GAC Newfoundland and Labrador

Fall Field Trip Oct 1 - 3, 2010

The Burin Peninsula and the Dawn of the Paleozoic

Leader: Paul Myrow

Technical Information:
Paul Myrow, Guy Narbonne, and Rick Hiscott

(Summary guidebook prepared by Andrew Kerr)

GEOLOGICAL ASSOCIATION OF CANADA
NEWFOUNDLAND AND LABRADOR SECTION

2010 FALL FIELD TRIP

THE BURIN PENINSULA AND THE DAWN OF THE PALEOZOIC

Technical Material by
Paul Myrow[1], Guy Narbonne[2], and Rick Hiscott[3]

Summary guidebook written and compiled by Andrew Kerr [4]

[1]Department of Geology
Colorado College
Colorado Springs, CO, 80903, U.S.A.

[2]Department of Geological Sciences
Queen's University
Kingston, ON, K7L 3N6

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

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

Cover illustration: The site of the Global Stratotype Section and Point (GSSP) for the base of the Cambrian at Fortune Head. The official dawn of the Paleozoic Era is just above the prominent bench in the lower part of the outcrop (photo by Andrew Kerr, July 2010).

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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. However, GAC is not responsible for providing PPE to field trip participants.

Specific Hazards

Most of the stops on this field trip are in coastal localities, and will be accessed by hiking, along trails or across country. Appropriate footwear, with good ankle support, is required. Waterproof footwear may be useful in some areas. Care should always be taken when visiting any site, especially those adjacent to the coast or in roadcuts, where the hazard of falling debris from the slopes above is a real one. In such situations, participants must not put themselves in jeopardy by attempting to ascend such slopes, and must maintain a safe distance from them. In coastal settings, participants may be vulnerable to freak waves, and should maintain a safe distance from the high water line. Weather is unpredictable and participants should be prepared for a wide range of temperatures and conditions. Always take suitable clothing. A rain suit and sweater are essential at almost any time of the year in Newfoundland. Some stops are at the top of steep cliffs or slopes, or require descending slopes to shoreline outcrops. Participants should stay well back from the cliff edge at all times. Overhangs are common on unconsolidated cliffs, and often are not visible from above. Do not walk straight down steep slopes if others are also on the slope below. Instead, proceed down slopes at an angle. In coastal stops, participants should beware of seaweed and slippery surfaces, and should stay away from locations vulnerable to wave action. Watch for uneven surfaces, loose boulders and also sharp outcrop surfaces. Subsequent sections of this guidebook contain the stop descriptions for the field trip. In addition to the general precautions and hazards noted above, these make note of specific safety concerns. Participants should read these cautions carefully and always take appropriate precautions for their own safety and the safety of others. ***In the final analysis, your safety and liability are your own responsibilities.***

OVERVIEW OF FIELD TRIP

GAC (Newfoundland and Labrador Section) Fall Field Trips have a long tradition of highlighting unique geological features of our Province, and/or providing a venue for the presentation and discussion of new research work. The 2010 trip falls into the first category in that it will take us to an unusual package of sedimentary rocks that is of global importance for stratigraphic correlation and understanding the origins of the Phanerozoic biosphere. The rocks of the Rencontre Formation, Chapel Island Formation and the Random Formation encompass one of the most significant transitions in Earth History, i.e., the dawn of the Paleozoic Era. Our 2010 field trip is a derivative of a field trip that first ran in 1988, prior to the definition of the global stratotype for the Precambrian - Cambrian boundary. The location at Fortune Head was proposed for this site in 1987, and this choice was ratified in 1992. The boundary is defined primarily on the basis of trace fossil (ichnofossil) assemblages, and will be visited as part of this trip. The Burin Peninsula is one of very few locations around the world where a thick and essentially continuous sequence of fossiliferous rocks records the transition from the mysterious Precambrian to the familiar Cambrian. These sedimentary rocks contain much of paleontological interest, including abundant trace fossils, so-called “small shelly fossils”, various types of algae, and some rare soft-bodied megafossils. This biological record predates the evolution of the trilobites, which first occur almost 1 km above the type locality for the base of the Cambrian. These three formations also contain much of sedimentological interest. They are dominated by quartz-rich siliciclastic rocks (sandstones and siltstones) that record a wide range of fluvial, peritidal, subtidal and offshore environments, and they contain many diagnostic sedimentary structures. The field trip, led by Dr. Paul Myrow of Colorado College, will emphasize both sedimentological and paleontological aspects of the sequence, at a level conducive to understanding by nonspecialists.

The field trip itinerary is, as far as possible, a stratigraphic transect from oldest to youngest, beginning at the unconformable base of the Precambrian Rencontre Formation on Day 1. The Grand Bank Head section (Day 2 morning) includes the Rencontre Formation and the lower part of the Chapel Island Formation, across the Precambrian-Cambrian boundary. The Fortune Head section (Day 2 afternoon) starts at the very top of the Precambrian with a visit to the global stratotype, and then examines the middle part of the Chapel Island Formation. The Little Dantzic Cove section (Day 3) focuses on the upper part of the Chapel Island Formation, in which carbonate rocks become locally important, and the overlying quartzites of the Random Formation. The final stops, in the red mudstones and limestones above the Random Formation, represent the base of the widespread and familiar Cambrian shelf sequence of the Avalon Zone. This idealized stratigraphic treatment may of course be disrupted or reversed by weather and/or tidal conditions.

ABOUT THIS GUIDEBOOK

This guidebook was prepared specifically for the 2010 Field Trip as a self-guiding product at a technical level suitable for geologists who are not specialists in paleontology or sedimentology. Much of the information in it was adapted and simplified from a more detailed guidebook developed for the 1988 Field Trip associated with the National GAC-MAC meeting in St. John's (Myrow et al., 1988). Readers will note numerous references to this latter publication for details of specific stops and subjects. The Myrow et al. (1988) guidebook was provided in electronic format to participants as a resource for more detailed information, and remains available on request from GAC (Newfoundland and Labrador). A second source of considerable importance is the paper by Narbonne et al. (1987) that proposed and described the sequence as a candidate for the global stratotype, and provided a review of the paleontological record. This paper can be obtained through *Canadian Journal of Earth Sciences*. Several other subsequent journal publications (e.g., Landing et al., 1989; Myrow and Landing, 1992; Myrow and Hiscott, 1993; Gehling et al., 2001) were also important sources for the summary guidebook, and provide further reading for those interested in details. As this summary guidebook is a derivative product, it should not be used as a reference for information on this area or on these topics; the original publications noted above and listed in the bibliography should instead be cited as sources. Errors or omissions in this summary guidebook are entirely the responsibility of the compiler.

ACKNOWLEDGMENTS

GAC (Newfoundland and Labrador Section) field trips are only possible with abundant assistance from volunteers and in-kind support from corporate and government organizations. The Geological Survey of Newfoundland and Labrador (Department of Natural Resources) is thanked for assistance in the form of loaned vehicles, and for facilitating the production of this guidebook. The Department of Earth Sciences at Memorial University is thanked for providing a subsidy that assists GAC in offering a discounted rate for students. Leon Normore is thanked for acting as the onsite leader in 2010, and for looking after most of the logistics in Grand Bank and Fortune. John and Flo Smith of Granny's Motor Inn in Grand Bank are thanked for their assistance with lodging and accommodation, and for putting up with a bunch of noisy geologists for an entire weekend. The Parks and Natural Areas division of the Department of Tourism, Culture and Recreation are thanked for granting approval for a field trip within the Fortune Head Ecological Reserve, and for the assistance of their personnel.

PART ONE: GEOLOGY AND PALEONTOLOGY OF LATE PRECAMBRIAN AND EARLIEST CAMBRIAN SEDIMENTARY ROCKS OF THE BURIN PENINSULA

INTRODUCTION

The field trip area is located at the southern end of the Burin Peninsula (Figure 1), in the area around Grand Bank and Fortune. It is primarily focused on three packages of sedimentary rocks, i.e., the Rencontre Formation, the Chapel Island Formation and the Random Formation. The first part of the guide contains a brief discussion of the regional geology of the Avalon Zone and the Burin Peninsula area, followed by more details of these three formations from stratigraphic and lithological perspectives. This is followed by a general discussion of paleontological work on these formations, and the definition of this sequence as containing the global stratotype-section and point (GSSP) for the Precambrian-Cambrian boundary at Fortune Head. The information presented below is far from comprehensive, and is drawn for the most part from more detailed accounts of sedimentology (Myrow et al., 1988; Myrow and Hiscott, 1993) and paleontology (Myrow et al., 1988; Narbonne et al., 1987; Landing et al., 1989).

REGIONAL GEOLOGICAL SETTING

The Avalon Zone of eastern Newfoundland is a peri-Gondwanan continental fragment that was stranded on the eastern edge of North America, following Mesozoic seafloor spreading that led to the formation of the modern Atlantic Ocean (Wilson, 1966). The correlative rocks for the Avalon Zone lie in western Europe, north Africa and possibly South America; within North America, Avalonian rocks extend along the length of the Appalachian Orogen, and rocks of similar age likely also underlie many areas within the central mobile belt of the Appalachians (Figure 1). The development and affinities of the Avalon Zone are topics beyond the scope of this guidebook, but in general terms the entire region is dominated by plutonic, volcanic and sedimentary rocks of late Neoproterozoic (in part, Ediacaran) age. The geological record of the Avalon Zone represents the period between the Neoproterozoic Grenvillian Orogeny and the earliest events recorded in the development of the Appalachian-Caledonian Orogen (O'Brien et al., 1983, 1996). The Avalon Zone has a complex Precambrian stratigraphy, including abundant felsic volcanic sequences, and it was intruded by numerous late Precambrian granitoid plutons. In most areas, a well-developed sub-Cambrian unconformity separates these older rocks from a Paleozoic cover sequence, which includes Cambrian and Early Ordovician rocks, but likely extends into the Silurian in offshore areas. The Paleozoic cover sequence is faunally distinct from that of western Newfoundland, and is dominated by siliciclastic rocks, rather than carbonate sequences.

The Precambrian magmatic history of the Avalon Zone is complex, including major pulses at ~ 760 Ma, 680 Ma, 635-600 Ma and 575-560 Ma (e.g., O'Brien et al., 1996). Early events likely record rifting and amalgamation of individual subterranes, and the various components are believed to have been assembled into a composite entity by ~ 635 Ma, and then subjected to continued compressional events and magmatic activity. The youngest (Ediacaran) sedimentary rocks comprise a shallowing-upward sequence that records the filling of marine

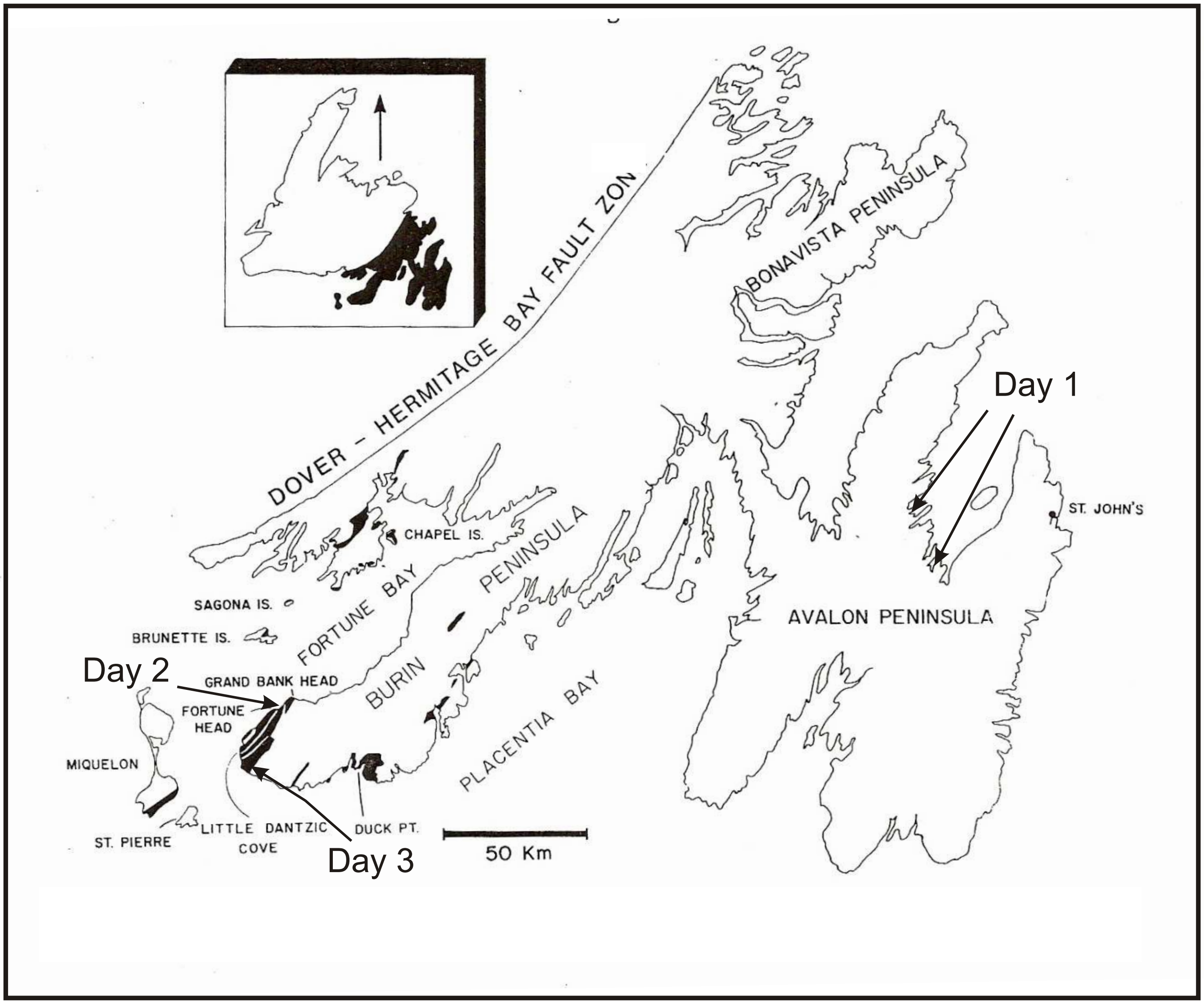

Figure 1. Location map showing the Burin Peninsula of Newfoundland within the Avalon Zone (filled on inset map) and the locations of areas visited on this field trip.

Filled areas on the main map represent the Precambrian-Cambrian boundary sequence of the Burin Peninsula area; other areas of Cambrian rocks are not indicated on this map.

Day 1 field trip stops are located in the Conception Bay area, on the way to Grand Bank.

Day 2 field trip stops are located at Grand Bank Head (morning) and at the Fortune Head Ecological Reserve (afternoon).

Day 3 field trip stops are located at Little Dantzic Cove.

Map reproduced from Myrow et al. (1988)

basins and subsequent fluvial sedimentation. Latest Precambrian and earliest Paleozoic rocks sit above this basin fill, representing a return to marine conditions, following a worldwide rise in relative sea level. In most places there is an unconformity at the base of the Paleozoic sequence. Many of the younger rocks within the Avalon Zone belong to the newly-defined *Ediacaran* period; however, this term is not widely used in this guidebook, because some of the text and diagrams predate its definition.

The Avalon Zone was affected by both late Precambrian and middle Paleozoic orogenic events. Paleozoic deformation exists throughout the region, but it was most marked in the western Avalon, including the Burin Peninsula. This deformation likely occurred during the Devonian, as it affects Silurian igneous rocks near Cape St. Mary's. Devonian plutonic rocks and volcanic sequences (mostly of felsic composition) also occur in the Avalon Zone. From the perspective of this field trip, the most significant effect of Paleozoic deformation was the folding of latest Precambrian and Cambrian sedimentary rocks, which led to extensive repetition of the sequence.

GEOLOGY OF THE SOUTHERN BURIN PENINSULA

The southern Burin Peninsula is one of the most interesting parts of the Avalon Zone in Newfoundland. This region contains its oldest rocks, in the form of the ~ 763 Ma Burin Group (Strong et al., 1978; Krogh et al., 1988), and its youngest rocks, in the form of the ~ 374 Ma St. Lawrence Granite. From the perspective of this field trip, it has another peculiarity - it is the only part of the Avalon Zone in which latest Precambrian (Ediacaran) strata pass conformably into Cambrian rocks. Elsewhere in the Avalon Zone, there is a marked disconformity beneath the Cambrian strata, or a profound unconformity where they are in contact with much older Precambrian rocks. On a worldwide basis, continuous Precambrian-Cambrian transitions are rare, and it has long been recognized that this thick and essentially continuous marine sequence had potential for definition of this critical boundary.

The Late Precambrian and Cambrian stratigraphy of the Avalon Zone, including the Burin Peninsula, is illustrated in Figure 2 (after Narbonne et al., 1987; Myrow et al., 1988). The oldest rocks in the area are represented by the Burin Group, a sequence of mafic volcanic rocks and related volcanogenic sedimentary rocks, considered to represent an ophiolite sequence. A sill-like gabbroic intrusion within the volcanic pile was dated at 763 ± 2 Ma (Krogh et al., 1988) and provides a minimum age for its formation. Altered ultramafic rocks, with associated mesothermal style gold mineralization, were described from the Burin Group by O'Driscoll et al. (2001). The most abundant rocks of the southern Burin Peninsula belong to the Marystown Group, a thick and complex sequence of mafic to felsic subaerial volcanic rocks and associated sedimentary rocks of terrestrial affinity. This is in fault contact with the older Burin Group, but is considered to be unconformable upon it; there is little reliable age information from the Marystown Group, but it may correlate with other felsic volcanic sequences in the Avalon Zone dated at ~ 620 to 600 Ma (O'Brien et al., 1996). A small area of siliclastic rocks east of Marystown, orginally termed the Rock Harbour Group by Strong et al. (1978), is now assigned to the Musgravetown Group, a thick sequence of marine to terrestrial sedimentary rocks that dominates the western Avalon Zone elsewhere, and which is correlated with the better-known sedimentary rocks of the Signal Hill Group in eastern Newfoundland (Figure 2). These rocks are

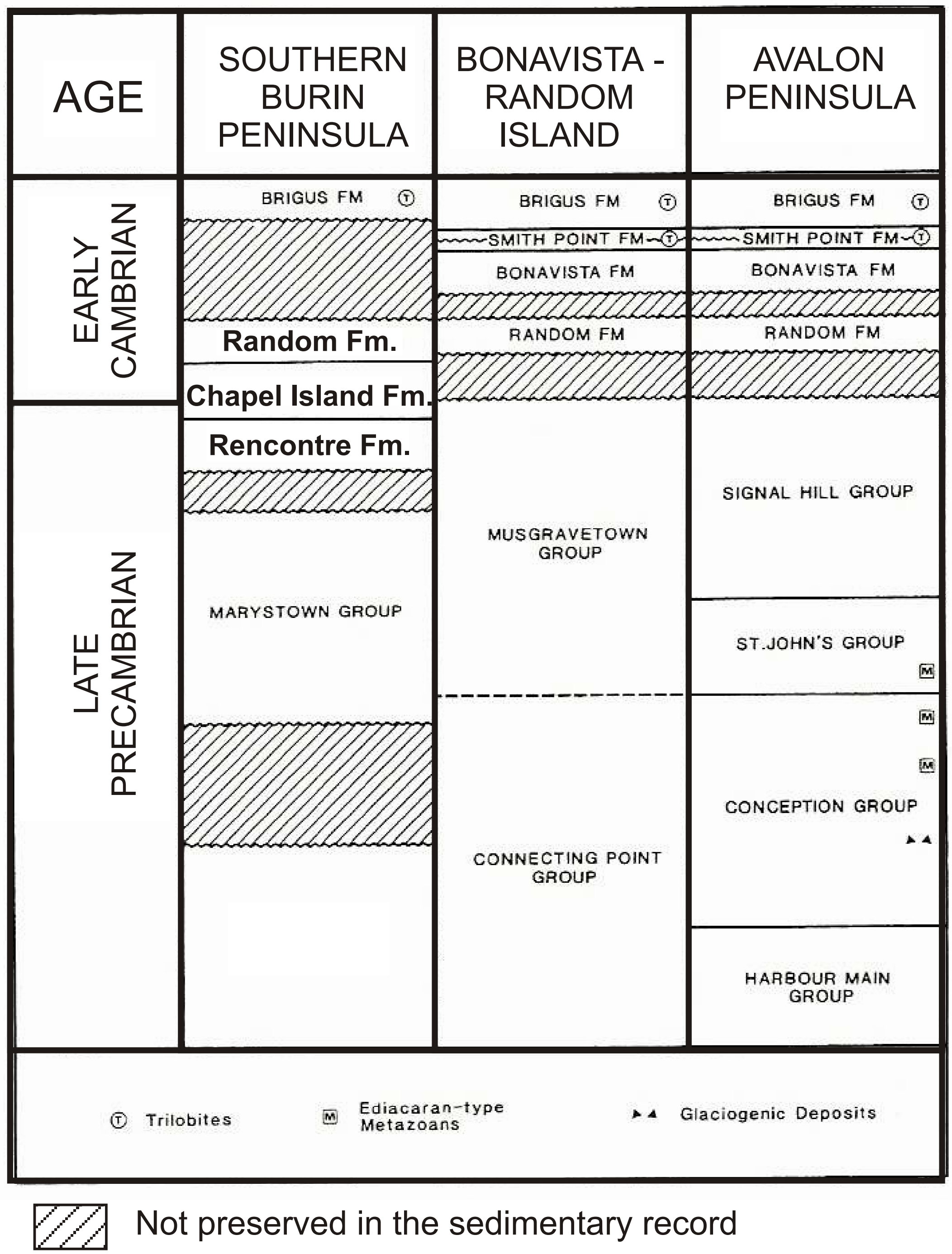

Figure 2 (Part A). The regional correlation of Upper Precambrian and Lower Cambrian strata in the Avalon Zone of Newfoundland, also showing the stratigraphic position of Ediacaran faunas, and glaciogenic sedimentary rocks. Note that some rocks in the upper part of the Precambrian would now be grouped as part of the Ediacaran Period.

The chart indicates the three formations that form the focus of the field trip, i.e., The Rencontre, Chapel Island and Random formations. Correlations in the lower part of the chart (Burin, Connecting Point and Harbour Main Groups) remain uncertain.

Chart modified from Narbonne et al. (1987)

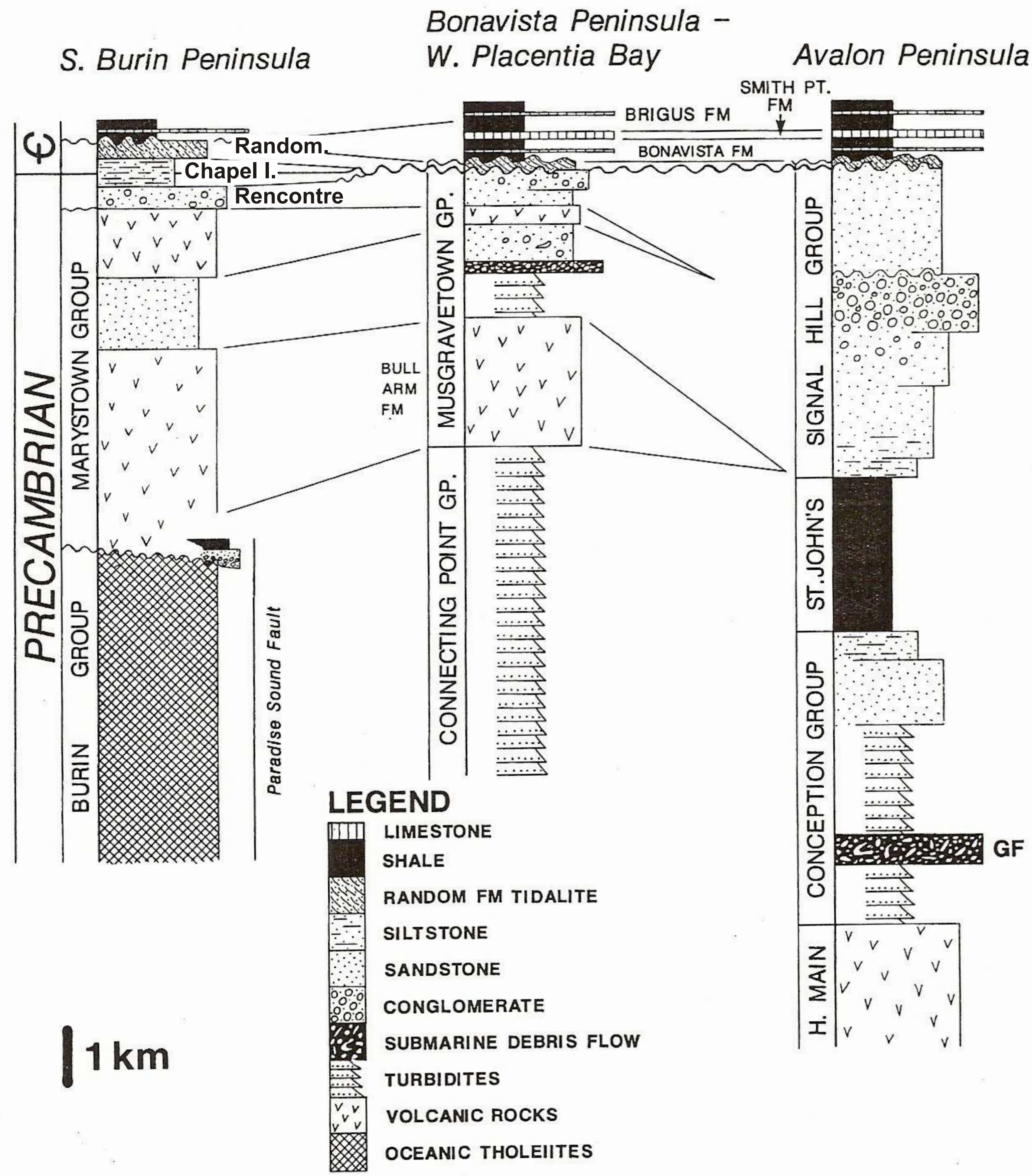

Figure 2 (Part B). Stratigraphic columns for the southern Burin Peninsula, Bonavista Peninsula - western Placentia Bay area, and the Avalon Peninsula. The chart shows that the Precambrian-Cambrian boundary sequence is preserved only on the Burin Peninsula. Elsewhere, the Cambrian rocks rest disconformably or unconformably upon older Precambrian rocks.

Chart modified from Myrow et al. (1988)

nowhere in contact with the Marystown Group, and their mutual relationship is unknown. Precambrian plutonic rocks are locally abundant on the Burin Peninsula, notably north of Marystown, and intrude the Marystown Group; some may be deep-level equivalents of the felsic volcanic rocks that dominate the latter.

Precambrian rocks that clearly postdate the Marystown Group are of restricted extent, and these are considered to correlate with the upper (largely fluvial) strata of the Musgravetown Group and Signal Hill Group. In the area of the field trip, these latest Precambrian sedimentary rocks are termed the Rencontre Formation, and they sit unconformably upon volcanic rocks of the Marystown Group. The Rencontre Formation passes conformably upwards into shallow marine sedimentary rocks of the Chapel Island Formation, which transcends the Precambrian-Cambrian boundary. Most of the Chapel Island Formation is now placed within the Cambrian. The Chapel Island Formation in turn passes conformably into the quartzites and sandstones of the Random Formation. In total, this transitional Precambrian - Cambrian sedimentary sequence contains > 1000 m of sedimentary rocks, and it appears to be continuous. Elsewhere in the Avalon Zone (Figure 2) this transitional sequence is missing, but on the southern Burin Peninsula, the most significant disconformity is *above* the Random Formation, such that the Bonavista and Smith Point formations are absent from the record (Figure 2).

The marine siliciclastic and volcanogenic sedimentary rocks of the Conception Group, Connecting Point Group and St. John's Group are not present on the Burin Peninsula (Figure 2). There is thus no record of Neoproterozoic glacial periods equated with the so-called "Snowball Earth" events, and there are no known fossils of the enigmatic soft-bodied organisms that represent the first complex multicellular life forms on Planet Earth (the Ediacaran Fauna). Aside from stromatolites preserved in thin limestone lenses within the Burin Group (Strong et al., 1978), the oldest body fossils in the area are very rare impressions of soft-bodied megafossils in the Chapel Island Formation (Narbonne et al., 1987). The late Neoproterozoic glacial episodes referred to as "Snowball Earth" are a broad and controversial topic in their own right; readers are referred to Hoffman and Schrag (2000) and Harland (2007) for details. In Newfoundland, the Gaskiers Formation in the Conception Group represents the youngest of these glacial episodes, and its termination is believe to record global warming induced by high CO_2 levels created by continued volcanic activity. Shortly after this event, complex multicellular organisms first appear in the geological record, in the ~ 565 Ma Mistaken Point Formation of the Conception Group (see Narbonne, 1998). The relationship between these pivotal events, and the sudden diversification of multicellular life in the Cambrian, remain an interesting and controversial area of research. Two outcrops relevant to this latest Precambrian history will be visited on Day 1, enroute to Grand Bank.

The Chapel Island Formation contains a rich and diverse assemblage of trace fossils, and it is these that are actually used to pinpoint the Precambrian-Cambrian boundary, because the soft-bodied organisms that generated the traces are not preserved. However, the formation also contains a less comprehensive assemblage of "small shelly fossils", representing the very first hard-shelled organisms that existed before the first trilobites.

No Ordovician or Silurian rocks are known on the Burin Peninsula. The youngest rock unit is the Devonian St. Lawrence Granite (~ 374 Ma; Kerr et al., 1993) and the compositionally similar Grand Beach and Winterland porphyries are also Devonian (~ 396 Ma; Krogh et al., 1988). Late Devonian to Carboniferous sedimentary rocks also occupy a very small area in Mortier Bay, and are termed the Spanish Room Formation. The St. Lawrence Granite is well-known for its fluorite veins, which have been mined intermittently since the second world war. These are the only economic mineral deposits presently known on the peninsula, although there are some scattered gold prospects.

GEOLOGY OF THE FIELD TRIP AREA

This section of the guidebook provides information on the latest Precambrian to early Cambrian rocks of the Rencontre Formation, Chapel Island Formation and Random Formation. It is drawn from previous guides and papers (Narbonne et al., 1987; Myrow et al., 1988; Myrow and Hiscott, 1993; Myrow and Landing, 1992; Gehling et al., 2001), and these should be consulted for full details.

Rencontre Formation

The Rencontre Formation is restricted in extent within the field-trip area. Its lowermost rocks are coarse-grained, conglomeratic deposits, which sit unconformably upon felsic volcanic and pyroclastic rocks of the Marystown Group. These are interpreted as proximal alluvial deposits. This basal facies is overlain by sandstones, siltstones and mudstones interpreted to represent fluvial to marginal marine environments, evolving to peritidal settings just below the transition to the overlying Chapel Island Formation (Myrow et al., 1988). Smith and Hiscott (1984) suggested that the Rencontre Formation was deposited in a narrow fault-bounded basin developed during a period of active strike-slip faulting.

Stratigraphy of the Chapel Island Formation

Most of the stops on the field trip lie within this formation. The name “Chapel Island Formation” was first used by Widmer (1950) for red and green siltstones exposed on that island, and elsewhere in the northern Fortune Bay area (Figure 1). The sedimentary rocks that lie beneath the Random Formation on the southern Burin Peninsula were correlated with the Chapel Island Formation by Hutchinson (1962). The Chapel Island Formation in the field trip area was subdivided into five members by Bengtson and Fletcher (1983), and this subdivision was employed by Crimes and Anderson (1985). Myrow (1987) and Myrow et al. (1988) retained these five members for the most part, but redefined some of their boundaries and thicknesses, and suggested that Member 2 could be increased in thickness, and divided into two parts. The stratigraphy of the Chapel Island Formation, and the interpreted depositional environments, are shown in Figure 3, modified slightly from Narbonne et al. (1987). Myrow et al. (1988) used a numbering system for the various sedimentary facies within the Chapel Island Formation, which is retained here for stop descriptions. For a listing of the numbered facies and their characteristics, see Table 1, reproduced from Myrow et al. (1988).

The base of the Chapel Island Formation is defined in the Grand Bank Head section, where it is marked by the transition from the red sandstones and siltstones of the Rencontre Formation into a dominantly grey and green facies. The basal Member 1 of the formation is

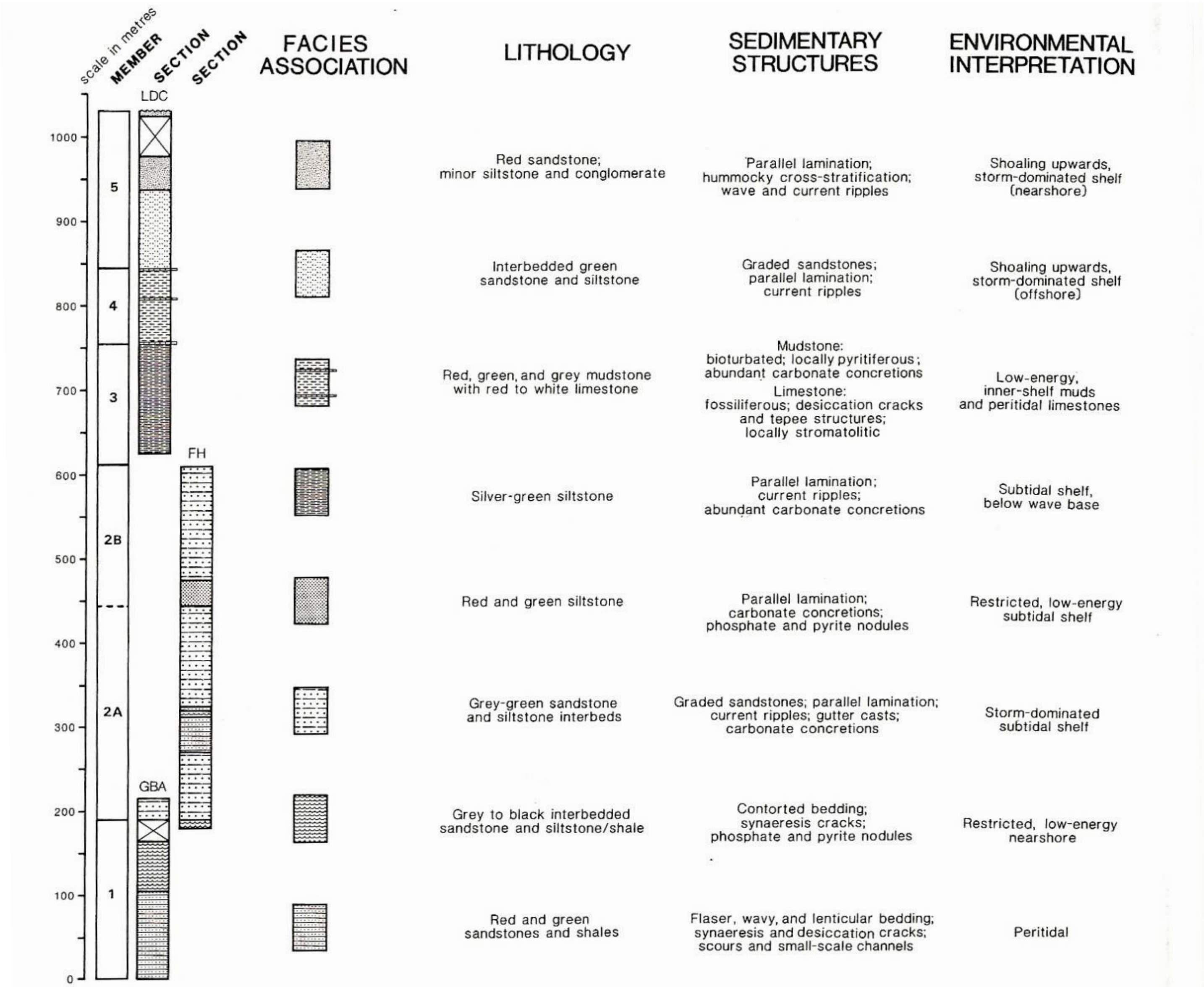

Figure 3. Stratigraphy, facies associations, rock types, sedimentary structures and inferred depositional environments for the Chapel Island Formation. Member-level subdivisions are those of Myrow (1987) and Myrow et al. (1988), modified from those proposed by Bengtson and Fletcher (1983). GBA - Grand Bank Head Section; FH - Fortune Head Section; LDC - Little Dantzic Cove Section.

Reproduced from Narbonne et al. (1987).

approximately 180 m thick, and consists of thin- to medium-bedded, green to red sandstones, silstones and shales, with some laminated black shales and grey shaly siltstones in its upper portion. The base of Member 2 is defined best in the Fortune Head section, by the first appearance of distinctive grey-green and green siltstone beds. Member 2 is estimated to have a total thickness of about 430 m, and is subdivided into two parts (2a, some 265 m thick; and 2b, some 165 m thick). It is dominated by grey-green to silver siltstones, with thin sandstone units. Some thin intervals of red and siltstone occur within Member 2 (Figure 3), and the upper part of the member (2b) was orginally included with Member 3 of Bengtson and Fletcher (1983). Member 2 is of particular importance, as the Precambrian-Cambrian boundary global stratotype is located 2.4 metres above its base at Fortune Head (Figure 3). The generally monotonous nature of the sedimentary rocks within this part of the sequence is an important attribute from the perspective of boundary definition, because it suggests that environmental influences on changes in trace fossil assemblages should be minimal.

Members 3, 4 and 5 of the Chapel Island Formation are best defined in the Little Dantzic Cove section. The redefined Member 3 has a thickness of approximately 150 m, and is dominated by laminated grey siltstones that contain carbonate concretions. Its base is gradational, and records a decrease in both the proportion of sandstone and thicknesses of individual sandstone beds. Member 4 consists of red and green bioturbated mudstones, pyritiferous mudstones, and thin micritic, nodular or stromatolitic limestones. The latter include some of the earliest truly fossiliferous limestones known in the geological record. Member 4 is distinct from all other rocks within the Chapel Island Formation, and is less than 100 m thick. Its base is defined as the first limestone bed in the succession, and its top is defined by a very distinctive and widely correlatable limestone bed that contains prominent algal structures. The uppermost Member 5 has a total thickness of 178 m. The lower part of Member 5 consists of green sandstones and silty sandstones that show a progressive increase in the proportion of sandstone and bed thickness. The upper part of the member is dominated by medium- to thick-bedded micaceous sandstones, typically brown or red in colour. The latter resemble parts of the overlying Random Formation.

Sedimentology of the Chapel Island Formation

Myrow et al. (1988) and Myrow and Hiscott (1993) provide a detailed discussion of sedimentary structures and sedimentary environments, summarized also in Figure 3. Member 1 is interpreted to represent tidal-flat environments, in which deposition was strongly influenced by reversing tidal currents. Member 2 represents several depositional environments interpreted to be broadly deltaic, with transient fluvial periods represented by the thin sequences of red-and-green beds. Storm processes are interpreted to play an important role in the development of the sandstone facies and various structures observed within these rocks, including the “gutter-cast facies”, suggest that some are “tempestites”. Evidence for submarine slides and gravity flows within Member 2 suggest a high sedimentation rate, consistent with a deltaic environment. Member 3 is less complicated from a facies perspective and was interpreted to be deposited largely below storm wave base in a siltstone-dominated outer shelf environment, in which thin sandstone beds represent “distal tempestites”. The distinctive Member 4 is suggested to have formed in a low-energy, muddy shelf in which the ocean water was oxygen-stratified, and the rate of sediment supply was low. Limestone deposition was restricted to the peritidal

Table 1. Facies characteristics for Chapel Island Formation

FACIES	LITHOLOGY	SEDIMENTARY STRUCTURES	ENVIRONMENTAL INTERPRETATION
FACIES 6.1a/b	Red micaceous sandstone; minor siltstone and conglomerate	Parallel lamination; hummocky and swaly cross-stratification; wave ripples	Prograding storm-dominated shelf (nearshore)
FACIES 5.1/5.2	Interbedded green sandstone and sandy siltstone	Graded sandstones,; parallel lamination; current ripples; rare convolute bedding	Prograding storm-dominated shelf (offshore)
FACIES 4.3	Red to white micritic and stromatolitic limestone	Fossiliferous; desiccation cracks; tepee and sheetcrack structures; mud mounds; planar/columnar stromatolites; oncolites	Peritidal; low energy
FACIES 4.2	Gray mudstone	Burrowed; pyrite nodules; pyritic steinkerns	Low energy dysaerobic shelf
FACIES 4.1	Red and green mudstone	Bioturbated; abundant carbonate concretions	Low energy oxygenated inner shelf
FACIES 3.1	Green laminated siltstone	Parallel lamination; current ripples; carbonate concretions; current/parting lineations	Outer shelf (sub wave-base)
FACIES 2.3/2.4	Red and green laminated siltstone	Red: parallel lamination, wave-ripple lamination Green: carbonate nodules, pyrite nodules	Low energy subtidal shelf; Delta abandonment facies
FACIES 2.2	Thin to medium bedded gray-green sandstone and siltstone	Grading; wave and combined-flow ripples; pebble lags; parallel lamination; mass movement deposits; HCS; graded rhythmites	Storm-influenced subtidal Lower delta front/prodelta
FACIES 2.1	Very thin to thin bedded gray-green sandstone and siltstone	Abundant gutter and pot casts; pinch-and-swell and lenticular bedding; unifite siltstone beds	Storm-influenced shallow subtidal Upper shoreface/delta front
FACIES 1.4	Medium bedded red sandstone and shale	Channel sandstones; parallel lamination; shale rip-up clasts; synaeresis/desiccation cracks	Peritidal, high energy,tidal influence
FACIES 1.3	Gray to black laminated sandstone and shale	Contorted bedding; synaeresis cracks; pyrite and phosphate nodules; channel sandstones	Semi-restricted low-energy
FACIES 1.1/1.2	Red and green sandstone and shale	Flaser, wavy and lenticular bedding; scour and channel sandstones; synaeresis/desiccation cracks; parallel and ripple cross-lamination	Peritidal, tidally-influenced

Reproduced from Myrow et al., 1988

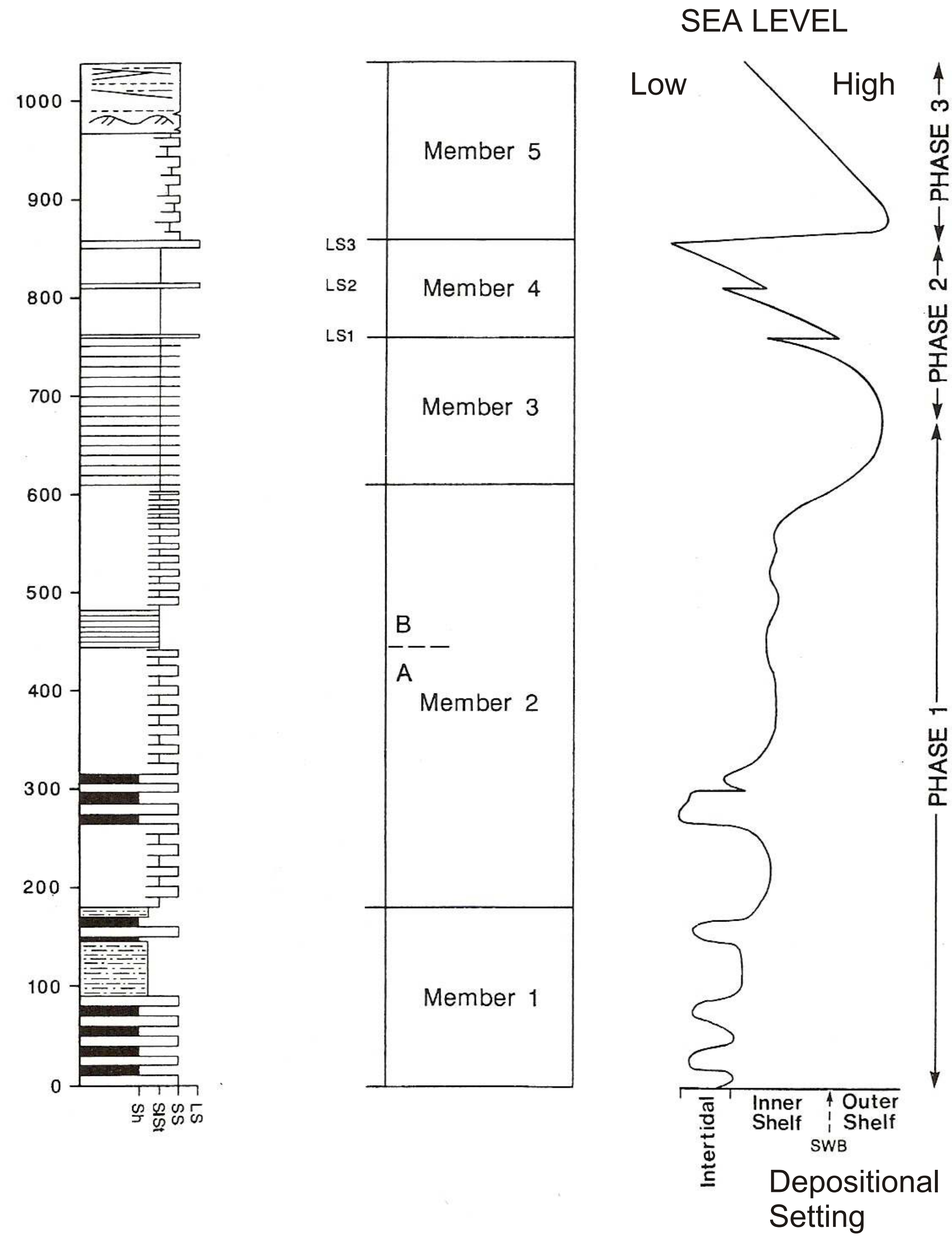

Figure 4. Generalized stratigraphic section through the Chapel Island Formation, showing the five members defined by Myrow (1987) and inferred changes in the depositional environment of the sediments relative to sea level. SWB - Storm wave base.

Reproduced from Myrow et al. (1988).

zone, and these marker units represent episodes of regression (Myrow and Landing, 1992). The overlying Member 5 is interpreted to represent a shoaling-upward sequence developed in a storm-dominated offshore to shoreface environment.

The overall stratigraphic sequence of the Chapel Island Formation, and the transitions in inferred sedimentary environments (Figure 3; Table 1) are interpreted in terms of a marine transgression (represented by Members 1, 2 and lower Member 3), followed by falling sea levels (represented by upper Member 3 and Member 4). Member 4 is also interpreted to record a period of restricted sediment supply. The subsequent transition from Member 4 to Member 5 is interpreted to record rapid deepening, followed again by progressive shallowing. The evolution of the Chapel Island Formation in terms of sea-level change and depositional environments is summarized in Figure 4. Although the sedimentary environment may not have been *constant* during the critical interval at the base of the Cambrian, any environmental changes were slow and muted, suggesting that trace fossil assemblages would not be strongly or suddenly affected.

Random Formation

The quartzites and sandstones of the Random Formation represent the first rocks within the Cambrian of eastern Newfoundland that can be correlated over wide areas. In the field-trip area, the Random Formation is in conformable contact with the underlying Chapel Island Formation. Elsewhere, the base of the Random Formation is an unconformity or a significant disconformity (Figure 2). Two sedimentary facies are described from the Random Formation in the Fortune Bay area, i.e., red micaceous sandstones, and white cross-bedded quartz arenites (Hiscott, 1982). The red micaceous sandstones are closely similar to Member 5 of the Chapel Island Formation. The cross-bedded quartz arenites are very distinctive rocks, and these occur above the red micaceous sandstones in the Little Dantzic Cove section.

Younger Cambrian Rocks

The top of the Random Formation is also a disconformity in many parts of the Avalon Zone, and the rocks that sit above it differ from place to place. The red mudstones and limestones that overlie the Random Formation at Little Dantzic Cove are believed to represent the Brigus Formation, rather than the underlying Smith Point and Bonavista Formations. Thus, a significant part of the Cambrian record is missing (Figure 2).

PALEONTOLOGY AND BIOSTRATIGRAPHY

Greene and Williams (1974) first reported the occurrence of small shelly fossils in the Chapel Island Formation at Little Dantzic Cove; this led to several subsequent paleontological studies (Bengtson and Fletcher, 1983; Crimes and Anderson, 1985; Narbonne et al., 1987; Landing et al., 1989; Gehling et al., 2001). No detailed discussion of this work is presented here, and the following summary is drawn largely from Narbonne et al. (1987), Myrow et al. (1988) and Gehling et al. (2001).

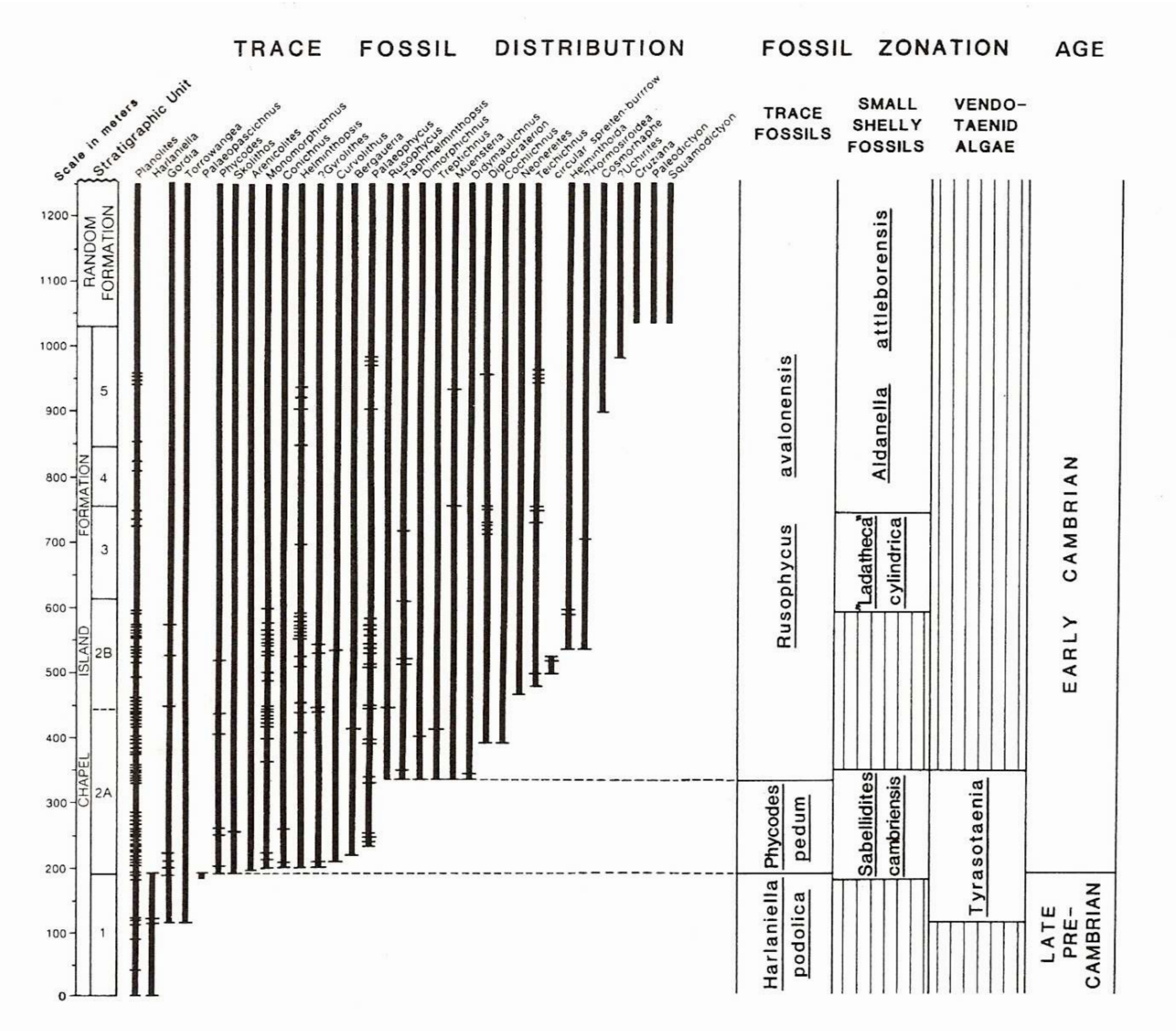

Figure5. Distribution of fossils within the Chapel Island Formation and the Random Formation. Note the sudden increase in diversity that marks the Precambrian - Cambrian boundary location. From Myrow et al. (1988), modified after Narbonne et al. (1987).

Summary of Body and Trace Fossils

The small shelly fossils were described in a preliminary survey by Bengtson and Fletcher (1983), and were also investigated by Narbonne et al. (1987). These are most abundant in the upper part of the Chapel Island Formation, notably in the carbonate-bearing Member 4. Very few fossils of this type occur elsewhere in the sequence, and their stratigraphic distribution was described as "not particularly complete" (Narbonne et al., 1987). The earliest occurrence is in the top of Member 1 and base of Member 2 (near the global stratotype), but these specimens of *Sabellidites cambrienensis* are poorly preserved. The most diverse assemblages of small shelly fossils come from the limestone beds in Member 4 at Little Dantzic Cove, but the surrounding siliciclastic rocks are generally not fossiliferous.

Bengtson and Fletcher (1983) recognized that the Chapel Island Formation contained a rich and diverse trace fossil assemblage, and that changes in trace fossil types between their members 1 and 2 might provide a basis for defining the base of the Cambrian. Crimes and Anderson (1985) completed a more detailed study and found that Member 1 contains just four ichnogenera, all of which had been described from latest Precambrian rocks elsewhere, whereas Member 2 contains no less than 15 ichnogenera. Such a pattern suggests a sudden increase in biodiversity near the boundary between these two members. The trace fossils in Member 2 include arthropod traces (*Monomorphichnus*), feeding burrows (*Phycodes*, *Nereites*), vertical dwelling burrows (*Skolithos, Arenicolites*) and graphoglyptids (*Protopaleodictyon*). Narbonne et al. (1987) concluded that three distinct trace fossil zones could be defined within the Chapel Island Formation (Figure 5). The lowermost is the *Harlianella podolica* zone, represented by Member 1 and the lowest 2.4 m of Member 2. This is succeeded by the *Phycodes pedum* zone, represented by the remainder of Member 2a, and then by the *Rusophycus avalonensis* zone, represented by Member 2b and the higher strata of the formation (Figure 5). The first appearance of *Phycodes pedum*, and the disappearance of *Harlianella podolica*, were suggested to indicate the location of the Precambrian-Cambrian boundary. Sketches of the characteristic trace fossils reported from this critical section are depicted in Figure 6 (from Myrow et al., 1988), and photographs of key specimens are provided by Narbonne et al. (1987).

It should be noted that the trace fossil *Phycodes pedum*, used to define the GSSP (Figure 5) was later reassigned to the genus *Treptichnus* by Jensen and Grant (1992; see also discussion by Gehling et al., 2001). However, for the sake of consistency with other publications used as sources for this field trip, the original name of *Phycodes pedum* has been retained throughout the remainder of this guide.

Definition of the Precambrian - Cambrian Global Stratotype

Following initial discussions by Bengtson and Fletcher (1983) and Crimes and Anderson (1985), the Chapel Island Formation became one of three contenders for the global stratotype Precambrian-Cambrian boundary (Cowie, 1985). The other candidate sections were located in the Ulukhan-Sulugar region of Siberia, and in the Meishucun region of China; both of these are relatively thin sequences of carbonate rocks, which contain abundant small shelly fossils but very few trace fossils. In contrast, the sequence on the Burin Peninsula is dominated by siliciclastic rocks that contain abundant trace fossils, but relatively few shelly fossils. Narbonne

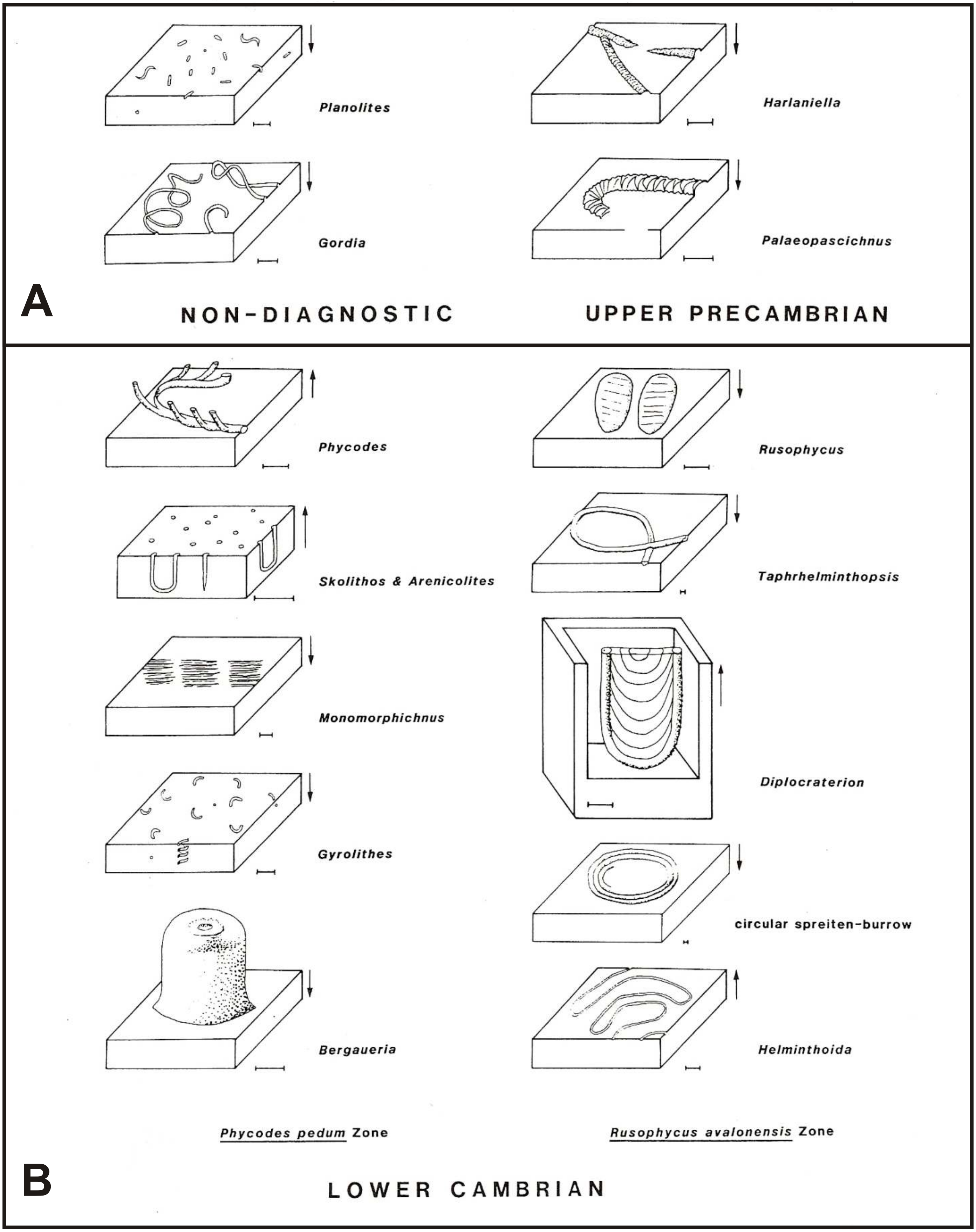

Figure 6. Drawings of the most common and typical trace fossils found within the Chapel Island Formation. (A) Precambrian examples; (B) Lower Cambrian examples. In all cases, the scale bar represents 1 cm. Reproduced from Myrow et al. (1988).

et al. (1987) presented a thorough discussion of the merits and demerits of the three candidates, and pointed out the problems in using carbonate successions; the likelihood that such thin sequences are not continuous was posed as a significant disadvantage. Trace fossils in siliciclastic successions, such as those in Newfoundland, were proposed to have several advantages for boundary definition. In particular, they are less subject to postmortem transport, and do not show the strong provincialism of small shelly fossils. Although trace fossils display facies restriction in that they are almost always found in sandstones and siltstones, such siliciclastic rocks are more common than carbonates in sequences that span the Precambrian-Cambrian boundary elsewhere in the world. A location 2.4 m above the base of Member 2 of the Chapel Island Formation (Figure 3, Figure 5) was proposed for the Global Stratotype by Narbonne et al. (1987). In 1987, the International Working Group tasked with defining this boundary met in St. John’s, and visited the sections. A subsequent vote led to a majority decision in favour of establishing the Global Stratotype at Fortune Head. This choice was eventually ratified by the International Union of Geological Sciences (IUGS) in 1992. The Ecological Reserve at Fortune Head was later established to protect the site.

An interesting addendum to the definition of this Global Stratotype comes from a the recent study by Gehling et al. (2001). During field work in 1999, it was discovered that the trace fossil *Phycodes pedum* (now known as *Treptichnus pedum*), occurs up to 4 metres below the proposed boundary location, and that there are possible indications of the same genus even deeper in the underlying Precambrian section. Thus, the GSSP location no longer corresponds to the first appearance of this characteristic trace fossil, although it still defines the last occurrence of characteristic Precambrian trace fossils such as *Harlaniella*. Gehling et al. (2001) suggested that a re-evaluation of the trace fossil zones for this interval (but not the boundary itself) may be needed in future years.

QUATERNARY GEOLOGY AND GLACIAL HISTORY (from M. Batterson, GSNL)

Debate on the extent of glaciation in Newfoundland was in nowhere more pronounced than on the southern Burin Peninsula, where sediments exposed in coastal sections are central to the glacial chronology of regional glacial events. In several sections two till units, separated by sands or silt, were cited by previous researchers as evidence for pre-Wisconinsan sedimentation (unusual in the province).Foraminiferal assemblages in these sands and silts were indicative of deposition within the Sangamon interglacial (~100,000 years BP). Tucker and McCann (1980) associated the lower till with the “Fortune Bay” glacial event, with ice flowing southeast, and the upper till was related to a north and northwest flow of ice from an offshore source on the continental shelf. The latter view was contentious, because it contradicted the classical view of highland glaciation and radial ice flow towards the coast. lowlands and the coast. The Quaternary section at Little Dantzic Cove is up to 25 m thick and sits in a bedrock depression between two rocky headlands. The Quaternary stratigraphy is considerably more complex than previously described and shows lateral and vertical variability. Although the middle part of the section includes some laminated silts and sands, these are interpreted to have formed adjacent to the grounding line of a large tidewater glacier, rather than representing an interglacial period. There appears to be no evidence at Little Dantzic Cove to suggest that the silty and sandy sediments were deposited before the last, late Wisconsinan glacial period. This thick section of Quaternary sediments will be seen on the walk to the Little Dantzic Cove section on Day 3.

PART TWO: FIELD TRIP STOP DESCRIPTIONS

This section of the guidebook contains locational and geological information on the stops to be visited during the field trip. The descriptions are abbreviated, and original sources (notably Myrow et al., 1988) should be consulted by those with an interest in specific details. Kilometerage measurements on roads are approximate, and the precision of vehicle odometers varies by as much as ± 10% in our experience. The UTM coordinates, where provided, are with reference to the 1927 North American Datum (NAD) which appears on most printed topographic maps for the area. They can be converted approximately to the 1983 NAD by adding 65 m to the east coordinate and adding 220 m to the north coordinate. Note also that landmarks may disappear or change characteristics with the passage of time.

DAY ONE (afternoon): GLACIOGENIC SEDIMENTARY ROCKS, EDIACARAN FOSSIL SITES, AND VIEWS OF MORTIER BAY

Although the primary focus of this excursion is the latest Precambrian - earliest Cambrian succession of the southern Burin Peninsula, the trip from St. John's to Grand Bank will incorporate two stops that are also relevant to the transition from the Precambrian (dominated by unicellular life forms) to the complex and intricate biosphere of the Paleozoic. The background for these stops is not summarized in detail here. Readers are referred to Hoffman and Schrag (2000) and Harland (2007) for discussion of the "Snowball Earth" hypothesis, and to Narbonne (1998; 2005) for information about Ediacaran organisms.

Stop 1.1: Gaskiers Formation (Conception Group), near Harbour Main

From St. John's, drive west on the Trans-Canada Highway to the intersection for the Holyrood Access Road (Route 62), and follow this road into the town of Holyrood. From the junction of Routes 62 and 60 in Holyrood, continue for 8.8 km west on Route 60 to Harbour Main, and then turn right on a side road for about 0.7 km, parking in a cleared area opposite the church. The outcrops are located on the shoreline about 250 m south of the church, where there is a small cove and a rocky peninsula; the larger outcrop is located at 337265E / 5255975N. This location reveals diamictites (glaciogenic marine sedimentary rocks) of the Gaskiers Formation, within the Conception Group. These are overlain by red mudstones and a thin grey limestone that is the only known example of a "cap carbonate" associated with late Neoproterozoic glacial deposits in Newfoundland.

The small peninsula consists almost entirely of structureless diamictite, which is a very poorly-sorted conglomerate-like rock with a very fine grained matrix and a variety of clasts, most of which resemble typical Avalon Zone rock types. However, there are also scattered clasts of limestone, which resemble the overlying carbonate unit. The diamictites are largely structureless, but they appear to strike roughly north-south, parallel to the shore. The main part of the outcrop, by the road, exposes the upper section of the diamictite, which is reddish in colour compared to the greenish variety on the point. Just above the transition from green to red is a zone of laminated mudstones, into which larger clasts ("dropstones ?") appear to have settled. This is overlain by a bright red laminated mudstone, which contains very few clasts of any type, and then by a 0.5 m thick grey to white-weathering limestone. This has a gradational lower contact, defined by the appearance of numerous limestone nodules in the underlying mudstone, but becomes more carbonate-rich and homogeneous towards the top. The relationship between the diamictite-dominated peninsula and the more complete sequence exposed close to the road is not easy to understand, because the strike of the latter outcrop seems to be almost east-west, rather than north-south.

Myrow and Kaufman (1999) interpret the diamictite as a glacial deposit, likely representing a submarine debris-flow, rather than a true subglacial tillite. The change in colour upwards is interpreted to reflect increasing oxygenation of seawater in the later stages of the glacial episode, and the bright red mudstone is interpreted as a flooding surface. The limestone is interpreted to represent a “cap carbonate” recording unusually warm conditions following sudden deglaciation. The carbonate unit is very unusual in the context of the Conception Group, as it is the only limestone bed in about 4 km of strata. In equivalent outcrops to the north, red mudstones and the carbonate unit occur as large clasts and blocks in diamictite. Carbonate clasts are also seen in other outcrops of the Gaskiers Formation. It is thus possible that the mudstones and carbonate rocks in the main part of the outcrop represent a huge slumped block, derived from a nearby shelf-like environment.

Stop 1.2: Ediacaran Fossils in the Mistaken Point Formation, Spaniard’s Bay

From Stop 1.1, there are two routes to Stop 1.2. First, return to Route 60 and continue west. After a few kilometres, the Harbour Main access road leads back to the Trans-Canada Highway. Continue west on the Trans-Canada Highway to the junction for Bay Roberts and Carbonear (Veterans’ Memorial Highway), and follow this north for 19 km to the Spaniard’s Bay exit, and then follow the access road into Spaniard’s Bay. Turn left on Route 60, which soon leads to the beach at Spaniard’s Bay, south of the large church. Turn right at the road junction by the beach, and drive to the end of this short road. This stop can also be reached by following Route 60 all the way from Harbour Main, which is a scenic trip, but may take longer. A trail leads for about 250 metres to the tip of this small peninsula in Spaniard’s Bay, where the fossils are on a large bedding plane very close to the point. Note that the intervening land is privately owned, and that the town of Spaniard’s Bay is seeking to acquire the site as a park. *Under no circumstances should the fossil-bearing surfaces be hammered, and there must be no attempts at fossil collection, because they are protected under legislation.* The site is best accessed at low tide, and there may be large quantities of seaweed here, which is slippery (*TAKE CARE WALKING AROUND !*). It is also a nuisance, because it may obscure parts of the fossil surface. There are no previous stop descriptions for this locality, although it has been known for many years, and is indicated on the regional geology map (King, 1988). The site is one of several in the Spaniard’s Bay area that is discussed in a recent paper by Narbonne et al. (2008) that provided much new information on the fine structure of Ediacaran organisms.

The small peninsula consists of thinly-bedded, deep-water siltstones and mudstones of the Mistaken Point Formation (Conception Group). In comparison to the famous “D” and “E” surfaces at Mistaken Point, this fossil horizon is small and less densely-populated, but some of

the specimens show exceptional preservation and resolution of detail. This is due in part to the finer-grained nature of volcanic ash horizons that preserved the soft-bodied creatures with “more pixels” than at Mistaken Point. The most common fossils are Fractofusus (also known as “spindles”, and frond-like organisms known as Charnia, but other genera also occur here.
There are more questions than answers about the Ediacaran biota (see discussions by Narbone, 1998; 2005). The exact age of this locality is as yet unknown, but assuming that stratigraphic correlations are correct, these complex organisms lived ca. 565 Ma. The glaciogenic sedimentary rocks of Stop 1.1 are probably only 10-15 Ma older than these richly fossiliferous beds, so complex multicellular organisms must have evolved very quickly once the Earth thawed out.

Stop 1.3. Mortier Bay Viewpoint, Marystown

From Stop 1.2, return to the Trans-Canada Highway, and then continue down the Burin Peninsula Highway to Marystown. The viewpoint is on the left (east) side of the road at the north end of the town. This viewpoint, with excellent vistas across Mortier Bay, provides a good rendezvous point for field trip vehicles and illustrates some aspects of local geology.

Mortier Bay is a superb natural deepwater harbour that is used for servicing offshore petroleum infrastructure and also the site of the province’s only shipyard. The hills in the distance are the largely mafic volcanic rocks of the ~ 763 Ma Burin Group, which is the oldest component of the Avalon Zone in Newfoundland. Beyond these (but not visible) are the sedimentary rocks originally assigned to the Rock Harbour Group and considered to be still older than the Burin Group (Strong et al., 1978); these have now been reassigned to the younger Musgravetown Group., and Low ground in the foreground consists mostly of Cambrian rocks of the “Inlet Group” (Strong et al., 1978) which is dominated by red and grey-green mudstones that remain poorly-known from a stratigraphic perspective. The long thin point just south of the offshore shipping facility consists of Devonian to Carboniferous sedimentary rocks of the Spanish Room Formation, which comprises the youngest rocks of the Burin Peninsula. The region to the north of the road - and most of the southern Burin Peninsula - is dominated by mafic to felsic volcanic and associated volcaniclastic rocks of the Marystown Group.

DAY TWO (morning): RENCONTRE AND LOWER CHAPEL ISLAND FORMATIONS, GRAND BANK HEAD SECTION

The morning stops for Day 2 begin at the base of the Precambrian Rencontre formation, and cover the lower section of the Chapel Island Formation, crossing the Precambrian-Cambrian boundary on the east side of Grand Bank Head. The faunal and lithological contrasts across the boundary can be observed here, but are not as precisely constrained as at the global stratotype, which will be visited this afternoon. The stop locations for Day 2 are illustrated in the sketch maps of Figure 7.

Stop 2.1: Base of the Rencontre Formation

This stop is equivalent to Stop 1A in the detailed guidebook of Myrow et al. (1988). These coastal outcrops are located in the town of Grand Bank, north of the Home Hardware store. From the Burin Peninsula highway, take the western access road for downtown Grand Bank (Main Street) and follow it for about 800 m to the modern church on the right. Turn left just past the church, and then turn left again after about 200 m; this road leads to the hardware store. Just beyond the store is the wide shingle beach of Admiral's Cove, where there is abundant parking. Walk back towards the store on the road, and access the coastal outcrops by the "No Dumping" sign, walking north. The outcrop of interest is located at UTM 593920E / 5217150N.

The outcrop shows well-bedded, gently-dipping conglomerates and coarse-grained sandstones of the basal Rencontre Formation dipping gently to the northwest. The dip is much gentler than will be seen in the remainder of the Grand Bank Head section. The clast population in the conglomeratic rocks is dominated by felsic volcanic material and grey quartz pebbles. The contact with felsic volcanic rocks of the Marystown Group is not readily visible here (there is usually a lot of seaweed), but is interpreted as an unconformity. Outcrops about 75 m along the shoreline to the northeast reveal sheared volcanic agglomerates and associated felsic volcanic rocks. The basal Rencontre Formation at this locality strongly resembles the familiar conglomerates and sandstones exposed on Signal Hill in St. John's, which are the youngest Precambrian strata in the eastern Avalon Peninsula. They also resemble the uppermost parts of the Crown Hill Formation on the Bonavista Peninsula and near Cape St. Mary's. However, in these latter locations conglomerates are overlain disconformably by either the Random Formation or younger Cambrian strata, and the 1 km thick section represented by the Chapel Island Formation is absent.

Stop 2.2: Middle and Upper Parts of the Rencontre Formation

This stop corresponds to Stop 1B in the detailed guidebook of Myrow et al. (1988), and is located on the west shore of Admiral's Cove (Figure 7). From Stop 2, return to the parking area by the beach and cross the beach to outcrops on the other side. There is a sign warning that the Grand Bank Head trail is closed for safety reasons, but do not be concerned - you are walking at your own risk, and the town of Grand Bank is not responsible! The section to be examined at Stop 2.2 starts with the first outcrops (UTM 593445E / 5217380N) and runs for about 160 m to the northwest, where there is a prominent bedding-parallel quartz vein. The rocks strike

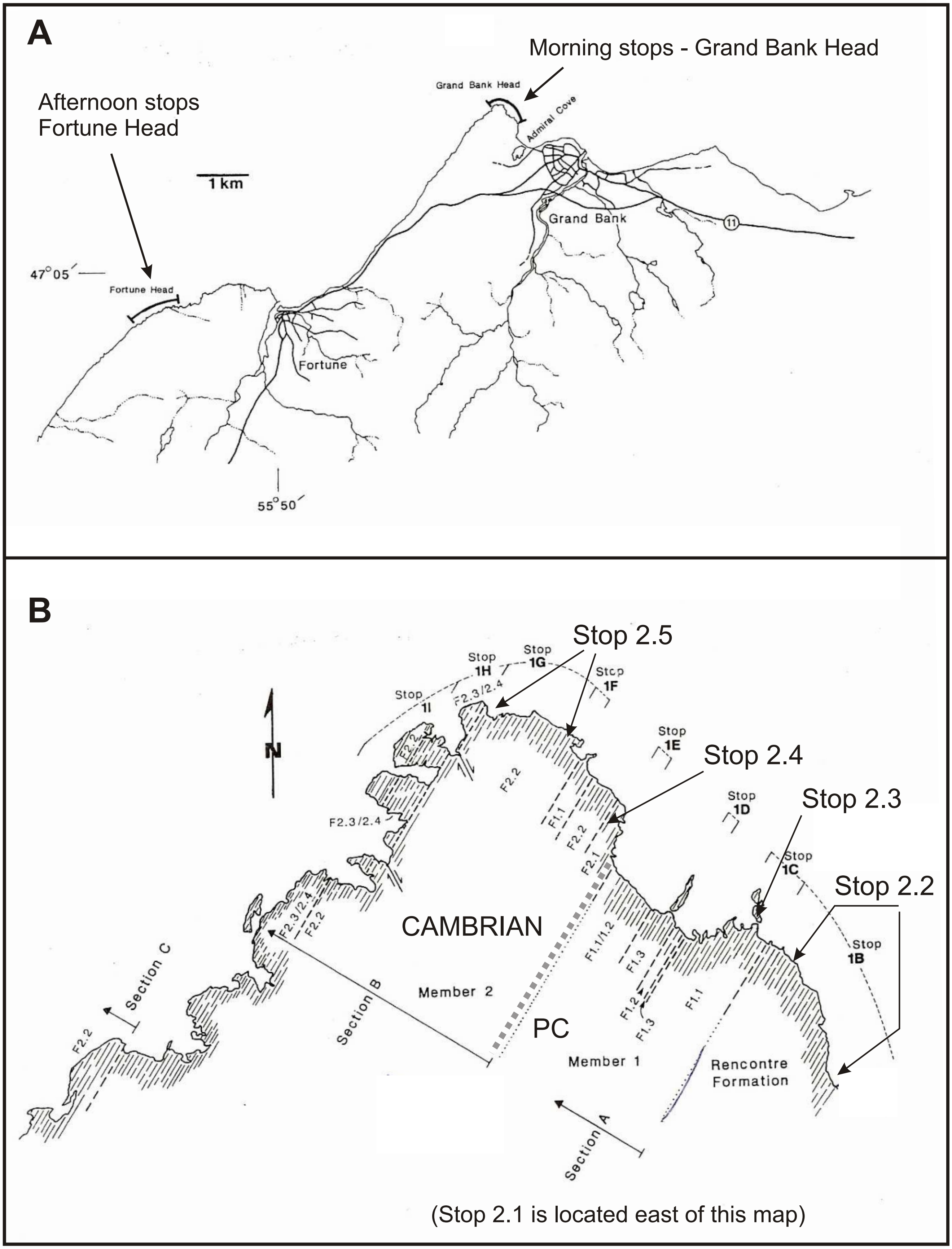

Figure 7. (A) Locations of the Grand Bank Head and Fortune Head Sections. (B) Sketch map showing the locations of field trip stops at Grand Bank Head. Stop 2.1 is located to the east of the map area, in Grand Bank. Modified after Myrow et al. (1988).

northeast, and dip moderately to the northwest. The entire section here is placed within the latest Precambrian.

The section exposes about 100 m of strata dominated by reddish, micaceous sandstones, siltstones and rarer mudstones. Sedimentary structures include ripple marks, intraformational conglomerates, and cross-bedding; no fossils have been reported. Myrow et al. (1988) provide further sedimentological details. The depositional environment is interpreted to be marginal marine or peritidal, in contrast to the rocks of Stop 2.1, which likely formed in a fluvial environment. The Rencontre Formation is described and interpreted in more detail by Smith and Hiscott (1984).

Stop 2.3: Lowermost Chapel Island Formation (Member 1)

This stop corresponds to Stop 1C in the detailed guide of Myrow et al. (1988); however, not all features described are easily accessible by a large group.

From Stop 2.2, access along the shore is difficult, so climb the slope to the top of the low cliff, and continue north for about 150 m, and then return towards the shore, at a location where there are prominent offshore rocks and a narrow point representing an incipient seastack. This spot is located at UTM 593370E / 5217675N. The outcrops on this point can be accessed with care, but larger groups may have to take turns as space is limited. Extreme care should be exercised in descending to this point, and close to the steep cliffs that bound it. *STAY AWAY FROM THE EDGES AT ALL TIMES !*

The rocks here are steeply-dipping and there are very few bedding surfaces or soles visible. The red to grey-green sandstones, siltstones and mudstones represent Facies 1.1 of Myrow et al. (1988; Table 1). Cyclic sequences within the sandstones have lower units of structureless sandstone with shale clasts, overlain by laminated sandstones, and capped by current ripples, and erosional surfaces are common in this facies. The depositional environment is interpreted to be shallow marine, but strongly influenced by tides. Very few trace fossils are present here, but the Precambrian species *Harlaniella podolica* was reported by Bengtson and Fletcher (1983). The trace fossils *Intrites* and *Planolites* are also reported from this section (Myrow et al., 1988).

From Stop 2.3, there is a good view into a steep-walled cove containing well-laminated grey, green and reddish beds. This represents Stop 1D of Myrow et al. (1988) and contains the Precambrian-Cambrian boundary on the northwestern side. However, access to this location is potentially dangerous, so the boundary itself will be visited instead at Fortune Head.

Stop 2.4: Cambrian Rocks of the Chapel Island Formation (Member 2)

This stop corresponds to Stop 1E in the detailed guide of Myrow et al. (1988). From Stop 2.3, continue northwestward along the coastal trail for about 120 m, and descend again to easily accessible shoreline outcrops that expose abundant soles. The southeastern edge of the stop is located at UTM 593195E / 5217880N. It is bounded by cliffs; these are not high, but they are certainly dangerous, and care should be taken in examining nearby surfaces. *STAY AWAY FROM*

THE EDGES AT ALL TIMES ! Although this location is not within the Ecological Reserve, it does contain some remarkable bioturbated surfaces, and it is important that these not be damaged through futile attempts at sampling. *DO NOT HAMMER THE OUTCROPS !*

The rocks at this stop are mostly silver to grey siltstones, including discontinuous beds of grey-green sandstone. These represent Facies 2.1 of Myrow et al. (1988), which is also known as the “gutter cast facies”; however, this particular facies is better exposed at Fortune Head, where the rocks are less deformed. Myrow et al. (1988) explain the formation of gutter casts in detail, as a consequence of storm-influenced currents. The most obvious sedimentary features are rippled surfaces, but sand dykes are also present. The depositional environment is interpreted to be shallow marine (subtidal) and influenced by storm activity. Storm-generated flows deposited the thin sandstone beds (“tempestites”), and developed the gutter casts, although the latter are not easily seen here.

This location contains superb examples of Cambrian trace fossils, notably on soles at the southern end of the outcrop (look for the marker “B10” painted on the rock surface). The most abundant is the species *Phycodes pedum*, which is used in defining the Precambrian-Cambrian boundary. A soft-bodied megafossil impression is reported here by Myrow et al. (1988) and is described as similar to the Ediacaran form *Spriggia*.

Stop 2.4 continues to the northwest for 50 to 75 m, but in this area much of the material consists of huge fallen blocks. However, the bedding and sole surfaces of these blocks contain well-developed sedimentary structures, and trace fossils are abundant.

Stop 2.5: Member 2 of the Chapel Island Formation at Grand Bank Head.

This stop includes the coastline from Stop 2.4 to Grand Bank Head, representing stops 1F and 1G in the detailed guide of Myrow et al. (1988; Figure 7). The coastal trail continues northwest to these locations, but safe access to the all of the shoreline outcrops is limited. However, many features can be observed from a distance. Grand Bank Head is located at UTM 593156E / 5217900N. The headland is surrounded by high cliffs, and care should be exercised. *STAY AWAY FROM THE EDGES AT ALL TIMES !*

The section from Stop 2.4 to 2.5 consists of silver-green siltstones containing thin beds of grey-green sandstone. These correspond to Facies 2.2 (Table 1), and their features are described in detail by Myrow et al. (1988). Sole markings on sandstone beds show consistent paleocurrent directions towards the northeast, and the bases of many beds are erosional surfaces. Myrow et al. (1988) also report “disorganized beds”, which are interpreted as debris-flows indicative of liquefaction and slumping. Several different types of “disorganized bed” are described, including raft-bearing beds that contain laminated clasts, and so-called “unifite” beds that range from structureless to complexly-laminated. The different types are interpreted to represent laterally equivalent “facies” that record the progressive evolution of gravity flows during their downslope motion. The “disorganized beds” are also well-exposed at Fortune Head, in the equivalent strata. The depositional environment for Facies 2.2 at these stops is interpreted to be near-shore or inner shelf, between the shoreline and the storm wave base. The sandstone beds are interpreted as “tempestites” recording the influences of periodic storms. Trace fossils exposed in this section include *Phycodes*, *Monomorphichnus*, *Treptichnus*, *Diplocraterion*, *Helmenthopsis*, and *Rusophycus* (Narbonne et al., 1987; Myrow et al., 1988; see Figure 6)

The outcrops on Grand bank Head consist of massive grey to silver-green sandstones, with some reddish siltstone units. The thick red siltstone unit seen at the end of the trail is a marker horizon within Member 2 that will also be seen at Fortune Head, near the lighthouse. Grand Bank Head enjoys some great views on a clear day. In a northerly direction is Brunette Island, the largest island in Fortune Bay. The island was the site of an ill-fated experiment in which buffalo from western Canada were introduced in the hope that they might prosper on the barren inland areas of the island. However, it seems that prairie buffalo were unfamiliar with the concept of seacliffs, and the unfortunate beasts fell to their deaths, one by one.

From Grand Bank Head, return to Admirals Cove Beach and the parking area. It is possible to retrace the route through the preceding stops, but there are other ATV trails that cut across the small peninsula directly, and these provide a slightly quicker route.

DAY TWO (Afternoon): FORTUNE HEAD AND THE GLOBAL STRATOTYPE SECTION AND POINT (GSSP) FOR THE PRECAMBRIAN-CAMBRIAN BOUNDARY

The afternoon stops for Day 2 focus on the section of the Chapel Island Formation that is superbly exposed around Fortune Head, and which serves as the GSSP for the Precambrian-Cambrian boundary. The shoreline traverse begins just below the boundary and continues through Member 2 of the Chapel Island Formation, overlapping in part some of the stops from Grand Bank Head. All of the stops this afternoon lie within the Fortune Head Ecological Reserve, which was established in 1994 to protect the GSSP and surrounding outcrops. *Reserve regulations specifically prohibit the collection of fossils and samples, and this extends to plants and all other natural materials. Outcrops in this area should not be hammered or otherwise defaced, and all participants are required to respect these conservation regulations.* Given its reserve status, it is ironic that the boundaries include the former dump site for the town of Fortune, which unfortunately sits just above the GSSP location. Attempts have been made to remediate the site.

Stop 2.6: Lunch Stop at Fortune Head Lighthouse

From Grand Bank, drive west on route 210 to Fortune, and through the town. Continue south of the town for a distance of 2.6 km from the junction for ferry terminal in Fortune, and turn right on the gravel road leading to the lighthouse and ecological reserve. The road has a few potholes and rutted sections, but should be passable by all vehicles. The lighthouse is located 3.2 km from the highway; keep left at the junction shortly before you reach it. There is limited space for parking in several spots adjacent to the lighthouse, where there is a small metal plaque containing information on the ecological reserve. The lighthouse itself serves as a scenic location to eat lunch and look at the views of Brunette Island and the French island of Miquelon. From this point we will walk northeast to the GSSP location, and then work upsection along the coast to the southwest, eventually returning to the lighthouse on the coastal trail. The stops in the Fortune Head area are illustrated in the sketch map in Figure 8.

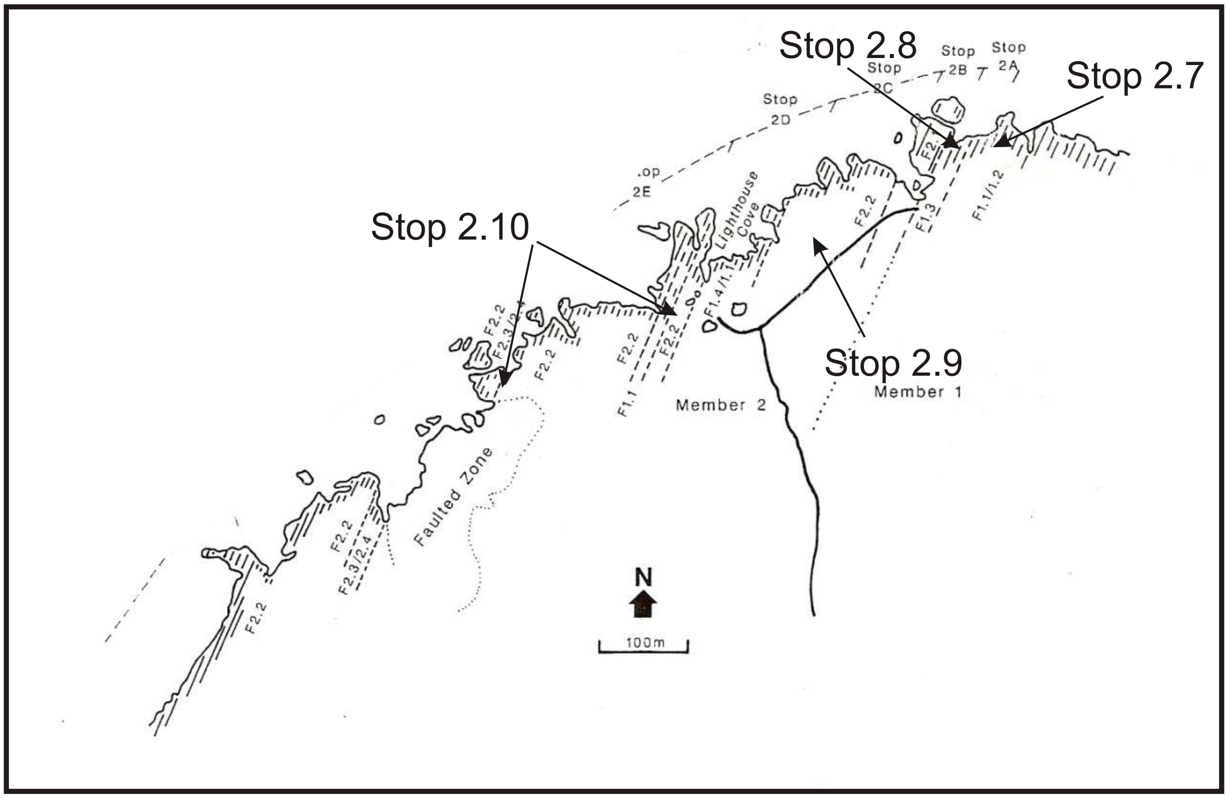

Figure 8. Sketch map showing the locations of field trip stops at Fortune Head. Modified after Myrow et al. (1988).

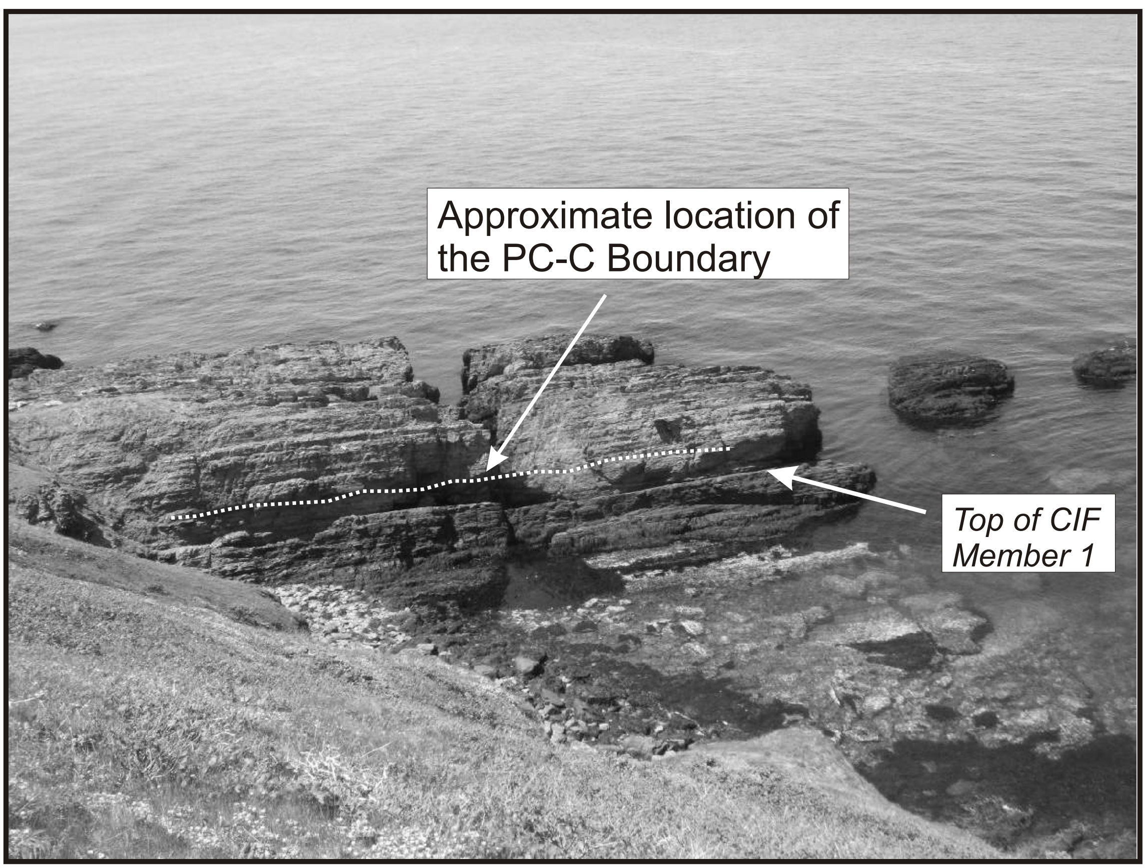

Figure 9. Photograph of the location of the Global Stratotype Section and Point (GSSP) for the Precambrian - Cambrian boundary. Photo by A. Kerr, July 2010.

Stop 2.7: Precambrian - Cambrian Boundary Global Stratotype Location

From the lighthouse, walk back along the gravel road, and then turn left at the junction. The side road leads through the former site of the Fortune town dump. From the dump site, ascend the hill to the east (UTM 586885E / 5213960N), from where there is a good view back across to the stratotype location (Figure 9). Grand Bank Head is visible to the east from here. This location corresponds to stops 2A and 2B in the detailed guide of Myrow et al. (1988).

The Precambrian-Cambrian boundary is located in the low cliffs on the west side of this small cove. The prominent bench near the base of the cliff is the top of Member 1 of the Chapel Island Formation, and the boundary is located 2.4 m above this, within Member 2a. Rocks to the east, including the reddish bedding surfaces, belong to the Precambrian, and those to the west belong to the Paleozoic. Access to the outcrops at the boundary is not a simple matter. The route on the eastern side of the cove is potentially dangerous because of the cliffs. The safest option is to descend a scree-filled gully in the centre of the cove (Figure 8), and then return up the rocky gully at its west side. *THESE ROUTES REQUIRE SCRAMBLING AND CROSSING LOOSE SURFACES, AND THEY ARE NOT EASY WALKING - EXTREME CARE MUST BE TAKEN, AND PARTICIPANTS SHOULD REALIZE THAT THEY ACCESS THE SITE AT THEIR OWN RISK. THE OUTCROP SURFACES AROUND THE BOUNDARY LOCATION MAY BE SLIPPERY AND TREACHEROUS, AND THE SITE IS POTENTIALLY DANGEROUS IF THERE ARE LARGE WAVES. BE CAREFUL !*

Outcrops on the east side of the cove belong to Member 1 of the Chapel Island Formation, and correspond to Facies 1.1 and 1.2 of Myrow et al. (1988), interpreted as peritidal. They contain synaerisis cracks and some dessication cracks, and abundant current ripples; some of the best examples are on fallen blocks within the cove. There are also examples of the simpler Precambrian trace fossils such as *Gordia* and *Planolites*. The prominent bench in the cliff at the west side of the cove exposes some of the youngest Precambrian strata, at the top of Member 1. It must be accessed with care, as it may be slippery. Only a small group of people can look at this surface at the same time. Trace fossils are visible on this surface, notably at its very outer edge, but some of these more closely resemble those described from the overlying Cambrian rocks, as noted by Gehling et al. (2001). The Precambrian-Cambrian boundary is located 2.4 m above the prominent bench representing the top of Member 1, but it is not marked in any tangible way unless you can see the trace fossils.

Outcrops at the top of the low cliff in Figure 9 belong to Facies 2.1 of Myrow et al. (1988), i.e., the “gutter cast facies”. There are prominent examples of these structures at this part of the stop, where they can be observed in both cross-section and plan view. Detailed descriptions of these are provided by Myrow et al. (1988), along with interpretation of the processes involved in their formation. There are also “disorganized beds” indicative of soft-sediment instability; these are equivalent to those noted previously in the Grand Bank Head section. The strata in the upper (Cambrian) part of the section contain typical trace fossils of the *Phycodes pedum* zone, also including arthropod traces (*Monomorphichnus*), vertical dwelling burrows (*Skolithos* and *Arenicolites*) and other types of burrows (e.g., *Conichnus*). Examples of these are illustrated in Figure 6.

Stop 2.8: Upper Part of Member 2 of the Chapel Island Formation

From the point sitting above the Precambrian-Cambrian boundary, return around the dump site, to examine the outcrops on the west side of the small cove. These correspond to Stop 2C in the detailed guide of Myrow et al. (1988). The remainder of the stop includes the accessible coastal outcrops between this point and Stop 2.9 at Lighthouse Cove.

The lowest beds at this site correspond to those at Stop 2.7, and contain “gutter casts”. Higher in the section are several “raft-bearing” beds interpreted to record soft-sediment instability and slumping. These pass upward into rocks that resemble the lower part of the section, but which also include medium- to coarse-grained, white quartz arenite beds. Overall, this section is interpreted to record a cycle of deepening and then shallowing. The raft-bearing beds are interpreted as the downslope facies equivalent of the “disorganized” beds seen lower in the section, but they are of course higher in the stratigraphy. Trace fossils are abundant in this section, but this does not mean that they are easy to see.

Stop 2.9: Red Beds in Member 2 at Lighthouse Cove

This stop is at a prominent zone of red sandstones and shales exposed on the cliffs east of Lighthouse Cove (Figure 8), and corresponds to Stop 2D in the detailed guide of Myrow et al. (1988), located at 586620E / 5213925N. The trail from Stop 2.8 leads here directly.

The red beds define a fining-up sequence from high-energy fluvial environments to lower-energy shallow marine environments, and are assigned to Facies 1.4, 1.1 and 1.2, respectively. These are interpreted to record a transient return to a periodically emergent environment, within the dominantly subtidal marine succession of Member 2. Myrow et al. (1988) describe sedimentary structures in detail; the most obvious are synaeresis and dessication cracks, small current ripples, and mud-chip conglomerates. No trace fossils have been reported from this stop. This stop is equivalent to the red beds seen previously at Grand Bank Head.

Stop 2.10: Coastal Outcrops East of Lighthouse Cove (Upper Part of Member 2)

The remainder of the Fortune Head traverse includes some 200 m of strata exposed to the east of Lighthouse Cove, which represent the upper part of Member 2 of the Chapel Island Formation. This section contains much of interest, including more disorganized and raft-bearing beds, and also some of the distinctive trace fossils that define the *Rusophycus avalonensis* zone, to which the higher parts of the Chapel Island Formation are assigned. The outcrops correspond to Stops 2E and 2F in the detailed guide of Myrow et al. (1988), but it is not likely that all of these can be visited in the time available for this excursion. At the end of the section, follow the trail back to the lighthouse.

DAY THREE: UPPER CHAPEL ISLAND FORMATION AND RANDOM FORMATION, LITTLE DANTZIC COVE AREA

Day 3 of the field trip consists of a coastal traverse through the upper section of the Chapel Island Formation and into the sandstones and quartzites of the Random Formation. The hike totals some 8 km, and is of the out-and-back variety; we will walk directly to the north (lower) end of the section, and then work gradually back. The starting point for the excursion is at Pieduck Point. To reach this, drive through Fortune to a point 11.8 km from the river bridge, and turn right on a dirt road. The turning is 1 km north of the Point Crewe Heritage Park. The dirt road is potholed and rough in sections, but is passable with care. There is a large area for parking by the shed at Pieduck Point, about 2.3 km from the highway. From here, obvious ATV trails lead northward towards Little Dantzic Cove. The stop locations for Day three are located in the sketch map of Figure 10. If the weather is clear, there are excellent views of the French islands of St. Pierre et Miquelon from this coastline. The trail is located close to the coast, and some outcrops are visible from it, mostly representing Cambrian rocks. The first large outcrop is at the south end of Little Dantzic Cove, and consists of steeply-dipping white to pale yellow quartzites of the Random Formation. From this point, there are two choices of route. If the tide is low, it may be quickest to walk across the beach and rejoin the trail near where the brook flows into the sea. However, if the tide is high, it is better to ascend the sandy bluff behind the beach and follow the top of this ridge, descending to the brook at its northern end. The sandy bluff at this locality represents the thick Quaternary section that has generated much debate with respect to glacial chronology and events (see earlier discussion). North of the brook, the trail runs along the top of the cliffs, and care must be taken where it is steep. Follow the trail north from Little Dantzic Cove for about 1 km to the start of the section (see coordinates below). In total, this hike will certainly take more than 1 hour, and possibly as much as 1 hour and 30 minutes. The rocks in the Little Dantzic Cove section are continuously exposed, and dip to the south.

Stop 3.1: Siltstones of Member 3 of the Chapel Island Formation

This stop corresponds to Stop 3A in the detailed guide of Myrow et al. (1988). It is located at UTM coordinate 576965E / 5200810N. It consists of grey-green siltstones, with thin sandstone beds, representing Facies 3.1 (Table 1). Carbonate concretions are obvious in this outcrop, and are common throughout Member 3. There is a wide range of sedimentary structures, described in detail by Myrow et al. (1988). The rocks at this stop are interpreted to represent a more distal marine environment than those of Member 2, but the sandy beds are similarly interpreted to record the influences of storms. They are described as “distal tempestites” by Myrow et al. (1988). A limited range of trace fossils is present, of which the most common varieties are *Diplocraterion* and *Teichichnus*, both characteristic of the *Rusophycus avalonensis* zone.

Stop 3.2: Base of Member 4 of the Chapel Island Formation

This stop is located about 150 m south of Stop 3.1, at UTM coordinate 576940E / 5200620N, and corresponds to Stop 3B in the detailed guide of Myrow et al. (1988).

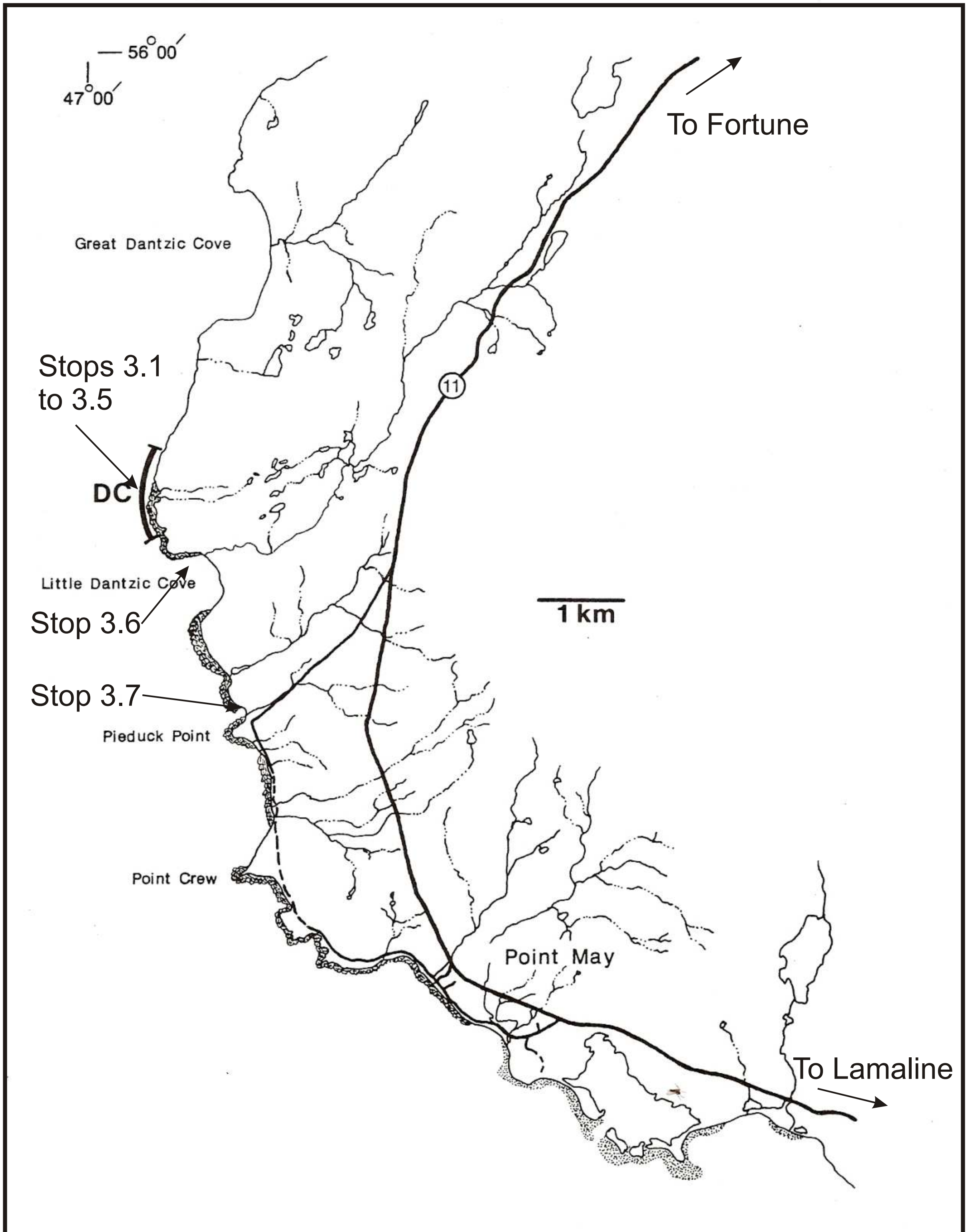

Figure 10. Location of the Little Dantzic Cove Section and the field trip stops. Modified after Myrow et al. (1988).

At this location, there are two beds that exhibit colour gradation from grey at the bottom to red at the top, and a prominent zone of carbonate nodules is developed within the intervening section. At the top of the second red unit is a thin limestone bed (termed LS1 by Myrow et al., 1988), which marks the base of Member 4 of the Chapel Island Formation. It is the first of three limestone beds, which each have very distinct characteristics, as illustrated in Figure 11. This first limestone bed is only about 15 cm thick and it lacks obvious megascopic physical or biogenic structures. Concretionary textures, and partially coalesced nodules in its lower section, suggest a largely diagenetic origin. The associated clastic sedimentary rocks are bioturbated purple, red and green mudstones, representing Facies 4.1 of Myrow et al. (1988). The mudstones are interpreted to record low-energy depositional settings that had low sedimentation rates. The limestone is interpreted to have formed in a peritidal setting from both direct chemical precipitation and from biogenic fixation by algae. Overall, Member 4 of the Chapel Island Formation is interpreted to represent a large-scale shallowing-upward sequence (Figure 4), within which there are several smaller shallowing-upward cycles, three of which are capped by limestone beds. This is the first of these cycles. Despite bioturbation, trace fossils are rare in the clastic rocks, but they do contain some of the earliest known shelly fossils, including slender cone-shaped shells (*Ladatheca*), snail-like shells (*Aldanella*) and bivalve-like shells (*Watsonella*). These are described in more detail by Bengtson and Fletcher (1983) and Narbonne et al. (1987).

Stop 3.3: Middle Limestone Bed in Member 4 of the Chapel Island Formation

This stop is located on a narrow point just over 100 m south of Stop 3.2. The point is easily recognized by its white colour, and is located at UTM 576975E / 5200510N. Note that this location may be inaccessible or dangerous if there are large waves and should always be approached with caution. Only a small group can be accommodated on the narrow outcrop at one time. It corresponds to Stop 3C in the detailed guide of Myrow et al. (1988). *NOTE THAT THIS LOCATION IS POTENTIALLY DANGEROUS IF THERE ARE LARGE WAVES !*

This limestone bed (LS2) is thicker and more complex and thicker than the first limestone bed visited at Stop 3.3 (Figure 11). It is also the lowest bed within the Cambrian of Newfoundland to contain abundant small shelly fossils. Some of these are very large, with circular cross-sections of about 1 cm; most of them are described as hyolithids (Narbonne et al., 1987). Hyolithids are small conical shells, whose affinities to other invertebrates are poorly known, although some consider them to be the earliest molluscs; they became extinct in the Permian. The lower part of the limestone is structureless and resembles the limestone from Stop 3.3, but the upper section contains many fossils. At the top of the bed there are low-relief oncolites with an onion-skin weathering pattern, which are overlain by a nodular limestone, possibly containing large burrows.

The LS2 limestone is interpreted to have formed in a well-oxygenated subtidal setting in which fragments of algal mats, perhaps derived from the intertidal zone, were rolled around by currents or waves. It represents the top of a second shallowing-upward cycle within Member 4.

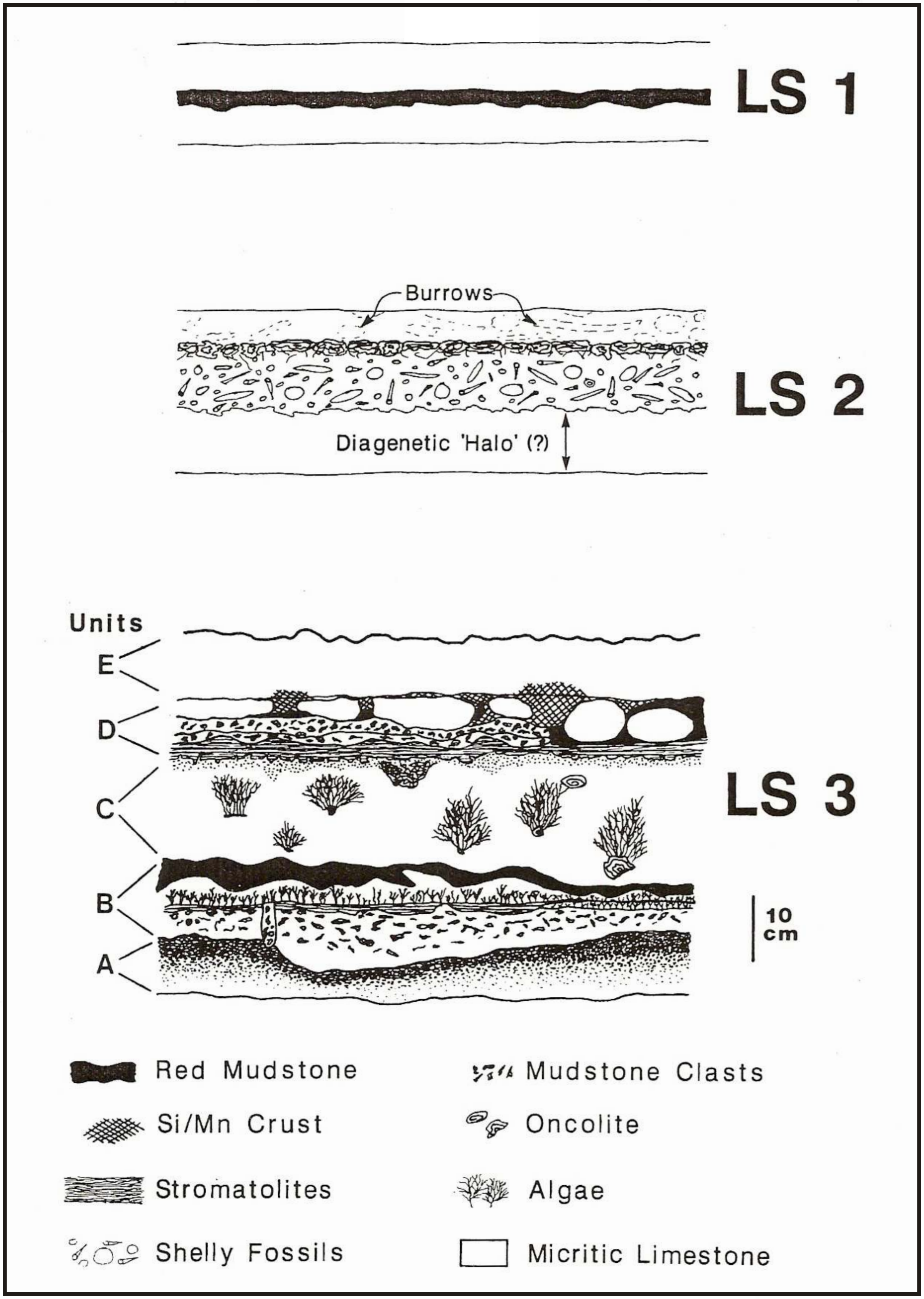

Figure 11. Sketches of the three distinct limestone beds in Member 4 of the Chapel Island Formation at Little Dantzic Cove. LS1 represents Stop 3.2; LS2 represents Stop 3.3, and LS3 represents Stop 3.4. The vertical scale is the same for all three sketches. Modified after Myrow et al. (1988).

Stop 3.4: Top of Member 4 of the Chapel Island Formation

This stop is located about 75 m south of Stop 3.3, and is easily visible from that locality. It corresponds to Stop 3D in the detailed guide of Myrow et al. (1988). If the tide is low, it is possible to cross the seaweed-covered outcrops from Stop 3.3 with care, but if the tide is high, it may be necessary to leave the shoreline at Stop 3.3, and climb down again on to the point, which is again marked by a prominent limestone unit, located at UTM 576935E / 5200430N. It is larger than the Stop 3.3 outcrop, but still has limited space for a large group. *NOTE THAT THIS LOCATION IS POTENTIALLY DANGEROUS IF THERE ARE LARGE WAVES !*

This is the third and most spectacular limestone unit within Member 4 (LS3; Figure 11) and it is the only one that can be traced from Dantzic Cove to other outcrops in the area. It ranges in thickness from 50 to 80 cm, and contains five distinct units, labelled A to E, which are described in detail by Myrow et al. (1988; see Figure 11). The lowest unit (A) is pinkish-green and structureless; it resembles LS1 and the lower part of LS2. This is overlain by a stromatolitic unit (B), which appears to have an erosion surface at its base. This is in turn overlain by a pink limestone (C) that contains disseminated quartz silt, and also some bush-like organic structures interpreted to be of algal origin. Obvious round oncolites are associated with some of these. The next unit (D) is a stromatolitic limestone similar to unit B, which contains some prominent biohermal structures consisting of pink micritic limestone. The uppermost unit (E) consists of bioclastic limestone, containing local accumulations of coarse shelly debris.

The limestone unit is interpreted to mostly record a relatively low-energy intertidal setting that was influenced by periodic storms. In addition to the algae, the bed contains a diverse assemblage of shelly fossils, described by Bengtson and Fletcher (1983), Landing et al. (1987) and Narbonne et al. (1987).

Stop 3.5: Member 5 of the Chapel Island Formation

From Stop 3.5, walk about 250 metres to the south and return to the shoreline to examine outcrops located at 576900E / 5200180N. This stop corresponds to Stop 3G in the detailed guide of Myrow et al. (1988), and represents the upper part of Member 5, which is placed within Facies 6.1 (Table 1). The outcrop consists greenish-pink to pink or locally red sandstone; bedding planes commonly show ripples. Detailed descriptions of this and other outcrops within Member 5 are provided by Myrow et al. (1988). Trace fossils observed at this location include *Diplocraterion*, *Paleaophycus* and *Planolites*. Overall, Member 5 of the Chapel Island Formation represents a shoaling-upward sequence in which both bed thickness and grain size progressively increase. If time permits, some intervening outcrops between Stop 3.4 and this stop will be briefly visited to illustrate the progressive change in depositional setting.

Stop 3.6: Random Formation Quartzites and Overlying Brigus Formation

From Stop 3.5, continue southward for about 150 m, to outcrops located at 577015E / 5200030N. The section from this point to the brook at the north end of Little Dantzic Cove exposes the Random Formation, dominated by white to pale yellow, cross-bedded quartz arenites. This section corresponds to stops 3I and 3J in the detailed guide of Myrow et al. (1988).

It can be viewed from the top of the bluff, but is best accessed by walking to the brook, and then back along the beach.

The uppermost section of the Random Formation, near the brook, contains a 30 to 50 cm thick conglomerate containing large quartz arenite blocks, along with pebbles of phosphatic shale, quartz, siltstone and possibly chert. The uppermost unit of the Random Formation consists of cross-bedded micaceous sandstone with a distinctive pale purple colour. This is overlain by red and green shales, and pink limestones of the Brigus Formation; there is a significant unconformity between the two formations. For more details on the sedimentological aspects of the Random Formation, see Myrow et al. (1988) and Hiscott (1982).

The conglomeratic unit is interpreted to record early lithification on a local scale, followed by erosion and incorporation into younger sediments with extraformational debris, suggesting the presence of a disconformity. The purple cross-bedded sandstone is a persistent feature at the top of the Random Formation in Newfoundland, and its presence seems to be independent of exactly which Cambrian sedimentary formation sits immediately above it. It is therefore interpreted to record the redistribution and winnowing of eroded quartz sands during the transgression that accompanied deposition of the younger Cambrian formations. The outcrops at the south end of the beach also provide excellent exposures of white cross-bedded quartzites.

Stop 3.7: Top of the Random Formation near Pieduck Point

From Stop 3.6, walk southward through or around Little Dantzic Cove. The outcrops at the south end of the cove are the Random Formation quartz arenites once more, indicating the presence of a synclinal fold structure between Stop 3.6 and here. Continue southward, following the same trails used on the inbound hike. Shortly before reaching Pieduck Point, walk to the shore to examine outcrops located at 577785E / 5198320N. These are the last outcrops of the field trip.

These outcrops are identical to those seen at Stop 3.7, representing the very top of the Random Formation and the overlying Brigus Formation. However, the sequence here dips and faces north, due to regional folding. The purple-tinged sandstone unit at the top of the Random Formation is very well-displayed in this outcrop.

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