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# STRATIGRAPHIC STUDIES OF THE WATTS BIGHT FORMATION (ST. GEORGE GROUP), PORT AU PORT PENINSULA, WESTERN NEWFOUNDLAND

W.D. Boyce, L.M.E. McCobb[1] and I. Knight
Regional Geology Section
[1]National Museum of Wales (Cardiff, UK)

## ABSTRACT

*The lithostratigraphy of the Tremadocian Watts Bight Formation (St. George Group) is best known in the Isthmus Bay section where it includes superb microbial mound complexes and is part of a Skullrockian transgressive–regressive sequence that also includes rocks of the lower Boat Harbour Formation. Twenty kilometres to the west, however, the mounds are no longer dominant although still sporadic near the base. The succession there, instead, consists of monotonous, thickly bedded, stylonodular lime mudstone and wackestone with frequent thin sheets and lenses of grainstone and rudstone. The facies support a more open, subtidal shelf setting in the west of the peninsula, deposited during the basal transgressive stage of the sequence, likely correlating with the Stonehenge transgression defined in the central Appalachians.*

*Trilobites along with other macrofossils were systematically recovered from the lower part of the Watts Bight Formation 1.5 km west of Ship Cove and from the Isthmus Bay section, Port au Port Peninsula. The Skullrockian trilobite genera,* Bellefontia *and* Symphysurina, *are identified for the first time from the west Newfoundland platformal sequence. These trilobites are indicative of the informal* "Millardicurus millardensis" *and* "Hystricurus" ellipticus *assemblage zones of western Newfoundland. The presence of* Bellefontia gyracantha *(Raymond, 1910)?,* "Hystricurus" ellipticus *(Cleland, 1900) and* Symphysurina myopia *Westrop* in *Landing* et al.*, 2003 indicates a correlation with the Tribes Hill Formation of New York State, USA, which, in turn, provides a linkage to the McKenzie Hill Formation of Oklahoma.* Millardicurus *sp.* cf. M. armatus *(Poulsen, 1937) provides a faunal linkage with the Antiklinalbugt Formation of North-East Greenland.*

## INTRODUCTION

Detailed stratigraphic studies of coeval Early Ordovician carbonates of western Newfoundland and Northeast Greenland have been ongoing for several decades. Part of this work includes the study of pioneering collections of fossils from the mountain fjords and icefields of North-East Greenland by John W. Cowie and Peter J. Adams of Bristol University from 1950 to 1953 (*see* Cowie and Adams, 1957). These collections are now housed at the National Museum of Wales, and are the subject of several studies by the authors under the leadership of Lucy McCobb (McCobb and Owens, 2008; McCobb *et al.*, 2009, 2010a, b; and Boyce *et al.*, 2010; McCobb *et al., in preparation*). Independently, detailed stratigraphic studies of the succession in North-East Greenland by Knight and Boyce in 2000 and 2001, as part of a collaborative GEUS expedition (Stouge *et al.*, 2001, 2002, 2003), have contributed to the redefinition of the Ordovician carbonate stratigraphy (Stouge *et al.*, *in press*) and enabled fairly accurate stratigraphic location of the fossils of the Cowie and Adams collections (McCobb *et al.*, *in preparation*).

In western Newfoundland, stratigraphic studies of the St. George Group have been ongoing (*see* Knight and James, 1987, 1988; Knight *et al.*, 2007, 2008; Boyce and Knight, 2009, 2010). It has been long understood that the rocks of the two disparate parts of the Laurentian paleocontinent were coeval and, in part, lithologically similar. Nonetheless, it has been the melding of these various research projects that has highlighted that the trilobite faunas in coeval early (Gasconadian/Skullrockian to Stairsian/Demingian) and late Early (Jeffersonian/Tulean to Cassinian/Blackhillsian) Ordovician strata in western Newfoundland and North-East Greenland have common characteristics, and encouraged the present study in western Newfoundland. Stairsian (Demingian) trilobites and other faunas although well documented in western Newfoundland are absent however in North-East Greenland, highlighting a cryptic, Stairsian-long disconformity in the Greenland succession (Stouge *et al.*, *in press*) whose presence was first recognized by Poulsen (1930, 1937).

## PREVIOUS BIOSTRATIGRAPHIC WORK

Most macrofossil studies of the Lower Ordovician limestones of the eastern Port au Port Peninsula have involved molluscs. Hyatt (1894) described several new cephalopod genera and species from the St. George Group, later restudied by Ulrich *et al.* (1942, 1944). Flower's (1978) field reconnaissance study recording various cephalopod and gastropod taxa was followed by those of Yochelson (1992) and Rohr *et al.* (2000), who studied silicified gastropod material. General paleontological information is found in Schuchert and Dunbar (1934), Sullivan (1940), Johnson (1949), Riley (1962), Corkin (1965), Whittington and Kindle (1969), Boyce (1989) and Knight *et al.* (2008). The recent detailed conodont studies of Ji (1989) and Ji and Barnes (1993, 1994a, b) provided the basic data for the cluster analysis studies of Zhang and Barnes (2004a, b).

## LITHOSTRATIGRAPHY

The Watts Bight Formation on the Port au Port Peninsula is best known from the Isthmus Bay section, located at the eastern end of the Port au Port Peninsula in western Newfoundland (Figures 1 to 4). The section is well known because of studies of microbial mounds of the Green Head mound complex and small-scale cyclicity by Pratt and James (1982, 1986; *see* Knight *et al.*, 2008) and the conodont monograph of Ji and Barnes (1994a). The 564-m-thick succession of dominantly cyclic carbonates (Section 2 of Ji and Barnes, 1994a, pages 75-77) ranges through the uppermost strata of the latest Cambrian Berry Head Formation (Port au Port Group) to the basal part of the Middle Ordovician (Whiterockian) Table Point Formation (Table Head Group) (Figure 3). Two, long-lived Tremadocian and Floian, third-order megacycle sequences were recognized, separated by a significant disconformity termed the Boat Harbour Disconformity (Knight and James, 1987, 1988; Knight *et al.*, 2007, 2008). Nonetheless, building on the stratigraphic studies of Ji and Barnes (1994a), Knight *et al.* (2008) further divided the Tremadocian rocks into two sequences, separated by an older disconformity within the lower part of the Boat Harbour Formation (*see* Figure 3). Below the disconformity, a long-term sequence including the upper Berry Head Formation, the Watts Bight Formation and the lower member of the Boat Harbour Formation form a deepening-shallowing Skullrockian succession that is terminated at the lower disconformity. The Stairsian Middle Boat Harbour Formation consisting of numerous cyclic peritidal carbonate parasequences occurs above the lower disconformity and terminates at the Boat Harbour Disconformity (Knight *et al.*, 2008).

Rocks of the Watts Bight Formation, primarily due to the efforts of Pratt and James (1982,1986) and Ji and Barnes (1994a), are best known from the Isthmus Bay section, where they are shown to consist of a lower and upper mound member and a middle member of burrowed and grainy carbonate (Knight *et al.*, 2008). The lower member is essentially the Green Head mound complex of Pratt and James (1982).

Work over the last few years has indicated that the lithostratigraphy of the Watts Bight Formation of the Isthmus Bay section is somewhat unique and not replicated when the formation is traced 20 km to the west. There, three detailed but incomplete sections, 30 to 60 m thick, were measured through the lower part of the formation between Lower Cove and Ship Cove (Figure 5, Plates 1 and 2), as part of an ongoing effort to understand this unit throughout the region. Two of the sections are equivalent to sections 5 and 7 of Ji and Barnes (1994a, page 4, Text-figure 2). The logging of their section 7 at the Lower Cove roadcut, indicates that the base of the Watts Bight Formation coincides with Z7-5B (Plate 1; Figure 5) and is at least 8 m higher in the section, than that used by Ji and Barnes (1994a, appendices A and B). The base of the formation may be obscured below sea level along the base of the cliffs at Ship Cove, so tight correlation of the sections is in the future. The conodont sample sites of Ji and Barnes (1994a) remain highlighted by blue painted numbers on the outcrop. Most but not all of the Lower Cove sites are visible, allowing their log to be matched with ours. Of three numbers found at Ship Cove, only one (Z5-2) is still readable, however. Nevertheless, using Z5-2 and the stratigraphic distances between con-

**Plate 1.** *The Lower Cove section in a roadcut west of the cove. The measuring stick straddles the Watts Bight Formation–Berry Head Formation contact. Note sample location Z7-005B (arrow) at the base of the Watts Bight Formation limestone above a recessively weathering dololaminite bed. Measuring stick is 1.5 m long.*

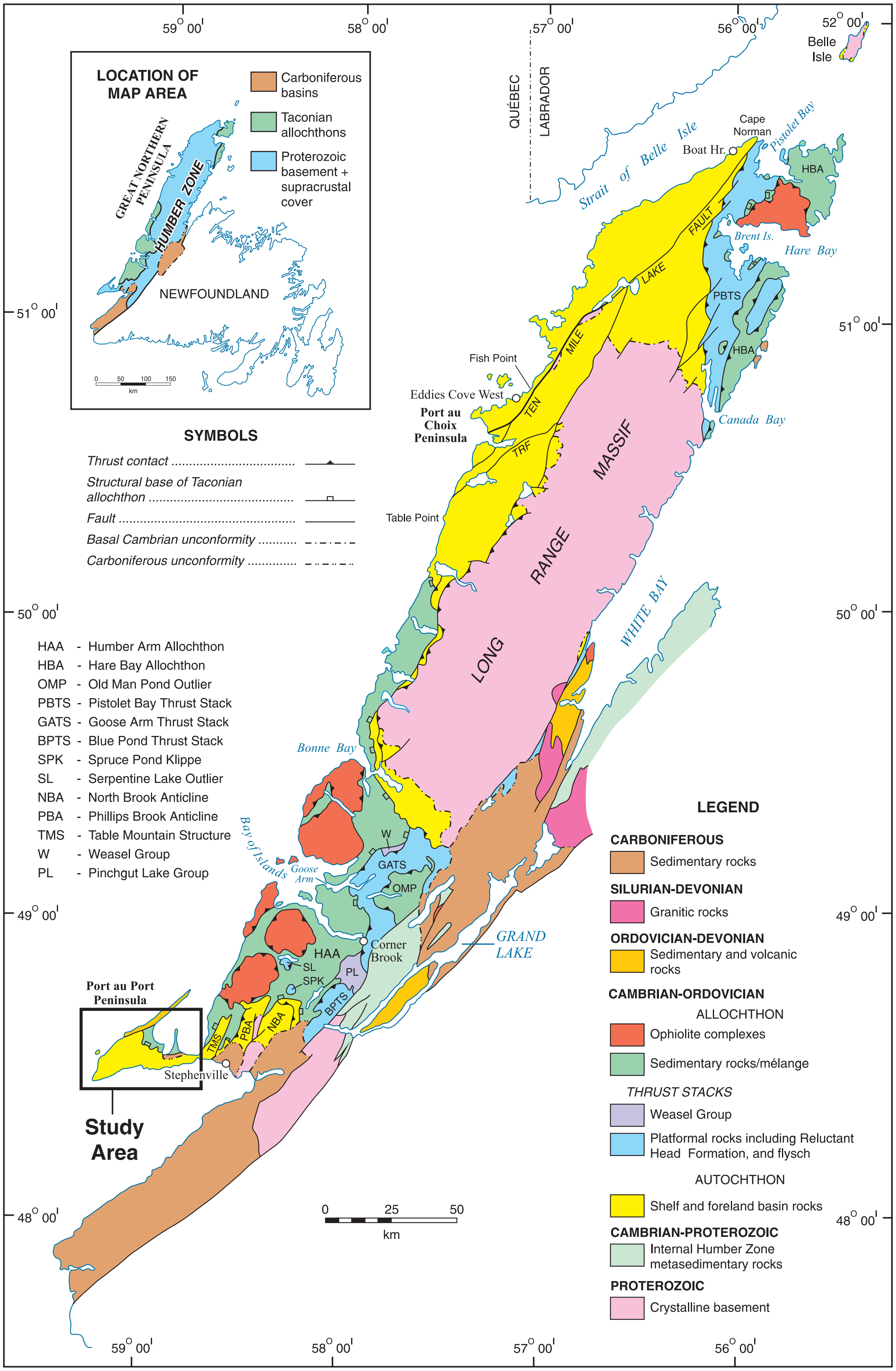



**Figure 1.** *Geology of western Newfoundland terranes and location of study area. TRF: Torrent River Fault.*

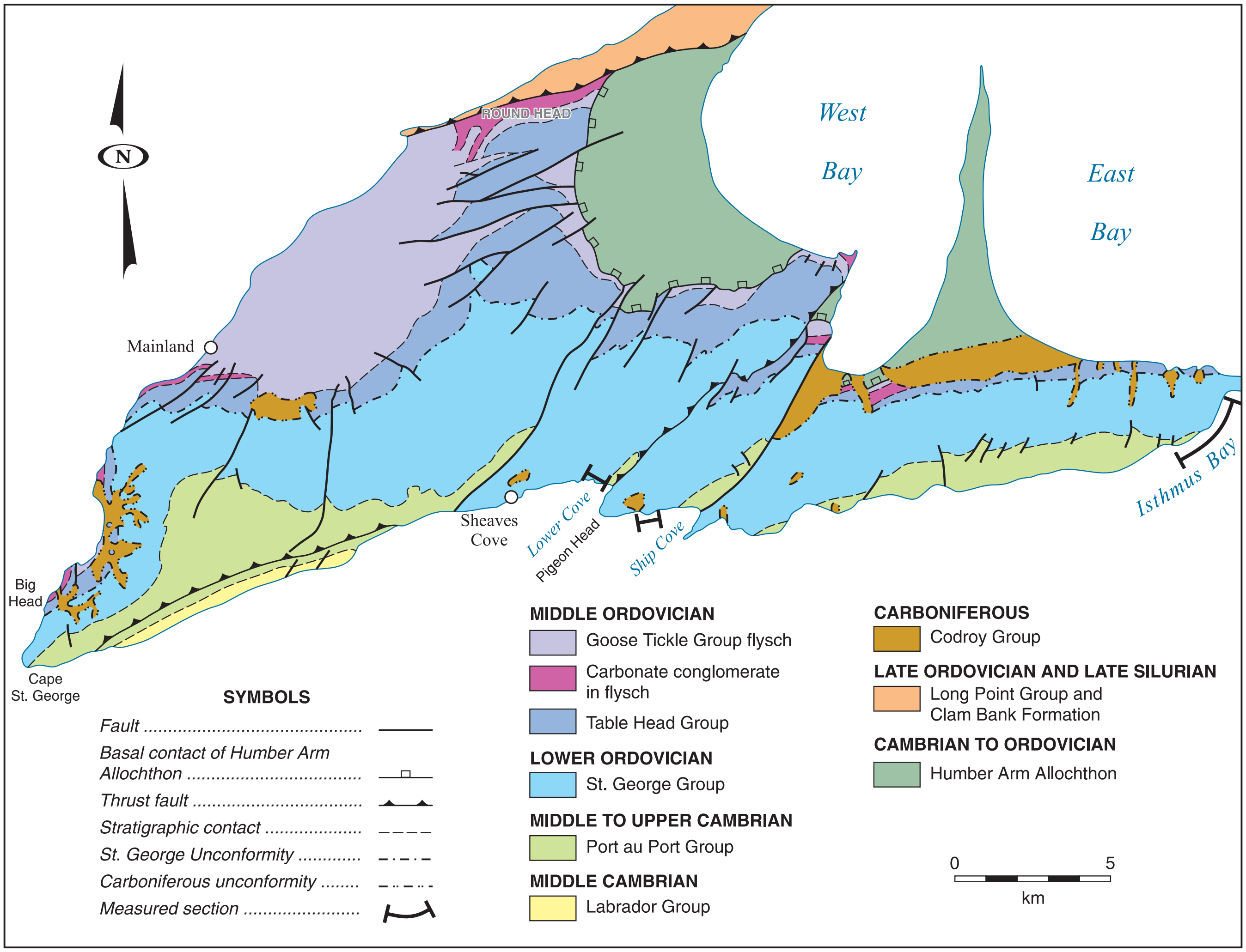



**Figure 2.** *Geology of the Port au Port Peninsula and location of sections studied in the Watts Bight Formation.*

**Plate 2.** *Bedded limestones of the Watts Bight Formation at the Ship Cove section 1.5 km west of Ship Cove. Red conglomerates fill a Carboniferous paleovalley at the head of the inlet.*

odont samples given by Ji and Barnes (1994a, page 92) in the appendix for the Ship Cove section, it is possible to roughly locate the twelve conodont samples with our trilobite samples.

The sea cliffs along the south coast of the peninsula from Ship Cove to Lower Cove host essentially southwest-striking and gently northwest-dipping rocks cut by numerous high-angle, and in some cases thrust, faults (Plate 3). This has complicated the section either by repetition or loss, juxtaposing in some places, such as Pigeon Head (Section 6 of Ji and Barnes, 1994a, pages 78-79, 92-94), lower Watts Bight Formation rocks against middle Boat Harbour Formation, which is, in turn, juxtaposed against rocks of the upper Boat Harbour Formation inland of the coast. In addition, some of these fractures are dextral strike-slip faults of various magnitudes that displace the lower Paleozoic section in an essentially clockwise sense, bringing more outboard shelf rocks northward on to the peninsula as it is traced westward.

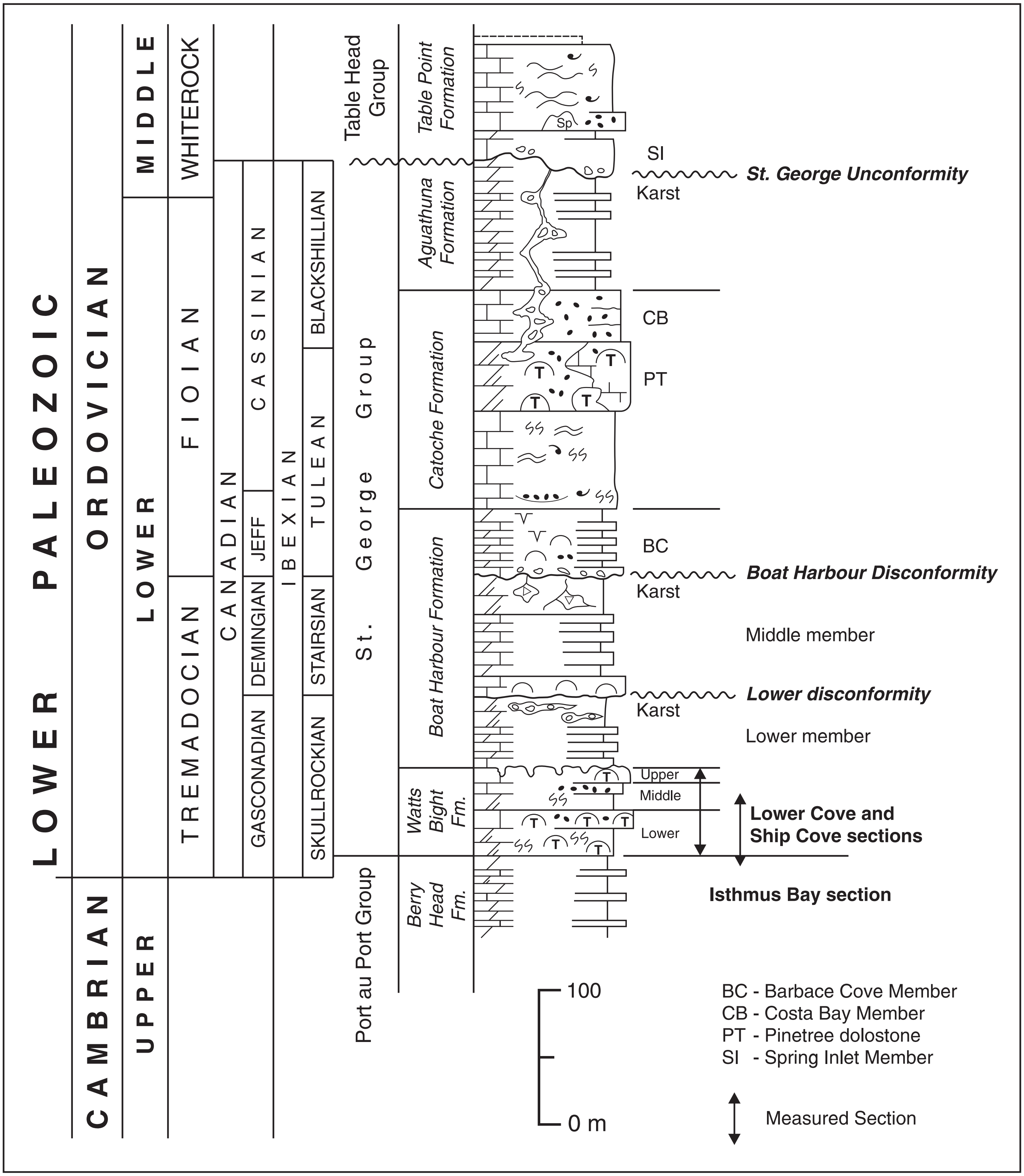



**Figure 3.** *Stratigraphy of the St. George Group, Port au Port Peninsula showing stratigraphic intervals logged in measured sections.*

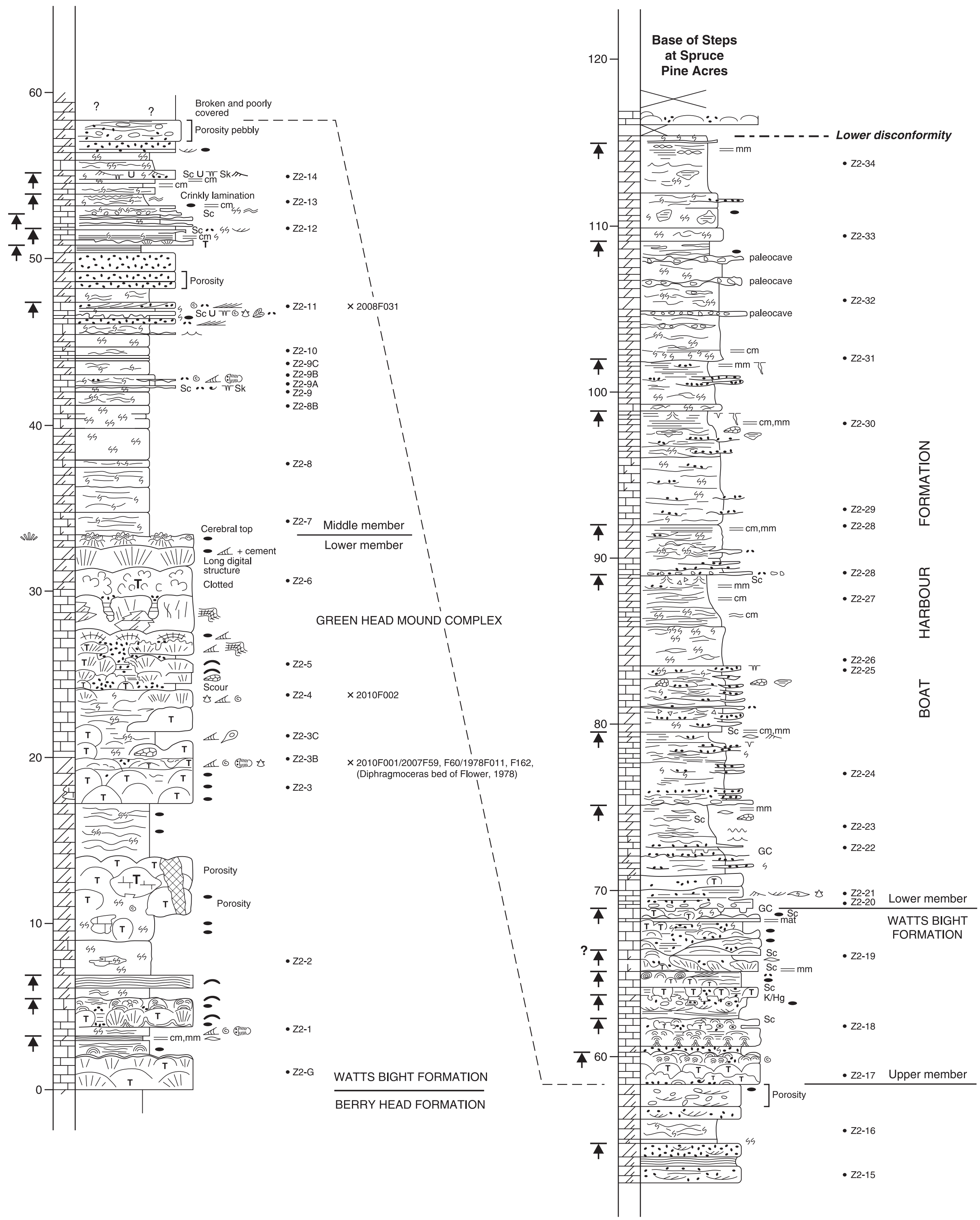



**Figure 4.** *Detailed graphic log of the Watts Bight Formation and Lower member of the Boat Harbour Formation, Isthmus Bay section, Port au Port Peninsula. Modified from Knight* et al., *(2008, page 125, Figure 4). Macrofossil localities and conodont localities of Ji and Barnes (1994a) also shown. See symbols list on Figure 5.*

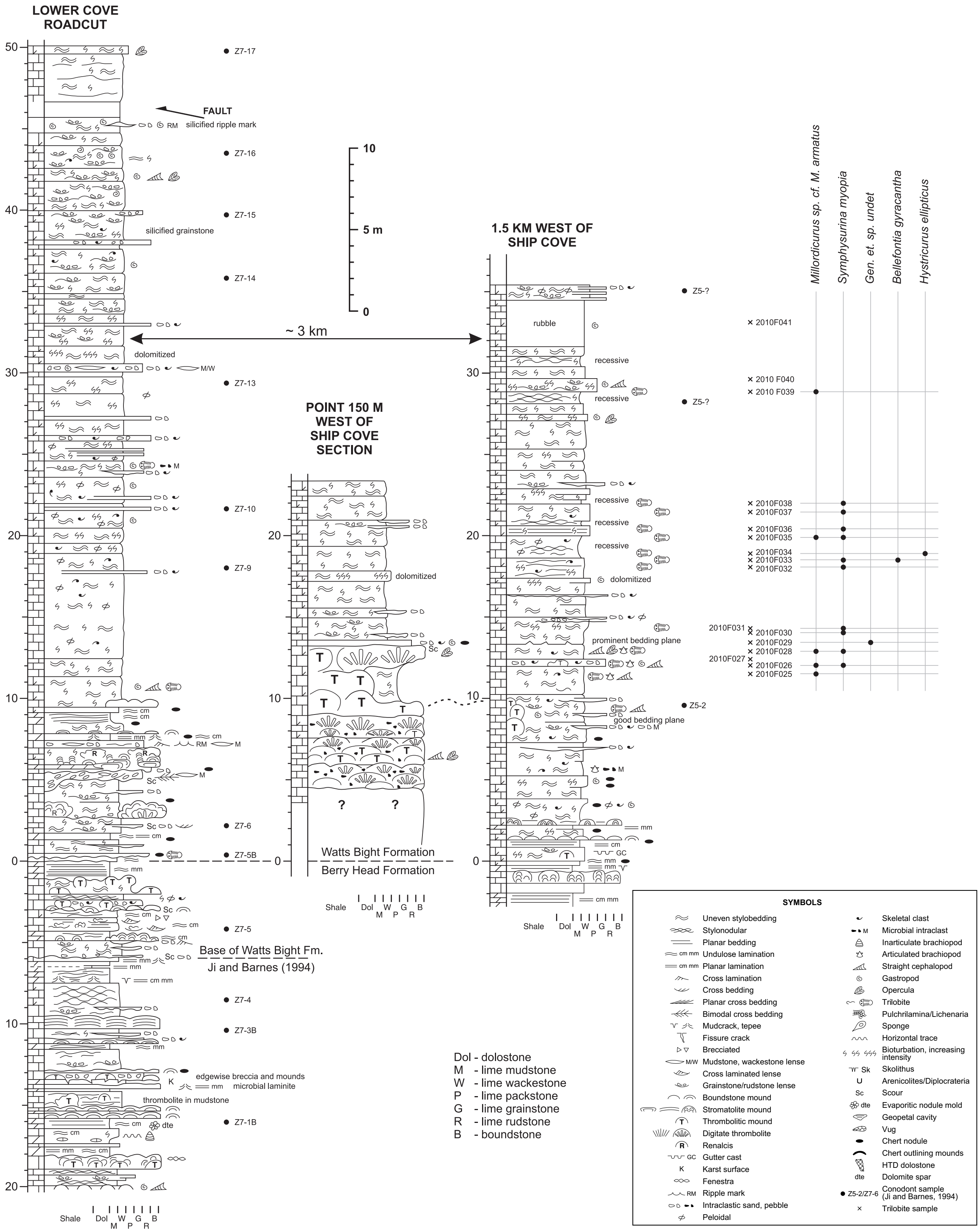



**Figure 5.** *Detailed graphic logs of sections through the lower Watts Bight Formation at Ship Cove and Lower Cove, Port au Port Peninsula. The ranges of trilobites recovered at the Ship Cove section are also shown. Conodont localities of Ji and Barnes (1994a) also shown for the Ship Cove and Lower Cove sections.*

**Plate 3.** *A thrust fault (arrow) cuts Watts Bight Formation limestones near the Ship Cove section (Plate 2). The highly fractured rock in the cove to the left is caused by a high-angle fault that strikes through the inlet. Red Carboniferous conglomerates occur to the left.*

**Plate 4.** *Limestone section through the lower Watts Bight Formation measured near Ship Cove. The well-stratified, stylobedded, lime mudstone to grainstone yielded scattered fossils including new trilobites, brachiopods and cephalopods.*

In the Ship Cove–Lower Cove area, microbial mound complexes are no longer dominant, although they still form an important, and locally, impressive facies at the base of the formation (Figure 5; *see* below). The succession, instead, consists of monotonous, thick-bedded, stylonodular lime mudstone and wackestone with frequent thin sheets and lenses of grainstone and rudstone (Plate 4). The finer grained muddy limestone is invariably rubbly weathering. A typical feature of the succession is the alternation of rubbly and recessively weathering stylonodular layers with resistant beds of burrowed and stylobedded, dolomitic limestone, which are commonly grainier (Plate 5). Prominent and persistent bedding planes displaying solitary to clustered, often silicified, mollusc fossils and small centimetre-size conical? microbial mud or fecal mounds are common (Plates 6 to 8). The coarser beds are generally lenticular and sheet-like, although indistinct grainy zones can occur in the bedded muddy facies. The grainstones and rudstones are dominantly intraclastic and often fossiliferous (Plates 9 and 10). Large, crossbedded, aerially restricted ripple marks ornament some of the grainstones lenses that can also be silicified. The aerially restricted ripples are likely starved and locally their crests are decapitated by a planar scour (Knight *et al.*, 2008). Trilobites were newly discovered in the section west of Ship Cove, together with brachiopods, gastropods and cephalopods.

Grainstones, rich in fossil debris, have been seen onlapping small (decimetre) microbial boundstones that are also quite fossiliferous within the bedded muddy facies. A number of wackestone beds in the lower 10 m of the section west of Ship Cove are rich in dark grains of microbial origin. Traced westward over tens of metres, however, the bedded

**Plate 5.** *Recessive, rubbly weathering, stylonodular limestone alternating with more resistant beds of bioturbated dolomitic limestone. West of the Ship Cove section close to Pigeon Head. Measuring stick is 1.5 m long.*

sediments, with only a few spaced small microbial mounds close to the base of the formation at Ship Cove (Plate 11), are abruptly replaced by a skeletal–microbial mound complex that is best exposed on a narrow point of land between two faults that are the locus of Carboniferous paleovalleys or sinkholes filled by terrestrial red conglomerate and breccia (Plates 2 and 3). The microbial complex on the point consists of sheet-like bodies of large metre-size mounds of clotted and digitate thrombolite, the digitate structure forming impressive radiating fans within some parts of the complex (Plates 12 and 13). Bedded muddy limestone onlaps against the northern edge of the complex (Plate 14), sug-

**Plate 6.** *Centimetre-size mounds on a prominent bedding plane at the Ship Cove section. Hammer is 32 cm long. Lens cap (arrow) is by cephalopod of Plate 7.*

**Plate 7.** *Silicified cephalopod in a bioturbated limestone, Ship Cove section. See Plate 6. Lens cap is 5.5 cm diameter.*

**Plate 8.** *A cluster of gastropods in a bioturbated dolomitic limestone, outcrop above Lower Cove roadcut section. Penny is 1.2 cm diameter..*

**Plate 9.** *A bed of intraclastic and fossiliferous, pebbly grainstone–rudstone in the Lower Cove roadcut section. The grainstone is locally replaced by dark chert.*

gesting that it may be a large isolated robust mound buildup on the Watts Bight shelf or perhaps an arm or spur of a larger bioherm. Large cephalopods and gastropods (Plate 15) are entrapped in the mounds that are also crossed by narrow, somewhat sinuous, gulleys and wider channels filled with grainstone. The top of the bioherm is truncated by a prominent planar erosion surface (Plate 16) suggesting that the mounds either grew into the surf zone, where they were eroded, or were perhaps planed off during an interval of sea-level fall.

The Watts Bight Formation in the Lower Cove and Ship Cove sections, conformably and gradationally overlies the Berry Head Formation composed of shallowing-upward peritidal cycles of metre-thick limestone and dolostone. Stromatolitic and, locally, thrombolitic boundstone occurs in the limestone beds, which also include stylonodular and burrowed lithofacies and minor grainstone. The only macrofossil recovered from the formation is an inarticulate brachiopod found 17 m below the top of the formation. The dolostones range from laminites, some of which are mudcracked, to those that display flaser and lenticular fabrics. A number of brecciated zones mark the tops of some of the peritidal cycles in the Berry Head Formation, a feature not seen at Green Head, Isthmus Bay (Knight *et al.*, 2008, Figure 4, column A). The importance of these broken tops to the cycles is yet to be assessed. Loss of metre-thick dololaminite from the cycles occurs into the basal Watts Bight Formation, which does retain one or two shallowing-upward cycles for approximately 8 m.

The Watts Bight Formation of the Ship Cove and Lower Cove sections is interpreted to have been deposited in an open, subtidal-shelf setting that prevailed over the western

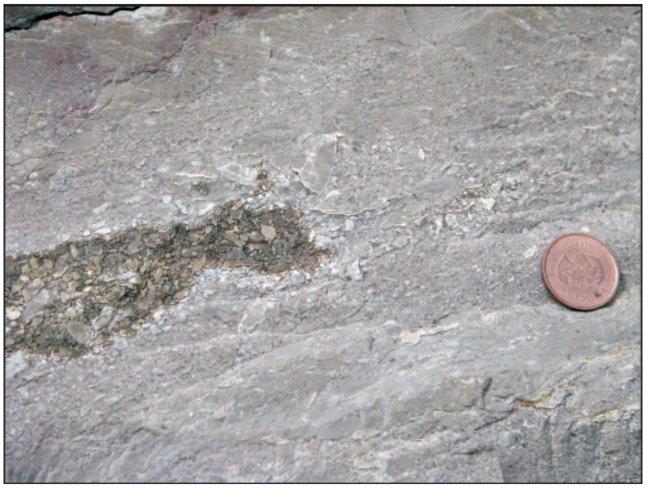


**Plate 10.** *Close up of the chert and pebbly grainstone of Plate 9. Penny is 1.2 cm diameter.*

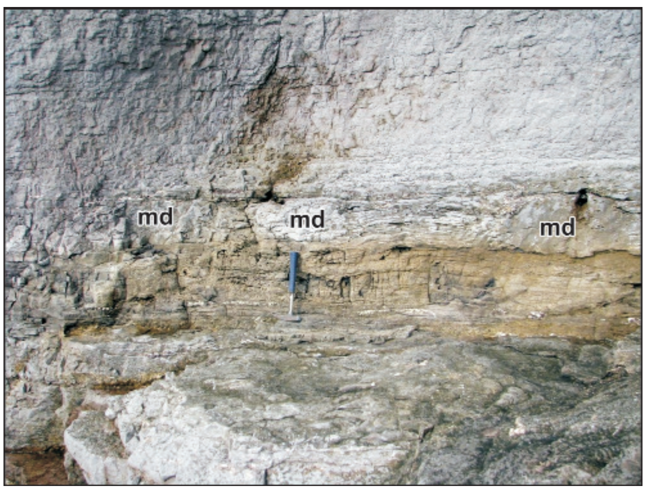



**Plate 11.** *A 30-cm-dolostone bed lying beneath well-stratified limestone near the base of the cliff section at Ship Cove. Note small boundstone mounds (md) spaced at intervals at the base of the thick limestone. Hammer is 32 cm long.*

part of the peninsula. As at Isthmus Bay, the formation appears to gradationally overlie the upper Berry Head Formation, in which stromatolitic and thrombolitic mounds are present. Nonetheless, only a few metres into the succession in the west, the succession is dominated by stylonodular and bedded to bioturbated limestones suggesting fairly rapid transgression and the deposition of subtidal muddy carbonate. The thrombolitic mound complex seen west of Ship Cove is both an impressive and robust complex but of apparently limited extent, as illustrated by the abrupt change to stratified subtidal muddy carbonates in all directions. This gives weight to the probability that the microbial buildup was local and not part of a barrier. It likely accreted into the surf zone where it was eroded, only to be abruptly overlain by the ubiquitous burrowed and stylobedded limestones, as

**Plate 12.** *The hummocky top of a bed of thrombolite boundstone mounds in the middle of the mound complex on a narrow point 150 m west of the Ship Cove section. Stratified limestones of the latter outcrop on the far side of the inlet. Arrow indicates the top of the complex. Measuring stick is 1.5 m long.*

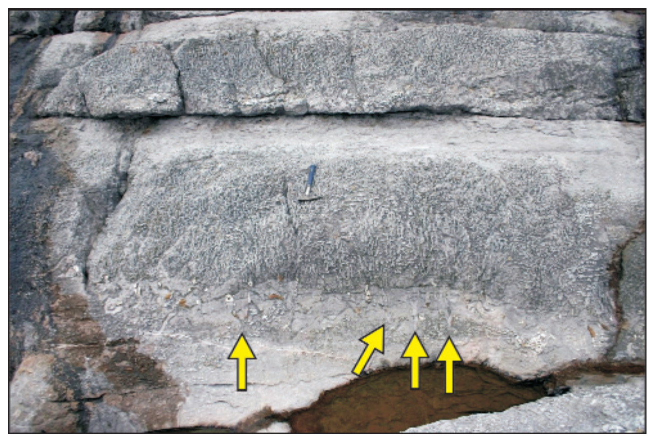


**Plate 13.** *Cross-sections of beds of thrombolitic boundstone in an impressive complex west of the Ship Cove section. Note the bush-like digitate fabric (at hammer) picked out by dolomitization and a number of vertical horn-shaped organisms (arrows), possibly sponges, below the bushes. White calcite spar lines tubular cavities of possible cephalopods. Hammer is 32 cm long.*

the shelf was drowned with continuing Skullrockian sea-level rise. This transgressive character on the part of the Watts Bight Formation, long recognized in western Newfoundland (James *et al.*, 1989), fits neatly with the Stonehenge transgression of Taylor *et al.* (1992) and is readily recognized in the microbial and shaly carbonates of the Antiklinalbugt Formation in North-East Greenland (Stouge *et al.*, *in press*; McCobb *et al.*, *in preparation*).

**Plate 14.** *Stratified limestone of the Watts Bight Formation onlapping the northern edge of the boundstone mound complex of Plates 12 and 13 to right of stick. The edge of the complex is outlined. The stratified limestone is gently curved by compaction against the mound. Measuring stick is 1.5 m long.*

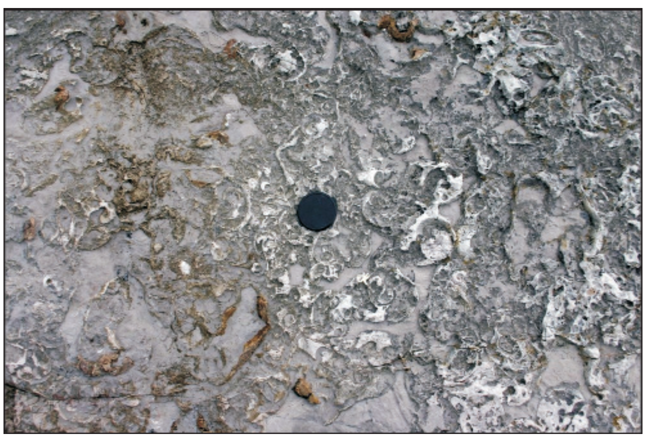


**Plate 15.** *Clustered molluscs trapped in the boundstone complex of Plates 12 to 14. Edges of small microbial heads are locally silicified. Lens cap is 5.5 cm wide.*

## BIOSTRATIGRAPHY

### WATTS BIGHT FORMATION (LOWER MEMBER)

#### Isthmus Bay Section

The lower member of the Watts Bight Formation at Isthmus Bay collectively yielded the following taxa:

Arthropoda–Trilobita
*"Hystricurus" ellipticus* (Cleland, 1900)
Brachiopoda–Articulata
*Finkelnburgia* sp. undet.
Mollusca–Cephalopoda
ellesmeroceratid gen.et sp(p). undet.
Mollusca–Gastropoda

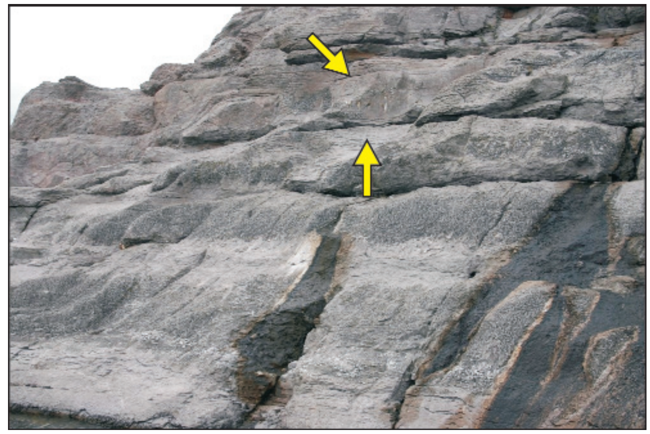


**Plate 16.** *The planated top of the thrombolitic boundstone complex (upper arrow) of Plates 12 to 15 overlain abruptly by stratified limestone. Although stratified limestone occurs in pockets in the complex (lower arrow), the planated top of the complex suggests that it was erosionally truncated before the upper stratified carbonates were deposited. Middle bed is about 40 cm thick.*

*Ecculiomphalus* sp. undet.
Gen.et sp(p). undet.
*Ophileta* sp. cf. *O. supraplana* Ulrich *in* Bridge, 1930

The only trilobite horizon is 2010F001 (Figure 4), which contains *"Hystricurus" ellipticus* (Cleland, 1900) (Plate 19B), indicative of the informal Early Canadian (Gasconadian) *"Hystricurus" ellipticus* assemblage zone of Boyce (1997) (Figure 6). This horizon was collected within the same bed as Z2-3B, approximately 20 m above the base of the formation and close to the base of the Green Head mound complex; it coincides with the bases of the shallow-water (SW) *Polycostatus falsioneotensis–Rossodus tenuis* Assemblage Zone and the deeper water (DW) *Cordylodus angulatus* Lineage Zone (Ji and Barnes, 1994a).

***1.5 km West of Ship Cove***

Trilobites were discovered in the Ship Cove section, together with brachiopods, gastropods and cephalopods (Figure 5). Between about 11.5 to 33 m above the base of the formation, the lower member collectively yielded the following:

Arthropoda–Trilobita
*Bellefontia gyracantha* (Raymond, 1910)?
*"Hystricurus" ellipticus* (Cleland, 1900)?
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937)
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003
Brachiopoda–Articulata
*Finkelnburgia* sp. undet.
Mollusca–Cephalopoda
ellesmeroceratid gen.et sp(p). undet.

| Series | Stage | Conodont Zones (Ross *et al.*, 1997) | Shelly Fossil Zones (Ross *et al.*, 1997) | Trilobite Zones - Western Newfoundland (Boyce & Stouge, 1997; Boyce, 1997; Boyce *et al.* 1992, 2000) |
|---|---|---|---|---|
| Ibexian Series | Blackhillsian | Ra *Reutterodus andinus* | Hm *Hesperonomiella minor*<br>Pn *Pseudocybele nasuta* | HIATUS<br>*Cybelopsis speciosa*<br>*Gignopeltis rarus* |
| | Blackhillsian | Oc *Oepikodus communis* | Pi *Presbynileus ibexensis*<br>Tt *Trigonocerca typica* | *Benthamaspis gibberula*<br>*Strigigenalis caudata* |
| | Tulean | AO *Acodus deltatus-Oneotodus costatus* | Pc *Protopliomerella contracta* | *Strigigenalis brevicaudata*<br>*Peltabellia knighti* |
| | Tulean | | Hc *Hintzeia celsaora* | HIATUS |
| | Stairsian | Md *Macerodus dianae* | Rs *Rossaspis superciliosa*<br>Te *Tesselacauda* | *Randaynia saundersi*<br>*Leiostegium proprium*<br>*Hystricurus oculilunatus* |
| | Stairsian | LD "Low diversity interval" | LK *Leiostegium-Kainella* | HIATUS |
| | Stairsian | Rm *Rossodus manitouensis* | Pa *Paraplethopeltis* | Barren interval |
| | Skullrockian | Ca *Cordylodus angulatus*<br>Ia *Iapetognathus* n. sp.<br>Cl *Cordylodus lindstromi*<br>Ci *Cordylodus intermedius* | BX *Bellefontia-Xenostegium*<br>Sy *Symphysurina* | *Parahystricurus* sp. I<br>*"Hystricurus" ellipticus*<br>*"Millardicurus millardensis"* |
| | Skullrockian | | Mi *Missisquoia* | *Missisquoia typicalis* |
| | Skullrockian | Cp *Cordylodus proavus* | Ea *Eurekia apopsis* | |

**Figure 6.** *Trilobite biostratigraphy of the St. George Group in western Newfoundland, after Boyce (1989, 1997), Boyce and Stouge (1997) and Boyce* et al. *(1992a, b; 2000). The Ibexian conodont and trilobite zonations of Ross* et al. *(1997) are also shown.*

Mollusca–Gastropoda
Gen.et sp(p). undet.

*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) and *Symphysurina myopia* Westrop (Plates 17 and 18) range through much of the section; below 19 m into the section they are assigned to the *"Millardicurus millardensis"* assemblage zone of Boyce (1997). The appearance of "*Hystricurus" ellipticus*? at 2010F034 (Plate 19A) at the 19 m level in the Ship Cove section marks the base of the "*H." ellipticus* assemblage zone (Figure 6). The species occurs no more than a few centimetres above 2010F033, which contains *Bellefontia gyracantha* (Raymond, 1910)? (Plate 20).

## Discussion and Correlation

The Ibexian Series (Ross *et al.*, 1997) is currently used as the correlation standard for latest Cambrian–Early Ordovician sedimentary rock sequences developed around the ancient continental margin of Laurentia. It was proposed to replace the previously utilized Canadian Series. The Ibexian Series is defined in the Notch Peak, House, Fillmore and Wah Wah formations of the Great Basin (western United States), that formed a major depo centre on the northern paleo-margin of Laurentia. In ascending order, it is subdivided into the following stages: Skullrockian, Stairsian, Tulean and Blackhillsian. The bases of these stages are

**Plate 17.** (opposite page) Millardicurus *sp. cf.* M. armatus *(Poulsen, 1937) from the Watts Bight Formation, 1.5 km west of Ship Cove. A-D) Cranidia from 2010F025. A) Field photograph of* in situ *mold. B) Dorsal view of clay replica (NFM F-795). C) Field photograph of* in situ *mold, showing occiptal spine. D) Dorsal view of clay replica (NFM F-796). E). Librigena, dorsal view of clay replica (NFM F-797) from 2010F026. Length of lateral border is about 1.5 cm. F) Librigena, dorsal view of clay replica (NFM F-798) from 2010F039. Length of lateral border is about 0.8 cm.*

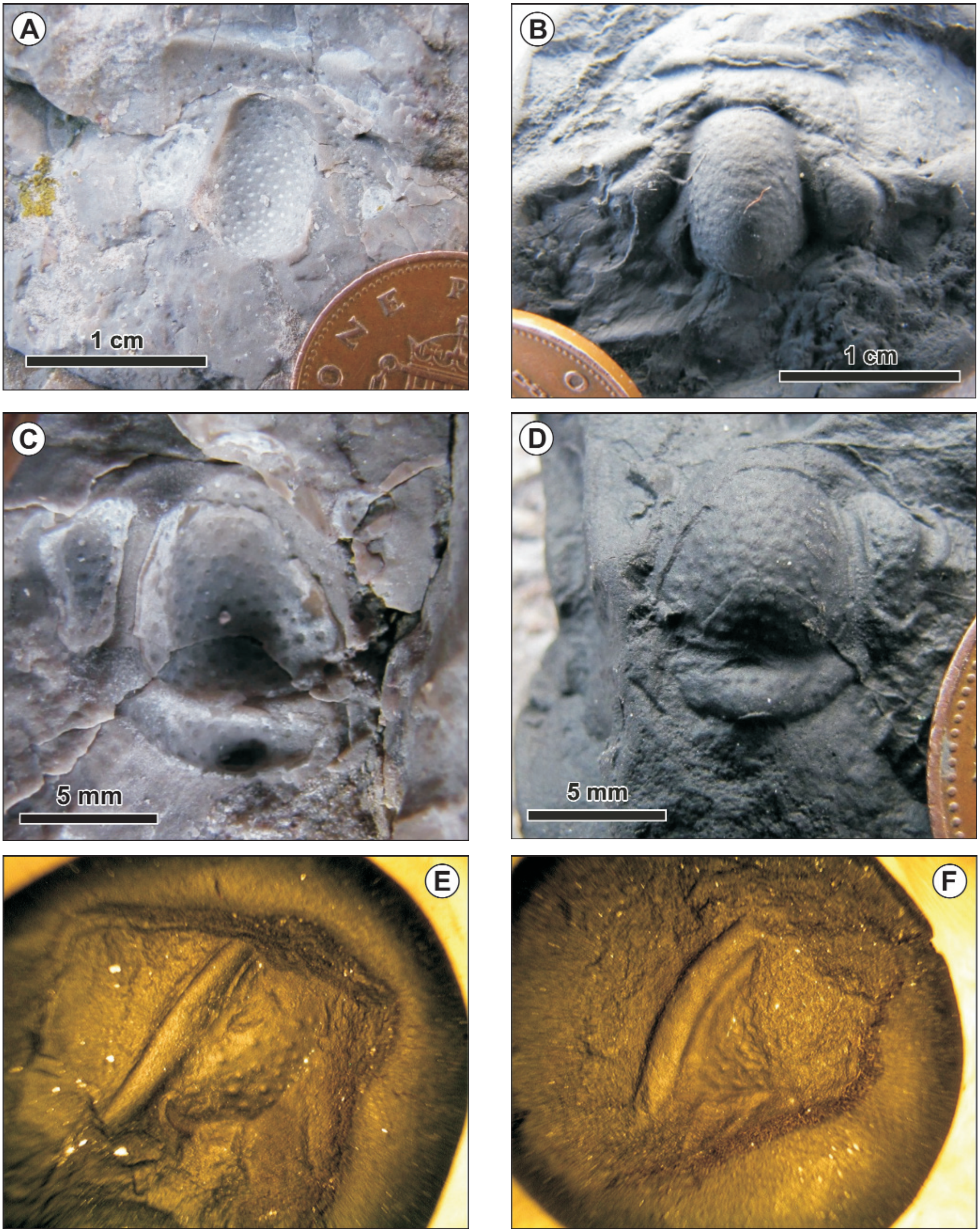



**Plate 17.** *Caption on opposite page.*

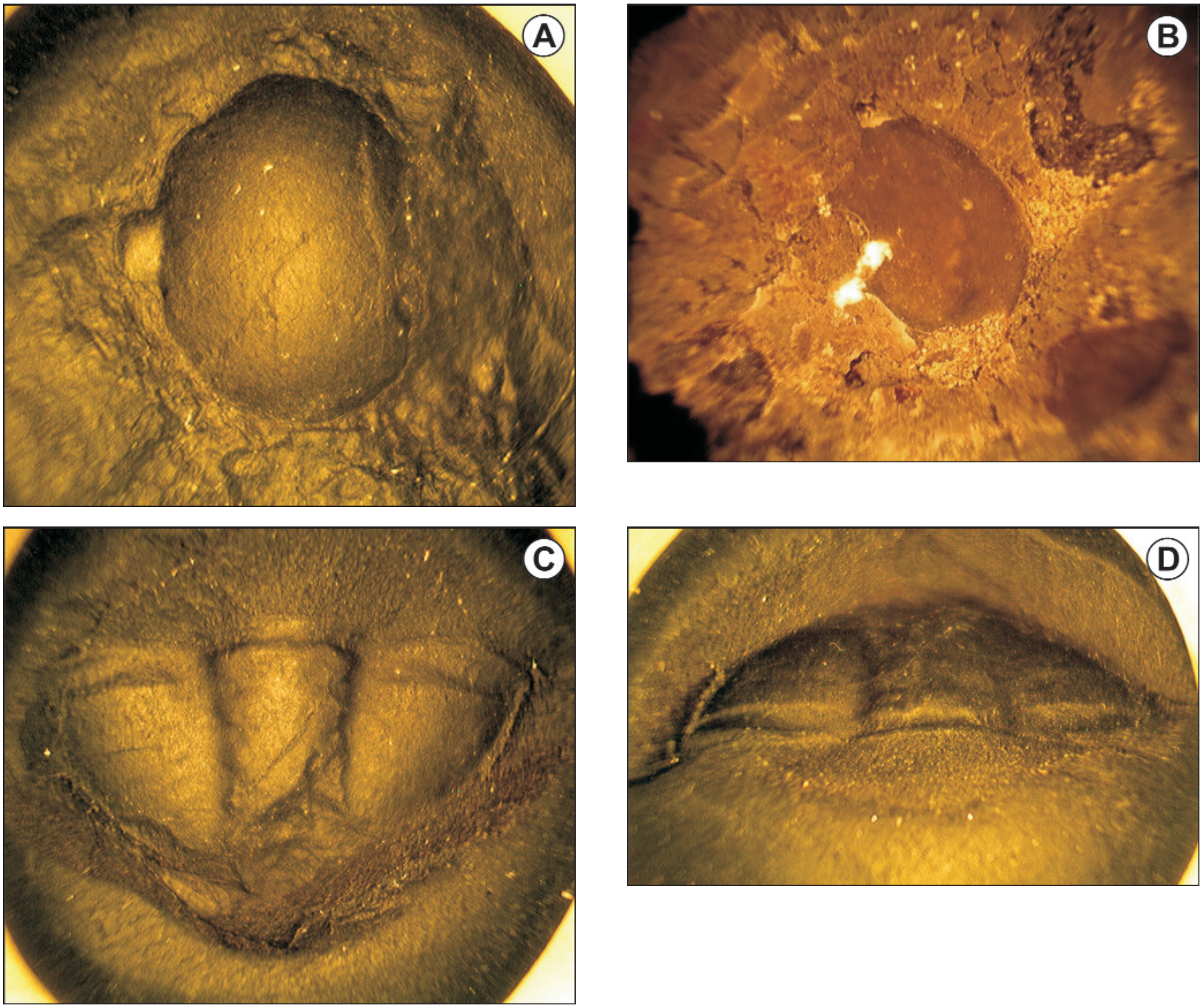
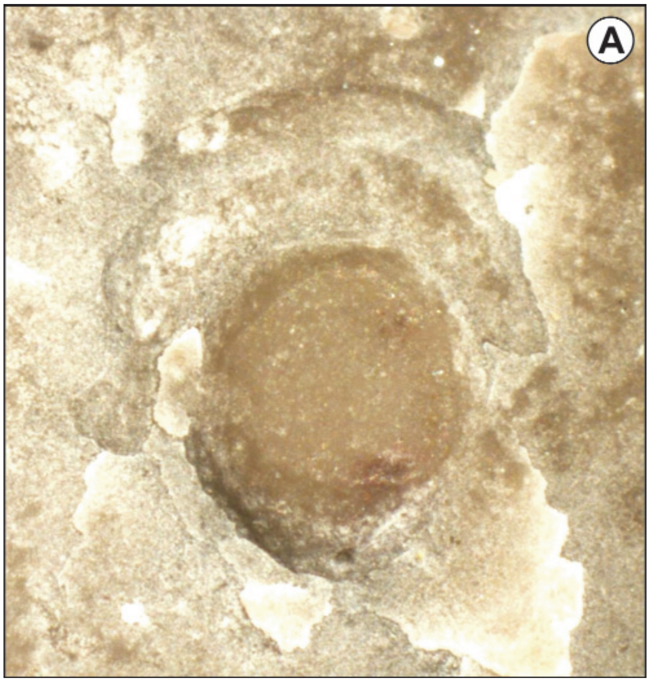



**Plate 18.** Symphysurina myopia *Westrop* in *Landing* et al., 2003 *from the Watts Bight Formation, 1.5 km west of Ship Cove. A) Cranidium, dorsal view of clay replica from 2010F024 (NFM F-799), showing characteristic tiny palpebral lobe. Length is about 1 cm. B) Librigena, dorsal view (NFM F-800) from 2010F030. Width is about 0.5 cm. C-D) Pygidium, dorsal and inclined anterior views of clay replica from L.M.E. McCobb's discovery horizon 2010F036 (NFM F-801). Width is about 1.8 cm.*

defined by the First Appearance Datums (FADs) of individual trilobite species. The stages are further subdivided into zones, again based on trilobites, except for the *Hesperonomiella minor* brachiopod zone at the top of the Ibexian. A subordinate conodont zonation is defined within the Ibexian sequence.

Generally, trilobite-based correlations with regions outside the Ibexian type area of Northern Laurentia are difficult, owing to a lack of common species (Loch, 2007, pages 8 and 9). In practice, most correlations are done using the widespread conodont taxa. Boyce (2010a, b) recommended that the trilobite-based stages of the Ibexian Series be redefined on the basis of the conodont faunas, to better reflect this reality.

Trilobite-based correlations are straightforward along the length of the Caledonian–Appalachian–Ouachita Orogen within Southern Laurentia (*e.g.*, northwest Scotland, western Newfoundland, New York, Oklahoma, Missouri, Arkansas), due to the wealth of common trilobites and other macrofossil taxa. It is this belt of rocks for which the Canadian Series was originally proposed.



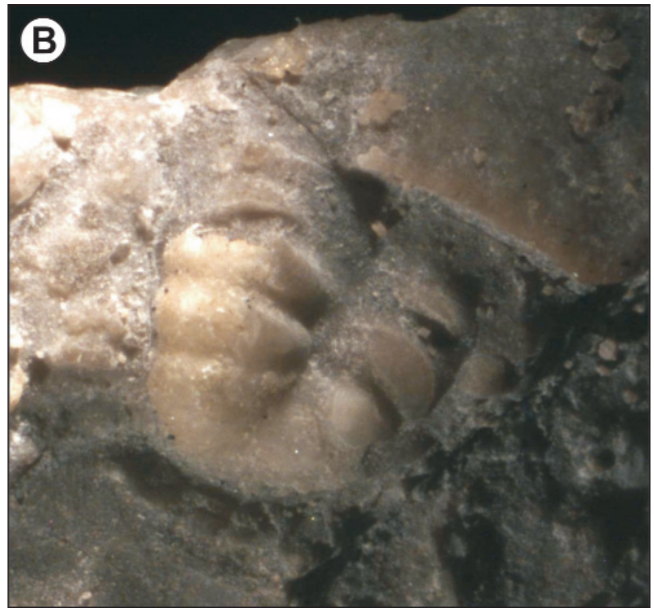




**Plate 19.** "Hystricurus" ellipticus *(Cleland, 1900) from the Watts Bight Formation. A) Cranidium (NFM F-802), dorsal view, showing prosopon of tubercles, from 2010F034, section 1.5 km west of Ship Cove. Width is about 3mm; B) Pygidium (NFM F-803), oblique dorsal view, from 2010F001, Isthmus Bay section. Length is about 3 mm.*

**Plate 20.** Bellefontia gyracantha *(Raymond, 1910)? from the Watts Bight Formation, 1.5 km west of Ship Cove. Cranidium, dorsal view of clay replica from 2010F033 (NFM F-804). Length is about 1.5 cm.*

**Conodonts**

The Watts Bight Formation in each section studied is rich in conodonts spanning the deeper water (DW) *Cordylodus lindstromi* to *Cordylodus angulatus* Lineage Zones (Ji and Barnes, 1994a - Figures 18, 19 and 20). The basal contact of the formation with the Berry Head Formation lies within the *Cordylodus lindstromi* Lineage Zone and is replaced within the first 20 to 30 m of the Watts Bight Formation at each section by *C. angulatus* Lineage Zone. The latter extends to the top of the middle member 12 m below the top of the formation (Ji and Barnes, 1994a; Knight *et al.*, 2008); only scattered conodonts occur in the upper boundstone member. Above the guttered, erosional contact with the Boat Harbour Formation (Knight *et al.*, 2008), conodonts of the *C. angulatus* zone are abruptly replaced by the rich fauna of the shallow-water (SW) *Rossodus manitouensis–Polycostatus sulcatus* Assemblage Zone of Ji and Barnes (1994a), which terminates at the disconformity at the top of the Lower member of the Boat Harbour Formation.

*"Hystricurus" ellipticus* and *Bellefontia gyracantha*? at Ship Cove occur approximately 19 m above the bed picked as the base of the formation. This essentially coincides with the LAD[1] of *Teridontus nakamurai* (Nogami, 1967) and the FAD[2] of *Cordylodus angulatus* Pander, 1856, *Teridontus obesus* Ji and Barnes, 1994a and *Variabiloconus bassieri* (Furnish, 1938). *Cordylodus lindstromi* Druce and Jones, 1971 occurs only once, 6 m below *C. angulatus*. *"Hystricurus" ellipticus* also occurs 20 m above the base of the formation close to the base of the Green Head mound complex at Isthmus Bay. Its occurrence coincides with the bases of the deeper water (DW) *Cordylodus angulatus* Lineage Zone and the shallow-water (SW) *Polycostatus falsioneotensis*[3]*–Rossodus tenuis* Assemblage Zone as well as the tops of the shallow-water (SW) *Teridontus nakamurai–Semiacontiodus nogamii* Assemblage Zone and the deeper water (DW) *Cordylodus lindstromi* Lineage Zone.

At the Lower Cove section, the FAD of *C. angulatus*, *V. bassleri* and *Loxodus bransoni* Furnish, 1938 and the LAD of *T. nakamurai* and *Semiacontiodus nogamii* (Miller, 1969) occur approximately 30 m above the base of the formation. *C. lindstromi* is recovered only 20 m below the contact within the Berry Head Formation and the FAD of *Cordylodus intermedius* Furnish, 1938 and *Semiacontiodus iowensis* (Furnish, 1938)[4] coincides with the base of the formation.

### Trilobites

The trilobite zonation proposed by Boyce (1997) and Boyce and Stouge (1997) for the uppermost Berry Head Formation and the Watts Bight Formation in western Newfoundland is a composite, informal zonation, based on scattered, impoverished collections. In ascending order, it comprises, the "*Millardicurus millardensis"*[5], "*Hystricurus" ellipticus*[6], and *Parahystricurus* sp. I, assemblage zones.

In the Watts Bight Formation on Port au Port Peninsula, the "*Millardicurus millardensis"* assemblage zone extends to the base of the overlying "*Hystricurus" ellipticus* assemblage zone. Fortey and Skevington (1980) and Fortey *et al.* (1982) described *Hystricurus millardensis* Hintze, 1953 from allochthonous boulders in the Cow Head Group – in the Broom Point Member of the Green Point Formation at Broom Point. The species was subsequently reported from a limestone bed in the uppermost Berry Head Formation a few metres below the base of the Watts Bight Formation at Goose Arm (Knight and Boyce, 1991).

The type occurence of *Hystricurus millardensis* Hintze, 1953 is in the Barn Canyon Member of the House Formation, in the southern House Range, Ibex area of western Utah where it occurs low in the early Skullrockian *Symphysurina brevispicata* Subzone of the *Symphysurina* Zone (Hintze, 1953, page 168; Plate VI, Figures 17-21; Adrain and Westrop, 2006a, pages 658-663; Figures 7-9). Recent trilobite studies in the Ibex area however, (Adrain *et al.*, 2003; Adrain and Westrop, 2006a, b) created uncertainty concerning trilobites of the genus *Hystricurus* Raymond, 1913. They substantially revised the trilobite genus, based on silicified material, erecting many new genera to accommodate the numerous species assigned to that genus by Ross (1951) and Hintze (1953). Whereas at least forty-eight species previously were recognized, Adrain *et al.* (2003, page 562) restricted *Hystricurus* to the following:

- *Hystricurus conicus* (Billings, 1859)
- *Hystricurus deflectus* Heller, 1954
- *Hystricurus eos* (Kobayashi, 1955)
- *Hystricurus oculilunatus* Ross, 1951
- *Hystricurus* sp. cf. *H. deflectus* Heller, 1954 of Adrain *et al.* (2003, pages 563-564; Figures 4D, H, L)
- *Hystricurus* sp. nov. A of Adrain *et al.* (2003, page 563; Figures 4B, F, J)
- *Hystricurus* sp. nov. B of Adrain *et al.* (2003, page 563; Figures 4C, G, K)

Adrain and Westrop (2006a) made *H. millardensis* the type species of their new genus *Millardicurus*. In their review of the species, they concluded that many reports of *M. millardensis* outside the type area were erroneous and that the Cow Head material of Fortey and Skevington (1980) and Fortey *et al.* (1982) represented a new unnamed species, which they termed *Millardicurus* new species A (Adrain and Westrop, 2006a, pages 669-670). As the identification of the

[1] Last Appearance Datum
[2] First Appearance Datum
[3] Landing *in* Landing *et al.* (1996, page 676) regards *Polycostatus falsioneotensis* Ji and Barnes, 1994a as a junior synonym of *Semiacontiodus iowensis* (Furnish, 1938).
[4] *Polycostatus falsioneotensis* Ji and Barnes, 1994a and *Polycostatus sulcatus* (Furnish, 1938) — see Landing *in* Landing *et al.* (1996, page 676).
[5] formerly *Hystricurus millardensis*.
[6] formerly *Hystricurus ellipticus*.

Goose Arm material is now uncertain and has yet to be re-examined, the assemblage zone is designated here *"Millardicurus millardensis"*.

The *"Hystricurus" ellipticus* assemblage zone is known only from the two sections at Ship Cove and Isthmus Bay, where it is restricted to a very narrow interval, low in the formation; it is associated with *Bellefontia gyracantha* (Raymond, 1910) at Ship Cove. Its association with the FAD of *C. angulatus* at both sections indicates a Skullrockian *C. angulatus* Zone age. Because Adrain *et al.* (2003) did not recognize *Hystricurus ellipticus* (Cleland, 1900) as a species of their restricted genus, the use of *"Hystricurus" ellipticus* (Cleland, 1900) here reflects this generic uncertainty.

The upper *Parahystricurus* sp. I assemblage zone is recognized in the Watts Bight Formation at Fish Point (near Eddies Cove West) and from transported strata on the Brent Islands in the Hare Bay–Pistolet Bay thrust stack. In both cases, the only trilobite present is *Parahystricurus* sp. I of Ross (1951), recovered from a white grainstone–boundstone association close to the top of the formation. This zone has not been found on the Port au Port Peninsula.

**Correlation**

*Bellefontia gyracantha* (Raymond, 1910)?,*"Hystricurus" ellipticus* (Cleland, 1900) and *Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 indicate a correlation with the Tribes Hill Formation and equivalents of New York State, USA (Cleland, 1900, 1903; Fisher, 1954; Flower, 1968; Fisher and Mazzulo, 1976; Westrop *et al.*, 1993; Landing *et al.*, 1996, 2003). There, they are grouped in the *Clelandia parabola* fauna and are correlated with the *Bellefontia franklinense* subzone of the McKenzie Hill Formation of Oklahoma (Stitt, 1983; Westrop *et al.*, 1993).

According to Fisher (1954), *Bellefontia gyracantha* (Raymond, 1910) occurs in his Fort Johnson, Palatine Bridge, Wolf Hollow and Fonda members of the Tribes Hill Formation, whereas *"Hystricurus" ellipticus* (Cleland, 1900) is restricted to the Fonda member. Westrop *et al.* (1993, page 1618) found Fisher's members "difficult to apply consistently in the field" and treated the Tribes Hill Formation as an undivided disconformity-bounded unit between the underlying Little Falls Dolomite (Cambrian) and the overlying Middle Ordovician Black River or Trenton groups. Consequently, Landing *et al.* (1996) proposed a new internal stratigraphy for the Tribes Hill Formation: the Sprakers Member (new), Van Wie Member (new), Wolf Hollow Member (revised) and Canyon Road Member. *"H." ellipticus* ranges from the Van Wie Member to the lower Canyon Road Member while *B. gyracantha* ranges from the upper Sprakes Member to the Canyon Road Member (Westrop *et al.*, 1993, page 1621-1622, Figures 6, 7 and 8 utilizing Landing *et al.*, 1996, Figures 2 and 3, pages 658-659); only in three sections do the two species overlap. *Symphysurina myopia* Westrop (*in* Landing *et al.*, 2003) occurs in the Wolf Hollow Member of the Tribes Hill Formation at the Tristates Quarry, New York, where it is associated with *Hystricurus* sp. and the conodont species *Loxodus bransoni* Furnish, 1938 and *Scalpellodus longipinnatus* Ji and Barnes, 1994a.

The conodont fauna from the upper part of the underlying Little Falls Formation comprises *Clavohamulus elongatus* Miller, 1969, *Teridontus nakamurai* (Nogami, 1967), *Monocostodus sevierensis* (Miller, 1969) and *Semiacontiodus nakamurai* Miller, 1969; it correlates with the *Clavohamulus elongatus* Subzone of the *Cordylodus proavus* Zone (Landing *et al.*, 1996, page 661). The Little Falls Formation also contains *Millardicurus* new species A (Adrain and Westrop, 2006a, page 669).

According to Landing *et al.* (1996, page 661), *Acanthodus uncinatus* Furnish, 1938, *Cordylodus angulatus* Pander, 1856, *Laurentoscandodus triangularis* (Furnish, 1938), *Semiacontiodus iowensis* (Furnish, 1938), *Variabiliconus bassleri* (Furnish, 1938) and *Variabiliconus? lineatus* (Furnish, 1938) abruptly appear in the lower 1.5 m of the the Sprakers Member and are joined by *Loxodus bransoni* Firnish, 1938 at 2.3 m above the base.

Landing *et al.* (2003, page 94, Figure 12) indicated a *Rossodus manitouensis* age for the Tribes Hill Formation, but Kröger and Landing (2007, page 842, Figure 2) preferred a *Cordylodus angulatus* to mid-*Rossodus manitouensis* age range supported by the presence of *C. angulatus* at its base. This indicates that the Tribes Hill Formation correlates both with the Watts Bight Formation and the Lower member of the Boat Harbour Formation. Unlike the Tribes Hill Formation that rests disconformably upon eroded Late Cambrian Little Falls Formation, the Watts Bight Formation rests gradationally upon the Berry Head Formation.

The lower Watts Bight Formation also likely correlates closely with the Stonehenge Formation of Pennsylvania, Maryland and northern Virginia (Taylor *et al.*, 1992).

*Millardicurus armatus* (Poulsen, 1937) is an abundant fossil in the Antiklinalbugt Formation (Fimbulfjeld Group) of North-East Greenland; it figures prominently in the collections of Poulsen (1937), Cowie and Adams (1957), as well as those made in 2000 by W.D. Boyce and I. Knight. Furthermore, *Symphysurina* occurs at various levels and in all 'members' of the Antiklinalbugt Formation, often co-occurring in samples with *M. armatus.* The numerous species present, whilst not including *S. myopia*, indicate a biostratigraphic range equivalent to the '*S. brevispicata* Subzone' to '*S. bulbosa* Subzone' of the type Ibex area (Loch *et al., in* Miller *et al.*, 2003). A probable *Bellefontia* pygidium was collected from the Middle Limestone-Shale of the Antiklinalbugt Formation by Boyce and Knight in 2000, and a similar pygidium is found in the Cowie and Adams (1957) collection, further supporting correlation with the Watts Bight Formation, and providing evidence for an upper biostratigraphic range corresponding to the *Bellefontia* Zone (Stitt, 1983). The orthid brachiopod *Finkelnburgia* is also a common member of both the Watts Bight and Antiklinalbugt Formation faunas (McCobb *et al*., 2009); it was first identified in the Isthmus Bay section by G.A. Cooper *in* Whittington and Kindle (1969, page 658). The Antiklinalbugt Formation spans *Cordylodus intermedius* to *Rossodus manitouensis* conodont zones however, (Stouge *et al.*, *in press*; McCobb *et al.*, *in preparation*) suggesting that it is longer lived than the Watts Bight Formation and is also time equivalent of some part of the Berry Head Formation as well as the Lower member of the Boat Harbour Formation. Interestingly, the Antiklinalbugt Formation in North-East Greenland terminates at a disconformity that spans the Stairsian, an interval when the Middle member of the Boat Harbour Formation was being laid down

## CONCLUSIONS

1. The Watts Bight Formation's tripartite stratigraphy at the Isthmus Bay section is not regionally developed westward across the expanse of the Port au Port Peninsula. The biohermal mound facies, so common at Isthmus Bay, forms only geographically isolated biohermal complexes near the base of the formation, as it is traced to the west. Sections in the middle of the peninsula at Ship Cove and Lower Cove are instead dominated by subtidal, stylonodular and burrowed, fossiliferous lime mudstone and wackestone and commonly occuring lenses of storm derived, intraformational grainstone and rudstone and some small patches of microbial boundstone.
2. The Ship Cove–Lower Cove succession is indicative a more open, subtidal shelf setting.
3. Trilobites of the lower Watts Bight Formation on the Port au Port Peninsula are assigned to informal *"Millardicurus millardensis"* and *"Hystricurus" ellipticus* assemblage zones of western Newfoundland. *Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) and *Symphysurina myopia* Westrop *in* Landing *et al*., 2003 are the most common and longest ranging trilobites in the Ship Cove section. The associated conodonts indicate a correlation with the Skullrockian *Symphysurina brevispicata* to *S. bulbosa* trilobite subzones of the type Ibex area.
4. *Hystricurus ellipticus* and *Bellefontia gyracantha* (Raymond, 1910)?, assigned to the informal *H. ellipticus* assemblage zone, occur together low in the formation; the assemblage zone appears to coincide with the base of the *C. angulatus* Lineage Zone of Ji and Barnes (1994a).
5. The lower member of the Watts Bight Formation correlates with the Tribes Hill Formation of New York State, McKenzie Hill Formation of Oklahoma and the Antiklinalbugt Formation of North-East Greenland.

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*Note: Geological Survey file numbers are included in square brackets.*

**APPENDICES — Macrofossil horizons in the lower member of the Watts Bight Formation (St. George Group), Port au Port Peninsula, NTS 12B/10 (Stephenville), UTM Zone 21, NAD27**

"1978F", "2007F", "2008F", "2009F" and "2010F" = W.D. Boyce's macrofossil samples. "Z2-" = conodont horizons of Ji and Barnes (1994a, page 76) and Zhang and Barnes (2004a, b). The UTM coordinates and the altitude are shown in metres as indicated by GPS. "(+)" and "(-)" signify fossil casts and moulds, respectively.

## APPENDIX 1 – Isthmus Bay Section

**2008F031 = Z2-11**
371954E, 5378319N, 9 m.

Mollusca–Gastropoda
*Ecculiomphalus* sp. undet.

**2010F002 = Z2-4**
371923E, 5378251, 1 m.

Brachiopoda–Articulata
*Finkelnburgia* sp. undet.
Mollusca–Cephalopoda
ellesmeroceratid gen.et sp. undet.
Mollusca–Gastropoda
Gen.et sp(p). undet.

**2010F001 = 2008F005[7] = 2007F060[8] = 2007F059[9] = 1978F162[10] = 1978F011 = Z2-3B**
Green Head mound complex. 371924E, 5378216, 1.9 m.

Arthropoda–Trilobita
*"Hystricurus" ellipticus* (Cleland, 1900) – cranidium (+)[11], pygidium (-)– see Plate 19B
Brachiopoda–Articulata
*Finkelnburgia* sp. undet.
Mollusca–Cephalopoda
ellesmeroceratid gen.et sp(p). undet. – in mound[12]
Mollusca–Gastropoda
Gen. et sp(p). undet. – in mound[13]
*Ophileta* sp. cf. *O. supraplana* Ulrich *in* Bridge, 1930 – in interfill

**Note:** This is the *Diphragmoceras* Bed of Flower (1978).

7 371923E, 5378220N, 8 m
8 371922, 5378220, 7 m
9 371927E, 5378228N, 10 m
10 P.A.P. - 1 (Port au Port 1).
11 collected in 1977 by Dr. R.K. Stevens; subsequently identified by W.D. Boyce.
12 Photographed, not collected.
13 Photographed, not collected.

**APPENDIX 2 – 1.5 km west of Ship Cove**

**2010F041**
Flaggy rubble by coastal (ATV?) trail/road. 353008, 5375205, 28 m.

Mollusca–Gastropoda
Gen. et sp. undet.

**2010F040**
352962, 5375215, 28 m.

Mollusca–Cephalopoda?
Gen. et sp. undet.
Mollusca–Gastropoda
Gen. et sp. undet.

**2010F039**
352952, 5375210, 29 m.

Arthropoda–Trilobita
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) – librigenae (+, -) – see Plate 17F

**2010F038**
Stratigraphically above 2010F037, below 2010F039.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 –pygidium (+)

**2010F037**
White-weathering rubble. 352946, 5375186, 23 m.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – cranidium (+)

**2010F036**
L.M.E. McCobb's discovery horizon. 352968, 5375170, 28 m.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – pygidium (-) –see Plate 18C, D

**2010F035**
White-weathering rubble. 352938, 5375183, 25 m.

Arthropoda–Trilobita
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) — librigena (-)
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 — cranidium (-), pygidia (+, -)

**2010F034**
352968, 5375170, 26 m.

Arthropoda–Trilobita
*"Hystricurus" ellipticus* (Cleland, 1900)? – tiny cranidium (+)– see Plate 19A

**2010F033**
352955, 5375172, 19.3 m.

Arthropoda–Trilobita
*Bellefontia gyracantha* (Raymond, 1910)? –see Plate 20
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003

**2010F032**
352935, 5375182, 26 m.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003

**2010F031**
~ 1.0 m above 2010F029.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – cranidium(-)

**2010F030**
Stratigraphically above 2010F029, below 2010F031.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – librigena (+) – see Plate 18B

**2010F029**
Prominent, flat bedding plane; lots of fossils were "circled". 352943, 5375156, 22 m.

Arthropoda–Trilobita
Gen.et sp. undet.
Brachiopoda–Articulata
Gen.et sp. undet.

**2010F028**
~ 0.50 m below 2010F029. 352924, 5375167, 15 m.

Arthropoda–Trilobita
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) –cranidium (+)
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – pygidium (+)

**2010F027**
352924, 5375167, 12 m.

Mollusca–Gastropoda
Gen. et sp. undet.

**2010F026**
Mound-flanking and -capping beds 352940, 5375157, 14 m.

Arthropoda–Trilobita
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) – cranidia (+, -), librigenae (+, -) – see Plate 17E
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003
Brachiopoda–Articulata
*Finkelnburgia* sp. undet.

**2010F025**
Mound bed.

Arthropoda–Trilobita
*Millardicurus* sp. cf. *M. armatus* (Poulsen, 1937) –cranidia (-); clay and latex replicas made, photographed – see Plate 17A-D
Brachiopoda–Articulata
*Finkelnburgia* sp. undet.
Mollusca–Cephalopoda
Gen. et sp. undet.

**Note:** 2010F025 and 2010F026 are separate but partly equivalent samples.

**2010F024**
Stratigraphically unlocated material between 2010F025 and 2010F040.

Arthropoda–Trilobita
*Symphysurina myopia* Westrop *in* Landing *et al.*, 2003 – cranidium (-) – see Plate 18A
Mollusca–Cephalopoda
ellesmeroceratid gen. et sp. undet.
Mollusca–Gastropoda
Gen. et sp. undet.