and then turn right around the northern side of the harbour (there is also a shortcut across the small wooden bridge). Follow the road south towards Goodland Point, and turn right on Sandy Point Road to the shore. Walk a short distance north to examine outcrops on the shore, located near the remains of two wharves. The outcrops are best viewed at low tide, and under morning or evening light.

Note that the tidewashed outcrops are very smooth and may be slippery. The fossils are protected by legislation and it is illegal to damage them or attempt any collection. No hammering is permitted!

The outcrops here lie at the base of the Murphy's Cove Member of the Mistaken Point Formation, at a similar stratigraphic level to the Murphy's Cove locality (Stop 2.6). However, the fossil assemblage here is more diverse, and it is easier to see a variety of forms. It also includes the holotype of the new genus *Hadrynichorde* (Hofmann et al., 2008).

Stop 2.9: Dubiofossils at Goodland Point

Walk or drive back along Sandy Point Road, and then turn right, down to the end of the road at Goodland Point. A large bedding plane here can only be viewed safely at low tide. This stop will only be made if time permits.

Note that the tidewashed outcrops are very smooth and may be slippery. The fossils are protected by legislation and it is illegal to damage them or attempt any collection. No hammering is permitted !

The wave-washed portion of the bedding surface contains large ovoidal impressions that resemble huge versions of *Aspidella*. The biological origin of these features is not firmly established, and they are presently described as dubiofossils. If they are true fossils, any associated fronds must have been enormous in comparison to the generally puny *Charnia* forms. They are of interest because they represent the oldest potential Ediacaran fossils in the area, as they are hosted by the Goodland Point Member of the Mistaken Point Formation (Hofmann et al., 2008). The surface also contains a large example of *Ivesheadia*, which is similar in size to the dubiofossils, raising the possibility of a link between these genera. The latter example is only partly exposed and is very hard to locate !

Stop 2.10: Shepherd Point

From Stop 2.9, retrace the road for about 0.6 km, and turn right on a gravel road that leads to Shepherd Point, about 0.5 km from the junction. Approach the seashore on foot. This stop may also be omitted due to time constraints.

Caution is advised here if the seas are rough, because there is a hazard from large breaking waves close to the edge of the low cliffs. Stay back !

These outcrops of well-laminated grey to green siltstones are the oldest rocks exposed in this part of the Bonavista Peninsula, and are assigned to the Drook Formation of the Conception Group, which underlies the fossiliferous Mistaken Point Formation. At this spot, the beds dip at about 10° to the west, but they are essentially horizontal to the east of here, and then dip in the opposite direction at shallow angles. This is the core of the gentle antiformal structure named the Catalina Dome (O'Brien and King, 2005). The Drook Formation is fossiliferous in the type Mistaken Point area, and in fact contains the oldest complex fossil yet known on Earth, which is a large frond-like organism. However, in the Bonavista area, the Drook Formation has not yet yielded fossils. The discovery outcrops for the Ediacaran Biota in the Bonavista area are located on the other side of the bay from here, in the cliffs east of Murphy's Cove (Stop 2.6).

Stop 2.11: Spillars Cove; Trace of the Spillars Cove - English Harbour Fault Zone

From Stop 2.8, return to Route 230 through Catalina, and drive towards Bonavista. There are two routes; the quicker follows Route 230 directly to the outskirts of Bonavista, but the scenic diversion through Elliston is worth considering. From Bonavista, take the right turn for Spillars Cove and Elliston, and then take the left turn into the community of Spillars Cove. From Elliston, turn right at the Spillar's Cove turning. Park close to the prominent black outcrops that form a "rib" in the centre of the bay. Spillars Cove is a spectacular rocky bay between Cape Bonavista and Spillars Point; in recent years it has become associated with the sinking of the fishing boat Ryan's Commander, with its tragic loss of life.

Spillars Cove is a zone of structural complexity related to the Spillars Cove - English Harbour fault zone, which is an important regional structure. The rocks on the east side of the cove are amongst the youngest in this part of the area, representing the sandstones of the Gibbett Hill Formation (Signal Hill Group). The west side of the cove is represented by unseparated rocks of the Musgravetown Group. The effects of strong brittle deformation are clearly visible in these outcrops. These outcrops are enigmatic, because the brittle deformation and tectonic brecciation obscures their original nature. The compiler visited these briefly on a wet day, and wondered if they might represent a fractured, altered mafic dyke within the fault zone. If this is the case, perhaps the location could yield geochronological constraints on the timing of fault activity.

Stop 2.12: "The Dungeon"

From Stop 2.11, return towards Bonavista. Dungeon Provincial Park is signposted to the right about 1.5 km from Stop 2.11; this is a narrow dirt road with some rough sections. The Dungeon itself is easily located by the wooden viewing platform and interpretation signboards.

The cliffs around the Dungeon are steep and should not be approached too closely. If you were to fall, this particular Dungeon would be very difficult to escape from.

The Dungeon is a collapsed sea cave developed in steeply dipping grey sandstones and siltstones of the Musgravetown Group (Rocky Harbour Formation). It now forms a large cavity with sheer walls and a small beach, connected to the open ocean by two archways. The beds dip steeply towards the water, although there is some local variation in attitude. The coastal outcrops above the arches are easily accessible, and have a well-developed cleavage developed essentially at right angles to strike; this is perhaps the reason for the preferential erosion of this zone. The Dungeon also appears to be controlled by a high-angle fault zone that is clearly visible in its internal cliffs, and runs essentially north-south, parallel to the coast. The fault is marked by intense fracturing and some rusting, and there are signs that bedding is locally deflected against it. Gently-dipping white quartz veins also seem to record crenulation possibly related to motions on this fault.

In a wider sense, the Dungeon can be viewed as sea-stacks in the process of formation. The surrounding coastline of Lance Cove contains many examples of sea-stacks that attest to the operation of this process over long periods of time.

Stop 2.13: Cape Bonavista

From Stop 2.12, continue northward on the dirt road, which eventually swings inland and joins the road to Cape Bonavista. Continue northward for approximately 1.5 km to see the best outcrops. The cape itself, and the historic lighthouse, are located a short distance beyond this point, at the end of the road.

Cape Bonavista is surrounded by high sheer cliffs and lashed by large waves; the cliff edges should be avoided at all times !

The large outcrops north of Red Cove expose steeply west-dipping grey to beige or pale pink sandstones, interbedded with fine granule conglomerates. These form part of the “Cape Bonavista Facies” described by O’Brien and King (2002; 2004a). These rocks are reported to contain large-scale cross-bedding, and also distinctive magnetite-rich sandstone and conglomerate units that may serve as potential marker horizons. It is not easy to examine the rocks closely where they are wave-washed, and the attractions of this stop are mostly those of scenery and history.

DAY THREE: FROM TRINITY TO TICKLE COVE

Stop 3.1: Trinity Village Copper Showing

From Port Rexton, drive to Route 230 and drive west for about 3 km, then turn left on Route 239 at the signpost for Trinity and Dunfield. Continue along this winding road, and then take the next left turn for the historic village of Trinity. The stop is about 1.1 km from this junction, on the left hand side of the road, about 150 m beyond a small bus shelter. There is ample parking space across from the outcrops.

The Trinity Village copper showing is a small occurrence, by any standards, but it illustrates a style of mineralization that is quite widespread in the surrounding area. The host rocks are dark grey to greenish, thickly laminated siltstones and fine-grained sandstones assigned to the Rocky Harbour Formation (Musgravetown Group). Copper mineralization is mostly associated with a steeply-dipping fracture zone that displays rusty weathering, and scattered malachite, mostly on fracture surfaces. This is probably a high-angle brittle fault, and it is associated with quartz veining in specific beds. The restriction of quartz veins may be a function of greater competency and brittle fracturing in certain units. The mineralization appears to be of minor extent, although local lore holds that the best material was used for the foundation of a nearby house many years ago !

The historic town of Trinity, with its many historic buildings, lies about 1 km along the road, on a headland projecting into a superb natural harbour. If time permits, we will make a brief tourist excursion.

Stop 3.2: Fifield's Pit Copper Showings

From Trinity and Stop 3.1, return to Route 230, and drive northward towards Bonavista for about 2 km, and then turn left on Route 236, signposted for Kings Cove. This is a gravel road, but is part of the highway system, and is generally well-maintained. Continue north on this road for about 3.7 km, crossing two bridges, and turn into a large gravel pit on the right hand side of the road, close to Lockston Path Provincial Park.

Fifield's Pit contains one of the larger copper showings hosted by the Rocky Harbour Formation, although mineralization is in many areas difficult to see. There are several areas of disseminated sulphide mineralization; one of the better spots is close to GPS coordinate 325770E/5366850N, at the north end of the gravel pit. The outcrops in the pit are dominated by dark grey to grey-green siltstones, which locally display beautiful lamination. In some areas, there are spectacular soft-sediment deformation structures, including small-scale isoclinal folds; these are best seen on some of the large blocks, rather than outcrop surfaces. Mapping by Cornerstone Resources indicates that the regional structure is that of an overturned syncline, but the monotonous nature of the rocks makes detailed analysis difficult (Lane, 2004).

Many parts of the outcrops are rusty, reflecting the presence of disseminated pyrite. However, mineralization is reported to also contain fine-grained chalcocite, chalcopyrite and bornite. The most visible copper mineral is malachite, widely dispersed on fracture surfaces. The

locality was tested by drilling in 2002, and revealed anomalous copper (300 ppm to 1300 ppm) over widths up to 46 m, but no sign of strong mineralization. The best value from surface sampling was 2300 ppm Cu (0.23%). Similar mineralization occurs at World Pond, some 2 km to the east of here, but drilling also returned only weakly anomalous copper values (Lane, 2004; Seymour et al., 2005; MODS file 2C/06/Cu003).

Stop 3.3: King's Cove Lighthouse Section (Brook Point)

From Stop 3.2, continue northward on Route 236 until it joins the paved Route 235, southeast of Kings Cove. Note that this section of Route 236 is commonly rougher than the section south of Lockston Path Provincial Park. Turn left on Route 235 for Kings Cove. Kings Cove is one of the more picturesque towns in the field trip area, and appears to have retained a larger number of old buildings than many communities. In the town, take the signposted turn for the lighthouse trail, which leads to a small parking area by the wharf. From here, hike northeastward along the well-defined trail, which is an old road, through the meadows, and then through coastal woodlands for about 1 km, to the Kings Cove lighthouse. The meadows are known as "Pat Murphy's meadows", and were the inspiration for the famous folk song of that name. From the lighthouse, descend carefully to the shoreline section following the directions below.

Note that the cliffs are locally steep here, and it is dangerous to approach them too closely; also, do not venture into any areas where the rocks are wet or seaweed-covered - keep a safe distance from the water at all times ! The southeast edge of the bedding surface at the first part of the stop is formed by a vertical drop to deep and rough water, so do not approach it too closely !

The stratigraphy of the Rocky Harbour and Crown Hill formations in the Duntara-Keels area is indicated in Figure 12, modified after Lane (2004). The trail to the lighthouse is mostly within rocks of the upper part of the Rocky Harbour Formation (Kings Cove North Facies of O'Brien and King, 2005); several small outcrops reveal these rocks enroute. Beach outcrops below Pat Murphy's Meadow contain interesting "ball and pillow" soft-sediment structures that suggest rapid sedimentation in a deltaic environment that may have been the precursor to the terrestrial environment represented by the Crown Hill Formation. Vertically below the lighthouse, these grey to greenish-grey sandstones (which are here inaccessible) pass into the red beds of the Crown Hill Formation, which is the upper unit of the Musgravetown Group. This location is known locally as Brook Point, and is the type area for the Brook Point Facies of O'Brien and King (2005), which here forms the lowermost portion of the Crown Hill Formation. The Rocky Harbour - Crown Hill transition is marked by a sudden increase in the abundance of arkosic quartzite beds. There is no mineralization of note, but there are superb sedimentary structures and some enigmatic rock types. It is also a very scenic locality.

From the lighthouse, descend with care along the prominent bedding surface that leads towards the water; the surface is rough and provides good traction. Be careful of the drop on the water side of this surface. At its lower end, it is then possible to clamber down over boulders to the lowermost bedding surface in this outcrop, which faces a spectacular vertical cliff showing well-developed cyclic bedding. The grey rocks of the uppermost Rocky Harbour Formation can

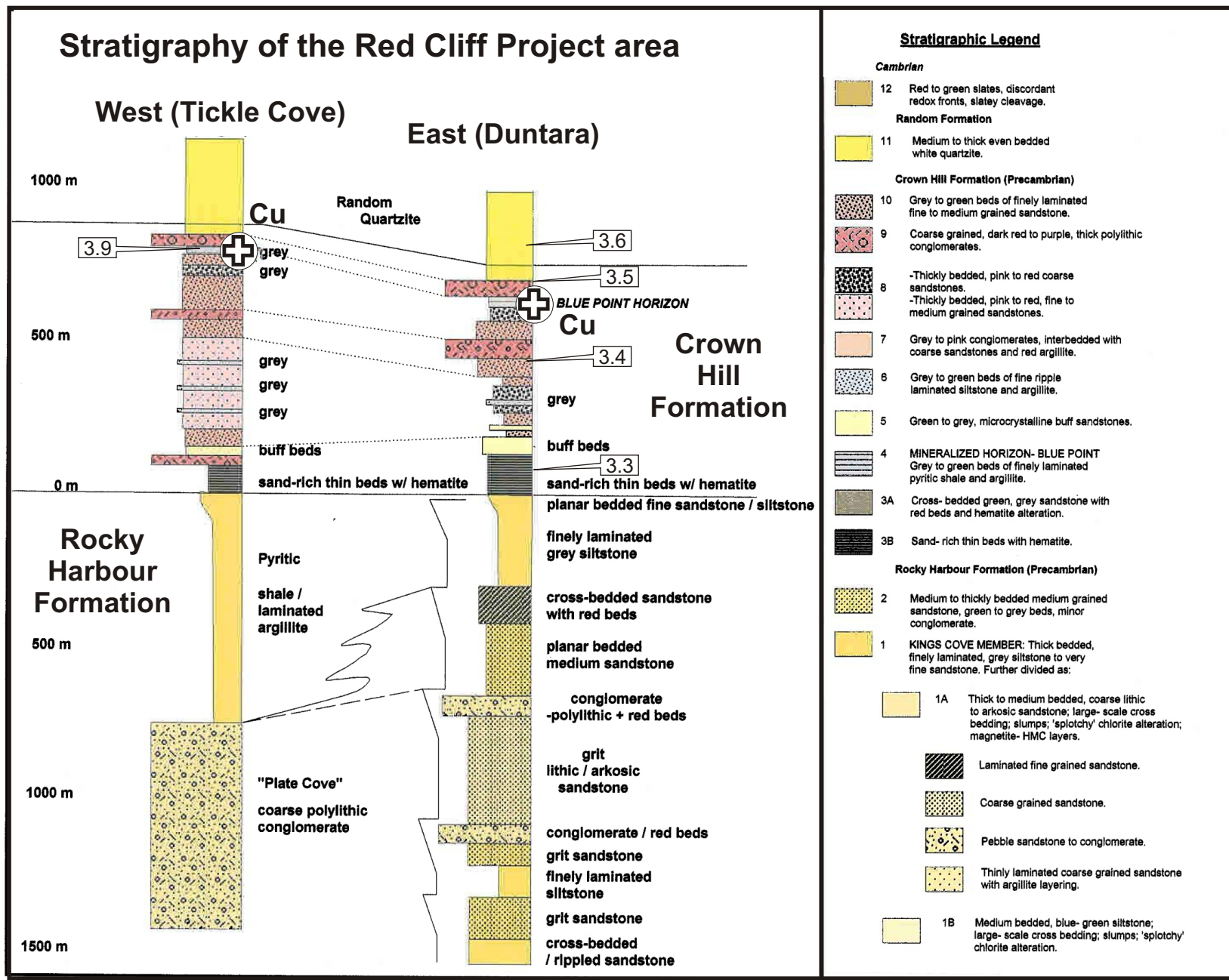


Figure 12. Stratigraphic sections of the upper Rocky Harbour Formation, Crown Hill Formation and Random Formation in the Duntara - Keels - Plate Cove area, showing the approximate levels of field trip stops. Modified after Lane (2004).

be seen below, close to the bottom of the cliff. The basal Crown Hill Formation is dominated by arkosic sandstones and conglomerates, typically of red to purple colour, interbedded with white to pale yellow fine-grained sandstones and siltstones. Sedimentary structures are abundant in these rocks, and the finer grained rocks have a finely-banded to locally contorted appearance suggestive of algal laminations. Some units appear blotchy and are perhaps bioturbated.

From this surface, return to the bedding surface that leads to the lighthouse, and continue up section. There is a zone of prominent low-angle quartz veining, which is followed by a sequence of sandstones and fine-grained conglomerates that show well-developed cross-bedding and some spectacular sand-dyke structures generated by loading at the bases of conglomeratic units. Beyond here, it is more difficult to proceed up section, and it may be necessary to move inland towards the trees, and then return to the shore on the next prominent bedding surface. The next part of the section shows some distinctive, well-laminated, yellow-green units that are of controversial origin. These have been suggested to represent rocks that were originally dolomitic sandstones developed in a tidal-flat (sabhka) environment where algal activity was important (Thorsen, 2004; Lane, 2004). However, these units also have the general appearance of tuffaceous sandstones and siltstones seen elsewhere in the Avalon Zone (O'Brien and King, 2005), and may thus be of volcanogenic origin. These yellow-green units are reported to be anomalous in copper (O'Brien and King, 2004a; Lane, 2004). These yellow-green outcrops are very slippery when wet, but the fine lamination of possible algal origin is worthy of close examination. It is expected that the field trip group will have diverse opinions on the origin of these rocks !

It is possible to proceed further up section from these outcrops, but it requires climbing some rather steep rock faces, and is therefore not advised. The overlying rocks are mostly red sandstones of the Duntara Harbour Facies (O'Brien and King, 2005) which will be visited at the next stop. The Brook Point Facies, as seen at this stop, appears to be laterally discontinuous, as it is not observed on the other side of the Keels Peninsula (O'Brien and King, 2004a; Lane, 2004).

Stop 3.4: Duntara Harbour Sandstones and Duntara Fault

From Stop 3.3, hike back to Kings Cove, and then drive northward to Duntara, and take the branch road through the village. Park just before the bridge by the wharf. The rocks can be examined in two places, immediately south of the wharf, and then on the north side of the cove, across the river. The river is best crossed using the bridge, unless you wish to test out your rubber boots.

The red sandstones at this locality form part of the Duntara Harbour Facies of O'Brien and King (2005), which here overlies the spectacular variegated section at Brook Point (see above; Figure 12). The relatively gently-dipping beds south of the wharf contain mudcracks on bedding planes and in cross-section, where they are truncated and eroded by overlying beds. The Bay at Duntara is also the site of an important structure termed the Duntara fault, which divides the Keels Peninsula into two geologically discrete areas (Figure 6). The area to the north of the Duntara fault contains most of the known copper mineralization, and the prospective grey (reduced) units of the Tickle Cove and Blue Point facies of O'Brien and King (2005). Lane (2004) suggests that the south side of the fault is uplifted by as much as 200 m relative to the

north side, such that the upper members of the Crown Hill Formation have been eroded. It has also been suggested that the fault zone may have been active during or soon after sedimentation and could have acted as a conduit for mineralizing fluids. However, there is no sign of directly-associated copper mineralization, and the map pattern of the structure suggests that it was not affected by the folding seen within the sedimentary rocks.

The effects of the Duntara fault zone can be seen here in the form of brittle fracturing and the development of local schistose zones within the red sandstones north of the river

This stop also lies close to the Blue Point copper showing, which is located in inaccessible coastal outcrops about 1.5 km northeast of here. This is the best-known copper showing in the area, and is hosted by a distinctive grey reduced unit within the dominantly red (oxidized) sequence. Mineralization consists of chalcopyrite, chalcocite and malachite, and much of the copper minerals appear to have replaced earlier syngenetic or diagenetic pyrite. Surface samples contain up to 1.4% Cu and 19 g/t Ag. The unit was tested by drilling in areas inland from the showing, and has lateral continuity; the best results to date were 1% Cu and 12 g/t Ag over some 14 m, and 2% Cu and 23 g/t Ag over 6 m (Graves et al., 2002; Seymour et al., 2005). The area northeast of Duntara continues to represent one of the most favourable locations for further exploration and definition of SSC-type deposits in the field trip area. The Tickle Cove showing (Stop 3.9, below) is considered to represent the lateral equivalent of the Blue Point horizon on the west side of the Keels Peninsula.

It is hoped that some mineralized core from the Blue Point Horizon will be available for inspection at this stop, or at some other convenient point during the field trip.

Stop 3.5: Uppermost section of the Crown Hill Formation

From Stop 3.4, continue northward to Keels. The road winds through the hills and then descends a steep grade above the ocean towards the community, passing some prominent red outcrops which form this stop. There is only limited parking space here, but there is virtually no traffic.

The roadcut outcrops are high and steep; be aware that debris could fall, and avoid any overhanging sections.

There is an excellent view northwestwards across the synclinal structure of the Keels area; the prominent white cliffs in the distance represent the Random Formation (on the far side of the syncline; these are bedding planes dipping towards you), and the red and green slates at the quarry are the Cambrian sedimentary rocks. These outcrops are red conglomerates that form the upper section of the Crown Hill Formation (Figure 12), which eventually passes up into the Random Formation (stop 3.6). The conglomerates contain pebbles of felsic volcanic rocks, white to grey quartz, and other rock types, including orange felsite and porphyry. There are well-developed but discontinuous red argillitic lenses, and this material is also present as prominent and locally spectacular rip-up clasts. Note the steep dip of the beds compared to the previous stop at Duntara.

The lower section of this long outcrop appears white, because it is riddled with quartz veins. However, the amount of quartz is deceptive, because the outcrop surfaces have developed along the veins themselves. The veining in this location, and at Stop 3.6, may be related to some faults that in part define the Crown Hill - Random formational contact in this area, although it is considered to be an originally conformable stratigraphic transition.

Stop 3.6: Random Formation quartzites

From Stop 3.5, continue down the hill past the beach, and turn right on the road to the slate quarry. Park at the turnoff (there is plenty of space) and descend to the outcrops on the northwest side of this small but beautiful sandy beach. The second part of the stop, if time permits, is located on the southeast side of the beach, about 2 minutes walk from here.

The outcrops at the northwest side of the beach here are white to pale yellow quartzites, with some interbedded conglomerates dominated by granule to pebble quartz clasts. They display superb cross-bedding and lamination, including herringbone structures indicative of frequent current reversals. The rocks here are closely similar to some of those on the other side of the beach, but generally lack any red, argillitic interbeds; however, there is one small purplish siltstone unit amongst the quartzites. The Random Formation here is thick compared to its type section on Random Island near Clarendville. On the southeast side of the beach, there appears to be a downsection transition from pure quartzites into reddish and purple sandstones and conglomerates, which again display well-developed cross-lamination. It is not entirely clear how much of this apparent contrast is related to the fact that these outcrops are not as well wave-washed, but the rocks here contain several red argillitic interbeds, which are more characteristic of the Crown Hill Formation. Thus, although there is a clear contrast in sedimentary environment between the two formations, the shift from terrestrial to shallow marine conditions was not a sudden event, but a progression over time.

Stop 3.7 : Cambrian slates, redox boundaries and minor copper mineralization

From Stop 3.6, continue to the slate quarry. There is a locked gate, and it will likely be necessary to walk the last few hundred metres to the site.

This is an abandoned quarry operation and there are numerous steep drops on the edges of the pits, which are not marked or protected. Equipment and other industrial debris (e.g., cables and wires) also present specific hazards. There is a hazard from falling debris beneath some of these faces, and there is deep water in at least one of the pits. Parts of the stop also lie close to the ocean, from which there is a wave hazard. Please be cautious everywhere in this area !

This quarry was developed in the 1990s to exploit attractive but not particularly high quality red and green slates developed within Cambrian rocks on the southeast flank of the Keels syncline, where there is a well-developed subvertical axial plane cleavage. The red and green colouration here reflects oxidation-reduction effects in the original mudstones and shales; some of these were likely syngenetic or diagenetic, but much of the colour variation has been

superimposed and transgresses primary bedding. There is also some minor sulphide mineralization, which is reported to be locally Cu-enriched (Lane, 2004).

The large face adjacent to the flooded pit illustrates the attitude of primary bedding, which is here defined by units that contain prominent grey, nodular reduction zones, some of which likely contain minor carbonate. These dip at about 45° to the northwest. The reduction zones can be seen in many of the large blocks littered around the pit edge, and they have very sharp boundaries against their red host rock. At the north end of the quarry, in the area of the small metal building that looks like a privy but was perhaps more likely an explosives store, the boundary between the predominantly red unit of the quarry and adjacent green slates is well exposed. This is a high angle boundary that obviously truncates the bedding in adjacent outcrops, and is also discordant to the well-developed cleavage. The exact timing of the reduction (or oxidation ?) Process is not clear, but it is obviously post-depositional.

Sulphide mineralization occurs in the northwest wall of the quarry site at several spots, where it is in general terms associated with another redox front transition into a grey green, poorly-cleaved unit. Disseminated pyrite is present in the latter rocks, and is in most cases associated with fractures, but there are also nodule and vein-like pods of massive pyrite. There is no visible malachite staining in any of these zones, but samples from the quarry area reportedly contained up to 0.5% Cu, although such values are likely not representative. It has been argued that the presence of this Cu-rich mineralization in the Cambrian indicates that potentially more significant SSC-type mineralization in the underlying Crown Hill Formation (e.g., Blue Point, Tickle Cove) may have formed during the Cambrian (Lane, 2004).

Stop 3.8: The Devil's Footprints

From Stop 3.7, return to the parking area, and then continue into the village of Keels. This is a scenic place, with some beautifully restored old buildings and some interesting and innovative conversions of old sheds and shacks into summer homes. Stay left at the junction for the museum and continue along the narrowest section of the road. There is a sign for the Devil's Footprints that marks the trailhead, but it is best to continue to a spot about 75 m beyond the old church, where there is space to park. The best-developed set of satanic footprints is clearly visible in the outcrops on the shoreline (north) side of the road at this spot. From here, walk back to the trailhead, and descend to the gravel beach to examine outcrops on the far side of it, below the cabins.

The Devil's Footprints have a natural rather than supernatural origin. They are cavities left where limestone nodules have weathered out of the roadside outcrops. The orientation of the footprints defines the bedding in the Cambrian rocks at this spot; they dip gently to the southeast, because we are now on the opposite side of the main synclinal structure from Stop 3.7. There remains a strong axial-plane cleavage. On the trail to the beach, there are also well-developed "footprints", which can be examined more closely.

For geologists, the outcrops on the far side of the beach are the most interesting, as they form the core of the synclinal structure. At first side, they appear steeply-dipping, but this is a manifestation of the intense axial plane cleavage; the red and green colour variations here are

syndepositional (or diagenetic) and define subhorizontal bedding, with a red unit sitting above a grey-green unit. The latter is rather heterogeneous in appearance and in many areas it has the appearance of a deformed conglomeratic rock, in which the clasts have been flattened. However, this is not the case, because the grey areas that resemble clasts are actually limestone nodules or concretions that developed in the original sedimentary rock. In many areas, they exhibit colour variation, and can be seen to truncate laminations. Nevertheless, there is a component of flattening here in the core of the fold. These concretions have presumably remained intact because Lucifer chose not to approach the water when he walked through Keels leaving his footprints !

Stop 3.9: The Tickle Cove Showings

From Stop 3.8, return through Duntara to King's Cove, and turn right on Route 235 for Plate Cove. After travelling about 9 km, turn right again for Open Hall, Redcliff and Tickle Cove. This is a very pretty road, with lovely views and many red outcrops. Continue through the village of Tickle Cove and park at the end of the road, about 7.9 km from Route 231, and a few hundred metres past the end of the pavement. Walk down to the shore, and go north for 50 to 100 metres; the rusty outcrops should be obvious.

The rocks exposed enroute to Tickle Cove mostly form part of the Red Cliff facies of the Crown Hill formation, which consists of red siltstones, argillites and sandstones, interbedded with conglomerates. However, the Tickle Cove showing is hosted by a reduced unit of grey, laminated siltstones that is directly correlated with the Blue Point Horizon, site of the most important copper showing outlined to date in this area (Figure 6; Lane, 2004). The section at Tickle Cove is equivalent to that revealed in the inaccessible cliffs at the Blue Point Prospect (Figure 12). The purple and red conglomerates of the upper Crown Hill Formation immediately overlie sandstones and siltstones that include the grey, reduced unit that hosts most of the copper. The reduced unit is up to 20 m thick in this area. The main part of the showing consists of a prominent rusty-weathering bed, and it generally lacks the malachite staining that one would expect in association with copper. The host rock is a fine-grained pyritic siltstone to mudstone, which also contains finely disseminated chalcocite; native copper has also been reported locally. In several areas, pyrite cubes of presumed diagenetic origin have been partially replaced by copper-bearing minerals (Lane, 2004; MODS file 2C/11/Cu006). The best areas to see mineralization are wave-washed surfaces around the intertidal part of the cobble beach, where pyrite, chalcocite and some native copper can be observed. The best results from surface sampling were 0.89% Cu and 2.1 g/t Ag (Froude, 2001); systematic sampling of the outcrop gave 0.18% Cu over approximately 3 m (Lane, 2004). The same unit extends eastward from here, and another similar showing in an inland location contains 0.35% Cu (Lane, 2004). No drilling or other advanced exploration has been attempted at the Tickle Cove showing.

The grey argillitic rock that forms the host to most of the mineralization here can be examined closely in loose blocks near the beach; some of these display superb lamination, and possible algal structures.

Stop 3.10: The Arch Hole

From Stop 3.7, drive back into Tickle Cove and park at the signposts for the Arch Hole. The short trail to this interesting feature is easy to find and follow.

The cliffs at the viewpoint are steep and dangerous; stay away from the edge at all times !

The Arch Hole is another interesting example of coastal erosional processes; it is a large sea-arch preserved in a small offshore island. The outcrops consist of red argillites, sandstones and conglomerates of the Red Cliff Facies of O'Brien and King (2005). These dip gently towards the east, but contain a strong subvertical cleavage, presumably related to the parasitic folds developed on the flanks of the regional anticlinal structure that underlies the western part of the Keels Peninsula (Figure 6). This combination of bedding and cleavage provides many thin slabs that show superb lamination and sedimentary structures; the load structures where conglomerate units overlie siltstone or mudstone are particularly notable. On the trail to the Arch Hole, the view over Tickle Cove Harbour reveals the grey, reduced unit that correlates with the mineralized rocks at Stop 3.7. The islands in the harbour form part of a paired anticline and syncline. The cliffs around the Arch Hole show the cross-cutting boundaries between red beds and reduced green beds. This indicates that not all contrasts between red and grey beds in the Crown Hill Formation are of synsedimentary origin, and some formed after burial as a result of fluid migration through regional aquifers.

It has been suggested by some that Tickle Cove has the largest Arch Hole in Newfoundland, or that it could be termed the Arch Hole capital of Newfoundland. Fortunately, neither of these options has yet been adopted as a tourist slogan. Tickle Cove is also famous as the inspiration for the famous folk song Tickle Cove Pond, which refers to the lake immediately inland from the community.

Optional Stops on the Return Trip to St. John's

If time permits, there will be a short stop at Plate Cove, a short distance west of the junction for Tickle Cove. This stop exposes spectacular polymict conglomerates that dominate the Rocky Harbour Formation in the west, adjacent to areas dominated by volcanic rocks of the Bull Arm Formation. The conglomerates (Plate Cove Facies of O'Brien and King, 2005) may be time-equivalent to some of the finer-grained clastic sedimentary rocks in the east, suggesting that the basin was filled from source areas in the west. These conglomerates may also be equivalent to the Cannings Cove Formation, examined on Day 1.

Although the Bonavista Peninsula contains some of the best examples of possible SSC-type mineralization in the Avalon Zone, the Crown Hill Formation and other components important to mineralization of this type continue to the southeast into the area of Random Island and the Deer Harbour Peninsula (Figure 1). If time permits, there will be a short stop just east of Clarendville, where there are views across to these rocks on the eastern side of Random Island. There will also be a short excursion along the road between Southwest Brook to Little Heart's Ease, which provides an excellent cross-section from the volcanic rocks of the Bull Arm Formation into the Musgravetown Group. The outcrops of the latter are likely time-equivalent to

those of the Rocky Harbour Formation in the Trinity - Port Rexton area, but from a lithological perspective, they are more akin to the terrestrial sedimentary rocks of the Crown Hill Formation. Copper mineralization is locally present in reduced units within this sequence (Lane, 2004), but is not easily accessible for field trip visits. The exact locations for optional stops near Plate Cove and around Clarenville were not available at the time of field trip guide preparation.

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