

EARLY ORDOVICIAN TRILOBITE FAUNAS OF  
THE BOAT HARBOUR AND CATOCHE FORMATIONS  
(ST. GEORGE GROUP) IN THE BOAT HARBOUR-  
CAPE NORMAN AREA, GREAT NORTHERN  
PENINSULA, WESTERN NEWFOUNDLAND

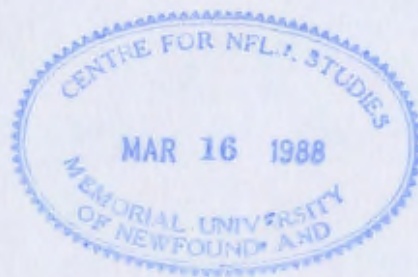
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EARLY ORDOVICIAN TRILOBITE FAUNAS OF THE BOAT HARBOUR AND  
CATOCHE FORMATIONS (ST. GEORGE GROUP) IN THE BOAT HARBOUR -  
CAPE NORMAN AREA, GREAT NORTHERN PENINSULA, WESTERN NEWFOUNDLAND

by



William Douglas Boyce, B.Sc. (Honours)

A Thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science

Department of Earth Sciences,  
Memorial University of Newfoundland

St. John's

December, 1983

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ABSTRACT

Detailed biostratigraphic sampling of the Lower Ordovician Boat Harbour and Catoche Formations in the Boat Harbour - Cape Norman area of western Newfoundland has yielded hitherto unrecorded trilobite faunas so far unparalleled in richness and diversity anywhere in the Appalachians.

Thirty species are systematically treated. Three new genera are proposed (Randaynia, Magnusnasus and Parapeltabellia). Seventeen species are new (Leiostrigium proprium, Randaynia saundersi, R. langdoni, Hillyardina minuspustulata, H. levis, Hystricurus pseudoculilunatus, Magnusnasus proprius, Parahystricurus smithiae, Bolbocephalus stevensi, Jeffersonia angustimarginata, Parapeltabellia botharbourensis, Peltabellia knighti, P. pseudopeltabella, Strigigenalis brevicaudata, Grinnellaspis newfoundlandensis, Uromystrum forteyi and Benthamaspis hintzei). Hyperbolochilus Ross is a junior synonym of Hillyardina Ross.

Five new biostratigraphic zones are proposed, three of which are based on trilobites. These zones, in ascending order, are as follows:

- 1) Barren Interzone I,
- 2) Randaynia saundersi Assemblage Zone,
- 3) Barren Interzone II,
- 4) Strigigenalis brevicaudata Range Zone and
- 5) Strigigenalis caudata Range Zone.

These zones are correlated with the standard trilobite zonation of the proposed Ibexian Series as well as the stages of the classical Canadian Series.

A major Early Ordovician (Late Tremadoc - Early Arenig) faunal and sedimentological break is documented in western Newfoundland. The disconformity represented by a solution surface and pebble horizon is documented faunally by the absence of Ross-Hintze trilobite zone G1. This break is correlated with comparable breaks in the four major trilobite provinces which then existed, and it is proposed that these breaks are related to a world-wide Late Tremadoc - Early Arenig regressive event followed by a Early Arenig transgressive event.

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This thesis is dedicated to C.H. Kindle, pioneering western Newfoundland paleontologist.

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"Remember that trilobites, with few exceptions - mainly Cullison's work, are poorly known in the Canadian of the Ozarks, Mississippi Valley and Appalachians" (Flower, written communication, December 27, 1978).

## 1. INTRODUCTION

### 1.1 Problems

For over a century there has been a distinct paucity of systematic paleontological research into the trilobite faunas of the autochthonous Early Ordovician St. George Group of western Newfoundland. Until recently the most comprehensive treatment was that of Billings (1865). There are two reasons for this. Firstly, the lithostratigraphy of the Cambrian-Ordovician carbonates as a whole was poorly understood and secondly, most previous work was large-scale regional geological mapping.

Before the breakthrough studies of Stevens (1970), Knight (1977a,b, 1978, 1980a,b, 1983), Levesque (1977), Knight and Saltman (1980), Klappa et al. (1980), Stouge and Godfrey (1982) and Pratt and James (1982), the lithostratigraphy of the St. George and Table Head Groups was poorly understood. With the exception of Schuchert and Dunbar (1934), Kindle (1945) and Johnson (1949), most previous workers labored under the erroneous assumptions that the St. George Group consisted primarily of sparsely fossiliferous dolostone and that only the autochthonous Table Head Group and the allochthonous Cow Head Group contained any appreciable amount of fossiliferous Ordovician limestone (e.g. Oxley, 1953; Nelson, 1955; Woodard, 1957). Consequently, with the exception of Billings (1865), Raymond (1913, 1925), Kindle (1945), Johnson (1949) and Whittington (1953), most previous paleontological investigations have concentrated on the Table Head Group (Whittington,

1961, 1965, 1968; Whittington and Kindle, 1963, 1969) and the Cow Head Group (Rasetti, 1954; Kindle and Whittington, 1958; Whittington, 1961, 1963, 1968; Whittington and Kindle, 1963, 1969). Of the studies including trilobites from the St. George Group only Billings (1865), Raymond (1913, 1925) and Whittington (1953) provided detailed systematic descriptions.

Most of the original studies done in western Newfoundland were large-scale regional mapping efforts in relatively inaccessible terrain (e.g. Cooper, 1937; Betz, 1939; Walthief, 1949; Oxley, 1953; Nelson, 1955; Woodard, 1957; Baird, 1960; Lilly, 1961, 1963) some of which were summarized and augmented by Cumming (1983). The time demands of producing geological maps and reports in such areas presumably discouraged determined fossil searches and mitigated against the collection of any but the most common or striking fossils (generally gastropods and cephalopods) from any given outcrop.

Because of the insufficient systematic investigation of the St. George trilobite faunas, biostratigraphic correlations with the standard Ross (1951) - Hintze (1953) Ordovician trilobite zones in Utah - Nevada have been hampered. Most previous correlations have been based on the generic similarity of the trilobite faunas (e.g. Kindle and Whittington, 1958; Whittington, 1968; Whittington and Kindle, 1963, 1969). Ross and Ingham (1970) and Fähræus (1977a) have demonstrated the inherent inaccuracy of this practice. Their documented examples show that faunas of high generic similarity may be of radically different ages. Fortey (1974, 1976, 1979a, in press), Fortey and Skevington

(1980), and Fortey et al. (1982) have proposed, however, regional and intercontinental correlations based on common trilobite species. These correlations have been confirmed by graptolite and conodont data in the same studies. Correlations based on specific identity (i.e. the presence of one or more common species), the author therefore, regards as more reliable than those based on generic similarity.

Biostratigraphic correlations of the St. George trilobite faunas with those of the classic deposits of the Canadian Series in New York - Vermont and Missouri - northern Arkansas (Fähræus, 1977b; Flower, 1964; Whittington, 1968) have also been hampered. This is a result of the lack of detailed lithostratigraphic studies and up-to-date systematic studies of the faunas of these areas as well.

The most complete systematic studies of the Early Ordovician trilobite faunas of New York - Vermont are those of Cleland (1900, 1903), Dwight (1884), Fisher (1954), Flower (1968b,c), Taylor and Halley (1974), Welby (1962), Whitfield (1886, 1889a,b, 1896, 1897) and Whittington (1953), and for Missouri - northern Arkansas those of Cullison (1944), Heller (1954) and Ulrich and Bridge (1934). Because these studies are generally out-of-date, trilobite-based correlations between the classic Canadian Series deposits and the Ross-Hintze zones have also so far proven fruitless. Macrofaunal correlations have largely been based on the generic similarities of the cephalopod and gastropod faunas (Flower, 1964, 1968a;b,c, 1976, 1978).

## 1.2 Previous Work

Until recently the most complete work on the Early Ordovician trilobite faunas of the St. George Group was that of Billings (1865). Raymond (1913, 1925) and Whittington (1953) subsequently redescribed and revised some of Billings' genera. Kindle (1945) and Johnson (1949), in unpublished manuscripts, and Whittington and Kindle (1969) added preliminary identifications of several genera and species not known to Billings. However, significant additions to Billings' (1865) pioneering study came only with the work of Boyce (1978, 1979a,b, 1983), Fortey (1979a,b, 1980a) and Boyce in Stouge and Boyce (1983).

Fortey (1979a) reinvestigated in detail the original collection area of Billings' (1865) described trilobites on Port au Choix Peninsula (Fig. 1.1). Here he recognized two successive faunas comprising more than twice the number of trilobite species than Billings had recorded. Boyce (1978, 1979a,b) discovered two previously unknown faunas in the Boat Harbour - Cape Norman region (Fig. 1.1) stratigraphically beneath those of Fortey (1979a). These new faunas were found to be separated by a significant faunal and sedimentological break. Both Boyce (1979a,b) and Fortey (1979a,b, 1980a) correlated their faunas with those of the standard Ross (1951) - Hintze (1953) zonation of Utah - Nevada. For the first time these correlations were based on common species rather than genera.

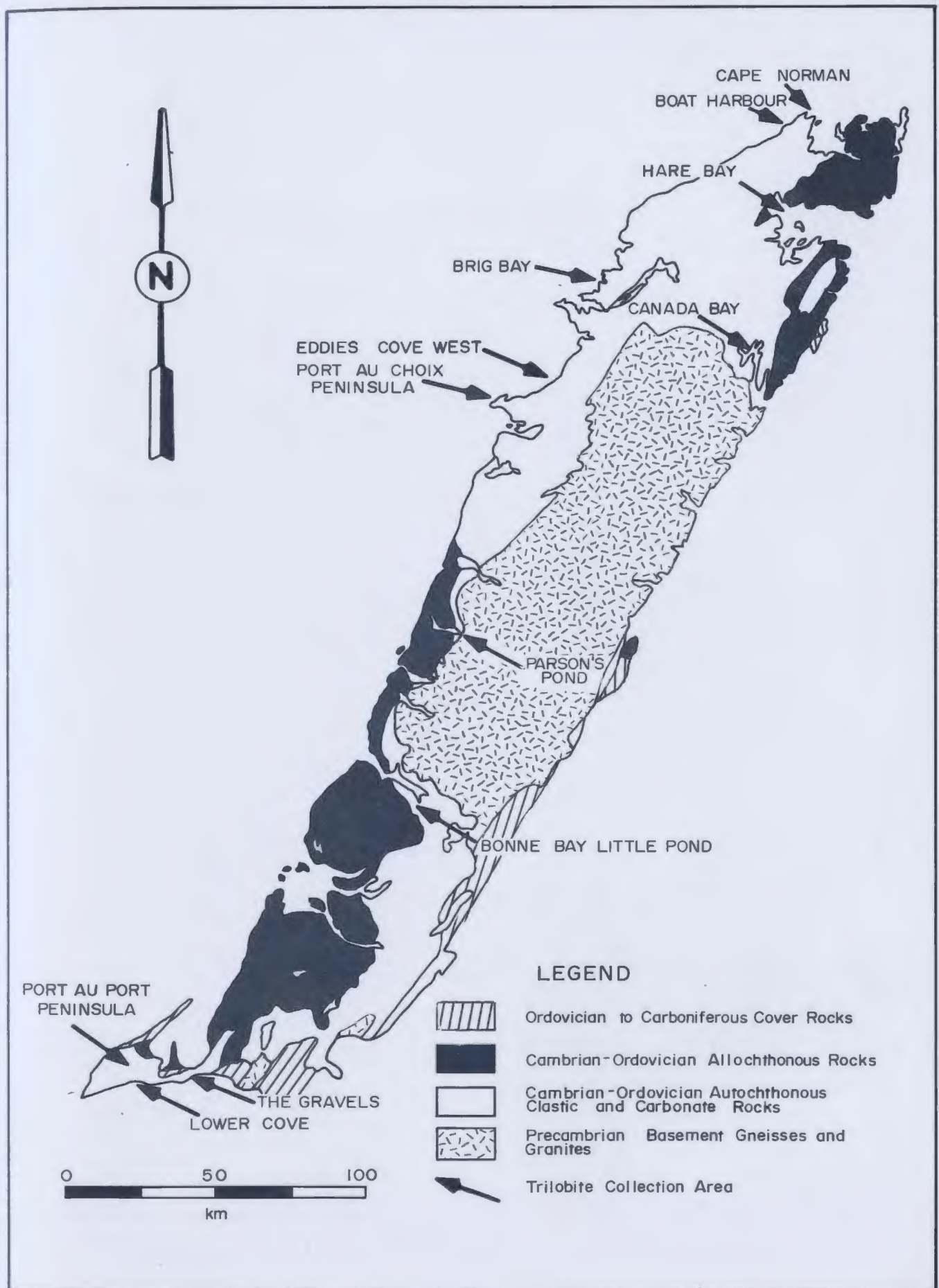


Figure 1.1. Geological elements and trilobite collection areas of western Newfoundland.

### 1.3 Purpose

The purpose of this study is twofold:

#### A. Systematic Descriptive Paleontology

The primary purpose of this portion of the study is to taxonomically describe the trilobite faunas of the Boat Harbour and Catoche Formations in the Boat Harbour - Cape Norman region.

#### B. Biostratigraphy

The biostratigraphic aspects of this study are regarded as having the most practical value. The main purposes are:

1. to erect a biostratigraphic zonation for the Boat Harbour and Catoche Formations.

2. to correlate the trilobite faunas with those of the standard Ross (1951) - Hintze (1953) Ordovician trilobite zones of Utah - Nevada, and the classic deposits of the Canadian Series in New York - Vermont and Missouri - northern Arkansas (Fähræus, 1977b; Flower, 1964; Whittington, 1968).

3. to propose, on the basis of the above correlations, a correlation of the Canadian Stages proposed by Flower (1964, p. 17-19) with the Ross - Hintze zones.

4. to document a major Early Ordovician (Late Tremadoc - Early Arenig) faunal and sedimentological break in western Newfoundland.

All biostratigraphic correlations proposed in this study are based on specific identity (i.e. the presence of one or more common species).

#### 1.4 Methods

Preliminary trilobite collections were obtained from the study area during the summer of 1976. After it became evident that previously unknown faunas were represented, further collections were obtained in the summer of 1977. At that time a detailed bed-by-bed composite lithostratigraphic section was measured at Boat Harbour (Fig. 1.1). Individual beds were measured to the nearest centimetre using a metre stick. Small covered intervals (less than 1 m) were also measured with the metre stick but larger ones were estimated using paced distances and bed geometry.

#### Note:

Several covered intervals in the Boat Harbour sequence were not measured by the author. Instead, thickness values obtained by Knight (1977b) and Pratt (1979) have been utilized. These intervals are indicated in the appropriate portions of Appendix A.

During the summer of 1978 the Boat Harbour section was revisited. Certain problematical intervals were restudied for clarification purposes. The sequence was then the object of detailed bed-by-bed sampling for trilobites. Other macrofossils were also collected (i.e. articulate and inarticulate brachiopods, cephalopods, echinoderms (eocrinoid debris), gastropods, and ostracods. Each fossiliferous horizon located was sampled whether or not trilobites were present, and a sample was



taken for conodont analysis. The author is collaborating with Drs. I. Knight (Newfoundland Department of Mines and Energy) and S. Stouge (University of Copenhagen) on the new trilobite and conodont faunas recovered. Preliminary results of this collaboration have already been published (Stouge, 1982; Stouge and Boyce, 1983; Boyce et al., 1983).

During the summer of 1978 the author also measured a lithostratigraphic section north of the lighthouse at Cape Norman, 7<sup>0</sup> km northeast of Boat Harbour (Fig. 1.1). Each fossiliferous horizon located here was also sampled for trilobites and conodonts.

During the field seasons of 1976 - 1978 and 1980 - 1982 additional trilobite (and conodont) collections were made in the following areas: Canada Bay, Hare Bay, Brig Bay, Eddies Cove West, Port au Choix, Parson's Pond, Bonne Bay Little Pond, and Port au Port Peninsula (Fig. 1.1).

In the laboratory the best trilobite specimens were readied for photography in the following ways. Firstly, specimens obscured by rock matrix were prepared out using either a hand-held variable stroke percussion vibratool or a hand-held variable speed rotary grinder. Secondly, negative fossil impressions were coated with liquid latex (when available) to obtain a positive replica. Before photography, specimens were coated with either black photoengraver's opaque or dilute India ink, then whitened with a thin layer of ammonium chloride to heighten contrast and surface detail. A bellows-mounted 35 mm Leica with Panatomic-X film was used to photograph the specimens, which were illuminated by a strong NW microscope light and a weaker NE one.

## 2. LITHOSTRATIGRAPHY

### 2.1 Terminology

Autochthonous Lower Ordovician carbonates in western Newfoundland are grouped together in the St. George Group (Kluyver, 1975; Knight, 1978, 1980b). Knight (1978, 1980b) subdivided these platformal limestones in the Boat Harbour - Cape Norman area into three lithostratigraphic units - the Watts Bight, Boat Harbour and Catoche Formations. Knight's terminology has been widely utilized (Boyce, 1978, 1979a,b, 1981b, 1983; Klappa et al., 1980; Knight, 1980a, 1983; Knight and Edwards, 1978a,b; Knight and Saltman, 1980; Snow and Knight, 1979; Stouge, 1980, 1981, 1982, 1983a,b; Stouge and Boyce, 1983; and Stouge and Godfrey, 1982), consequently it is adopted for this study as well. The component formations of the St. George Group in the study area (Fig. 2.1) are described below. The descriptive carbonate terminology follows Dunham (1962).

### 2.2 Watts Bight Formation

The Watts Bight Formation (Knight, 1978) is the lowest unit of the St. George Group in the study area. It consists of about 80 to 100 m of dark gray to black, wuggy, bituminous and sucrosic diagenetic dolostones. The dolostones, which are massive and thickly bedded, have a cream, light gray and white burrow-mottling and are medium to coarsely crystalline. The dolostones replaced bioturbated lime mudstones and stromatolitic boundstones consisting of mounds up to 2 m in diameter.

SYSTEM	SERIES	GROUP	KNIGHT (1977A,B)	KNIGHT (1978)	KNIGHT (1980 B) STOUGE (1981) THIS STUDY		
ORDOVICIAN	ARENIG	ST GEORGE	DIAGENETIC CARBONATES	DIAGENETIC CARBONATES	DIAGENETIC CARBONATES		
			CATOCHÉ FORMATION	CATOCHÉ FORMATION	CATOCHÉ FOAMATION	LOWER LIMESTONE SEQUENCE	
				WATTS BIGHT FORMATION	UNNAMED UNIT	PEBBLE BED	PEBBLE BED
			UPPER DOLOSTONE LIMESTONE FACIES			UPPER MEMBER	BOAT HARBOUR FORMATION
			WATTS BIGHT FORMATION	WATTS BIGHT FORMATION	LOWER MEMBER	LOWER MEMBER	LOWER MEMBER
					WATTS BIGHT FORMATION	WATTS BIGHT FORMATION	WATTS BIGHT FORMATION

Figure 2.1. Review of St George Group lithostratigraphic nomenclature in the Boat Harbour-Cape Norman study area.

The formation, especially the lower part, is rich in black and gray chert which occurs as nodules and streaks and also replaces stromatolites. The middle part of the formation contains thin bedded, bioturbated, gray and honey-colored lime mudstones and wackstones, dolostones, packstones and grainstones, some yellow dolostones and coarse crystalline, honey-colored dolostones (Knight, 1977a,b, 1978, 1980a).

The unit is best exposed at the type section along the coast at Watts Bight, 2 km southwest of Boat Harbour. It also underlies much of Boat Head (Fig. 2.2).

The Watts Bight Formation is sparsely fossiliferous and to date has only yielded silicified ellesmeroceratid cephalopods and large, low-spined gastropods.

### 2.3 Boat Harbour Formation

The Boat Harbour Formation (Knight, 1980b; Stouge, 1981) is about 130 m thick. It is subdivided into two members (Knight, 1978).

The Boat Harbour Formation may disconformably overlie the Watts Bight Formation in the study area. Knight (1980a, p. 5) reports a breccia zone on the northeastern point of Boat Head above the uppermost Watts Bight dolostones (Fig. 2.2). A dolomite-chert breccia horizon cemented by chert and fine crystalline dolostone also occurs at the contact between the two formations south of the study area in the Eddies Cove East - Salmon River area (Knight, 1980a). There the breccia

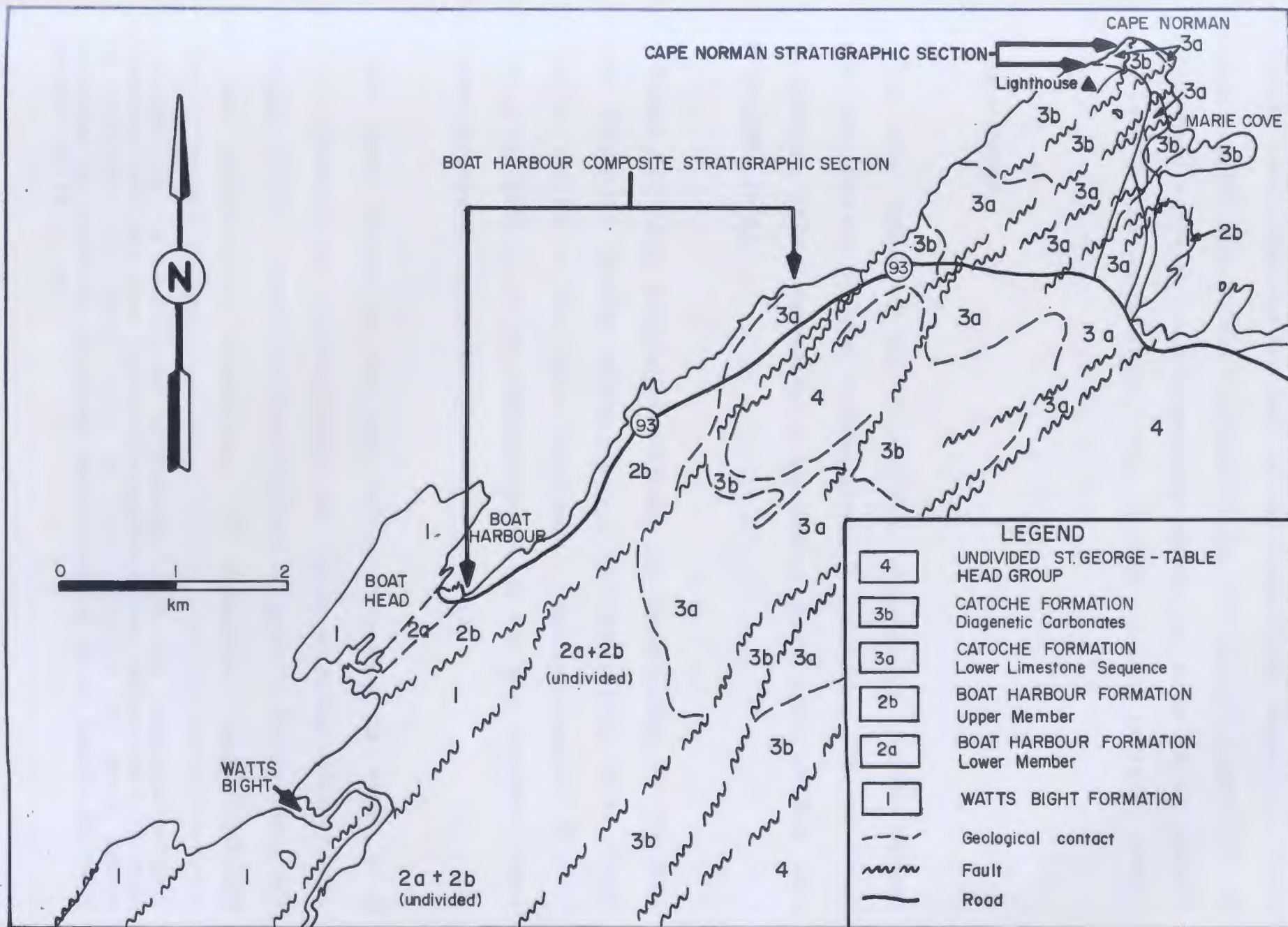


Figure 2.2. Geology of the Boat Harbour- Cape Norman study area and location of measured stratigraphic sections. Geology modified from Knight and Edwards (1978a,b).

vertically penetrates the top beds of the Watts Bight Formation. These features suggest that either a disconformity (of unknown magnitude) or a stratabound collapse breccia possibly related to solution of evaporites occurs at the Watts Bight - Boat Harbour contact (Knight, 1980a, p. 5).

(a) Lower Member

The lower member of the Boat Harbour Formation is poorly exposed in the type section at Boat Harbour where it underlies the bay (Fig. 2.2). However, inland exposures of the member occur south of Boat Harbour (Knight, 1978).

Knight (1977a,b) originally included the lower member of the Boat Harbour Formation in the upper part of the underlying Watts Bight Formation, calling it the Upper Dolostone - Limestone Facies. He subsequently assigned it to the "Unnamed Unit", as the Boat Harbour Formation was originally called (Knight, 1978, p. 141).

The lower member of the Boat Harbour Formation is about 45 m thick. It consists of (1) thin bedded and laminated primary dolostones, (2) vuggy, coarse crystalline honey-colored diagenetic dolostones, (3) gray and honey-colored limestones, (4) diagenetic pseudobreccias\*

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\* Pseudobreccia - a name coined by Cumming (1968) for limestone/primary dolostone that has been intensely diagenetically dolomitized so that the original rock remains only as clots, streaks and small masses surrounded by prismatic crystals and mosaics of white sparry dolomite (Knight, 1977b, p. 21).

replacing burrowed lime mudstone and wackestone, and (5) rare beds of dull brown and white burrow-mottled, blocky weathering, vuggy, coarse crystalline, dark gray to black diagenetic dolostone (Knight, 1978).

To date, no fossils have been recovered from the lower member of the Boat Harbour Formation in the study area.

(b) Upper member

The upper member of the Boat Harbour Formation consists of interbedded limestones and dolostones. It is best exposed in the type section along the coast northeast of Boat Harbour (Fig. 2.2). The base of the member is here placed at the base of a 1.48 m bed containing distinctive chert-rimmed algal mounds (Bed 1 of Section BHS-1, Appendix A). The top of the member (and the formation) is defined at the top of a 2.42 m bed of laminated and mudcracked, apparently unfossiliferous blue-gray lime mudstone and wackestone with buff dolomitic laminae (Bed 40 of Section BHS-6, Appendix A).

The thickness of the upper member of the Boat Harbour Formation as measured by the author was found to be nearly 87 m (Appendix A), a figure somewhat at variance with the 125 m thickness recorded by Knight (1978, Fig. 3). This discrepancy is easily explained. Knight (1977a,b) originally included the upper member of the Boat Harbour Formation in the overlying Catoche Formation, which he estimated to be 125 m in thickness (Knight, 1977b, p. 17). When Knight (1978, p. 141) separated the upper member of the Boat Harbour Formation from the Catoche

Formation, he apparently neglected to subtract the 40 m still remaining in the Catoche (see Knight, 1978, Fig. 3) from their original combined thickness. If this error is corrected then the thickness of the upper member according to Knight (1978, Fig. 3) is 85 m, a figure very close to the author's value of 87 m.

The lower 71 m of the upper member of the Boat Harbour Formation is composed of repetitive shoaling-upward sequences. Four lithofacies are commonly developed in these sequences. From bottom to top they are: (1) stromatolitic and thrombolitic lime boundstones, (2) extensively bioturbated lime mudstones and wackestones, (3) sparsely bioturbated dolomitic lime mudstones and wackestones, and (4) laminated primary dolostones (dolomite mudstones and wackestones) and dolomitic lime mudstones.

The stromatolitic and thrombolitic lime boundstones are light blue-gray and hackly weathering, massive and irregular bedded, sparsely fossiliferous and dark blue-gray when fresh. They occur as isolated mounds and coalesced mound complexes and commonly contain black, orange or white chert. Lime grainstones and packstones, which are locally richly fossiliferous and oolitic, are commonly associated with the boundstones and generally occur in the intermound areas.

The extensively bioturbated lime mudstones and wackestones are light blue-gray, gray and rubbly weathering, massive and planar bedded, and dark blue-gray and gray when fresh. The abundant horizontal and vertical burrows, trails, etc. are preserved by buff and yellow



weathering argillaceous dolomitic material. These rocks are sparsely fossiliferous and generally only yield planispiral gastropods and rare cephalopods.

The sparsely bioturbated dolomitic lime mudstones and wackestones are light blue-gray and blocky weathering; massive to thin, planar bedded and laminated, and dark blue-gray when fresh. The rare horizontal burrows and trails are preserved by buff and yellow weathering argillaceous dolomitic material. Thin, irregular dolomitic laminae and layers, ripple-marks, flat-pebble conglomerates, and small scours and channels also occur. These rocks are moderately fossiliferous.

The laminated primary dolostones (dolomite mudstones and wackestones) and dolomitic lime mudstones complete many of the shoaling-upward sequences. These rocks are buff and cream weathering, thin and planar bedded, and dark blue-gray and gray when fresh. They are apparently unfossiliferous.

A "pebble bed" (Pl. 1A) occurs approximately 71 m above the base of the upper member of the Boat Harbour Formation (Knight, 1977b, 1978, 1980b; Boyce, 1978, 1979; Stouge, 1980, 1981, 1982; Stouge and Boyce, 1983) (Bed 9 of Section BHS-6, Appendix A). This 6 cm thick bed consists of buff weathering, fine grained, apparently unfossiliferous light blue-gray diagenetic dolostone which contains the following pebble types: (a) subangular to well rounded, white vug-quartz clasts up to 3 cm in diameter, (b) angular gray to black chert clasts up to 6 cm long, (c) subangular to subrounded gray chert clasts containing tiny



Plate 1A. The "pebble bed" of Knight (1977b, 1978) as exposed at Boat Harbour. Bed 9 of Section BHS-6, Appendix A. Metre stick for scale. Photo courtesy of Dr. I. Knight.



Plate 1B. Closeup of "pebble bed" showing irregular surface capped by thin seam of argillaceous dolomite wackestone (Bed 10 of Section BHS-6). Metre stick for scale. Photo courtesy of Dr. I. Knight.

pyrite crystals and (d) pyrite nodule clasts up to 1 cm in diameter. Small, straight, symmetrical bimodal ripples occur in the bed but, as Knight (1978, p. 143) reports, "the clasts show no evidence of sorting or movement by currents and 'pebble' density is variable within the horizon." Three 9 to 43 cm thick beds of fine crystalline diagenetic dolostone occur immediately beneath the "pebble bed" (Beds 6-8 of Section BHS-6, Appendix A). These beds, which total 91 cm in thickness, are planar bedded, bioturbated and rippled, apparently unfossiliferous and light blue-gray when fresh. They represent dolomitized limestones (Knight, 1978). The top of the "pebble bed" (Pl. 1B) is irregular, pitted and pot-holed (Knight, 1978) and capped by a thin 1 cm seam of apparently unfossiliferous dark gray argillaceous dolomite wackestone (Bed 10 of Section BHS-6, Appendix A). This thin seam is in turn overlain by a 29 cm thick bed of buff weathering, massive, fine crystalline, apparently unfossiliferous light blue-gray diagenetic dolostone containing rare 5 mm size black chert clasts (Bed 11 of Section BHS-6, Appendix A).

The upper 16 m of the Boat Harbour Formation, includes 1 to 7-m thick sequences of variably interbedded rock types. These include thin, irregularly bedded, extensively bioturbated, fossiliferous light blue-gray lime mudstones and wackestones to skeletal packstones with dolomitic burrow mottling; small circular stromatolite mounds up to 25 cm in diameter; and 3 cm thick beds and lenses of locally cross-laminated, intraclastic and skeletal packstone and grainstone. Upwards, the limestones in the sequences become unfossiliferous. Finely laminated and mudcracked primary dolostones (dolomite mudstones and wackestones) and

dolomitic lime mudstones cap the sequences. These rocks locally contain small, exceptionally well preserved stromatolite mounds and lenses of intraclastic dolomite packstone and grainstone with flat intraclasts up to 10 cm in length. One bed of stromatolitic lime boundstone composed of steep-sided, circular to elliptical mounds up to 1 m in diameter occurs near the base of this succession (Bed 25 of Section BHS-6, Appendix A).

The upper member of the Boat Harbour Formation is locally abundantly fossiliferous. To date it has yielded articulate and inarticulate brachiopods, straight and curved cephalopods, echinoderms (eocrinoid fragments), high- and low-spired and planispiral gastropods, as well as trilobites and conodonts.

#### 2.4 Catoche Formation

The Catoche Formation was originally defined by Kluyver (1975) at Catoche Point on Port au Choix Peninsula, south of the study area (Fig. 1.1). It was subsequently restudied by Knight (1977a,b, 1978, 1983) at the type locality, where the formation was redefined, and measured in the study area as well. In the study area the formation consists of a lower limestone sequence at least 40 m thick and an upper, 25 to 50 m thick sequence of diagenetic dolostones known informally as the "Diagenetic Carbonates" (Knight, 1977a,b, 1978).

The lower limestone sequence consists predominantly of lime mudstones and wackestones. These rocks are characteristically light blue-

gray and rubbly weathering, thin and lenticular bedded to massive and planar bedded, moderately bioturbated, fossiliferous, and dark blue-gray and gray when fresh. Burrows and trails are preserved by buff weathering, argillaceous dolomitic material. Lenses of skeletal and intraclastic lime packstone and grainstone and minor beds of gray weathering, apparently unfossiliferous diagenetic dolostone also occur.

The basal beds of the lower limestone sequence are exposed at the top of the measured Boat Harbour sequence, conformably overlying the uppermost beds of the Boat Harbour Formation (see Appendix A). The uppermost beds of the lower limestone sequence are exposed in the sea-cliffs at Cape Norman (Fig. 2.2). There, spectacular patches of white weathering dolomite-pseudobreccia occur in the limestones immediately below the dolostones of the "Diagenetic Carbonates".

The basal contact of the "Diagenetic Carbonates" is both conformable and laterally transgressive. These dolostones are light gray to yellow weathering, massive bedded, sparsely fossiliferous, vuggy to tight, medium to coarse crystalline, commonly bituminous, and dark gray to black when fresh. They commonly contain dark gray to black chert. Some light gray limestones occur above these dolostones in the core of a syncline 1.3 km inland of the Boat Harbour - Cape Norman coast. They are, so far, the highest beds of the St. George Group recognized in the study area.

Generally, the Catoche Formation in the study area is thin and hence probably incomplete. It is also more dolomitic and less fossiliferous.

ferous than that in the type area. In the Eddies Cove West - Port au Choix type area it is up to 165 m thick and the "Diagenetic Carbonates" range between 32 and 40+ m in thickness (Knight, pers. comm., 1982; Pratt and James, 1982).

The lower limestone sequence of the Catoche Formation in the study area has yielded articulate brachiopods, straight and curved cephalopods, echinoderms (eocrinoid fragments), high- and low-spined gastropods, ostracods, as well as trilobites and conodonts. To date the "Diagenetic Carbonates" have yielded only silicified straight and curved cephalopods, high- and low-spined gastropods, and receptaculitids.

### 3. BIOSTRATIGRAPHY

#### 3.1 Terminology

Recent papers by Murphy (1977) and Johnson (1979) have questioned and modified the biostratigraphic zonal concepts originally outlined in the International Stratigraphic Guide (Hedberg, 1976). Murphy (1977) stressed the importance of distinguishing between definition (the establishment of boundaries), characterization (unit content) and identification (the recognition of established units) when describing zones. Johnson (1979) emphasized the necessity of differentiating between boundaries based on stratal events and those based on phyletic events. Stratal events as defined by Johnson are biological events whose position in the stratal succession depends on biofacies and preservation (*i.e.* first appearance, migration, extinction). A phyletic event as defined by Johnson is a biological (specifically evolutionary) event such that there is no long-sustained diversity increase due to (taxonomic) splitting in a single lineage. Johnson (1979, p. 932) proceeding from the statement boundaries are defined; units are characterized stated that all types of biostratigraphic zones could be evaluated in terms of whether they did or did not employ boundaries and in terms of how they employed characterization. Johnson's analysis of the various kinds of biostratigraphic zones previously distinguished in the International Stratigraphic Guide (Hedberg, 1976) suggested they should be regrouped as three distinct types. Johnson's (1979, p. 932) revised classification of biostratigraphic zones is as follows:

Type 1 Zones - based on a characterization and lacking defined boundaries.

- a) Assemblage Zone - a group of strata characterized by a distinctive natural assemblage of all forms present or of the forms present of a certain kind or kinds (Hedberg, 1976, p. 50).
- b) Acme Zone - a group of strata based on the abundance or development of certain forms, regardless of either association or range (Hedberg, 1976, p. 50).

Type 2 Zones - based on boundaries defined by stratal events.

- a) Range Zone - a group of strata representing the stratigraphic range of some selected element of the total assemblage of fossil forms present (Hedberg, 1976, p. 50).
- b) Overlap Range Zone (= concurrent-range-zone of ISG-Hedberg, 1976; includes Opper-Zone of ISG-Hedberg, 1976) - the concurrent or coincident parts of the range-zones of two or more specified taxons selected from among the total forms contained in a sequence of strata (Hedberg, 1976, p. 55).
- c) Interval Zone - the stratigraphic interval between two distinctive biostratigraphic horizons (Hedberg, 1976, p. 50).

Type 3 Zones - based on boundaries defined by phyletic events.

- a) Lineage Zone - the body of strata containing specimens representing a segment of an evolutionary or developmental line or trend, defined above and below by changes in features of the line or trend (Hedberg, 1976, p. 58-59).

In this study Type 1 - assemblage zones and Type 2 - range zones have been found to have the most utility. With respect to the naming of the zones, the assemblage zone has been named for its most common trilobite; the range zones are named for the species defining them. Intervals lacking trilobites between successive zones have been called barren interzones following Hedberg (1976, p. 49).



### 3.2 Trilobite Zonation

#### a) Watts Bight Formation

To date only silicified ellesmeroceratid cephalopods and large low-spired gastropods have been recovered from this unit in the study area. Consequently, it remains unzoned with respect to trilobites.

#### b) Boat Harbour and Catoche Formations

So far the lower member of the Boat Harbour Formation in the study area has proven nonfossiliferous. Consequently, it is not zoned. Potential for zonation exists, however, farther south in the vicinity of Eddies Cove West. Here the author collected a low-diversity trilobite fauna (not yet described) from the lower member of the formation at Fish Point (Boyce, 1983, p. 11).

Five biostratigraphic zones are proposed in the upper member of the Boat Harbour Formation and the Catoche Formation in the study area. Following Ludvigsen (1982) for all faunal lists in this section, those species that continue from the subjacent zone are indicated by - and those that continue into the superjacent zone are indicated by +. The proposed zones, shown in Fig. 3.1 (in back pocket), in ascending order are as follows:

- 1) Barren Interzone I (0 to 2.31 m above base of Boat Harbour composite section)

This zone is characterized by an apparent complete lack of fossils.

- 2) Randaynia saundersi (Assemblage) Zone (2.31 to 66.21 m above base of Boat Harbour composite section)

This zone is characterized by the presence of the following trilobite species:

Hystricurus oculilunatus Ross  
Hillyardina minuspustulata sp. nov.  
Randaynia saundersi gen. et sp. nov.  
Hystricurus pseudoculilunatus sp. nov.  
Parahystricurus smithiae sp. nov.  
Hillyardina levis sp. nov.  
Paraplethopeltis seelyi (Whitfield)  
Parapeltabellia boatharbourensis sp. nov.  
Magnusnäsus proprius gen. et sp. nov.

Assigned collections: Upper member of the Boat Harbour Formation at Boat Harbour, BH-1 to BH-38.

The trilobites of the Randaynia saundersi Zone are predominantly hystricurids. None of the species range into the overlying zones.

- 3) Barren Interzone II (66.21 to 71.80 m above base of Boat Harbour composite section)

This zone is characterized by an abundance of planispiral gastropods and an apparent complete lack of trilobites.

Assigned collections: Upper member of the Boat Harbour Formation at Boat Harbour,, BH-39.

- 4) Strigigenalis brevicaudata (Range) Zone (71.80 to 83.88 m above base of Boat Harbour composite section)

The base of this zone is defined by the first appearance of the nominate species. The top of the zone is defined by the first appearance of Strigigenalis caudata (Billings) which the author regards as the direct evolutionary descendent of S. brevicaudata. The zone is characterized by the following trilobite species:

Grinnellaspis newfoundlandensis sp. nov.

Strigigenalis brevicaudata sp. nov.

+Jeffersonia angustimarginata sp. nov.

+Bolbocephalus convexus (Billings)

Peltabellia knighti sp. nov.

Randaynia langdoni sp. nov.

+Bolbocephalus stevensi sp. nov.

Peltabellia pseudopeltabella sp. nov.

+Petigurus nero (Billings)

+Isoteloides peri Fortey

+Benthamaspis hintzei sp. nov.

Assigned collections: Upper member of the Boat Harbour Formation at Boat Harbour, BH-40 to BH-93.

The trilobites of the Strigigenalis brevicaudata Zone are predominantly bathyurids. None of the species range into the underlying zones.

5) Strigigenalis caudata (Range) Zone (83.88 to 93.60 m above base of the Boat Harbour composite section plus 0 to 16.73 m above the base of the Cape Norman section plus 6 to 47 m above the base of Fortey's, 1979a, Port au Choix section)

The base of this composite range zone is defined at Boat Harbour at the first occurrence of the nominate species. As well as being a stratal event in the sense of Johnson (1979a, p. 932) the first appearance of S. caudata is also a phyletic event because, as Johnson (1979a, p. 935) states "there is no long sustained diversity increase due to splitting", the parent species in this case being S. brevicaudata. In fact there is no overlap at all in the two species' ranges. The top of the S. caudata range zone is tentatively defined as the last occurrence of the nominate species in Fortey's (1979a) Port au Choix section. Although the lower and upper boundaries of the S. caudata Zone have been defined, the internal details of the zone remain unclear because there is no overlap between the author's Boat Harbour and Cape Norman sections and Fortey's (1979a) Port au Choix section. However, information obtained by the author from a continuous section in the vicinity of Eddies Cove West (Boyce, 1983) will allow all three of these

sections to be linked. Preliminary analysis of the Eddies Cove West section, which is not discussed in this study, suggests that the Strigigenalis caudata Range Zone may be divisible into as many as three widely recognizable subzones, with all boundaries based on phyletic events.

The Strigigenalis caudata Zone is characterized by the following trilobite species:

- Jeffersonia angustimarginata sp. nov.
- Bolbocephalus convexus (Billings)
- Petigurus nero (Billings)
- Isoteloides peri Fortey
- Benthamaspis hintzei sp. nov.
- Strigigenalis caudata (Billings)
- Uromystrum affine (Poulsen)
- Ischyrotoma parallela sp. nov.
- Ischyrotoma anataphra Fortey
- Jeffersonia timon (Billings)
- Isoteloides sp. undet.
- Bathyurellus abruptus Billings
- Uromystrum forteyi sp. nov.
- Benthamaspis conica Fortey
- Punka? sp. undet.
- Carolinites genacinaca nevadensis (Hintze)
- Punka flabelliformis Fortey
- Catochia ornata Fortey

Strotactinus insularis (Billings)

Isoteloides latimarginatus Fortey

Benthamaspis gibberula (Billings)

Opipeuter sp. cf. O. angularis (Young)

Catochia glabra Fortey

Bathyrellus platypus Fortey

Assigned collections: Upper member of the Boat Harbour Formation and the lower limestone sequence of the Catoche Formation at Boat Harbour, BH-94 to BH-114; the lower limestone sequence of the Catoche Formation at Cape Norman, CN-1 to CN-20; the Catoche Formation at Port au Choix, lower 11 of Fortey's (1979a, Fig. 11) 13 unnumbered collections.

### 3.3 Correlative Faunas in the St. George Group

Since 1976, additional trilobite collections have been made by the author and others from the St. George Group outside the Boat Harbour - Cape Norman study area. These collections were made in the following areas: Canada Bay, Hare Bay, Brig Bay, Eddies Cove West, Port au Choix, Parson's Pond, Bonne Bay Little Pond and Port au Port Peninsula. The majority of the collections were made for the first time. The results are summarized in Table 3.1 and below.

#### a) Canada Bay

Johnson in Betz (1939, p. 19) identified a cranidium of Hystri-  
curus from the St. George Group limestones exposed here, but did not

Table 3.1. Correlative faunas in the St. George Group. Species comparisons are for only those species illustrated in this study. See Fortey (1979a) and Boyce (1983) for additional species comparisons of younger Catoche Formation faunas at Port au Choix and Eddies Cove West. BHF-Boat Harbour Formation, CF-Catoche Formation, BIF-Brent Island Formation, SAF-Southern Arm Formation, CBF-Corner Brook Formation, IBF-Isthmus Bay Formation.

TRILOBITE SPECIES	BOAT HARBOUR-CAPE NORMAN	CANADA BAY	HARE BAY	BRIG BAY	EDDIES COVE WEST	PORT AU CHOIX	PARSONS'S POND	PORT AU PORT PENINSULA
<i>Hystriocurus oculilunatus</i>	BHF	—	—	BHF	BHF	BHF	—	—
<i>Hillyardina minuspustulata</i>	BHF	—	—	—	—	—	—	—
<i>Randaynia saundersi</i>	BHF	—	—	BHF	BHF	—	—	—
<i>Hystriocurus pseudoculilunatus</i>	BHF	—	—	BHF	BHF	—	—	—
<i>Parahystriocurus emithiae</i>	BHF	—	—	—	BHF	—	—	—
<i>Hillyardina levis</i>	BHF	—	—	BHF	BHF	—	—	—
<i>Paraplethopeltis seelyi</i>	BHF	—	—	BHF	BHF	—	—	—
<i>Leioetegium proprium</i>	—	—	—	—	BHF	—	—	—
<i>Parapeltabellia boatharborensis</i>	BHF	—	—	—	—	—	—	—
<i>Magnusenasus proprius</i>	BHF	—	—	—	—	—	—	—
<i>Grimmellaspis newfoundlandensis</i>	BHF	—	—	—	CF	CF	—	—
<i>Strigigenalis brevicaudata</i>	BHF	—	—	—	—	—	—	—
<i>Jeffersonia angustimarginata</i>	BHF, CF	CF	—	—	BHF, CF	CF	—	—
<i>Bolbocephalus convexus</i>	BHF, CF	CF	SAF	—	BHF, CF	CF	CBF	IBF, CF
<i>Peltabellia knighti</i>	BHF	—	—	—	—	—	—	—
<i>Randaynia langdoni</i>	BHF	—	—	—	—	—	—	—
<i>Bolbocephalus stevensi</i>	BHF	—	BIF	—	BHF	—	—	—
<i>Peltabellia pseudopeltabella</i>	BHF	—	—	—	—	—	—	—
<i>Petigurus nero</i>	BHF, CF	CF	SAF	—	CF	CF	CBF	IBF, CF
<i>Isoteloides peri</i>	BHF, CF	CF	—	—	BHF, CF	CF	—	—
<i>Benthamaspis hintzei</i>	BHF, CF	—	—	—	BHF	CF	—	—
<i>Strigigenalis caudata</i>	BHF, CF	—	—	—	CF	CF	CBF	—
<i>Uromystrum affine</i>	CF	CF	—	—	CF	—	—	CF
<i>Isohyrotoma parallela</i>	CF	—	—	—	—	—	—	—
<i>Isohyrotoma anataphra</i>	CF	—	—	—	CF	CF	CBF	—
<i>Jeffersonia timon</i>	CF	—	SAF	—	CF	CF	CBF	CF
<i>Bathyporellus abruptus</i>	CF	—	—	—	CF	CF	CBF	—
<i>Uromystrum fortayi</i>	CF	—	SAF	—	CF	CF	—	—
<i>Benthamaspis conica</i>	CF	—	—	—	CF	CF	—	—

specify where it was collected. This suggests the presence of the Randaynia saundersi Zone.

Beds of the Catoche Formation exposed on Fane (Spruce) Island, west of Drummond (Davie) Island in Northeast Arm, have yielded the following trilobites: Bolbocephalus convexus (Billings), Isoteloides peri Fortey, Jeffersonia angustimarginata sp. nov., Petigurus nero (Billings) and Uromystrum affine (Poulsen) (Boyce, pers. comm. in Knight and Saltman, 1980, p. 19-20). These trilobites are indicative of the oldest part of the Strigigenalis caudata Zone.

b) Hare Bay

Murray in Murray and Howley (1881) first reported the occurrence of the S. brevicaudata to S. caudata Zone trilobite Petigurus nero (Billings) in Hare Bay.

The distinctive Strigigenalis brevicaudata Zone to lowest S. caudata Zone trilobite Bolbocephalus stevensi sp. nov. has been collected from limestones comprising the upper few metres of the Brent Island Formation of Stouge and Godfrey (1982) on Brent Islands (N.P. James, pers. comm., 1979). Dr. R.A. Fortey (British Museum - Natural History) has identified the following Strigigenalis caudata Zone trilobites from the basal beds of the conformably overlying Southern Arm Formation of Stouge and Godfrey (1982), also exposed on Brent Islands: Bolbocephalus convexus (Billings), Iliaenus sp., Jeffersonia timon (Billings) and Petigurus nero (Billings) (N.P. James, pers. comm., 1979).



The Southern Arm Formation has also yielded trilobites at a number of other localities in the Hare Bay area. Beds exposed at the community wharfs in Main Brook have yielded Jeffersonia timon (Billings). Petigurus nero (Billings) and Uromystrum forteyi sp. nov. have been collected on the north shore of Pradet Island (Boyce, pers. comm. in Stouge, 1981). Petigurus nero (Billings) has also been collected on Maria Island. These trilobites taken together are indicative of the Strigigenalis caudata Zone as well.

c) Brig Bay

Trilobites have been collected from the Boat Harbour Formation at a number of localities in the Brig Bay area. Paraplethopeltis seelyi (Whitfield) was collected from a thrombolitic lime boundstone bed forming the top of Moyrac Island, just north of Old Ferrolle Island. Hystericurus pseudoculilunatus sp. nov. and Randaynia saundersi gen. et sp. nov. were collected at the northern tip of Old Ferrolle Island, while Hillyardina levis sp. nov., Hystericurus oculilunatus Ross and Randaynia saundersi gen. et sp. nov. were obtained from the northwest side. Hystericurus oculilunatus Ross was also collected at Beach Point on the Dog Peninsula (Boyce, 1979a,b). These trilobites are all indicative of the Randaynia saundersi Zone.

d) Eddies Cove West

Along the coast north of Fish Point and south of Squid Cove, beds assigned by Knight (1983) to the Boat Harbour Formation have yielded

the Randaynia saundersi Zone trilobite Hystericurus oculilunatus Ross in association with rare straight cephalopods and the planispiral gastropod Lecanospira. At Fish Point, the lower member of the Boat Harbour Formation has yielded the trilobites Parahystericurus sp. cf. P. carinatus Ross and ?Paraplethopeltis sp. (Boyce, 1983). This represents an older previously unreported fauna.

In the vicinity of Eddies Cove West at Old Man Cove an incompletely exposed dolomitized interval occurs near the top of the upper member of the Boat Harbour Formation. This dolomitized interval the author regards as stratigraphically equivalent to the barren interval in Boat Harbour containing the "pebble bed" disconformity of Knight (1977b, 1978), i.e. Barren Interzone II, as pointed out by Knight (1983).

In Eddies Cove West, 21 fossiliferous horizons were sampled in the upper member of the Boat Harbour Formation below the Old Man Cove dolomitized interval. The following were identified: Hystericurus pseudo-oculilunatus sp. nov., Randaynia saundersi gen. et sp. nov., Hystericurus oculilunatus Ross, Parahystericurus smithiae sp. nov., Leiostegium proprium sp. nov., Tesselacauda sp. cf. T. depressa Ross sensu Demeter (1973; pl. 1, figs. 5, 6), Paraplethopeltis seelyi (Whitfield), Hystericurus sp. nov. 2 Boyce (1983) and Hillyardina levis sp. nov. Associated with these trilobites were brachiopods (Diaphelasma, orthids), cephalopods (Bassleroceras), echinoderms (eocrinoid debris) and gastropods (Ecculiomphalus, Lecanospira). The same fauna occurs below the Boat Harbour "pebble bed" in the Randaynia saundersi Zone.

Above the Old Man Cove dolomitized interval, 4 fossiliferous horizons were sampled in the upper member of the Boat Harbour Formation. The following were identified: Bolbocephalus stevensi sp. nov., Isoteloides peri Fortey, Bolbocephalus convexus (Billings), Benthamaspis hintzei sp. nov., Hystricurus sp. nov. 3 Boyce (1983 - probably the same species as Genus(?) sp.(?) Cullison, 1944; pl. XXXV, figs. 23, 24, and the undetermined pygidium of Hintze, 1953; pl. X, fig. 14), Jeffersonia angustimarginata sp. nov. and Bathurellus abruptus Billings. Essentially the same fauna occurs above the Boat Harbour "pebble bed" in the Strigigenalis brevicaudata and lower S. caudata Zones.

In the Eddies Cove West area, 41 fossiliferous horizons were sampled in the Catoche Formation. The following were identified: Isoteloides peri Fortey, Bolbocephalus convexus (Billings), Hystricurus sp. nov. 3 Boyce (1983), Jeffersonia angustimarginata sp. nov., Bathurellus abruptus Billings, Peltabellia sp. cf. P. willistoni Lochman, Petigurus sp. cf. P. groenlandicus Poulsen, Uromystrum affine (Poulsen), Petigurus nero (Billings), Grinnellaspis newfoundlandensis sp. nov., Benthamaspis sp. undet., Ischyrotoma sp. undet., Benthamaspis conica Fortey, Strigigenalis caudata (Billings), Isoteloides latimarginatus Fortey, Punka flabelliformis Fortey, Ischyrotoma anataphra Fortey, Uromystrum sp. nov. 1 Boyce (1983), Jeffersonia timon (Billings), Catochia ornata Fortey, Strotactinus insularis (Billings), Benthamaspis gibberula (Billings), Bolbocephalus sp. nov. 2 Boyce (1983 = Genus et sp. ind. Poulsen, 1937; pl. 8, fig. 2), Uromystrum forteyi sp. nov., Bathurellus platypus Fortey and Catochia glabra Fortey. The same species occur in the Strigigenalis brevicaudata and Strigigenalis caudata Zones above the Boat Harbour "pebble bed" and at Cape Norman.

e) Port au Choix

Fossiliferous beds of the Boat Harbour Formation are exposed in a roadside quarry along the Viking Trail, 4 km north of the junction with the road to Port Saunders. Here the Randaynia saundersi Zone trilobite Hystericurus oculilunatus Ross and the planispiral gastropod Lecanospira were collected (Boyce, 1983).

At Barbace Point on the north side of Barbace Cove on Port au Choix Peninsula a dolomitized interval occurs near the top of the upper member of the Boat Harbour Formation. This interval the author, agreeing with Knight (1983), regards as stratigraphically equivalent to the incompletely exposed Old Man Cove dolomitized interval at Eddies Cove West and the "pebble bed" interval at Boat Harbour; i.e. Barren Interzone II. In the Barbace Point dolomitized interval Knight (1983) has identified two sequences containing numerous quartz-lined spherical vugs. A solution surface has also been identified at the top of the second sequence.

Above the Barbace Point dolomitized interval, 6 fossiliferous horizons were sampled in the upper member of the Boat Harbour Formation. The only trilobite identified was the Strigigenalis brevicaudata to S. caudata Zone species Isoteloides peri Fortey (Boyce, 1983).

At Barbace Point on the north side of Barbace Cove on Port au Choix Peninsula, 7 fossiliferous horizons were sampled in the Catoche Formation. The following were identified: Isoteloides peri Fortey,

Benthامaspis hintzei sp. nov., Ischyrotoma sp. undet., Hystericurus sp. nov. 3 Boyce (1983), Jeffersonia angustimarginata sp. nov., Bolbocephalus convexus (Billings), Peltabellia sp. cf. P. willistoni Lochman, Grinnellaspis newfoundlandensis sp. nov., Petigurus sp. cf. P. groenlandicus Poulsen, Petigurus nero (Billings), Benthامaspis conica Fortey and Strigigenalis caudata (Billings). These species are indicative of the Strigigenalis brevicaudata and Strigigenalis caudata Zones.

At Catoche Point on the south side of Barbace Cove, Fortey (1979a) and Boyce (unpublished) sampled a minimum of 13 fossiliferous horizons in the Catoche Formation. The following have been identified: Isoteloides peri Fortey, Jeffersonia angustimarginata sp. nov., Bolbocephalus convexus (Billings), Petigurus nero (Billings), Benthامaspis conica Fortey, Strigigenalis caudata (Billings), Uromystrum forteyi sp. nov., Bathyurellus abruptus Billings, Punka sp. undet. Fortey (1979a), Carolinites genacinaca nevadensis Hintze, Punka flabelliformis Fortey, Catochia ornata Fortey, Isochyrotoma anataphra Fortey, Strotactinus insularis (Billings), Benthامaspis gibberula (Billings), Isoteloides latimarginatus Fortey, Petigurus sp. ind. Fortey (1979a), Jeffersonia timon (Billings), Opipeuter sp. cf. O. angularis (Young), Catochia glabra Fortey, and Bathyurellus platypus Fortey. Most of these species are indicative of the younger half of the Strigigenalis caudata Zone.

f) Parson's Pond

At the eastern end of Parson's Pond, limestones assigned by Boyce (1981b) to the Corner Brook Formation of Lilly (1961, 1963) have yielded the following Strigigenalis caudata Zone trilobites: Bathyrellus abruptus Billings, Benthamaspis sp. cf. B. conica Fortey, Bolbocephalus convexus (Billings), Ischyrotoma anataphra Fortey, Jeffersonia (= Bathyurina) sp., Isoteloides latimarginatus Fortey, Jeffersonia (= Bathyurina) timon (Billings), Petigurus nero (Billings), Strigigenalis caudata (Billings), Punka flabelliformis Fortey and Ischyrotoma sp. In addition, silicified articulate brachiopods and a cephalopod or echinoderm fragment were collected (Boyce, 1981b, p. 15-16).

g) Bonne Bay Little Pond

Approximately 2.1 km west-northwest of Bonne Bay Little Pond, limestones assigned by Boyce (1981a) to the Corner Brook Formation of Lilly (1961, 1963) have yielded the following Strigigenalis caudata Zone trilobites: Benthamaspis sp. indet. and Strotactinus insularis (Billings) (Boyce, 1980).

h) Port au Port Peninsula

Beds assignable to the uppermost part of the Isthmus Bay Formation (James et al., 1980; Pratt and James, 1982) and the lowermost part of the Catoche Formation are exposed just southwest of the southern bar of The Gravels. Here the author collected the following trilobites: Bolbo-

cephalus convexus (Billings), Isoteloides sp., Jeffersonia sp., and Petigurus nero (Billings). Whittington and Kindle (1969, p. 658) also report Peltabellia sp. from this locality. These trilobites probably represent the youngest part of the Strigigenalis brevicaudata Zone and/or the oldest part of the Strigigenalis caudata Zone.

Limestones of the Catoche Formation exposed north of Pigeon Head in Lower Cove have yielded the following trilobites: Bathyuirellus sp., Bolbocephalus convexus (Billings), Ischyrotoma sp., Isoteloides sp., Jeffersonia timon (Billings), Petigurus nero (Billings) and Uromystrum affine (Poulsen). Whittington and Kindle (1969, p. 658) also report Strigigenalis sp. from here. These species taken together are suggestive of the Strigigenalis caudata Zone.

#### 3.4 Correlative Formations in Platform Facies

Several of the species found in the Boat Harbour and Catoche Formations in the study area also occur in Early Ordovician platform facies rocks elsewhere. The common species and their formational occurrences are summarized in Table 3.2 and below. Pertinent conodont information is also mentioned in the text below where available.

##### a) Ellesmere Island, Arctic Canada

Poulsen (1946; pl. XXIII, fig. 40) illustrated an incomplete pygidium of the Strigigenalis brevicaudata to Strigigenalis caudata Zone trilobite Jeffersonia angustimarginata from the Canyon Elv Forma-

Table 3.2. Correlative formations in platform facies.

TRILOBITE SPECIES	WESTERN NEWFOUNDLAND	ELLESMERE ISLAND	EAST GREENLAND	COLORADO	NORTH DAKOTA
<i>Hystericurus oculilunatus</i>	Boat Harbour Fm.	_____	_____	Manitou Fm.	_____
<i>Jeffersonia angustimarginata</i>	Boat Harbour, Catoche Fms.	Canyon Elv Fm.	_____	_____	_____
<i>Bolbocephalus convexus</i>	Boat Harbour, Catoche Fms.	_____	Cape Weber Fm.	_____	_____
<i>Uromystrum affine</i>	Catoche Fm.	_____	Cape Weber Fm.	_____	_____
<i>Benthamaspis conica</i>	Catoche Fm.	_____	_____	_____	Deadwood Fm.
<i>Benthamaspis gibberula</i>	Catoche Fm.	Nunatami Fm.	_____	_____	_____



tion (Peel and Cowie, 1979) exposed at Scoresby Bay (Poulsen, 1946; pl. XXIV, fig. 2, locality 9). There it occurs associated with Grinnellaspis feilteni (Poulsen, 1946; pl. XXII, figs. 8, 9), a species closely resembling but not identical to G. newfoundlandensis.

The Canyon Elv Formation east of Ellesmere Island in Washington Land, northern Greenland contains the conodont Oepikodus communis (Ethington and Clark) (Stouge, 1982). In the study area this species first appears at the base of the Catoche Formation (Stouge, 1982, Fig. 3), 3.10 m above the base of the Strigigenalis caudata Zone; it continues to the top of this zone.

Poulsen (1946; pl. XXII, figs. 14-16) also illustrated an incomplete cranidium of Benthamaspis problematica Poulsen, 1946 from the Nunatami Formation (Poulsen, 1927) exposed at Cape Steven (Poulsen, 1946; pl. XXIV, fig. 2, locality 6). Fortey (1979a, p. 100) tentatively synonymized this species with the Strigigenalis caudata Zone species B. gibberula (Billings). The author concurs with this assignment. Among the trilobites associated with B. problematica is a species of Jeffersonia (= Genus et sp. indet II Poulsen, 1946; p. 329; pl. XXIII, figs. 6-9 only) closely resembling and possibly identical to the S. caudata Zone species J. timon (Billings).

b) East Greenland

The lower Strigigenalis caudata Zone trilobite Uromystrum affine (Poulsen), which occurs in the basal beds of the Catoche Formation, was

originally described by Poulsen (1937, p. 55; pl. 7, figs. 6, 7) from the eastern part of the anticline on the south coast of Ella Island. Here the Cape Weber Formation (Poulsen, 1930; Cowie and Adams, 1957; Peel and Cowie, 1979) also yielded Bolbocephalus groenlandicus Poulsen (1937, p. 48-49; pl. 5, figs. 9-13). The author has synonymized B. groenlandicus with the Strigigenalis brevicaudata to Strigigenalis caudata Zone species B. convexus (Billings).

c) Colorado

Berg and Ross (1959, p. 112; pl. 21, fig. 2) illustrated the Randaynia saundersi Zone trilobite Hystericurus oculilunatus Ross from the Manitou Formation in Williams Canyon near Colorado Springs. Ethington and Clark (1981, p. 9) report that the same beds have yielded the conodont Macerodus diana Fähræus and Nowlan, which also occurs in the Randaynia saundersi Zone in the study area.

d) North Dakota

Oculomagnus obreptus Lochman (1966, p. 541-542; pl. 62, figs. 1-7) occurs in subsurface beds of the Deadwood Formation in the Williston Basin of western North Dakota. Fortey (1979a, p. 102) assigned several of her illustrated specimens (Lochman, 1966; pl. 62, figs. 1, 2, 4) to the lower Strigigenalis caudata Zone species Benthampsis conica Fortey, assignments with which the author concurs.

### 3.5 Correlation with Ibexian Trilobite and Conodont Zonations

Ross and Hintze in Ross et al. (1982, p. 5-7 and 7-10, respectively) have recently championed the erection of the Ibexian Series to replace the traditionally accepted Canadian Series. To date there has been little comment on this proposal; it is discussed in detail in section 3.7. Suffice it to say, however, the Ibexian trilobite zonation of Ross (1951) and Hintze (1953) is the standard reference for Early Ordovician trilobite faunas of North America. Ethington and Clark (1981) have also recently proposed subdivisions for conodonts of the Ibex area relative to the trilobite zones. These subdivisions, which replaced earlier informally proposed "faunas" (Ethington and Clark, 1971), they designated as "intervals" rather than zones, wishing to await confirmation from collecting in other areas before defining more formal zones (Hintze in Ross et al., 1982, p. 9).

Table 3.3 and Fig. 3.2 summarize the ranges of those trilobite and conodont species in the Ibexian reference section which also occur in the Boat Harbour and Catoche Formations. What is immediately obvious upon comparison of the ranges of the two groups is that individual trilobite species have much shorter ranges than individual conodont species. With the exception of Macerodus diana, which ranges through two trilobite zones, the remaining conodont species range through four to eleven trilobite zones. (see Ethington and Clark, 1981, Fig. 3). The longest ranging trilobite species in Fig. 3.2, Hystericurus oculilunatus, ranges through only two trilobite zones; the remainder have ranges no greater than half a trilobite zone. The shorter

Table 3.3. Ibexian Series trilobite and conodont species common to western Newfoundland. Ibexian trilobite data from Hintze (1953), Terrell (1973) and Young (1973); conodont data from Ethington and Clark (1981). Western Newfoundland trilobite data from Boyce (1979a, b, 1983, this study) Fortey (1979a) and Boyce in Stouge and Boyce (1983); conodont data from Stouge (1982) and Stouge in Stouge and Boyce (1983).

TRILOBITE SPECIES	IBEXIAN ZONAL RANGE	WESTERN NEWFOUNDLAND ZONAL RANGE
<i>Hystericurus oculilunatus</i>	ZONE E-F	<i>Randaynia saundersi</i> Zone
<i>Benthamaspis hintzei</i>	Zone G <sub>2</sub>	<i>Strigigenalis brevicaudata</i> Zone- <i>Strigigenalis caudata</i> Zone
<i>Benthamaspis gibberula</i>	Zone H	<i>Strigigenalis caudata</i> Zone
<i>Carolinites genacinaca nevadensis</i>	Zone H	<i>Strigigenalis caudata</i> Zone
CONODONT SPECIES		
" <i>Scolopodus</i> " <i>quadruplicatus</i>	Zone D-I	Barren Interzone II- <i>Strigigenalis caudata</i> Zone
" <i>Scolopodus</i> " <i>gracilis</i>	Zone E-M	<i>Randaynia saundersi</i> Zone- <i>Strigigenalis caudata</i> Zone
<i>Macerodus diana</i>	Zone E-F	<i>Randaynia saundersi</i> Zone-Barren Interzone II
<i>Drepanodus gracilis</i>	Zone G <sub>1</sub> -I	Barren Interzone II- <i>Strigigenalis caudata</i> Zone
<i>Tropodus comptus</i>	Zone G <sub>1</sub> -I	Barren Interzone II- <i>Strigigenalis caudata</i> Zone
<i>Oepikodus communis</i>	Zone G <sub>2</sub> -K	<i>Strigigenalis caudata</i> Zone

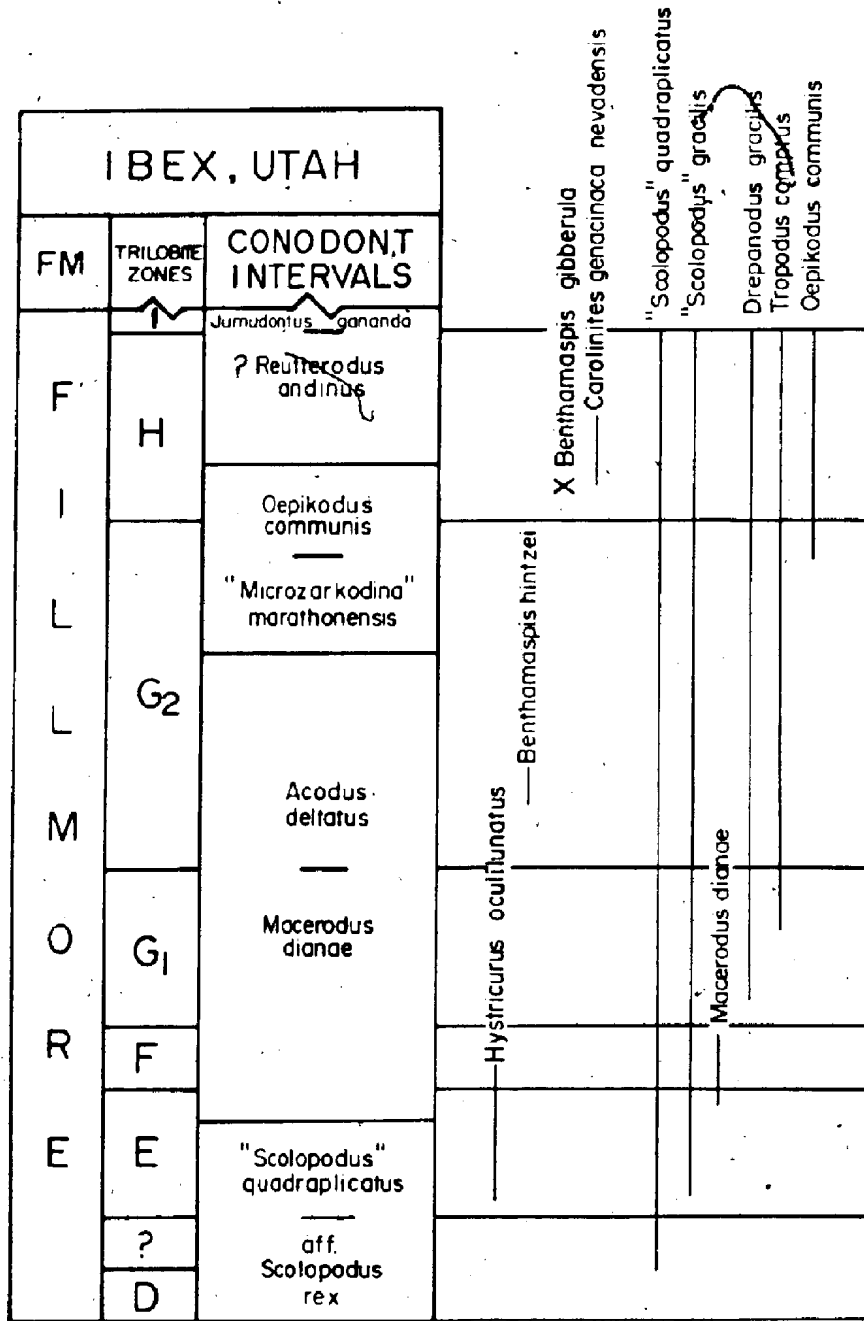


Figure 3.2. Ranges of Ibexian Series trilobite and conodont species common to western Newfoundland. Trilobite data from Hintze(1953), Terrell (1973) and Young (1973); conodont data from Ethington and Clark (1981).

trilobite ranges could be construed as indicating that trilobites were more susceptible to environmental factors than conodonts. However, Barnes and Fahraeus (1975) have shown that conodonts were quite strongly environmentally controlled. Furthermore, Fortey and Barnes (1977) have found that conodont communities in the Arenig-Llanvirn of Spitsbergen paralleled those of the trilobites. Harris and Repetski have also shown that conodont distribution in many of the same intervals as those covered by Ethington and Clark (1981) was controlled by determinable environmental factors to such an extent that some of the stratigraphic ranges of fossils may differ from place to place (reported in Ross et al., 1982, p. 3).

To summarize, the shorter ranges of the Ibexian trilobites the author regards as indicative of a higher evolutionary rate. Consequently, the Ibexian trilobite zonation of Ross (1951) and Hintze (1953) promises a greater degree of resolution as a biostratigraphic standard. The informal conodont zonation of Ethington and Clark (1981) remains the best standard where trilobites are absent, however. In this study primary reliance is placed on specific correlation of the trilobites; secondary reliance is placed on specific correlation of the conodont assemblages obtained by Barnes and Tuke (1970), Stouge (1982) and Stouge in Stouge and Boyce (1983).

The ranges of the trilobite and conodont species common to Ibex, Utah and western Newfoundland are compared in Fig. 3.3 (in back pocket). The actual correlations of the trilobite - conodont species associations are shown in Fig. 3.4 (in back pocket) and discussed

further in the text below. These figures also show the relation of Stouge's (1982) conodont faunas to the authors proposed trilobite zones.

Note:

Figures 3.2-3.4 and 3.6-3.9 have been plotted with the same vertical scale as Ethington and Clark's (1981) Fig. 3. The purpose is to show the relative thicknesses of all the rock sequences discussed in the text.

Hystricurus oculilunatus Ross, a characteristic species of the Randaynia saundersi Zone, ranges through most of Ibexian trilobite Zone E and the bottom half of Zone F (Hintze, 1953; Terrell, 1973); this suggests that Barren Interzone I is of Zone E age or older. The correlation of the Randaynia saundersi Zone with Ibexian Zones E and F is supported by the common presence of the conodont species "Scolopodus" gracilis Ethington and Clark and Macerodus dianae Fähræus and Nowlan. In the study area they occur together through most of the Randaynia saundersi zone and almost to the top of Barren Interzone II to the base of the "pebble bed". Macerodus dianae does not occur above this horizon. The mutual occurrence of "S." gracilis and M. dianae below the "pebble bed" in Barren Interzone II suggests that most of this barren interval is no younger than latest Zone F. In the Ibexian sequence the two species only range together from latest Zone E to latest Zone F.

Benthamaspis hintzei sp. nov. in the study area ranges through the uppermost part of the Strigigenalis brevicaudata Zone to the lowermost part of the Strigigenalis caudata Zone. In the Ibexian sequence this species occurs slightly above the lower one-fifth of Zone G<sub>2</sub>. This sug-

gests that the S. brevicaudata Zone lies totally within Zone G2 and that the base of the S. caudata Zone also occurs within Zone G2. The associated conodont species "Scolopodus" quadruplicatus Branson and Mehl, "Scolopodus" gracilis Ethington and Clark, Drepanodus? gracilis (Branson and Mehl) and Tropodus comptus (Branson and Mehl) support this correlation. In the Ibexian sequence these species do not occur together below the upper third of Zone G1; in the study area they occur in the uppermost part of Barren Interzone II above the "pebble bed". This suggests that the maximum possible age of this part of Barren Interzone II is latest Zone G1.

Benthamaspis gibberula (Billings) and Carolinites genacinaca nevadensis Hintze occur together in the upper part of the Strigigenalis caudata Zone on Port au Choix Peninsula (Fortey, 1979a, Fig. 11). Fortey (1979a, p. 64) has already pointed out the fact that these species occur together in Ibexian Zone H; they occur in the lower half of the zone. The associated conodont species "Scolopodus" quadruplicatus Branson and Mehl, "Scolopodus" gracilis Ethington and Clark, Drepanodus? gracilis (Branson and Mehl), Tropodus comptus (Branson and Mehl) and Oepikodus communis (Ethington and Clark) support this correlation. The upper part of the Strigigenalis caudata Zone may extend into Ibexian Zone I based on cephalopod data (Flower, 1978, Fig. 43.2).

In summary then Barren Interzone I is probably of Zone E age or older and the Randaynia saundersi Zone probably correlates with the later part of Zone E and most of Zone F. Barren Interzone II below the "pebble bed" is probably latest Zone F age whilst immediately above it



is of probable early Zone G<sub>2</sub> age. The Strigigenalis brevicaudata Zone lies entirely within Zone G<sub>2</sub>. The base of the Strigigenalis caudata Zone occurs within Zone G<sub>2</sub> whilst the top of the zone may extend into Zone I. These conclusions are in general accord with those of Boyce (1979a,b, 1983), Fortey (1979a) and Stouge (1982). The Ibex, Utah - western Newfoundland correlations are summarized in Fig. 3.5 (in back pocket). Figure 3.5 also shows the relation of Stouge's (1982) conodont faunas and Flower's (1978) cephalopod zones to the author's proposed trilobite zones.

Note:

The magnitude of the hiatus marked by the "pebble bed" was determined in the following way. The intervals marked by T<sub>1</sub> and T<sub>2</sub> in Fig. 3.4 were assumed to represent the same period of time because they contain identical trilobite-conodont species associations. The distance from T<sub>1</sub> to the "pebble bed" was measured on the western Newfoundland column then converted to the proportional distance on the Ibex, Utah column. The same procedure was followed for the distance from T<sub>2</sub> to the "pebble bed".

Boyce (1978) correlated the beds currently assigned to Barren Interzone I, the Randaynia saundersi Zone and the part of the Barren Interzone II below the "pebble bed" to Ibexian Zones B to D; the beds of the Strigigenalis brevicaudata and Strigigenalis caudata Zones were correlated with Zone G. These correlations, now known to be erroneous, were tentative correlations based on sparse, poorly preserved trilobite material.

Flower's (1978, Fig. 43.2) correlations differ somewhat from those of the author. He correlated the beds of Barren Interzone I, the Randaynia saundersi Zone and Barren Interzone II below the "pebble bed"

with Ibexian Zones D (in part) and E (his Bassleroceras - Lecanospira Zone IV). The beds of Barren Interzone II above the "pebble bed" and the Strigigenalis brevicaudata Zone (his Pycnoceras apertum Zone VI) Flower correlated with Ibexian Zone G1. The beds of the Strigigenalis caudata Zone (his Cassinoceras wortheni Zone VIII) Flower correlated with Ibexian Zone I. Flower's correlations were based on the generic similarities of the compared cephalopod and gastropod faunas.

### 3.6 Correlations with Standard Canadian Series Deposits

The Canadian Series was formally introduced by Dana (1874, p. 214) for the fossiliferous deposits of the Levis Formation exposed at Levis, Quebec (Fahraeus, 1977b, p. 982). However, at present, the Beekmantown Group of New York-Vermont and laterally equivalent deposits in Missouri-northern Arkansas are commonly utilized as the standard deposits of the Canadian Series (Flower, 1964; Whittington, 1968; Fahraeus, 1977b). Flower (1964, p. 17-19) treated the Canadian Series as a system and proposed four stages: Gasconadian - from Missouri-northern Arkansas, Demingian (= Roubidouxian of Fisher, 1982) - from New Mexico and New York, Jeffersonian - from Missouri-northern Arkansas and Cassinian from New York. The purpose of this portion of the study is to correlate the trilobite faunas of the Boat Harbour and Catoche Formations with those of the Canadian deposits of New York-Vermont and Missouri-northern Arkansas.

The trilobite species common to New York-Vermont, Missouri-northern Arkansas and western Newfoundland are listed in Table 3.4. The

Table 3.4. Canadian Series trilobite species common to western Newfoundland. Canadian Series trilobite data from Cullison (1944), Flower (1968c), Whitfield (1889a, 1897) and Whittington (1953). Western Newfoundland trilobite data from Boyce (1979a, b, 1983, this study), Fortey (1979a) and Boyce in Stouge and Boyce (1983).

TRILOBITE SPECIES	OCCURRENCES IN CANADIAN SERIES DEPOSITS				WESTERN NEWFOUNDLAND ZONAL RANGE
	NEW YORK-VERMONT		MISSOURI-NORTHERN ARKANSAS		
	STAGE	FORMATION	STAGE	FORMATION	
<i>Aspidoparia canadensis</i>	Demingian	Ft. Ann	-----	-----	<i>Aspidoparia canadensis</i> Zone
<i>Fibosia</i>	Demingian	Ft. Ann	-----	-----	<i>Aspidoparia canadensis</i> Zone
<i>Strophomena</i>	Cassinian	Ft. Cassin	Cassinian	Cotter	<i>Strophomena</i> Zone
<i>Burchardia</i>	Cassinian	Ft. Cassin	-----	-----	<i>Strophomena</i> Zone

ranges of these species are compared in Fig. 3.6 (in back pocket). The actual correlations of the trilobite species associations are shown in Fig. 3.7 (in back pocket) and discussed further in the text below.

a) New York-Vermont

The Randaynia saundersi Zone trilobites Hystericurus oculilunatus Ross and Paraplethopeltis seelyi (Whitfield) also occur in the standard deposits of the Demingian Stage, the Fort Ann and lower Bascom Formations of Fisher and Mazzullo (1976) and Mazzullo and Friedman (1975, 1977).

The trilobites Gen. et sp. ind. Whittington (1953, p. 670; pl. 68, figs. 30-32) and Nileus striatus Whitfield (1897, p. 184; pl. 5, figs. 5, 6) occur in the standard deposits of the Cassinian Stage, the Fort Cassin and upper Bascom Formation of Fisher and Mazzullo (1976) and Mazzullo and Friedman (1975, 1977). Fortey (1979a) synonymized these species with the Strigigenalis caudata Zone trilobites Strigigenalis caudata (Billings) and Benthamaspis gibberula (Billings), respectively, assignments with which the author concurs.

b) Missouri-northern Arkansas

Genus(?) sp.(?) Cullison (1944, p. 84-85; pl. XXXV, figs. 23, 24) occurs in the standard deposits of the lower part of the Jeffersonian Stage sensu Flower (1964), the Theodosia Formation of the Jefferson City Group (Cullison, 1944). This species, on morphological grounds, is

tentatively regarded as synonymous with the undescribed trilobite Hystericurus sp. nov. 3 reported by Boyce (1983) from beds at Eddies Cove West and at Barbace Point, Port au Choix Peninsula, beds assigned by the author to the Strigigenalis brevicaudata Zone. Here this species is associated with Peltabellia sp. cf. P. willistoni Lochman, 1966, a species closely similar to P. crassimarginata (Cullison, 1944) which also occurs in the Jeffersonian Theodosia Formation.

The author has synonymized Goniotelus semicircularis Cullison (1944, p. 84; pl. XXXV, figs. 25, 26) with the nominate species of the Strigigenalis caudata Zone. This species occurs in the Cotter Formation which was assigned by Flower (1964, p. 19) to the uppermost part of the Jeffersonian Stage.

If the synonymy of the Jeffersonian Goniotelus semicircularis Cullison and the Cassinian Gen. et sp. ind. Whittington as proposed by Fortey (1979a) and the author (this study) is correct, the Cotter Formation is probably better referred to the lowermost part of the Cassinian Stage rather than the uppermost part of the Jeffersonian Stage. This is in agreement with Flower (1978, p. 220, Fig. 43.2) who did, in fact, reassign the Cotter Formation to the lowermost part of the Cassinian.

c) Summary

The Randaynia saundersi Zone is probably Demingian, the Strigigenalis brevicaudata Zone is probably Jeffersonian, and the Strigig-

enalis caudata Zone is probably Cassinian. This information is summarized in Fig. 3.8.

### 3.7 Correlation of the Canadian Series with the Ibexian Series Trilobite Zonation

Ross and Hintze in Ross et al. (1982, p. 5-7, and 7-10, respectively), have recently championed the erection of the Ibexian Series (based on Lower Ordovician strata at Ibex, Utah) to replace the traditionally utilized Canadian Series. As Ross in Ross et al. (1982, p. 5) stated "The Canadian Series has been used for about 90 years by convention, really because there was nothing better. It lacks a coherent stratotype, is based largely on tradition and survived until now as a patchwork at best." Ross (p. 7) also pointed out that the name Canadian is far removed from Dana's (1874) concept of the Canadian Period and dependent on stratigraphic sections distant from the type areas near Quebec and northeastern New York. Because 1) the Canadian Series lacks any complete type section (see Section 3.5) and 2) the Ibex section is the standard biostratigraphic reference section for the Early Ordovician, it was recommended that the new term Ibexian Series be adopted in place of the Canadian Series (Ross in Ross et al., 1982, p. 7), a position which the author strongly favors.

Hintze in Ross et al. (1982, p. 7) enumerated the factors favoring the adoption of the Lower Ordovician strata at Ibex, Utah as the stratotype of the proposed Ibexian Series. These are:

NEW YORK-VERMONT MISSOURI N. ARKANSAS		WESTERN NEWFOUNDLAND				
SERIES	STAGE	F M	MBR	TRILOBITE ZONES	CONODONT FAUNAS	CEPHALOPOD ZONES
CANADIAN	COVINGTIAN	CALOCHE	LOWER	Strigigenalis caudata Zone	Fauna 4	Cassinoceras wortheni
	JEFFERSONIAN	BOATHR	Pebble bed DUMBER	Strigigenalis brevicaudata Zone	Fauna 3	Pycnoceras apertum
				Barren Interzone II		
				Randaynia saundersi Zone	Fauna 2	Bassleroceras-Lecanospira
				Fauna 1		

Barren Interzone I

Figure 38 Chart showing correlation of western Newfoundland trilobite zones, conodont faunas and cephalopod zones with the stages of the Canadian Series. J=Jeffersonian.

1. the abundance and diversity of taxa present (trilobites, conodonts, brachiopods, graptolites, cephalopods, etc.).
2. complete and unambiguous documentation of the rocks and the contained fossils.
3. excellent exposures which are easily accessible almost year-round.

Notwithstanding the above considerations, for the purpose of this section the Canadian Series is treated as still valid.

Correlations of the Canadian Series trilobite faunas with the Ibexian trilobite zonation of Ross (1951) and Hintze (1953) have been hampered because of the apparent low diversity and paucity of up-to-date systematic studies of the Canadian trilobite faunas. Common species have been masked under different names.

The trilobite species common to the Canadian and Ibexian Series are listed in Table 3.5. The actual correlations of the ranges of these species are shown in Fig. 3.9 (in back pocket). The correlation of the stages of the Canadian Series with the trilobite zones and conodont intervals of the Ibexian Series is summarized in Fig. 3.10.

The common occurrence of Hystricurus oculilunatus Ross suggests that the Demingian Stage is partly equivalent to Ibexian Zones E and F. This agrees with Flower (1964, 1978, p. 220; Figs. 43.2).

Hystricurus sp. nov. 3 of Boyce (1983), tentatively synonymized with the Jeffersonian Genus(?) sp.(?) Cullison (1944, p. 84-85; pl. 3



Table 3.5. Trilobite species common to Canadian and Ibexian Series. Canadian Series trilobite data from Cullison (1944), Flower (1968c) and Whitfield (1889a, 1897). Ibexian Series trilobite data from Hintze (1953), Terrell (1973) and Young (1973).

TRILOBITE SPECIES	OCCURRENCE IN CANADIAN SERIES	OCCURRENCE IN IBEXIAN SERIES
<i>Hystriocurus aculeatus</i>	Demingian Stage	Zone E-F
Genus(?) sp.(?)	Jeffersonian Stage	Zone G <sub>2</sub>
<i>Benthania gibberula</i>	Cassinian Stage	Zone H

NORTH AMERICA			
SERIES	STAGES	TRILOBITE ZONES	CONODONT INTERVALS
IBEXIAN	CANADIAN	I	<i>Jumudontus gananda</i>
		H	? <i>Reutterodus andinus</i>
		G <sub>2</sub>	<i>Oepikodus communis</i>
			" <i>Microzorkodina</i> " <i>marathonensis</i>
			<i>Acodus deltatus</i>
	ILLINOISAN	G <sub>1</sub>	<i>Macerodus diandae</i>
		F	" <i>Scolopodus</i> " <i>quadraplicatus</i>
	DEMINGIAN	E	—
		?	aff. <i>Scolopodus rex</i>
		D	

Figure 3.10. Correlation of stages of Canadian Series with trilobite zones and conodont intervals of Ibeixian Series.

XXXV, figs. 23, 24) the author tentatively regards, on morphological grounds, as synonymous also with the undetermined pygidium illustrated by Hintze (1953; pl. XX, fig. 14) from Zone G<sub>2</sub>. If valid, this suggests that the Jeffersonian Stage is partly equivalent to Ibexian Zone G<sub>2</sub>. This is in accord with Flower (1978, p. 220; Fig. 43.2).

The synonymy of the Cassinian species Nileus striatus Whitfield and the Zone H species Benthamaspis distinctus Young with Benthamaspis gibberula (Billings) (Fortey, 1979a, p. 100) suggests that the Cassinian Stage is partly equivalent to Ibexian Zone H. This is also in agreement with Flower (1978, p. 220; Fig. 43.2).

### 3.8 Correlation of the Ibexian Series Trilobite Zonation with the Standard British - Scandinavian Ordovician Graptolite Zonation

The relatively short-ranging Ibexian Zone E-F conodont species Macerodus dianae Fahraeus and Nowlan was originally defined from Bed 8 of the Cow Head Group of Kindle and Whittington (1958) (Fahraeus and Nowlan, 1978). Graptolites from the upper part of Bed 8 are indicative of the earliest Arenig Tetragraptus approximatus Zone (Kindle and Whittington, 1958) stratigraphically above M. dianae. This conodont does not occur later than Zone F. This suggests that Zones E and F lie at the top of the late Tremadoc Adelograptus hunnebergensis - Clonograptus tenellus Zone of Britain - Scandinavia and Zone G<sub>1</sub> lies partly or wholly within the Tetragraptus approximatus Zone.

Berry (1960; pl. 7, Figs. 1, 3) illustrated a trilobite specimen ("New genus related to Strigigenalis and Benthamaspis") from Zone 4 (Tetragraptus fruticosus 4 branched) of his graptolite zonation in the Marathon region of Texas, equivalent to the lower half of the Arenig Didymograptus deflexus Zone of Britain-Scandinavia (Skevington, 1963, 1968; Jackson, 1964). Fortey (1979a, p. 102, 104) synonymized this trilobite with Benthamaspis conica Fortey. In western Newfoundland B. conica occurs in beds correlative with Ibexian Zone G<sub>2</sub>. Underlying beds also contain Zone G<sub>2</sub> trilobites. This suggests that Zone G<sub>2</sub>, as well as Zone G<sub>1</sub>, is partly equivalent to the basal Arenig Tetragraptus approximatus Zone.

Fortey (1976) showed that in Spitsbergen the range of the Ibexian Zone H trilobite Carolinites grenacinaca nevadensis Hintze extends into Berry's (1960) Zone 5 (Tetragraptus fruticosus 3 and 4 branched) equivalent to the upper half of the Arenig Didymograptus deflexus Zone of Britain-Scandinavia (Skevington, 1963, 1968; Jackson, 1964).

In summary Zones E and F probably lie at the top of the late Tremadoc Adelograptus hunnebergensis - Clonograptus tenellus Zone, Zone G<sub>1</sub> and part of Zone G<sub>2</sub> lie within the basal Arenig Tetragraptus approximatus Zone, and the rest of Zone G<sub>2</sub> and Zone H probably lie within the Arenig Didymograptus deflexus Zone of Britain - Scandinavia. This information is summarized in Fig. 3.11 (in back pocket).

### 3.9 The Significance of the Boat Harbour "Pebble Bed"

Prior to 1977 no major breaks were recognized within the St. George Group. At that time Knight recognized a distinct sedimentary break 15 m below the top of the Boat Harbour Formation at Boat Harbour. Here he identified a lag deposit comprising chalcedonic and vug quartz and chert pebbles scattered upon an irregular solution surface and capped by a thin shale seam. This he called the "pebble bed" (Knight, 1977b, 1978). The full significance of this sedimentary break within the Boat Harbour Formation only became apparent with the collection of trilobite and, later, conodont faunas below and above the "pebble bed".

There is an abrupt change in the trilobite faunas coincident with the "pebble bed" (Boyce, 1978, 1979a,b, 1983; Boyce in Stouge and Boyce, 1983). Below, the trilobites are predominantly hystericurids; above they are largely bathyurids. There are no common taxa below and above the "pebble bed" (Boyce in Stouge and Boyce, Fig. 3.3; this study). There is also an abrupt change in the conodont faunas at the "pebble bed"; only a very few taxa are inherited from the older faunas (Stouge, 1982; Stouge in Stouge and Boyce, 1983, Fig. 2.2).

Below the "pebble bed" late Tremadoc Zone E-F trilobite and conodont faunas occur in the Boat Harbour Formation, whilst above, the faunas are indicative of early Arenig Zone G<sub>2</sub>; Zone G<sub>1</sub> faunas are not represented (Boyce, 1979a,b, 1983, this study; Stouge, 1982).

The absence of Zone G<sub>1</sub> faunas and the distinct and abrupt changes in both the trilobite and conodont faunas coincident with the "pebble bed" suggests that this is a disconformity produced by sea level lowering and subaerial exposure of the platform. This suggestion is in accord with that originally put forward by Knight (1978).

This major late Tremadoc-early Arenig regressive episode was followed by repetitive cyclic shoaling upward sequences in the upper 15 m of the Boat Harbour Formation. This suggests that sedimentation at first kept pace with sea level rise (Knight, pers. comm., 1983). The mudcracked unit at the top of the Boat Harbour Formation probably represents a smaller early Arenig regressive event. The shelf was subsequently drowned by a major transgressive event slightly later in the early Arenig and subtidal deposits of the Catoche Formation blanketed the platform.

An analogous horizon to the Boat Harbour "pebble bed" was located by Knight (1983) in the Eddies Cove West area; Boyce (1983) recognized a comparable gap in the biostratigraphic succession of the trilobite faunas.

The major regressive-transgressive events described above are also recorded in the Cow Head Group of western Newfoundland and in central Newfoundland.

Pre-Arenig deposits in the Cow Head Group (Kindle and Whittington, 1958) are predominantly of gravity slide and slump origin (Fähraeus and

Nowlan, 1978) - these are interpreted by the author as the result of collapse of the oversteepened edge of the carbonate platform during regressive episodes. The Arenig deposits are mostly bedded fine grained carbonates (Fähraeus and Nowlan, 1978) which the author interprets as having formed in deeper water during transgressive episodes. Fähraeus and Nowlan (1978, p. 449) also report a change in the composition of the conodont faunas coinciding closely with the Tremadoc-Arenig boundary; this they believe was related to one of the major regressive-transgressive episodes during the Early Ordovician.

Stouge (1980, 1982) reports a faunal gap between late Tremadoc and early Arenig conodont faunas occurring immediately below and above the Boat Harbour "pebble bed". However, in central Newfoundland, Stouge (1980) records the missing fauna from limestones exposed at South Catchers Pond. Stouge (1982) explained this by suggesting that during this late Tremadoc - early Arenig interval a major regression occurred. According to Stouge the western Newfoundland conodont faunas during this regression were forced to migrate seaward towards central Newfoundland; during the subsequent early Arenig transgression they migrated back to western Newfoundland. In central Newfoundland the early Arenig transgression is marked by a change from shallow water limestone deposition to deep water black shale deposition (Stouge, 1980).

The regional extent of these regressive-transgressive events is not confined to Newfoundland. An examination of existing literature indicates the presence of the same events elsewhere in the world, this

information is summarized in Fig. 3.12 (in back pocket). These areas are as follows:

a) southeastern Ontario, Canada

The lithostratigraphy and conodont biostratigraphy of the March and Oxford Formations in the area of Brockville, Ontario have recently been detailed by Bond and Greggs (1973, 1976) and Greggs and Bond (1971), respectively.

A well defined lithological break separates the predominantly clastic sediments of the March Formation (below) from the carbonates and sandy carbonates of the Oxford Formation (above). This abrupt lithological change Bond and Gregg (1976, p. 21) considered indicative of a disconformity, as there was evidence of erosion of the March Formation prior to deposition of the Oxford Formation.

A distinct change in the conodont faunas coincides with the abrupt contact between the March and Oxford Formations (Greggs and Bond, 1971). Many taxa make their first appearance in the succession immediately above the March - Oxford Formation contact (Bond and Greggs, 1976, p. 24). On the basis of their contained faunas the March and Oxford Formations were assigned to the late Tremadoc (Bond and Greggs, 1973, p. 1147) and the early Arenig (Bond and Greggs, 1976, p. 25), respectively. Oneotodus variabilis Lindstrom which is present in the March Formation also occurs in the upper member of the Boat Harbour Formation below the "pebble bed" (Stouge in Stouge and Boyce, Fig.



2.2). The following species which occur in the Oxford Formation, also are present in the Boat Harbour Formation above the "pebble bed": "Scolopodus" quadruplicatus Branson and Mehl and Oistodus inaequalis Lindstrom (Stouge in Stouge and Boyce, Fig. 2.2).

Trilobites have so far only been recovered from the lower sandy division of the Oxford Formation in southeastern Ontario where the following species have been identified (Ludvigsen, 1979a,b): Bolbocephalus convexus (Billings), Gignopeltis rarus (Billings), Goniotelina subrectus (Bradley), Strotactinus salteri (Billings) and Isoteloides sp. Of these species B. convexus has been shown to occur in western Newfoundland in rocks of demonstrable early Arenig Zone G<sub>2</sub>-H age; G. subrectus also occurs in the Fort Cassin Formation (Whittington, 1953) which has been demonstrated to contain the early Arenig Zone H species Benthamaspis gibberula (Billings). Combining the conodont and trilobite data, the Oxford Formation can, therefore, be no older than early Arenig Zone G<sub>2</sub>. This is at variance with Ludvigsen (1979c, Fig. 2) who depicts the Oxford as old as Zone F.

In the southeastern Ontario area lithostratigraphic and biostratigraphic evidence indicates a late Tremadoc-early Arenig regression at the top of the March Formation followed by an early Arenig transgression at the base of the Oxford Formation.

b) New York - Vermont, U.S.A.

An erosion surface separates the Fort Ann (= lower Bascom) Formation from the overlying Fort Cassin (= upper Bascom) Formation (Flower,

1968c; Mazzullo and Friedman, 1975; Fisher and Mazzullo, 1976). This erosion surface is overlain by a laminated dolomitic siltstone unit (the Ward Siltstone of Fisher, 1982), which may be analogous to the thin shale seam overlying the Boat Harbour "pebble bed".

The Fort Ann Formation is 30 to 35 m thick (100 to 115 ft - Flower, 1964, 1968c). The lower 12 m consists of alternating beds of gray weathering dolostone and highly fossiliferous, locally extensively bioturbated (vermicular) black limestone and dolomitic limestone. The upper part of the formation consists of 18 to 23 m of dolostone containing only rare, silicified fossils; thickness varies because the top of the formation is an erosion surface (Flower, 1964, 1968c).

The overlying Fort Cassin Formation is divided into three members (Fisher in Ross et al., 1982, Fig. 3, Fisher, 1982). The basal Ward Siltstone member is a 14 to 19 m thick unit of laminated dolomitic siltstone; thickness presumably varies because the member overlies the erosion surface developed at the top of the underlying Fort Ann Formation. The middle Sciota Member consists of 47 to 55 m of highly fossiliferous medium to dark gray dolomitic limestone with lighter gray, coarse calcarenitic lenses and interbedded tan weathering fine grained pale gray dolostones. The upper Providence Island Dolostone consists of at least 44 m of tan weathering, massive, fine grained bluish-gray dolostone (Fisher in Ross et al., 1982, Fig. 3); Flower (1964, Fig. 52) previously reported the thickness of this unit as 91 m (300 ft.).

The trilobite fauna of the Fort Ann Formation occurs in the lower 12 m thick limestone member and includes Hystericurus oculilunatus Ross and Paraplethopeltis seelyi (Whitfield); it correlates favorably with the late Tremadoc Zone E-F fauna found below the Boat Harbour "pebble bed". The Fort Cassin trilobite fauna occurs in the middle 50 m thick Sciota member and includes Strigigenalis caudata (Billings) and Benthamaspis gibberula (Billings); this correlates with the early Arenig Zone H Catoche Formation fauna. These correlations suggest a hiatus of greater magnitude than that in western Newfoundland as might be expected of strata deposited closer to the shore line of the Ordovician platform.

c) northern Estonia.

Roomusoks (1972) reports a stratigraphic break in upper Tremadoc deposits in northern Estonia followed by a transgression at the beginning of the Arenig. With this transgression a completely new inarticulate brachiopod fauna appeared (Roomusoks, 1972, p. 607).

d) Bohemia

Havlicek (1976, p. 352) states:

"The close of the Tremadoc and the beginning of the Arenig was a period of important paleogeographical changes, which are well documented from Bohemia. There the upper Tremadoc Milina Formation is composed of regressive deposits; sedimentation was predominantly chemical as is apparent from the fact that 50% or more of its total thickness is formed of chert. At the beginning of the Arenig, this regression was succeeded by a new transgression ....."

"When comparing the conditions at the base of the Arenig with those at the base of the Tremadoc, there is a similarity in that in some areas the majority of the upper Tremadoc fauna was destroyed at that time. The ensuing Arenig transgression then repopulated these areas with a new fauna of varying origins"

Bouček (1973, p. 143) reports the absence of the basal Arenig Tetragraptus approximatus Zone in Bohemia.

e) Morocco

Destombes (1962, p. 455; 1971) records a major Upper Tremadoc regression, followed by a Lower Arenig transgression in the Schistes des Fezouata of the Anti-Atlas Mountains.

f) Wales

There is a paleontological break at the upper boundary of the Tremadoc Series in Wales (and below the base of the Arenig as defined in Britain). The youngest Tremadoc rocks exposed there, the Amnodd Shales and equivalents (Williams et al., 1972), are of late Tremadoc Adelograptus hunnebergensis - Clonograptus tenellus Zone age (Cope et al., 1978; Owens et al., 1982). The fauna of the earliest Arenig (in the Scandinavian sense) Tetragraptus approximatus Zone has not been recognized; it is likely that it is not represented by graptolite-bearing strata (Skevington, 1969, p. 163). Fortey (1979a, p. 67) first suggested that the basal Arenig transgression of Wales was approximately coincident with the deepening event that accompanied the trilobite faunas of the Catoche Formation.

g) Australia

Webby et al. (1981; pl. 1) depict a hiatus within the Kelly Creek Formation of the Georgina Basin spanning the Bendigonian Be 1 Tetragraptus approximatus - Tetragraptus fruticosus Zone and half of Be 2 Tetragraptus fruticosus 4-branched. In terms of the British - Scandinavian graptolite zonation this corresponds to the early Arenig Tetragraptus approximatus Zone and the lower quarter of the Didymograptus deflexus Zone (Skevington, 1973; Table 1). This hiatus was first reported by Jones et al. (1971) because of a break in the succession of conodont faunas, although no physical discontinuity has so far been demonstrated (Webby et al., 1981). Shergold et al. (1976) depict the break as spanning an interval from middle to late Warendian (= Lancelfieldian La 1-2; Webby et al., 1981) in British - Scandinavian terms equivalent to the upper part of the late Tremadoc Adelograptus hunnebergensis - Clonograptus tenellus Zone (Ross et al., 1982). Shergold and Druce (1980) depict the break as extending from late Warendian to earliest Arenig, in British - Scandinavian terms latest Tremadoc Adelograptus hunnebergensis - Clonograptus tenellus Zone to earliest Arenig Tetragraptus approximatus Zone. As Webby et al. (1981, p. 29) note, the nature and timing of the break is in doubt but they suggest it may represent a short-lived early Arenig phase of regression.

3.10 Summary

During the early Ordovician western Newfoundland, southeastern Ontario, and New York - Vermont were all part of the equatorially dis-

posed Bathyrud Province (Whittington and Hughes, 1972, 1973). Because southeastern Ontario and New York - Vermont lay closer to the cratonic margin of the platform, which was developed around the Canadian Shield, late Tremadoc - early Arenig regression affected those areas first and lasted longer there; subsequent early Arenig transgression affected western Newfoundland first as it lay closer to the edge of the platform. The platform edge and continental slope were affected least by these events.

Northern Estonia during the early Ordovician was part of the Asaphid Province (Whittington and Hughes, 1972, 1973). Whittington and Hughes (1972, 1973, Fig. 3) depict this province as equatorially to tropically located, however, Coëks and Fortey (1982) have presented faunal evidence suggesting that its location was in more temperate latitudes.

During the early Ordovician, Bohemia, Morocco and Wales were part of the temperate latitude to polar Selenopeltis Province (Whittington and Hughes, 1972, 1973) developed around the supercontinent of Gondwanaland. Australia at this time was also attached to Gondwanaland but its position was at more tropical latitudes within the Asaphopsis Province (Whittington and Hughes, 1972, 1973).

During the late Tremadoc - early Arenig all the above faunal provinces were affected by a major late Tremadoc regressive event followed by a major early Arenig transgression. Fortey (1979a, p. 67) first addressed the question of contemporaneity of the early Arenig trans-

gression in western Newfoundland and Wales. He concluded that it might be necessary to invoke a world-wide sea level rise to account for its effects in what were then separate continental plates. It therefore follows that a world-wide sea level drop must be invoked for the late Tremadoc - early Arenig regression.

Donovan and Jones (1979) discussed in detail the causes of world-wide changes of sea level. For major changes (i.e. between 150 m and 300 m) they concluded that the following are likely to be most effective:

- 1) Changes in the volume of land ice - increases in the volume of land ice resulting in regressions, decreases resulting in transgressions.
- 2) Changes in the volume of ocean ridges - the development of oceanic ridges during continental fragmentation resulting in transgressions; the collapse of oceanic ridges during the formation of supercontinents resulting in regressions.

Another possible cause of world-wide changes in sea level is changes in the size of the earth, i.e. earth expansion/contraction. This cause is generally dismissed with little discussion, however, (Donovan and Jones, 1979; Hallam, 1981) despite its great explanatory potential. If the volume of water in the earth's oceans remained relatively constant throughout geological time then episodes of earth expansion would result in world-wide regressions, contractions would result in transgressions.

The late Tremadoc - early Arenig regression and subsequent early Arenig transgression precipitated widespread and profound evolutionary changes in the brachiopod, conodont, graptolite and trilobite faunas of the Bathyrid, Asaphid, Selenopeltis and Asaphopsis Provinces. In the Bathyrid Province hystericurid trilobite faunas were replaced by totally new bathyrid faunas; there was also a change in the composition of the conodont faunas. In the Asaphid Province a completely new inarticulate brachiopod fauna appeared. There was a marked change in the articulate brachiopod and graptolite faunas of the Selenopeltis Province. In the Asaphopsis Province there was a change in the conodont faunas.

Newell (1967) first proposed the hypothesis explicitly relating faunal extinctions and radiations to eustatic sea level changes and indicated that a good correlation exists between biotic diversity and the area of habitat available for colonization. A decrease in the area of epicontinental sea habitat during regression should, therefore, have a deleterious effect on the marine organisms and lead to widespread extinction; adaptive radiation of the survivors would take place during the subsequent transgression as a result of the consequent expansion of habitat area (Hallam, 1981, p. 225).

Sheehan (1973) related the Ordovician - Silurian changeover in North American brachiopod faunas to the Late Ordovician Gondwanaland glaciation; he suggested that sea level may have been lowered enough to severely stress the widespread shallow marine North American faunas, resulting in their eventual extinction. Sheehan (1973, p. 150) also



proposed a number of points to be established before glaciations could be considered as explaining faunal changeovers. These are:

- 1) The presence of a continental size glaciation must be confirmed and precisely dated.
- 2) The extent of the glaciation must have been sufficient to have caused a significant lowering of sea level.
- 3) The faunal changeover must be shown to have occurred during or immediately after glaciation.
- 4) The eustatic lowering of sea level should be reflected in the sedimentary record of shallow water seas as a world-wide regressive phase.

Of the above points, only 4) has been established with respect to the late Tremadoc - early Arenig regression. As far as the author knows there is no record of any glaciation during this time interval. Consequently, he proposes that there be a concerted search effort for late Tremadoc - early Arenig glacial pavements and tillites around the inner cratonic margin of the Selenopeltis Province of Gondwanaland, particularly in northwest Africa and northeast South America (see Whittington, 1973, Fig. 3). A search for dropstones would also be advisable in marine sediments rimming Gondwanaland in lower latitudes, i.e. in Australia and Antarctica.

Should no evidence for a glaciation during the late Tremadoc - early Arenig interval be uncovered then the hypotheses of oceanic ridge collapse and earth expansion merit serious attention.

#### 4. SYSTEMATIC PALEONTOLOGY

##### 4.1 Association of Trilobite Parts

Guidelines for the association of separate pieces of individual trilobite species have been outlined previously by Fortey (1979a, p. 63).

In general, the association of librigenae with cranidia is straightforward, accomplished merely by comparing their size, convexity, prosopon (surface ornamentation) and the fit of their facial sutures. The association of pygidia and hypostomata with cranidia, however, is more difficult. Fortunately the problem can be obviated if 1) a complete or nearly complete specimen is obtained or 2) the remains of a single species or several highly distinct species are concentrated in one horizon. Furthermore, pygidia and hypostomata often have the same type of prosopon and display similar degrees of effacement (or lack of it) and/or convexity as their associated cranidia. In particular, the glabella and the pygidial axis often have the same prosopon type.

##### 4.2 Terminology

The terminology utilized is that of Moore (1959) with additional terms from Opik (1967), Richter and Richter (1949), and Whittington (1965). The glabella includes the occipital ring except when the term preoccipital glabella is used. The common morphological nomenclature of trilobites is shown in Figure 4.1. The orientation of the trilobite exoskeleton is shown in Figure 4.2.

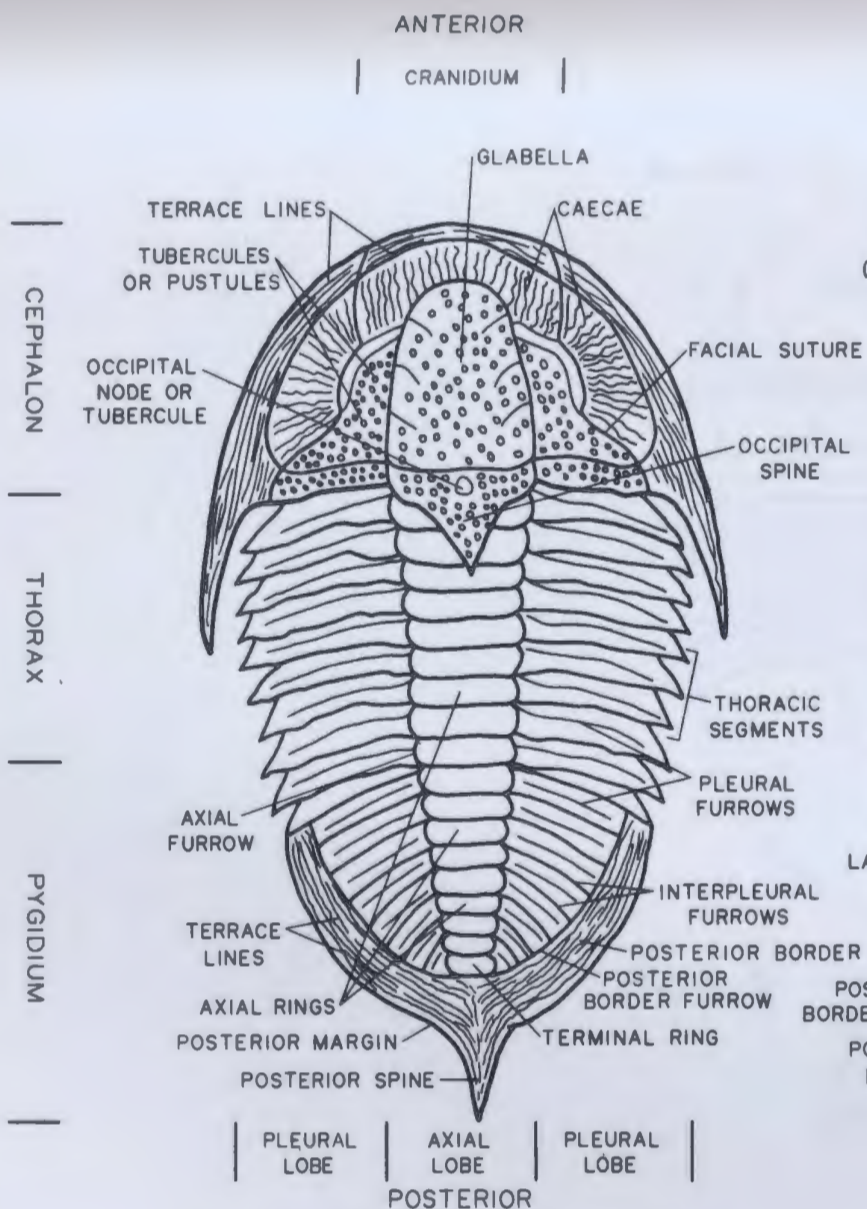


FIGURE 4-1A-GENERAL TRILOBITE MORPHOLOGY

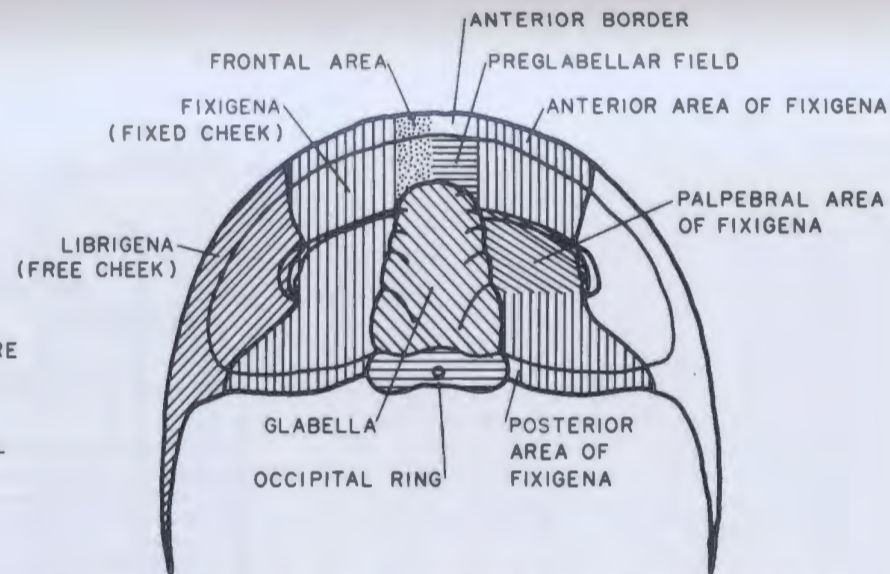


FIGURE 4-1B-MORPHOLOGICAL DIVISIONS OF THE CEPHALON OF A TYPICAL TRILOBITE

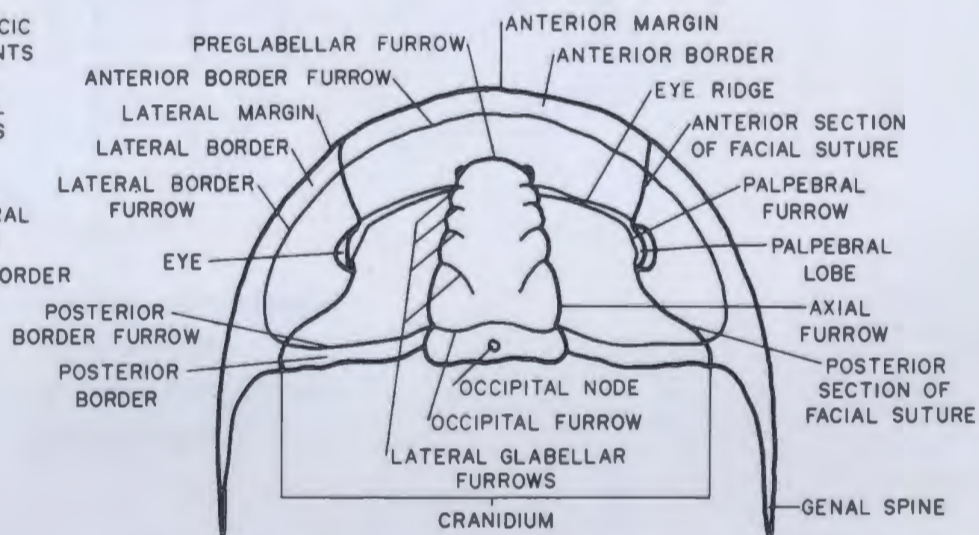


FIGURE 4-1C-CEPHALIC NOMENCLATURE OF A TYPICAL TRILOBITE

FIGURES 4-1A,B,C MODIFIED FROM FIGURES 28, 30, 31, RESPECTIVELY, OF MOORE (1959)

FIGURE 4.1. TRILOBITE MORPHOLOGIC NOMENCLATURE.

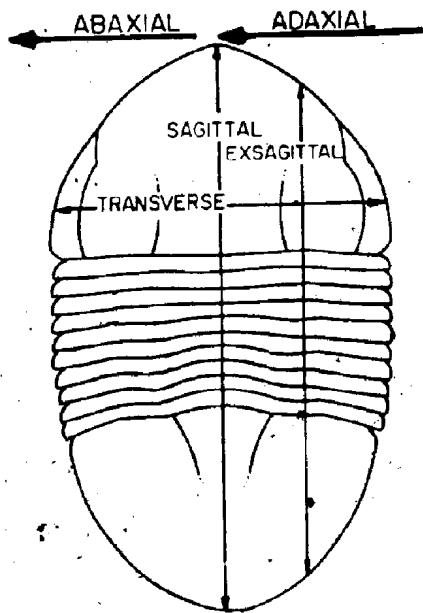


Figure 42 Trilobite orientational nomenclature.  
Modified from Moore (1959, Fig. 27)

#### 4.3 Location of Illustrated Material

The specimens illustrated in this study are housed in several different institutions, each of which has their own particular abbreviation. These are as follows:

A.M.N.H. - American Museum of Natural History, New York, New York, U.S.A.

G.M. - Geologisk Museum, Copenhagen, Denmark.

G.S.C. - Geological Survey of Canada, Ottawa, Ontario, Canada.

NFM - Newfoundland Museum, St. John's, Newfoundland, Canada.

U.S.N.M. - United States National Museum, Smithsonian Institution, Washington, D.C., U.S.A.

Y.P.M. - Yale Peabody Museum, New Haven, Connecticut, U.S.A.

#### 4.4 Systematic Descriptions

The classification followed is basically that of Moore (1959) except that Hupé's (1953) concept of the Bathyridae is used and the order Proetida of Fortey and Owens (1975) is recognized.

Order PTYCHOPARIIDA Swinnerton, 1915

Superfamily LEIOSTEGIACEA Bradley, 1925

Family LEIOSTEGIIDAE Bradley, 1925

Subfamily LEIOSTEGIINAE Bradley, 1925

Genus Leiostegium Raymond, 1913

Type species: Bathyurus quadratus Billings, 1860 from the Lévis Formation at Point Lévis, Quebec.

Diagnosis: Glabella straight-, parallel-sided, quadrate, subrectangular to gently tapering. Pygidium subtriangular, semicircular to parabolic; axis narrower than pleural fields; posterior border narrow to wide, convex.

Remarks: For some time there has been a debate as to whether Leiostegium Raymond, 1913 is more properly a subgenus of Lloydia Vogdes, 1890 or vice-versa (Berg and Ross, 1959; Lochman, 1964, 1965; Shaw, 1966; Flower, 1968a). Ross (1970, p. 73) pointed out that 1) the type specimen of Lloydia Vogdes is cranidium of Bathyurus bituberculatus Billings (1865, p. 410, fig. 391) characterized by discrete oblong preoccipital glabellar lobes, and 2) that no pygidium had ever been described for this species. Ross (1970, p. 74) further recommended that Lloydia be restricted to species having preoccipital glabellar lobes as in L.

bituberculatus. Until a pygidium is assigned to L. bituberculatus, thereby allowing the status of Lloydia and Leiostrigium with respect to each other to be clarified, the two are regarded as separate genera, and, following Ross (1970, p. 74), Lloydia is regarded as being monotypic.

Leiostrigium proprium sp. nov.

(Pl. 2, figs. 1-4)

1983 Leiostrigium sp. nov. - Boyce in Stouge and Boyce; pl. 16, figs. 1, 2.

Diagnosis: Glabella strongly convex, with weakly defined pair of preoccipital glabellar lobes. Pygidial axial lobe cylindro-conical; at least seven distinct axial rings. Posterior border strongly defined. Prosopon of dense punctae.

Derivation of name: From proprium (Latin), distinctive, referring to the nature of the prosopon.

Stratigraphic range: Upper member of the Boat Harbour Formation, unit 9 of Pratt's (1979) Eddies Cove West section.

Material: One (1) cranidium; one (1) pygidium.

Holotype: Cranidium, NFM F-110, from unit 9 of Pratt's (1979) section in the upper member of the Boat Harbour Formation at Eddies Cove West, western Newfoundland (designated herein).

Paratype: Pygidium, NFM F-111 from the same horizon as the holotype (designated herein).

Description: Glabella highly convex, transversely strongly vaulted, straight- and parallel-sided, anteriorly broadly rounded; it extends total cranidial length. Occipital ring sagittally narrow, subrectangular. Weakly defined pair of preoccipital glabellar lobes immediately. Preglabellar and axial furrows well defined, narrow deep; occipital furrow slightly less so. Preglabellar field lacking. Anterior border and anterior border furrow not preserved. Anterior fixigenal areas wide, convex, anteriorly steeply downsloping. Palpebral fixigenal areas only slightly wider than anterior fixigenal areas, abaxially horizontal to very gently downsloping, sagittally anteriorly steeply downsloping. Palpebral lobes relatively short, exsagittal length about one-quarter sagittal glabellar length, wide. Palpebral furrow indistinct, narrow, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas wide, weakly convex, posteriorly horizontal to weakly downsloping. Posterior border furrow well defined, wide, deep. Prosopon of dense punctae.

Hypostoma, librigenae and thorax unknown.



Pygidium moderately convex, oblong; length about three-fifths maximum width (estimated) at posterior end of articulating facets. Axial lobe cylindro-conical, transversely strongly arched, posteriorly gently tapering and abruptly rounded, highly convex; it extends about six-sevenths total pygidial length. At least seven axial rings (excluding terminal ring) of posteriorly decreasing sagittal width. Axial furrows distinct, narrow, deep. Pleural and interpleural furrows not developed. Posterior border strongly defined, narrow, weakly convex. Posterior border furrow distinct, narrow, deep. Prosopon of dense punctae.

Remarks: The only other presently known species of Leiostegium with a punctate prosopon is Leiostegium (Alloleiostegium) punctatum Zhou and Zhang (1978, p. 13, 24-25; pl. II, figs. 1-8) from basal Ordovician rocks of the Tangshan area, China. The clearly defined lateral glabellar furrows, the presence of three pairs of pleural furrows on the pygidium and the absence of a pygidial posterior border and posterior border furrow however, readily distinguishes this species from L. proprium.

Superfamily ASAPHACEA Burmeister, 1843

Family ASAPHIDAE Burmeister, 1843

Subfamily ISOTELINAE Angelin, 1854

Genus Isoteloides Raymond, 1910

Type Species: Asaphus canalis Whitfield, 1886 from the Fort Cassin Formation at Fort Cassin, Champlain Valley, New York.

Diagnosis: See Jaanusson in Moore (1959, p. 0341).

Isoteloides peri Fortey

(Pl. 2, figs. 5-8)

1958 ?Isoteloides cf. I. flexus Hintze - Sando, p. 842, 854; pl. 2, figs. 33-35.

1979a<sup>1</sup> Isoteloides peri sp. nov. - Fortey, p. 69-72; pl. 23, figs. 1-8.

1983 Isoteloides peri Fortey - Boyce in Stouge and Boyce; pl. 14, fig. 8; pl. 15, figs. 2, 5.

Diagnosis: Anterior sections of facial sutures slightly divergent. Eyes small. Pygidium about two-thirds as long as wide, distinct border of moderate width. Fortey (1979a, p. 69).

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 80.37 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Eight (8) cranidia; five (5) hypostomata; seven (7) librigenae; fourteen (14) pygidia.

Holotype: Cranidium, G.S.C. 56799, from the Catoche Formation, Port au Choix Peninsula, western Newfoundland (Fortey, 1979a).

Description: Fortey (1979a) has already provided a detailed description of I. peri which is not repeated.

Remarks: Sando (1958, p. 842, 854; pl. 2, figs. 33-35) illustrated Isoteloides cf. I. flexus Hintze from the Rockdale Run Formation near Chambersburg, Pennsylvania. According to Fortey (1979b, p. 38) this species is probably identical to I. peri. A comparison of the photographs of the two species suggests that Fortey may be correct in his assignment. Accordingly, the Isoteloides species from Pennsylvania is tentatively placed in synonymy with I. peri.

Subfamily SYMPHYSURININAE Kobayashi, 1955

Genus Randaynia nov.

Type species: Randaynia saundersi sp. nov. from the Boat Harbour Formation on Old Ferrolle Island, Brig Bay, western Newfoundland (designated herein).

Diagnosis: Cranidium highly convex, featureless except for concave anterior border, thorax with six or seven segments. Pygidium featureless except for 1) weakly defined axial lobe which is posteriorly tapering and abruptly rounded or truncated and 2) distinct posterior border which is flat to concave and of constant width.

Derivation of name: In honor of the late objectivist philosopher Ayn Rand.

Assigned species: Species which the author assigns to Randaynia nov. (in addition to those described in this study) include 1) Bathyrus taurifrons Dwight from the Rochdale Formation (Wappinger Group) at Rochdale, Dutchess County, New York (Dwight, 1884, p. 252-253; pl. VII, figs. 1-3); 2) Bathyrus perkinsi Whitfield from the Fort Cassin Formation (Beekmantown Group) at the mouth of Otter Creek, Vermont (Whitfield, 1897, p. 183; pl. V, figs. 7, 8); and 3) Asaphellus gyracanthus Raymond from the Tribes Hill Formation (Beekmantown Group) of the Mohawk Valley (Raymond, 1910, p. 39, 40; pl. XIV, figs. 5-7 and Fisher, 1954, p. 85, 87, 89, 90; pl. 4, fig. 10).

The unidentified pygidium illustrated by Ross (1951; pl. 26, fig. 15) from Zone G in the Garden City Formation of northeastern Nevada is questionably assigned to Randaynia; it may actually belong to Isoteloides or some other asaphid genus.

Remarks: Randaynia most closely compares with Bellefontia Ulrich in Walcott, 1924 and Parabellefontia Hintze, 1953. The differences are discussed below.

Randaynia is generally more effaced than Bellefontia; the cranidial and pygidial axes are not as well developed. In addition, the cranidial anterior border, the librigenal lateral border and the pygidial posterior border are concave-upward rather than convex-upward

as in Bellefontia. Randaynia also has no more than seven thoracic segments; see R. saundersi (this study; pl. 3, fig. 3). Bellefontia has at least eight thoracic segments; see B. mexensis Hintze (1953; pl. IV, fig. 6).

Randaynia is more strongly furrowed than the monotypic Parabellefontia. The cranial and pygidial axes are better defined; in Parabellefontia they are not developed. In addition, the cranial anterior border and librigenal lateral border are strongly developed; they are lacking in Parabellefontia. Furthermore, the pygidium of Randaynia has a strongly developed posterior border, which is also much wider than that of Parabellefontia. See Boyce (this study; pl. 3, figs. 1-7; pl. 4, figs. 1-5) and Hintze (1953; pl. III, figs. 1-8) to photographically compare the two genera.

Randaynia differs from both Bellefontia and Parabellefontia in that the posterior portion of the pygidial axis displays a prominent pair of muscle insertion scars (this study; pl. 3, figs. 2-4; pl. 4, fig. 3). The latter two genera do not exhibit this feature.

Undetermined genus and species No. 2 of Ross (1958, p. 567, 568; pl. 84, figs. 1, 2, 13-15) from the Valmy Formation of Nevada may be closely related but not congeneric with Randaynia. Although the cranidium and librigenae are comparable with those of Randaynia, particularly R. langdoni sp. nov., the pygidium lacks the distinctive flat to concave posterior border.

Randaynia saundersi sp. nov.

(Pl. 3, figs. 1-7)

1983 "Parabellefontia" sp. - Boyce in Stouge and Boyce, 1983; pl. 14, fig. 3; pl. 16; fig. 9.

Diagnosis: Cranidium sagittally long; anterior border wide; glabella undefined; palpebral lobes small, crescentic. Librigenal lateral borders wide, abaxially tapering; posterior borders lacking; genal spines long, wide. Pygidium semicircular; posterior border wide, posteriorly gently downsloping. Prosopon consists of fine terrace-lines.

Derivation of name: For P.D. Saunders, who introduced the author to Ayn Rand's writings.

Stratigraphic range: Upper member of the Boat Harbour Formation, 9.84 to 58.46 m above the base of the Boat Harbour measured sequence.

Material: Fourteen (14) cranidia; forty-four (44) librigenae; sixty-four (64) pygidia; one (1) nearly complete individual lacking librigenae; one (1) individual lacking cephalon.

Holotype: Nearly complete individual lacking librigenae, NFM F-94, from the Boat Harbour Formation on Old Ferrolle Island, Brig Bay, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-119 from BH-18; Librigena, NFM F-117 from BH-30; pygidia, NFM F-120 from BH-23; NFM F-121 from BH-30; the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Cranidium long, strongly convex; glabella undefined. Pre-glabellar, occipital and lateral glabellar furrows not developed. Axial furrows weakly defined; they extend anteriorly to line joining posterior ends of palpebral lobes, rarely to line joining anterior ends of palpebral lobes. Anterior portion of cranidium highly convex, anteriorly steeply downsloping. Anterior border well defined, wide, abaxially tapering, and broadly arched in anterior view. Palpebral fixigenal areas of cranidium weakly convex, abaxially gently downsloping, sagittally anteriorly gently to steeply downsloping. Palpebral lobes small, crescentic, short- exsagittal length about one-third total cranidial length; palpebral furrows not developed. Line through centers of palpebral lobes crosses cranidial sagittal line at about one-third cranidial length from posterior edge of cranidium. Posterior fixigenal areas of cranidium narrow, convex, posteriorly moderately steeply downsloping; posterior border furrow absent. Prosopon consists of very fine terrace lines parallel to anterior margin of cranidium, except for palpebral and fixigenal areas of cranidium which are smooth. Internal mould smooth also.

Hypostoma unknown.

Librigena with genal field highly convex. Lateral border wide, concave, abaxially tapering. Genal spine long. Posterior border

absent. Prosopon consists of fine terrace-lines, convex-forward on genal field and concave-forward on lateral border. On genal spine terrace-lines form forward-pointing tight chevron pattern.

Thorax consists of six or seven long, narrow segments of about equal size with large articulating half-rings. Pleural furrows distinct, narrow, deep, subparallel to anterior margins of pleurae. Axial furrows less distinct, narrow, shallow. Prosopon smooth except for fine, convex-forward terrace-lines on articulating half-rings.

Pygidium moderately convex, semicircular; length about three-fifths maximum width at posterior end of articulating facets. Axial lobe transversely weakly arched, posteriorly strongly tapering and abruptly truncated, weakly convex; it extends about three-quarters total pygidial length. Axial rings not developed. Prominent pair of muscle insertion scars at posterior end of axial lobe. Axial furrows weakly defined, narrow, shallow. Pleural and interpleural furrows generally not developed; weak pairs are displayed by pygidia greater than 1.5 cm in width, however. Posterior border well defined, wide - of constant width, flat to concave, posteriorly gently downsloping. Prosopon consists of fine terrace-lines parallel to posterior margin.

Randaynia langdoni sp. nov.

(Pl. 4, Figs. 1-5)

Diagnosis: Cranidium sagittally short; anterior border narrow; glabella, occipital ring and posterior border furrow weakly defined;



palpebral lobes large, broadly crescentic. Librigenal lateral borders well defined, concave; genal spines short, narrow. Pygidium subtriangular; axis well defined; posterior border well defined, narrow, flat to concave, posteriorly steeply downsloping.

Derivation of name: For G.S. Langdon, fellow graduate student.

Stratigraphic range: Upper member of the Boat Harbour Formation, 74.29 to 75.89 m above the base of the Boat Harbour measured sequence.

Material: Three (3) cranidia; one (1) librigena; nine (9) pygidia.

Holotype: Pygidium, NFM F-125, from BH-47 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-123; librigena, NFM F-124; pygidium, NFM F-126; from the same horizon as holotype (designated herein).

Description: Cranidium short, strongly convex. Glabella weakly defined, wide, straight-sided, anteriorly slightly expanding and broadly rounded; it extends about nine-tenths total cranidial length. Occipital ring weakly defined, narrow, subrectangular. Preglabellar furrow weakly defined, narrow, shallow. Axial furrows equally faint, nearly indistinct. Occipital furrow well defined, slightly convex-forward, wide, shallow; best defined medially. Lateral glabellar furrows not developed. Faint median glabellar ridge developed anterior to line

joining anterior ends of palpebral lobes. Preglabellar field about one-twentieth total cranial sagittal length. Anterior border well defined, narrow, concave, of constant width; flat in anterior view. Anterior fixigenal areas narrow, convex, anteriorly steeply downsloping. Palpebral fixigenal areas slightly wider, convex, abaxially and sagittally steeply downsloping. Palpebral lobes large, long-exsagittal length about one-half glabellar sagittal length, broadly crescentic, weakly defined. Palpebral furrow nearly indistinct. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas narrow, convex, posteriorly steeply downsloping. Posterior border furrow well defined, narrow, shallow. Posterior border flat to weakly convex, triangular (abaxially widening), posteriorly gently upsloping. Prosopon smooth.

Hypostoma unknown.

Librigena with genal field moderately convex. Lateral border well defined, narrow, concave; of constant width until point immediately anterior to posterior edge of ocular facial suture where it becomes abaxially tapering and disappears. Genal spine short, narrow. Prosopon smooth.

Thorax unknown.

Pygidium moderately convex, subtriangular; length about two-thirds maximum width at posterior end of articulating facets. Axial lobe well

defined, transversely weakly arched, posteriorly strongly tapering and abruptly rounded to pointed, weakly convex; it extends about six-sevenths total pygidial length. Axial rings generally not developed but eight prominent pairs of muscle insertion scars, as well as a median axial ridge occur on several specimens; up to four axial rings have been observed in small specimens. Axial furrows well defined, narrow, shallow. One pair of distinct, narrow, deep, pleural furrows. An incomplete pair of interpleural furrows cuts the posterior border only. On very small specimens 2 to 3 pairs of pleural and interpleural furrows may be seen. Posterior border well defined, narrow, flat to concave, posteriorly steeply downslping, of constant width. Prosopon smooth.

Remarks: The respective diagnoses of R. langdoni and R. saundersi serve to distinguish the two species.

Order PROETIDA Fortey and Owens, 1975

Subfamily HYSTRICURINAE Hupe, 1953

Genus Hillyardina Ross, 1951

1951 Hyperbolochilus Ross, p. 77

Type species: Hillyardina semicylindrica Ross, 1951, from the Garden City Formation of northeastern Utah.

Diagnosis: Glabella straight to convex-sided, anteriorly tapering and abruptly rounded to pointed. Occipital ring well defined, subrectangular. Preglabellar field wide, anteriorly steeply downsloping; median preglabellar furrow variably developed. Anterior border wide - of constant width, flat to strongly concave. Palpebral lobes small, plate-like. Anterior portions of facial suture slightly to strongly divergent; posterior portions strongly divergent. Posterior fixigenal areas acutely triangular. Cranial proson pustulose to smooth. Genal field of libigena highly convex. Lateral border wide, flat to strongly concave, abaxially gently tapering. Thorax with nine narrow thoracic segments of equal length; long, narrow, curved dorsal axial spine on fifth segment. Pygidium small, semielliptical to triangular. Axial lobe straight to convex-sided, posteriorly strongly tapering and abruptly rounded to pointed or truncated, composed of 3 to 5 axial rings. Pleural and interpleural furrows well developed, 3 to 4 pairs. Posterior border posteriorly steeply downsloping to vertical, flat to weakly convex.

Remarks: The closely similar genera Hillyardina and Hyperbolochilus were originally described by Ross (1951) from Zone F in northern Utah. Hyperbolochilus was differentiated from Hillyardina by the more strongly divergent anterior portions of the facial suture, lack of a median preglabellar furrow, shape of the glabella, position of posterior border furrow, lack of pustules and the lack of a boss within the genal angle (Ross, 1951, p. 77). They were particularly differentiated generically by the presence of the raised boss within the genal angle on Hillyardina and by the more strongly divergent anterior

portions of the facial suture of Hyperbolochilus. Hintze (1953) and Terrell (1973) suggested that these differences are of specific rather than generic value, thereby implying that the two genera are congeneric. Hintze (1953, p. 162-163; pl. VIII, figs. 5, 6) and Terrell (1973, p. 71-73; pl. 3, figs. 1-5) described Hillyardina sp. A from Zones E and F in western Utah. This species exhibits both the boss within the genal angle (Hillyardina) and the strongly divergent anterior portions of the facial suture (Hyperbolochilus).

Hillyardina minuspustulata sp. nov. exhibits the median preglabellar furrow characteristic of Hillyardina. The cranial prosopon is transitional between Hillyardina and Hyperbolochilus - the glabella exhibits the pustulose prosopon of Hillyardina whilst the rest of the cranium is smooth like Hyperbolochilus. The boss within the genal angle characteristic of Hillyardina is variably developed. Hillyardina levis sp. nov. also variably displays this boss although the rest of its features are typical of Hyperbolochilus.

Ross (1951), Hintze (1953) and Terrell (1973) were not able to assign pygidia to either Hillyardina or Hyperbolochilus. Hillyardina minuspustulata and H. levis belong to Hillyardina and Hyperbolochilus sensu Ross (1951), respectively. Their pygidia are clearly congeneric (compare pl. 5, fig. 2 and pl. 7, figs. 3, 4). On the basis of this fact and the previously mentioned intergradational nature of the morphological characters, the author proposes that Hillyardina semicylindrica Ross and Hyperbolochilus marginauctum Ross represent two different species of the same genus. Because Ross (1951) defined

Hillyardina first in his study, Hyperbolochilus is regarded as a junior subjective synonym of this genus.

Hillyardina minuspustulata sp. nov.

(Pl. 4, figs. 6-8; pl. 5, figs. 1, 2)

Diagnosis: Anterior border relatively narrow, strongly concave. Prosopon smooth except for pustulose glabella, except in smallest specimens.

Derivation of name: minus (Latin), less plus pustula (Latin), pimple plus ata, referring to the general lack of pustules.

Stratigraphic range: Upper member of the Boat Harbour Formation, 9.84 to 19.13 m above the base of the Boat Harbour measured sequence.

Material: Eighteen (18) cranidia; nine (9) librigenae; one (1) pygidium.

Holotype: Cranidium, NFM F-127, from BH-9 in the upper member of the Boat Harbour Formation, at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-128; librigena, NFM F-129; pygidium, NFM F-130; all from the same bed as holotype (designated herein).

Description: Cranidia range from 1.5 to 5 mm in length. Glabella strongly convex and transversely highly vaulted, convex-sided, anteriorly tapering and abruptly rounded to pointed; it extends about seven-tenths total cranidial length. Occipital ring narrow, rectangular. Preglabellar, axial and occipital furrows distinct, narrow, deep. Preglabellar field wide, about one-tenth total cranidial length, convex, anteriorly steeply downsloping. Median preglabellar furrow variably developed, when present extremely short. Anterior border furrow distinct, narrow, shallow. Anterior border narrow, about one-tenth total cranidial length, abaxially tapering, strongly concave, transversely broadly arched in anterior view. Anterior fixigenal areas wide, convex, anteriorly steeply downsloping. Anterior portions of facial suture strongly divergent. Palpebral fixigenal areas small, transversely extremely narrow, weakly convex, abaxially upsloping, sagittally horizontal to gently anteriorly downsloping. Palpebral lobes extremely small but relatively wide for their size, plate-like, short. - exsagittal length about one-fifth sagittal glabellar length. Palpebral furrow indistinct. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas generally not preserved but inferred to be transversely long, very acutely triangular, convex, posteriorly downsloping from shape of lateral portion of facial sutures on librigenae. Posterior portions of facial suture strongly divergent. Posterior border furrow distinct, narrow, deep. Posterior border wide, convex. On large specimens prosopon smooth except for scattered glabellar pustules; smaller specimens display pustules on rest of cranidium as well.

Hypostoma unknown.

Librigena with genal field highly convex. Lateral border furrow distinct, narrow, shallow. Lateral border wide - of constant width except posteriorly tapering from posterior border to end of genal spine. Postocular bass variably developed at genal angle. Genal spine short, abaxially narrow, curving posteriorly. Posterior border transversely short, sagittally wide, convex. Prosopon smooth.

Thorax unknown.

Pygidium acutely triangular, length (1 mm) about one-quarter maximum width (4 mm). Axial lobe transversely arched, straight-sided, posteriorly strongly tapering and abruptly truncated; it extends at least two-thirds total pygidial length. Five axial rings of posteriorly decreasing sagittal width including terminal ring consisting of an extremely small pair of tubercles. Axial furrows distinct, narrow, deep. Pleural fields poorly preserved but pleural and interpleural furrows developed. Posterior border wide - of constant width, about one-third total pygidial length, convex, posteriorly steeply down-sloping. Prosopon smooth.

Hillyardina levis sp. nov.

(Pl. 5, figs. 3-7; pl. 6, figs. 1-6)

1983 Hillyardina/Hyperbolechilus sp. nov. - Boyce in Stouge and Boyce; pl. 13, figs. 7, 8; pl. 14, figs. 1, 2.



Diagnosis: Anterior border wide, concave. Pygidial axial lobe concave-sided, posteriorly tapering and truncated - five axial rings, including terminal ring bearing two tubercles. Prosopon smooth.

Derivation of name: levis (Latin), smooth, referring to prosopon.

Stratigraphic range: Upper member of the Boat Harbour Formation 38.94 to 66.21 m above the base of the Boat Harbour measured sequence.

Material: Twelve (12) cranidia; sixteen (16) librigenae; six (6) pygidia; one (1) nearly complete individual lacking librigenae.

Holotype: Cranidium, NFM F-90, from BH-18 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-93; librigena, NFM F-92, NFM F-132; pygidium, NFM F-91, from the same bed as the holotype (designated herein). Cranidium, NFM F-133, from BH-23; pygidium, NFM F-134, from BH-30; both in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein). Nearly complete exoskeleton, NFM F-131, from the Boat Harbour Formation on Old Ferrolle Island, Brig Bay, western Newfoundland (designated herein).

Description: Glabella moderately convex and transversely broadly vaulted, convex-sided, anteriorly tapering and gently rounded; it extends at least three-fifths total cranidial length. Occipital ring

sagittally narrow, rectangular. Preglabellar, axial and occipital furrows distinct, narrow, deep. Weak lateral IP glabellar furrows variably developed. Preglabellar field wide, about one-tenth total cranial length, convex, anteriorly steeply downsloping. Anterior border furrow distinct, narrow, shallow, weakly convex-forward. Anterior border wide, about one-seventh total cranial length, of constant width, strongly concave, flat in anterior view. Anterior fixigenal areas wide, convex, anteriorly steeply, downsloping. Anterior portions of facial suture strongly divergent. Palpebral fixigenal areas small, weakly convex, abaxially horizontal to weakly upsloping, sagittally anteriorly gently downsloping. Palpebral lobes extremely small, plate-like, short, about one-fifth sagittal glabellar length; palpebral furrow not developed. Line through centers of palpebral lobes crosses glabellar sagittal line at about two-thirds glabellar length from posterior edge of occipital ring. Posterior fixigenal areas transversely long, very acutely triangular, posteriorly downsloping. Posterior border furrow well defined, narrow, deep. Posterior border narrow, convex. Prosopon smooth.

Hypostoma unknown.

Librigena with genal field highly convex. Lateral border furrow distinct, narrow, shallow. Lateral border wide, of constant width, except posteriorly tapering from posterior border to end of genal spine. Genal spine long, narrow, abaxially curving posteriorly. Posterior border transversely short, sagittally narrow, convex. Prosopon smooth.

Thorax composed of nine thoracic segments which are transversely long and sagittally narrow but of equal width. Long, narrow, curved dorsal axial spine on fifth segment.

Pygidium acutely triangular. Length about one-third maximum width. Axial lobe transversely weakly arched, concave-sided, posteriorly tapering and abruptly truncated; it extends about five-sixths total pygidial length. Five axial rings of equal sagittal width, including terminal ring bearing pair of tubercles. Axial furrows distinct, narrow, deep. Pleural fields flat, horizontal to posteriorly gently downsloping. Four pairs of pleural furrows which are distinct, wide, deep; three pairs of interpleural furrows which are distinct, narrow, deep. Furrows extend to edge of and slightly cut posterior border which is narrow, flat to weakly convex, steeply posteriorly downsloping and flat in posterior view.

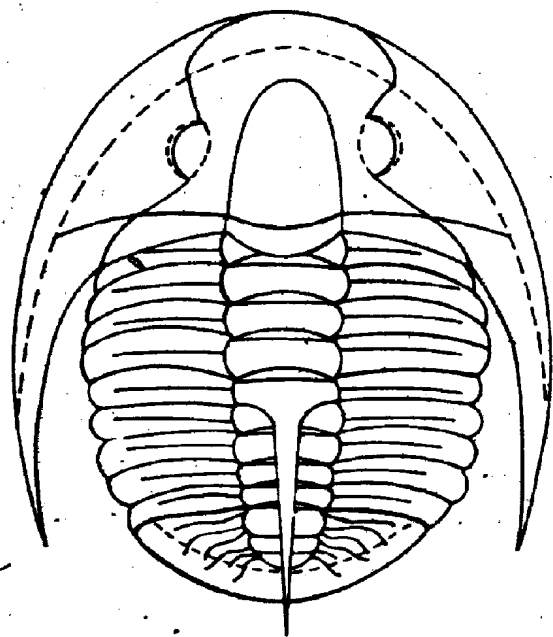
Remarks: The collection of a specimen of Hillyardina levis lacking only the librigenae (pl. 5, fig. 4) allows a comparative assignment of pygidia to other species. The pygidium illustrated by Ross (1951; pl. 19, figs. 32, 35) is assigned to H. semicylindrica Ross (1951, pl. 16, figs. 1-9) on the basis of its matching prosopon of tubercles. The pygidia and thorax illustrated by Ross (1951; pl. 19, figs. 33, 36, 37) are assigned to H. marginauctum (Ross, 1951; pl. 17, figs. 24-27, 30, 31, 34, 35) because of their matching smooth prosopon. The above cranidia and pygidia were all collected from the same horizon in Zone F. The pygidia illustrated by Hintze (1953; pl. VIII, fig. 13) and Terrell (1973; pl. 6, figs. 4, 7, 8, 10, 11) are assigned to

Hillyardina sp. A Hintze of Hintze (1953; pl. VIII, figs. 5, 6) and Terrell (1973; pl. 3, figs. 1-5).

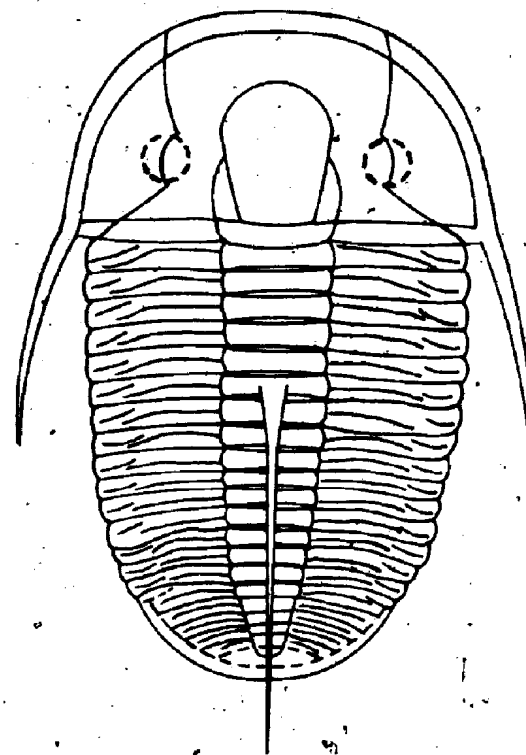
According to Fortey and Owens (1975) and Thomas and Owens (1978) the trilobite family Aulacopleuridae evolved in the Tremadoc from hystricurine species. Fortey and Owens (1975, p. 231) concluded that Hystricurus paragenalatus Ross, H. genalatus Ross and Parahystricurus pustulosus Ross are probable members of the hystricurine plexus from which Otarion (the earliest aulacopleurid arose). The author proposes, however, that Otarion was derived directly from Hillyardina.

The earliest known species of Otarion is Otarion (Aulacopleura) szechuanica (Lu, 1975; p. 187-189, 393-395; pl. XXXIV, figs. 8, 9) from the Tremadoc Dactylocephalus dactyloides Zone in the Panho Formation at Wanshengchan of Chunking, Szechuan, China. The latest known species of Hillyardina are all of late Tremadoc Ross-Hintze Zone F age; to date there are no demonstrably Arenig species.

Hillyardina is morphologically similar to Otarion. The shape, size and convexity of their cranidia, librigenae and pygidia are comparable, (see Figure. 4.3). Compare Hillyardina semicylindrica Ross (1951; pl. 16, figs. 1-9), H. marginauctum (Ross, 1951; pl. 17, figs. 24-27, 30, 31, 34, 35), H. sp. A Hintze (1953; pl. VIII; figs. 5, 6, 13) Terrell (1973; pl. 3, figs. 1-5, pl. 6, figs. 4, 7, 8, 10, 11), H. minuspustulata sp. nov. (this study; pl. 4, figs. 6-8; pl. 5, figs. 1, 2) and H. levis (this study; pl. 5, figs. 3-7; pl. 6, figs. 1-6) with Otarion (Aulacopleura) dawanensis (Lu, 1975; pl. XXXIV, figs. 8, 9),



Hillyardina marginauctum (Ross)  
Ordovician



Otarion (Otarion) diffractum Zenker  
Silurian

Figure 4.3. Reconstructions of Hillyardina and Otaron (prosopon omitted). Reconstruction of Hillyardina by the author, based on Ross (1953; pl. 17, figs. 25, 26, 35; pl. 19, figs. 33, 37). Reconstruction of Otaron modified from Moore (1959; fig. 39-4a).

O. (A.) roquemillerensis Chaubert (Thomas and Owens, 1978; pl. 7, fig. 9) and O. (A.) koninkii (Barrande-Thomas and Owens, 1978; pl. 7, fig. 10). The common morphological features of Hillyardina and Otarion include:

1. prelabellar field wide, anteriorly steeply downslping,
2. palpebral lobes small; palpebral furrows concave-outward,
3. anterior portions of facial suture slightly to strongly divergent; posterior portions strongly divergent,
4. posterior fixigenal areas acutely triangular,
5. cranial prosopon postulose to smooth,
6. genal field of librigena highly convex; length of genal spines similar,
7. thoraxes with narrow axes, broad pleural areas; long, narrow, curved dorsal axial spine,
8. pygidium small, semielliptical to triangular; narrow axes, broad pleural areas.

The two genera differ in the following respects:

1. Hillyardina has concave-upward anterior border; Otarion has convex-upward anterior border,
2. Hillyardina generally lacks eye ridges; Otarion has faint to well developed eye ridges,
3. Hillyardina generally lacks glabellar furrows although H. levis variably displays extremely weak IP furrows; Otarion has strongly developed furrows,
4. Hillyardina has 9 thoracic segments; Otarion has 13 to 22,
5. Hillyardina has axial spine developed on fifth thoracic segment; Otarion has axial spine developed on sixth segment,
6. Hillyardina has 3 to 5 axial rings and 3 to 4 pairs of pleural ribs in pygidium; Otarion has 5 to 8 axial rings and 3 to 7 pairs of pleural ribs.

The above differences are regarded as evolutionary changes. The most conspicuous trend is the increased segmentation of the cranium, thorax and pygidium. This is the Otarion (Aulacopleura) type evolutionary trend identified by Fortey and Owens (1975) for the Proetida. Fortey and Owens (1975, p. 237) considered that the Otarion (Aulacopleura) type, with its multiplication of thoracic segments, hence of thoracic appendages and "gill branches", may have been connected with a mode of life in deep water under relatively deoxygenated conditions.

They pointed out the occurrence of several species of Otarion (Aulacopleura) in deep water lithofacies comparable to those known to previously contain olenid trilobites.

Genus Hystericurus Raymond, 1913

Type species: Bathyrurus conicus Billings, 1859 from the Beekmantown Group at St. Timothy, Quebec.

Diagnosis: Glabella straight- to convex-sided, anteriorly tapering. Occipital ring subrectangular; occipital spine variably developed. Pre-glabellar, occipital and axial furrows well defined, deep. Lateral glabellar furrows absent or represented by shallow pits in axial furrows or by smooth patches on sides of glabella. Anterior border furrow distinct, narrow to wide, shallow to deep. Anterior border narrow, strongly convex to subtubular, convex-forward. Eye ridges not developed. Palpebral lobes large, long - exsagittal length one-third to one-half sagittal glabellar length, always extending to rear of glabellar midpoint, crescentic to semicircular. Line through centers of palpebral lobes crosses glabellar sagittal line at or very slightly forward of glabellar midpoint. Posterior border furrows well defined, wide deep. Prosopon of tubercles. Librigena with moderately convex genal field. Lateral border furrow distinct, narrow to wide, shallow to deep. Lateral border narrow, convex to subtubular. Genal spine long, convex. Prosopon of tubercles. Thorax with eleven segments. Axial lobe about one-third to one-half total width. Proximal half of each pleuron horizontal; distal half flexed gently to steeply downward. Tips of



pleurae spined or bluntly rounded. Pygidium subtriangular, semielliptical to semicircular. Axial lobe moderately to strongly convex, posteriorly tapering and abruptly rounded to truncated. Four or five axial rings including terminal ring. Axial and axial ring furrows well defined, deep. Pleural and interpleural furrows variably defined. Three or four pairs of pleural ribs. Prosopon of tubercles. Modified from Ross (1951, p. 39-40).

Remarks: The narrow, convex to subtubular anterior border, the absence of eye ridges and the distinctive prosopon of tubercles readily distinguish Hystericurus from Paraplethopeltis Bridge and Cloud, 1947.

Hystericurus oculilunatus Ross, 1951

(Pl. 6, figs. 7, 8; pl. 7, figs. 1-8; pl. 8, figs. 1-3)

1889a Bathyurus conicus Billings - Whitfield, p. 61-62; pl. 13, figs. 15-21.

1951 Hystericurus oculilunatus Ross, n. sp. - Ross, p. 47-48; pl. 10, figs. 1-3, 5, 8, 9, 12.

1951 Unassigned pygidium from Zone "F" - Ross; pl. 17, figs. 23, 28, 29.

1959 Hystericurus oculilunatus Ross - Berg and Ross, p. 112; pl. 21, fig. 2.

- 1959 Hystricurus conicus (Billings) - Poulsen in Moore, p. 0277, 0278; Figs. 204-4a,b.
- 1962 Hystricurus conicus (Billings) - Welby, p. 78, 79; pl. XIII, fig. 10.
- 1968c Hystricurus cf. conicus (Billings) - Flower, p. 33; pl. 7, fig. 4.
- 1973 Hystricurus acumensis Ross (in part) - Terrell, p. 73; pl. 1, fig. 8 not figs. 1, 4-6.
- 1973 Hystricurus oculilunatus Ross (in part) - Terrell, p. 73; pl. 1, figs. 11, 12, 14 not figs. 15, 16.
- 1983 Hystricurus oculilunatus Ross - Boyce in Stouge and Boyce; pl. 12, figs. 5, 6.

Diagnosis: Glabella slightly bell-shaped, convex sided. Anterior border narrow, highly convex, smooth. Palpebral lobes large, crescentic. Posterior fixigenae transversely long. Librigena lacks posterior border. Lateral border highly convex, smooth (internal mould) to terrace-lined (external mould), abaxially widening to posterior margin. Genal spine continuous with lateral border, long, highly convex, smooth (internal mould) to terrace-lined (external mould), posteriorly tapering, projects outward from posterior margin. Pygidium with prominent pair of tubercles on terminal ring. Four pairs of pleural ribs -

three pairs displaying paired tubercles; posterior pair small, poorly developed, no tubercles. Posterior border well defined, narrow, flat to convex-outward, smooth (internal mould) to terrace-lined (external mould), posteriorly gently downsloping, straight in posterior view with small postaxial arch. Prosopon of coarse tubercles.

Stratigraphic range: Upper member of the Boat Harbour Formation, 2.31 to 50.64 m above the base of the Boat Harbour measured sequence.

Material: Twenty-two (22) cranidia; four (4) librigenae; seventeen (17) pygidia.

Holotype: Cranidium, Y.P.M. 17960 (designated by Ross, 1951).

Paratypes: Librigena, Y.P.M. 17961 (designated by Ross, 1951); pygidium, Y.P.M. 18061 (the original of Ross, 1951; pl. 7, figs. 23, 28, 29 - designated herein).

Description: Glabella highly convex, transversely moderately vaulted, slightly bell-shaped, convex-sided, anteriorly tapering and broadly rounded; it extends about four-fifths total cranidial length. Occipital ring sagittally narrow, subrectangular, abaxially curving forward. Occipital and axial furrows well defined, wide, deep; preglabellar furrow shallower. Lateral glabellar furrows not developed. Preglabellar field narrow, convex, anteriorly moderately steeply downsloping, variable but averages about one-tenth total cranidial length. Anterior border furrow distinct, wide, deep. Anterior border transversely long,

narrow, highly convex, smooth (internal mould) to terrace-lined (external mould), in anterior view transversely gently arched. Anterior fixigenal areas wide, convex, anteriorly moderately steeply downsloping. Palpebral fixigenal areas only slightly wider than anterior fixigenal areas, abaxially horizontal to very gently upsloping, sagittally anteriorly gently downsloping. Vague alignment of tubercles suggests remnant ocular ridges. Palpebral lobes large, long - exsagittal length about one-half sagittal glabellar length, crescentic. Palpebral furrow distinct, narrow, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas long, narrow, convex, posteriorly steeply downsloping. Posterior border furrows well defined, wide, deep. Prosopon of coarse tubercles. Anterior border narrow, all furrows wider, deeper on internal mould than on external mould.

Hypostoma unknown.

Librigena with genal field moderately convex. Lateral border furrow distinct, wide, deep. Lateral border highly convex, smooth (internal mould) to terrace-lined (external mould), abaxially widening to posterior margin. Genal spine continuous with lateral border, long, highly convex, smooth (internal mould) to terrace-lined (external mould); it projects outward from posterior margin. Lateral border furrows well defined, wide, deep. No posterior border or posterior border furrows. Prosopon of coarse tubercles except for lateral border and genal spine.

Pygidium moderately convex, semicircular, length about one-half maximum width at posterior end of articulating facets. Axial lobe transversely gently arched, posteriorly gently tapering and truncated; it extends to posterior border, in profile posteriorly very gently downsloping. Three well defined axial rings of even sagittal width; terminal ring with prominent pair of tubercles. Axial and pleural furrows distinct, wide, deep. Pleural furrows curve progressively abaxially posteriorly and stop at posterior border. Four pairs of pleural ribs - three pairs displaying paired tubercles, posterior pair small, poorly developed, no tubercles. In posterior view pleural ribs and tubercles form nearly horizontal surface. Posterior border well defined, narrow, flat to convex-outward, smooth (internal mould) to terrace-lined (external mould). Posterior border furrow distinct, narrow, shallow. Prosopon of coarse tubercles except for posterior border. On internal moulds surface tuberculation is less pronounced and all furrows are wider.

Remarks: Although in western Newfoundland Hystericurus oculilunatus is known mostly from internal moulds, the smooth, convex anterior border, the slightly bell-shaped, convex-sided glabella, the large, crescentic palpebral lobes, the characteristic librigenae and the distinctive pygidium readily distinguish this species from all other presently known Hystericurus species.

Although Ross (1951, p. 47-48; pl. 10, figs. 1-3, 5, 8-9, 12) proposed the species, H. oculilunatus was originally described and illustrated by Whitfield (1889a, p. 61-62; pl. 13, figs. 15, 16, 18-21)

from "the subcrystalline layers of the Calciferous about one and a half miles north of Beekmantown Station on the Delaware and Hudson Railroad, three miles north of Plattsburgh, N.Y." (Whitfield, 1889a, p. 42, 62). Whitfield assigned his specimens to Bathyurus conicus Billings, 1859, which is the type species of Hystricurus Raymond (1913, p. 60). This assignment was accepted by Poulsen in Moore (1959, p. 0277, 0278; figs. 204-4a,b) and Welby (1962, p. 78, 79; pl. XIII, fig. 10) as well as by Flower (1968c, p. 33; pl. 7, fig. 4) who reported a cranidium of H. oculilunatus from the Fort Ann Formation (Beekmantown Group) of Fort Ann, New York as H. cf. conicus. Hystricurus conicus was originally described and illustrated by Billings (1859, p. 366; Fig. 12). Beekmantown Group at St. Timothy, Quebec. I. oculilunatus in that it possesses a more abruptly rounded glabella and a wider preglabellar field.

Ross (1951, p. 47-48; pl. 10, figs. 1-3, 5, 8, 9, 12) described H. oculilunatus from Ross - Hintze Zone F in the Garden City Formation of northeastern Utah and illustrated a pygidium from the same horizon (Ross, 1951; pl. 17, figs. 23, 28, 29) which the author now assigns to that species. The cranidial, librigenal and pygidial borders of the Utah specimens display fine terrace-lines, whereas the western Newfoundland and New York specimens do not. This is attributed to the fact that the latter material is represented primarily by internal moulds. Terrace-lines are generally preserved only on external moulds.

Sando (1957, p. 136-137; pl. 11, fig. 4) described and illustrated as Hystricurus? sp., from the Stonehenge limestone (Beekmantown Group) of Maryland, a pygidium similar but not identical to H. oculilunatus.

Berg and Ross (1959, p. 112; pl. 21, fig. 2) illustrated an incomplete cranidium of H. oculilunatus from the Manitou Formation of Colorado.

Terrell (1973, p. 73; pl. 1, figs. 11, 12, 14) illustrated H. oculilunatus from Ross - Hintze Zones E and F in the lower Fillmore Formation (Pogonip Group) of western Utah but incorrectly assigned its pygidium (Terrell, 1973; pl. 1, fig. 8) to H. acumensis (= H. acumenasus) Ross.

In summary, H. oculilunatus is a widespread, biostratigraphically important species. Besides the Boat Harbour Formation (St. George Group) of western Newfoundland it occurs in:

- a) the Fort Ann Formation (Beekmantown Group) of Plattsburgh and Fort Ann, New York (Whitfield, 1889a; Flower, 1968c) - in the type deposits of the Canadian Series (Fahraeus, 1977b; Flower, 1964; Whittington, 1968),
- b) the Manitou Formation of Colorado (Berg and Ross, 1959),
- c) Zone F in the Garden City Formation of northeastern Utah (Ross, 1951),
- d) Zones E and F in the lower Fillmore Formation (Pogonip Group) of western Utah and eastern Nevada (Hintze, 1953; Terrell, 1973).

Hystricurus pseudoculilunatus sp. nov.

(Pl. 8, figs. 4-8)

1983 Hystricurus sp. nov. - Boyce in Stouge and Boyce; pl. 12, figs. 7, 8.

Diagnosis: Glabella straight-sided. Median preglabellar furrow. Palpebral lobes large, semicircular. Librigenae with posterior border transversely short, smooth, distinct. Genal spine short. Pygidium with subdued pair of tubercles on terminal ring. Posterior border almost nonexistent (but well defined, narrow, smooth, posteriorly steeply down-sloping to vertical, in posterior view transversely gently arched).

Derivation of name: pseudes (Greek), false plus oculilunatus, referring to this species' resemblance to H. oculilunatus Ross.

Stratigraphic range: Upper member of the Boat Harbour Formation, 38.94 to 57.89 m above the base of the Boat Harbour measured sequence.

Material: Seven (7) cranidia; thirteen (13) librigenae; eleven (11) pygidia.

Holotype: Cranidium, NFM F-82, from BH-18 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).



Paratypes: Cranidium, NFM F-140; librigena, NFM F-139; pygidium, NFM F-83; all from the same bed as holotype (designated herein).

Description: Glabella highly convex, transversely strongly vaulted, straight-sided to very slightly convex-sided in larger individuals, anteriorly tapering and broadly truncated; it extends about four-fifths total cranidial length. Occipital ring sagittally narrow, rectangular. Preglabellar and axial furrows well defined, narrow, deep; occipital furrow wider. Lateral glabellar furrows not developed. Preglabellar field narrow, convex, anteriorly steeply downsloping, about one-tenth cranidial length. Median preglabellar furrow narrow, shallow, distinct. Anterior border furrow distinct, wide, deep, slightly narrower than occipital furrow, broadly convex-forward. Anterior border narrow, highly convex, smooth, in anterior view transversely strongly arched. Anterior fixigenal areas wide, convex, anteriorly steeply downsloping. Palpebral fixigenal areas wider than anterior fixigenal areas, abaxially upsloping, sagittally anteriorly steeply downsloping. Palpebral lobes large, long - exsagittal length about one-half glabellar length, semicircular. Palpebral furrow distinct, narrow, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about five-eighths glabellar length from posterior edge of occipital ring. Posterior fixigenal areas long, convex, posteriorly steeply downsloping. Posterior border furrows well defined, wide, deep. Prosopon of coarse tubercles reflected on internal moulds.

Hypostoma unknown.

Librigena with moderately convex genal field. Lateral border furrow distinct, wide, deep. Lateral border highly convex, smooth (internal mould) to terrace-lined (external mould), abaxially widening to and merging with posterior border. Genal spine continuous with lateral border, short, highly convex, smooth (internal mould) to terrace-lined (external mould); it projects outward from posterior border. Posterior border distinct, transversely short. Posterior border furrow distinct, shallow. Prosopon of coarse tubercles except for lateral border and genal spine.

Thorax unknown.

Pygidium moderately convex, semielliptical, length about one-half maximum width at posterior end of articulating facets. Axial lobe moderately convex, transversely gently arched, posteriorly gently tapering and truncated; ~~it~~ extends to posterior border, in profile posteriorly very gently downslping. Three well defined axial rings of even sagittal width, terminal ring with subdued pair of tubercles. Axial and pleural furrows well defined, narrow, deep. Pleural furrows curve progressively abaxially posteriorly and stop at posterior border. Four pairs of pleural ribs - three pairs displaying paired tubercles, posterior pair small, poorly developed, no tubercles. In posterior view pleural ribs form transversely downward-curving surface. Posterior border well defined, narrow, flat to slightly convex-outward, smooth, posteriorly steeply downslping to vertical, in posterior view transversely gently arched. Prosopon of coarse tubercles except for posterior border.

Discussion: The median preglabellar furrow, the straight-sided anteriorly tapering and broadly truncate glabella, the short posterior fixigenal areas and the greater overall degree of convexity of the cranidium readily distinguishes H. pseudoculilunatus from H. conicus and H. oculilunatus, the species it most resembles. In addition, the shorter genal spine and the narrower, vertical pygidial border of H. pseudoculilunatus readily distinguishes it from H. oculilunatus.

The close resemblance of H. oculilunatus and H. pseudoculilunatus as well as the fact that the latter succeeds the former in the Boat Harbour sequence suggests that H. pseudoculilunatus is an evolutionary descendent of H. oculilunatus. However, because these two species have not been found together in the same environment, the author suggests that evolution took place by allopatric speciation (Eldredge, 1971; Mayr et al., 1953). Furthermore, the author proposes that H. pseudoculilunatus records evolutionary trends which eventually culminated in the bathyurid genus Petigurus Raymond, 1913. These trends are:

- 1) increased convexity of cranidium and pygidium, especially axial region,
- 2) straighter, more parallel-sided glabella, narrower preglabellar area, and shorter anterior border,
- 3) glabella increasingly overhangs preglabellar area,

- 4) stronger and increased segmentation of axial rings and pleural ribs in pygidium,
- 5) increased narrowing and steepening of posterior pygidial border,
- 6) increased transverse arching of pygidial border.

South of the author's study area, in the Port aux Choix-Eddies Cove West region, the author has collected a trilobite which is morphologically and stratigraphically intermediate between Hystericurus pseudoculilunatus sp. nov. and Petigurus nero (Billings).

Genus Magnusnasus nov.

Type species: Magnusnasus proprius sp. nov. from the upper member of the Boat Harbour Formation (St. George Group) at Boat Harbour, western Newfoundland (designated herein).

Diagnosis: Cranidium highly convex. Glabella weakly defined, wide, elliptical to subcircular. Anterior border straight to convex-forward, narrow, convex-upward. Posterior border narrow, convex-upward.

Derivation of name: magnus (Latin), big and nasus (Latin), nose, referring to the size of the glabella.

Assigned species: The only species (besides the genotype) which the author assigns to Magnusnasus nov. is Undetermined genus and species B

of Roas (1951, p. 121-122; pl. 28, figs. 16, 20, 25-28) from Zone F in the Garden City Formation of northeastern Utah and Zone E in the Fillmore Formation (Pogonip Group) at Ibex, western Utah (the unassigned cranidia of Terrell, 1973; pl. 3, figs. 8, 11).

Remarks: Magnusnasus nov. most closely resembles Parahystricurus Roas, 1951 in size, shape and convexity. There are three important differences however. Firstly, Magnusnasus is more effaced than Parahystricurus; the glabella in particular is not as well defined. Secondly, despite its lesser definition, the glabella of Magnusnasus is rounder than that of Parahystricurus which is more bullet-shaped. Finally; Magnusnasus has a smooth prosopon; that of Parahystricurus consists of pustules and/or tubercles.

Magnusnasus proprius sp. nov.

(Pl. 9, figs. 1-3)

Diagnosis: Glabella relatively well defined; occipital ring distinct. Preglabellar field narrow.

Derivation of name: proprius (Latin), distinctive.

Stratigraphic range: Upper member of the Boat Harbour Formation, 66.21 m above the base of the Boat Harbour measured sequence.

Material: Four (4) specimens.

Holotype: Cranidium, NFM F-141 from BH-38 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella elliptical, highly convex, transversely moderately vaulted, convex-sided, anteriorly tapering and abruptly rounded; it extends almost seven-eighths total cranidial length. Occipital ring small, subtriangular. Preglabellar and axial furrows weakly defined, narrow, shallow; occipital furrow well defined, wide, deep, convex-forward. Lateral glabellar furrows not developed. Median glabellar tubercle present. Preglabellar field narrow, about one-sixteenth total cranidial sagittal length, convex, anteriorly steeply downsloping. Anterior border furrow distinct, narrow, shallow, broadly convex-forward. Anterior border extremely narrow, less than one-eighth total cranidial sagittal length, convex, of constant width, and flat in anterior view. Anterior fixigenal areas wide, convex, anteriorly steeply downsloping. Anterior portions of facial suture parallel to weakly divergent. Palpebral fixigenal areas the same width as anterior fixigenal areas, abaxially and sagittally convex and steeply downsloping and traversed by extremely narrow and faint ocular furrows. Palpebral lobes small, short - exsagittal length about three-tenths sagittal glabellar length, wide. Palpebral furrow distinct, wide, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas incompletely preserved, at least as wide as anterior and palpebral fixigenal areas. Posterior border furrow distinct, wide, shallow. Prosopon smooth.

Hypostoma, librigense, thorax and pygidium unknown.

Remarks: The less distinct, straighter, narrower anterior border, the narrower preglabellar area, the better defined, more convex glabella, the faint ocular furrows, and the more distinct, wider occipital and posterior border furrows readily distinguish Magnusnusus proprius from Undetermined genus and species of Ross (1951).

Genus Parahystricurus Ross, 1951

Type species: Parahystricurus fraudator Ross, 1951, from the Garden City Formation of northeastern Utah.

Diagnosis: See Ross (1951, p. 56, 57) for diagnosis of cranium, librigense. Pygidium oblong, subtriangular to semielliptical. Up to four axial rings. Pleural and interpleural furrows well developed, prosopon smooth.

Parahystricurus smithiae sp. nov.

(Pl. 9, figs. 4-8)

1983 Parahystricurus sp. nov. - Boyce in Stouge and Boyce, pl. 13, figs. 5, 6.

Diagnosis: Cranium highly convex. Glabella strongly convex, elliptical. Two pairs of lateral glabellar furrows - weakly defined, wide,

shallow. Median prelabellar furrow weakly defined, wide, shallow. Anterior border distinct but extremely narrow, flat to weakly convex, smooth. Posterior fixigenal areas long, narrow. Posterior border furrow weakly defined, wide, shallow. Cranidial prosopon of mixed fine pustules and coarser tubercles. Pygidium oblong, semielliptical. Four axial rings (including terminal ring) of posteriorly decreasing sagittal width. Three pairs of pleural furrows - distinct, wide, shallow. Three pairs of interpleural furrows - well defined, narrow, deep. Posterior border weakly defined but distinct, moderately narrow, flat, smooth, posteriorly steeply downslping. Pygidial prosopon smooth.

Derivation of name: For J.L. Smith in appreciation of her weight-loss supervision.

Stratigraphic range: Upper member of the Boat Harbour Formation, 38.94 to 58.46 m above the base of the Boat Harbour measured sequence.

Material: Thirty (30) cranidia; eleven (11) librigenae; two (2) pygidia.

Holotype: Cranidium, NFM F-88 from BH-30 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-142; librigena, NFM F-144; pygidium, NFM F-89, from the same bed as holotype (designated herein). Librigena, NFM



F-143, from BH-18 in the upper member of the Boat Harbour Formation at Boat Harbour; western Newfoundland (designated herein).

Description: Glabella highly convex, transversely strongly vaulted, elliptical, convex-sided, anteriorly abruptly rounded; it extends about nine-tenths total cranidial length. Occipital ring narrow, subtriangular. Two pairs of lateral glabellar furrows - weakly defined, wide, shallow. Posterior pair directed diagonally backwards from axial furrows, become progressively shallower. Anterior pair directed transversely across glabella, about one-third length of posterior pair. Occipital and axial furrows well defined, wide, deep. Axial furrows become markedly narrower and shallower in front of anterior pair of glabellar furrows, forming preglabellar furrow. Preglabellar field narrow, convex, anteriorly steeply downsloping. Median preglabellar furrow weakly defined, wide, shallow, about one-twentieth total cranidial sagittal length. Anterior border furrow distinct, narrow, shallow, convex-forward except for immediately anterior portion of preglabellar field where intersection with median furrow results in abrupt forward-concavity. Anterior border transversely long, sagittally narrow, flat to weakly convex, smooth, abaxially strongly tapering, in anterior view transversely gently arched. Anterior fixigenal areas wide, convex, anteriorly steeply downsloping. Palpebral fixigenal areas about the same width as anterior fixigenal areas, abaxially horizontal to very gently upsloping, sagittally horizontal to very gently downsloping. Palpebral lobes not preserved; palpebral furrows wide, shallow, suggest palpebral lobes relatively small - exsagittal length about one-fifth sagittal glabellar length. Line through centers of

palpebral furrows crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas long, narrow, weakly convex, posteriorly moderately steeply downsloping. Posterior border furrows weakly defined, wide, shallow. Posterior border extremely narrow, convex. Prosopon of mixed fine pustules and coarser tubercles.

Hypostoma unknown.

Librigena with genal field moderately convex. Lateral border furrow distinct, narrow, shallow. Lateral border narrow - of constant width, convex. Genal spine continuous with lateral border, smooth, convex; it projects outward from posterior margin. No posterior border or posterior border furrow. Prosopon of mixed fine pustules and coarser tubercles.

Thorax unknown.

Pygidium moderately convex, oblong, semielliptical, length about one-half maximum width at posterior end of articulating facets. Axial lobe weakly convex, transversely weakly arched, posteriorly gently tapering and truncate, extends about three-quarters total pygidial length. Four distinct axial rings (including terminal ring) of posteriorly decreasing sagittal width. Axial ring furrows abaxially deepen markedly. Axial furrows distinct, narrow, deep. Three pairs of pleural furrows - distinct, wide, shallow. Three pairs of interpleural furrows - well defined, narrow, deep. Pleural and interpleural furrows

posteriorly curve very gently backwards and stop slightly past posterior border. Posterior border weakly defined but distinct, moderately narrow, flat, smooth, posteriorly steeply downslping. Prosopon smooth.

Remarks: When Ross originally proposed Parahystricurus he stated that no pygidia could be assigned with certainty to the genus (Ross, 1951, p. 57). However, he illustrated a pygidium (Ross, 1951; pl. 19, figs. 6, 11, 15) which he thought was possibly referable to P. carinatus Ross (1951, p. 60-61; pl. 13, figs. 23-27, 30-32, 35-37). The present author has been able to associate cranidia and pygidia of Parahystricurus with certainty. Fossil horizon BH-30 in the Boat Harbour sequence yielded only three trilobite species, namely P. smithiae, Hillyardina levis and Randaynia saundersi. Since Hillyardina levis and R. saundersi were already known from nearly complete individuals (pl. , figs. ) and is a much larger trilobite than P. smithiae it is a simple matter to assign the small pygidia obtained to P. smithiae. The general similarity of Ross' illustrated pygidium that of P. smithiae (pl. 9, fig. 7) suggests that his proposed assignment of it to P. carinatus was correct.

The highly convex, elliptical glabella with its two faint pairs of lateral glabellar furrows, the long, narrow, weakly convex posterior fixigenal areas, and the characteristic dorsal surface ornamentation of the cranidium readily distinguish P. smithiae from most described species of Parahystricurus. However, Sando (1957, p. 137; pl. 11, fig. 3) described and illustrated an incomplete cranidium of Parahystricurus

from the Rockdale Run Formation (Beekmantown Group) of Maryland which closely resembles P. smithiae. This cranidium, which probably represents a new species of Parahystricurus, Sando assigned to Hystricurus. It differs from P. smithiae in that it is less convex, has a wider preglabellar area and is more strongly furrowed than P. smithiae.

Genus Paraplethopeltis Bridge and Cloud, 1947

Type species: Paraplethopeltis obesa Bridge and Cloud, 1947, from the Tanyard Formation of central Texas.

Diagnosis: Glabella strongly convex, straight- to convex-sided, anteriorly tapering. Occipital ring subrectangular; occipital spine variably developed. Preglabellar and axial furrows well defined, deep. Occipital furrow faint, shallow to well defined, deep. Lateral glabellar furrows not developed. Anterior border furrow indistinct to well defined, narrow to wide, shallow to deep. Anterior border narrow, concave, flat to convex, convex-forward. Eye ridges faint. Palpebral lobes small to large, short to long, crescentic. Posterior border furrows faint, shallow to well defined, deep. Cranial prosopon smooth. Librigena with moderately convex genal field. Lateral border furrow indistinct to well defined, narrow to wide, shallow to deep. Lateral border narrow to wide, concave, flat to weakly convex. Librigenal prosopon smooth. Pygidium subtriangular to semielliptical. Axial lobe wide, moderately to strongly convex, posteriorly tapering and abruptly to broadly rounded; end merges into posterior margin. Four or five

axial rings including terminal ring. Axial and axial ring furrows well defined, deep. Pleural and interpleural furrows well defined, deep. Three or four pairs of pleural ribs. Posterior border furrow faint. Posterior border narrow, convex to concave. Pygidial prosopon smooth. Modified and expanded from Lochman-Balk in Moore (1959, p. 0410).

Remarks: Lochman-Balk in Moore (1959, p. 0410) assigned Paraplethopeltis to the family Plethopeltidae Raymond, 1925. Paraplethopeltis closely resembles Hystricurus Raymond, 1913, being distinguished chiefly by its less convex anterior border, the presence of faint eye ridges and its distinctive smooth prosopon. For this reason the author has assigned Paraplethopeltis to the subfamily Hystricurinae Hupe, 1953.

Hintze (1953, p. 201) questionably referred to Paraplethopeltis two species with well defined anterior borders, i.e. Paraplethopeltis? genacurvis Hintze (1953, p. 202-204; pl. VII, figs. 1-5) and Paraplethopeltis? genarectus Hintze (1953, p. 204; pl. VII, figs. 6-9). A comparison of illustrated pygidia of the two species (Hintze, 1953; pl. VII, figs. 4, 5, 9) with that of Paraplethopeltis obesa Bridge and Cloud (1947; pl. 2, figs. 1-7, 12-14) suggests the three specimens are congeneric; the pygidia of these species are fully comparable with respect to size, shape, convexity, number of axial rings, and number and style of pleural and interpleural furrows. Consequently Paraplethopeltis? genacurvis and Paraplethopeltis? genarectus are assigned to Paraplethopeltis without question. The presence of a well developed anterior border in Paraplethopeltis is regarded as a derived or secondary evolutionary character.

Hintze (1953, p. 201) identified several other species as being congeneric with Paraplethopeltis? genacurvis and Paraplethopeltis? genarectus - hence with Paraplethopeltis (see above), namely Hystricurus? sp. E. Ross (1951; pl. 15, figs. 10, 11, 13, 14), Hystricurus? sp. I Ross (1951; pl. 17, figs. 1-3), Pachyranium? sp. Ross (1951; pl. 17, figs. 4-6, 9-11, 14, 15) and Hystricurus nudus Poulsen (1937; pl. 2, figs. 10), assignments with which the author concurs. Hystricurus? sp. E. is probably conspecific with Paraplethopeltis genacurvis, based on the close similarities of their crania and pygidia. Hystricurus? sp. I probably represents a new species of Paraplethopeltis while Pachyranium? sp. may represent Paraplethopeltis genarectus, the librigena illustrated by Ross (1951, pl. 17, figs. 6, 14) possibly belonging to Hystricurus? sp. I. Paraplethopeltis nudus is a distinctive species with a narrow concave-upward anterior border.

The author also assigns to Paraplethopeltis the following species:

Bathyrus cordai Billings, 1859

Bathyrus seelyi Whitfield, 1889a

Hystricurus? sp. aff. H.? genacurvis (Hintze) Berg and Ross 1959

Hystricurus cf. H. oculilunatus Ross - Ross (1970)

The earliest species of Paraplethopeltis (i.e. P. obesa Bridge and Cloud, 1947; P. depressa Bridge and Cloud, 1947; and P. carinifera

Flower, 1968b), earliest Ordovician in age, are characterized by poorly developed anterior borders, relatively small palpebral lobes and weakly defined occipital rings. The Trempealeauan (latest Cambrian) genus Plethopeltis Raymond, 1913 also exhibits these features. The main difference between the two genera is the greater degree of segmentation in the pygidium of Paraplethopeltis. The fact that Paraplethopeltis biostratigraphically succeeds Plethopeltis coupled with the close resemblance of the two genera suggests that Paraplethopeltis evolved from Plethopeltis.

Paraplethopeltis seelyi (Whitfield)

(Pl. 10, figs. 2-7; pl. 11, figs. 1, 2)

1889a Bathyrurus seelyi n. sp. - Whitfield, p. 62-63; pl. 13, figs. 8-14.

1913 Hystericurus cordai (Billings) - Raymond, p. 61.

1983 Paraplethopeltis seelyi (Whitfield) - Boyce in Stouge and Boyce; pl. 15, figs. 6-8.

Diagnosis: Cephalon highly convex. Glabella straight-sided, anteriorly tapering and broadly rounded. Eye ridges weakly developed. Palpebral lobes large, long, wide, broadly crescentic. Pygidium with four strongly defined axial rings and four pairs of strongly defined pleural furrows. Interpleural furrows not developed. Posterior border well defined, narrow, concave-outward, vertical.

Stratigraphic range: Upper member of the Boat Harbour Formation, 47.10 m above the base of the Boat Harbour measured sequence; thrombolitic lime boundstone bed forming the top of Moyrac Island, immediately north of Old Ferrolle Island; Unit 9 of Pratt's (1979) Eddies Cove West Section.

Material: Three (3) cranidia; one (1) librigena; four (4) pygidia.

Syntypes: Cranidium, A.M.N.H. 35502; librigena, A.M.N.H. 35503; cranidium, A.M.N.H. 35504; pygidium, A.M.N.H. 35505 (the originals of Whitfield, 1889a; pl. 13, figs. 8-14), from the Fort Ann Formation near Plattsburgh, New York.

Description: Glabella highly convex, transversely moderately vaulted, straight-sided, anteriorly tapering and broadly rounded; it extends about four-fifths total cranidial length. Occipital ring sagittally wide, rectangular. Preglabellar and axial furrows well defined, narrow, deep; occipital furrow slightly less so. Lateral glabellar furrows not developed. Preglabellar field narrow, convex, anteriorly steeply down-sloping, about one-fourteenth total cranidial length. Anterior border furrow well defined, narrow, deep; in front of glabella straight to slightly concave-forward, abaxially convex-forward. Anterior border transversely long, relatively wide, flat to abaxially slightly convex, horizontal to anteriorly very gently down-sloping, in anterior view transversely broadly arched. Anterior fixigenal areas wide, convex, anteriorly steeply down-sloping. Palpebral fixigenal areas only slightly wider than anterior fixigenal areas, abaxially horizontal to very



gently upsloping, sagittally anteriorly very gently downsloping. Eye ridges faint, extremely narrow. Palpebral lobes large, long - exsagittal length about two-fifths sagittal glabellar length, wide, broadly crescentic. Palpebral furrow distinct, narrow, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas narrow, convex, posteriorly moderately steeply downsloping. Posterior border furrow well defined, narrow, deep. Posterior border flat to slightly convex, posteriorly gently upsloping. Prosopon smooth.

Hypostoma unknown.

Librigena with genal field moderately convex. Lateral border furrow well defined, narrow, deep, abaxially shallowing. Lateral border wide, convex, abaxially expanding. Genal spine short, stubby. Posterior border furrow and posterior border not developed. Prosopon smooth.

Thorax unknown.

Pygidium highly convex, subelliptical, length about two-thirds maximum width at posterior end of articulating facets. Axial lobe moderately convex, transversely moderately arched, posteriorly gently tapering and abruptly rounded; it extends about nine-tenths total pygidial length. Four well defined axial rings (including terminal ring) of posteriorly decreasing sagittal width. Axial and axial ring furrows distinct, narrow, deep; axial ring furrows abaxially become

shallower. Four pairs of pleural furrows, equally distinct, narrow, deep, curve progressively backwards and stop at posterior border. Four pairs of well defined pleural ribs; interpleural furrows not developed. Posterior border well defined, narrow, flat to concave-outward, posteriorly steeply downsloping to vertical, in posterior view transversely broadly arched. Prosopon smooth; on inner mould pleural ribs finely punctate.

Remarks: Paraplethopeltis seelyi was originally described by Whitfield (1889a, p. 62-63; pl. 13, figs. 8-14) from "the lower six or eight feet of the Calciferous sandrock as exposed about one and a half miles north of Beekmantown Station, on the Delaware and Hudson Railroad, three miles north of Plattsburgh, N.Y. (Whitfield, 1889a, p. 42, 63). The collection locality, known as the "Kirby Ledge", is an old quarry, small and overgrown, which occurs in the lower 40 ft. (12 m) limestone unit of the Fort Ann Formation (Flower, written communication, December 27, 1978). Whitfield (1889a, p. 63) reports that P. seelyi probably also occurs at Comstock, Washington County, New York.

P. seelyi differs from the type species P. obesa Bridge and Cloud, 1947 in having a well defined anterior border, faint eye ridges, and only four axial rings (including the terminal ring) in the pygidium. In these respects P. seelyi closely resembles P. genacurvis Hintze (1953; pl. VII, figs. 1-5) and P. genarectus Hintze (1953; pl. 7, figs. 6-9). However, pygidia of the latter two species (Berg and Ross, 1959) have narrower, more conical axes and well developed interpleural furrows as well as pleural furrows. P. seelyi has a straight-sided glabella in

contrast to the convex-sided glabellas of P. genacurvis and P. genarectus and has shorter, stubbier genal spines.

Raymond (1913, p. 61) and the author (Boyce, 1979a, p. 8, 1979b) assigned P. seelyi to P. cordai (Billings, 1860, p. 321; Fig. 26). However, subsequent examination of the syntype cranium of P. cordai (G.S.C. 836c) from Levis, Quebec (pl. 10, fig. 1) showed that the strongly convex anterior border, the much wider and deeper preglabellar, axial, occipital and posterior border furrows, the lack of eye ridges, the narrower palpebral areas and the smaller palpebral lobes readily distinguish P. cordai from P. seelyi.

The convex-sided glabellas of P. genacurvis Hintze, 1953, P. genarectus Hintze, 1953, Paraplethopeltis sp. E (Ross, 1951 = Hystricurus? sp. E. Ross, 1951), Paraplethopeltis sp. I (Ross, 1951 = Hystricurus? sp. I Ross, 1951), Paraplethopeltis sp. (Ross, 1951 = Pachycranium? Ross, 1951), Paraplethopeltis sp. aff. P. genacurvis Hintze (Berg and Ross, 1959) and P. nudus (Poulsen, 1937) readily distinguish them from P. seelyi.

Paraplethopeltis seelyi (Whitfield) records evolutionary trends which the author believes eventually culminated in the bathyurid genus Bolbocephalus Whitfield, 1890. These trends are:

- 1) increased convexity of cranium and pygidium,

- 2) straighter and more parallel-sided glabella, narrower preglabellar field and shorter anterior border,
- 3) glabella increasingly overhangs preglabellar field,
- 4) shorter, stubbier genal spines,
- 5) progressive effacement and decreased segmentation of axial rings and pleural ribs in pygidium,
- 6) progressively less distinct posterior border,
- 7) transverse arching of posterior border.

Compare Paraplethopeltis seelyi Whitfield (pl. 10, figs. 2-7; pl. 11, figs. 1, 2) to Bolbocephalus jeffersonensis Cullison (1944, p. 77-78; pl. XXXIV, figs. 28, 29), currently the earliest known species of Bolbocephalus.

Superfamily BATHYURACEA Walcott, 1886

Family BATHYURIDAE Walcott, 1886

Subfamily BATHYURINAE Walcott, 1886

Genus Bolbocephalus Whitfield, 1890

Type species: Bathyrus seelyi Whitfield, 1886, non Bathyrus seelyi Whitfield, 1889a, from the Fort Cassin Formation (Beekmantown Group) at Fort Cassin, New York.

Diagnosis: See Whittington in Moore (1959, p. 0376-0377).

Bolbocephalus convexus (Billings, 1865)

(Pl. 11, figs. 3, 4)

- 1865 Dolichometopus? convexus (n. sp.) - Billings, p. 269; Fig. 253.
- 1924 Gignopeltis convexa (Billings) - Raymond, p. 455.
- 1925 "Dolichometopus" convexus (Billings) - Raymond, p. 164.
- 1937 Bolbocephalus groenlandicus n. sp. - Poulsen, p. 48-49; pl. 5, figs. 9-13.
- 1978c Gignopeltis convexus (Billings) - Ludvigsen, p. 76; pl. 1, fig. 5.
- 1979a Gignopeltis convexus (Billings) - Ludvigsen, p. 35; fig. 19E.
- 1979c Bolbocephalus convexus (Billings) - Ludvigsen, p. 861; pl. 1, figs. 5, 6.

1979a Bolbocephalus convexus (Billings) - Fortey, p. 78-80; pl. 26, figs. 1-10; pl. 28, figs. 9, 10.

1983 Bolbocephalus convexus (Billings) - Boyce in Stouge and Boyce; pl. 15, figs. 9, 10.

Diagnosis: Glabella sagittally relatively short, anteriorly rapidly expanding, in dorso-ventral plane highly convex. Pygidium generally effaced, interpleural furrows almost obsolete, posterior border not developed. Modified from Fortey (1979a, p. 78).

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 72.48 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Six (6) cranidia; eleven (11) librigenae; twenty-four (24) pygidia.

Holotype: Pygidium, G.S.C. 718 from the Catoche Formation on Port aux Choix Peninsula, western Newfoundland (the original of Billings, 1865; fig. 253 - by monotypy, Fortey, 1979a).

Description: Fortey (1979a, p. 78-80) has already provided a detailed description of B. convexus which is not repeated.

Remarks: Fortey (1979a, p. 80) distinguished Bolbocephalus groenlandicus Poulsen, 1937 from B. convexus on the basis of more distinct

interpleural furrows on the pygidium and dense, rather than scattered punctation on the internal mould. The author has observed that the definition of the interpleural furrows in B. convexus is quite variable; dense punctation also occurs. Consequently B. groenlandicus is regarded as a junior subjective synonym.

Fortey (1979a, p. 80) suggested that the more convex, effaced Bolbocephalus species would prove to be characteristic of faunas younger than Ross-Hintze Zones G1 and G2. The author suggests the opposite is true. The youngest species of Bolbocephalus the author has found in western Newfoundland is a strongly furrowed form conspecific with genus et. sp. ind. Poulsen, 1937 (= Bolbocephalus sp. nov. 2 Boyce, 1983, p. 12). It occurs widely in the Catoche Formation in western Newfoundland, associated with the Zone H species Benthamaspis gibberula (Billings). This Bolbocephalus species may also be conspecific with the strongly furrowed Bolbocephalus species illustrated as unassigned pygidium 7 by Young (1973; pl. 6, figs. 14, 15). This species also occurs in a fauna of Zone H age.

Bolbocephalus stevensi sp. nov.

(Pl. 11, figs. 5-8)

Diagnosis: Glabella sagittally relatively long, almost parallel-sided, anteriorly only slightly expanding. Pygidium with posterior border well defined, relatively narrow. Axial lobe highly convex, posteriorly tapering and abruptly rounded; four well defined axial rings excluding

terminal ring. Two anterior pairs of interpleural furrows incomplete, almost nonexistent. Four pairs of pleural furrows well defined, deep.

Derivation of name: For Dr. R.K. Stevens (Memorial University) who originally collected the species.

Stratigraphic range: Upper member of the Boat Harbour Formation, 75.44 to 84.56 m above the base of the Boat Harbour measured sequence.

Material: Three (3) cranidia; nine (9) pygidia.

Holotype: Pygidium, NFM F-149, from BH-95 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-148, from BH-69; pygidium, NFM F-150, from Bed 39 of Section BHS-6; pygidium, NFM F-151, from BH-87; all in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella highly convex, transversely moderately vaulted, sagittally relatively long, almost straight- and parallel-sided, anteriorly only slightly expanding and abruptly rounded, forward protruding; it overhangs anterior border. Forward glabellar outline broadly semicircular. Occipital ring sagittally relatively wide, rectangular. Preglabellar, occipital and axial furrows well defined, narrow, deep. Lateral glabellar furrows not developed. Preglabellar field



and anterior border not preserved on ctenidium illustrated (pl. 11, fig. 5). - Anterior fixigenal areas narrow, flat to weakly convex, anteriorly steeply downsloping. Palpebral fixigenal areas about twice the width of anterior fixigenal areas, abaxially horizontal, sagittally anteriorly very gently downsloping. Palpebral lobes relatively large (for Bolbocephalus) - exsagittal length about one-third sagittal glabellar length, wide, crescentic. Palpebral furrow distinct, narrow, deep. Line through centers of palpebral lobes crosses glabellar sagittal line at one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas weakly convex, posteriorly gently downsloping. Posterior border furrow distinct, narrow, deep. Prosopon smooth. Internal mould finely punctate except for palpebral lobes.

Hypostoma, librigena and thorax unknown.

Pygidium highly convex, semielliptical, length about one-half maximum width at posterior end of articulating facets. Axial lobe strongly convex, cylindro-conical, transversely arched, posteriorly gently tapering and abruptly rounded; it extends about four-fifths total pygidial length. Four well defined axial rings of even sagittal width and terminal ring with faint pair of tubercles at its posterior end (representing muscle insertion areas - visible on internal mould only). Postaxial area moderately steep, flat, posteriorly downsloping. Axial furrows distinct, deep, narrow. Four pairs of pleural furrows deeper, more distinct; they slope backwards posteriorly and stop at posterior border. Posterior border relatively narrow, flat, posteriorly

moderately steeply downsloping. Two anterior pairs of interpleural furrows very shallow, incomplete, almost nonexistent; interpleural furrows start just ahead of posterior border furrow and slope backwards posteriorly, stopping at posterior margin. Posterior border furrow indistinct. Prosopon smooth. Internal mould finely punctate.

Remarks: The relatively long, nearly parallel-sided, only slightly anteriorly expanding glabella and the relatively large palpebral lobes of the cranidium and the strongly convex, cylindro-conical axial lobe with four well defined axial rings, the two anterior pairs of incomplete almost nonexistent interpleural furrows and the four pairs of well defined, deep pleural furrows of the pygidium readily distinguish B. stevensi from all other presently known species of Bolbocephalus. The morphologically closest species B. jeffersonensis Cullison (1944, plate XXXIV, figures 28, 29) has a relatively short, essentially straighter- and more parallel-sided glabella compared to B. stevensi. In addition the pygidial axial lobe of B. jeffersonensis contains only three clearly defined axial rings compared to the four present in B. stevensi. The type species B. seelyi (Whitfield - Whittington, 1953; pl. 66, figs. 1-10, 12-14, 17, 21, 22; text-figure 2) differs from B. stevensi in that the glabella is more convex and anteriorly expanding, the pygidium has extremely strongly developed interpleural as well as pleural furrows, and a prosopon of fine granules or pustules.

Genus Jeffersonia Poulsen, 1927

Type species: Jeffersonia exterminata Poulsen, 1927, from the Nunatami Formation at Nunatami, on the south coast of Washington Land, northwest Greenland.

Diagnosis: Pygidium moderately convex, slightly wider than long. Axial lobe strongly convex, conical. Five axial rings, including terminal ring; posterior two weakly defined. Axial furrow strongly impressed, narrow. Posterior border broad, slightly concave. Posterior margin almost evenly rounded. Prosopon of fine granules (Modified from Poulsen, 1927, p. 303).

Remarks: Poulsen (1927, p. 303) defined the new species exterminata on two pygidia and attributed it to Jeffersonia Ulrich, manuscript. Ulrich never published a generic diagnosis so Jeffersonia exterminata Poulsen became the type species by monotypy (Cullison, 1944, p. 70).

Cullison (1944) attributed nine new species to Jeffersonia. Whittington (1953, p. 662) doubted that all these species were congeneric and suggested that the name Jeffersonia ought to be used solely for the type species.

Poulsen (1937, p. 51) erected the genus Bathyrina. The type species Bathyrina megalops Poulsen (1937, p. 52; pl. 6, figs. 14, 15; pl. 7, fig. 1) was defined on two cranidia from the Cape Weber Formation at Mt. Gunvor, East Greenland. Fortey and Bruton (1973) evidently

were able to associated pygidia with cranidia of Bathyrina; they reported the presence of Bathyrina cf. timon (Billings). Bathyrina timon (Billings, 1865, p. 261; fig. 244) was previously known from pygidia only.

Fortey (1979a) redescribed B. timon and illustrated its pygidia and cranidia from the Catoche Formation on Port au Choix Peninsula in western Newfoundland.

The pygidia of Bathyrina timon (Billings) and Jeffersonia exterminata are similar:

- 1) The pygidia are wider than long.

The pygidium of J. exterminata has a length/width ratio of 0.88 (Poulsen, 1927; pl. 20, fig. 28). The pygidium of B. timon illustrated by Fortey (1979a; pl. 25, fig. 3, the original of Billings, 1865; fig. 244) has a length/width ratio of 0.78.

- 2) The posterior margins of both pygidia are almost evenly rounded.
- 3) The pygidial borders of both species are broad and flat or slightly concave-upward.
- 4) The pygidial axial lobes of both species are strongly convex, conical and divided into five axial rings (including the terminal ring) of which only the anterior three are well defined.

- 5) The pygidial prosopon consists of granules or tubercles.

On the basis of the above morphological similarities and the fact that Jeffersonia Poulsen, 1927 was defined ten years before Bathyrina Poulsen, 1937, the author herein assigns Bathyrina timon to Jeffersonia.

The author suggests that Bathyrina will eventually prove to be a junior subjective synonym of Jeffersonia because presently known species can be assigned to either genus depending on whether cranidia or pygidia are used in the assignment. However, until cranidia and pygidia are assigned to Jeffersonia exterminata and Bathyrina megalops, respectively, the congenericity of the two species will remain unproven.

Jeffersonia angustimarginata sp. nov.

(Pl. 12, figs. 1-6)

1946 Genus et sp. indet. II (in part)<sup>1</sup> - Poulsen, p. 330; pl. XXIII, fig. 10 only.

1979a Bathyrina sp. indet. - Fortey, p. 78; pl. 28, figs. 8, 10, 11.

1983 Bathyrina sp. - Boyce in Stouge and Boyce; pl. 13, fig. 4. ..

Diagnosis: Pygidium strongly convex. Axial lobe with four well defined axial rings. Four pairs of deep interpleural furrows. Postaxial area steep (almost vertical), posteriorly downslping. Posterior border smooth, narrow, flat to slightly concave-upward, moderately downslping. Prosopon of fine granules or tubercules.

Derivation of name: From angustus (Latin) narrow, and marginis (Latin), border, plus ata (feminine), referring to the characteristic narrow border of the pygidium.

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 71.80 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Six (6) cranidia; fifteen (15) pygidia.

Holotype: Pygidium, NFM F-87, from BH-101 in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-152, from BH-40 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland; cranidium, NFM F-153, from BH-112 in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella strongly convex, transversely strongly vaulted, straight- and parallel-sided to anteriorly slightly expanding, anteriorly gently rounded, forward protruding; it overhangs anterior border. Anterior glabellar outline broadly elliptical. Occipital ring sagittally narrow, rectangular. Preglabellar furrow poorly defined, narrow, shallow. Occipital and axial furrows well defined wide, deep. Axial furrows anteriorly less well defined, narrower, shallower. Lateral glabellar furrows not developed. Preglabellar field not developed. Anterior border furrow indistinct. Anterior border narrow, convex; abaxially of constant width; anterior profile immediately in front of glabella is convex-forward, abaxially concave-forward. Anterior and posterior fixigenal areas narrow, convex, steeply down-sloping. Palpebral fixigenal areas large, high, abaxially upward-sloping. Palpebral lobes large, narrow, semielliptical. Palpebral furrow indistinct, narrow, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about six-tenths glabellar length from posterior edge of occipital ring. Prosopon of fine granules or tubercles except for anterior border and palpebral lobes. Tuberculation only faintly reflected on internal moulds, however, internal moulds of glabellar axes display fine, scattered pits.

Hypostoma, librigenae and thorax unknown.

Pygidium strongly convex, semicircular, length about four-fifths maximum width at posterior end of articulating facets. Axial lobe strongly convex, cylindro-conical, transversely arched, posteriorly gently tapering and abruptly rounded; it extends about seven-eighths

total pygidial length. Four well defined axial rings of posteriorly decreasing sagittal width and distinctiveness and terminal ring. Lateral lobes partially developed on abaxial portions of anterior two rings. Axial furrows well defined, deep. Four pairs of pleural furrows, well defined, deep; they slope posteriorly backwards and stop at posterior border. Posterior border well defined, smooth, narrow, flat to concave-upward. Prosopon of fine granules or tubercles except for posterior border; internal mould finely punctate except for posterior border.

Remarks: The prosopon of fine granules or tubercles, the axial lobe with four, rather than three, well defined axial rings and the relatively narrow border readily distinguish pygidia of J. angustimarginata from those of the stratigraphically later J. timon. The pygidium of the type species J. exterminata Poulsen (1927, plate XX, figure 28) is less convex, more effaced and only has three easily recognizable axial rings.

Cullison (1944) described and illustrated nine species of Jeffersonia from the Rich Fountain, Theodosia and Cotter Formations of Missouri and northern Arkansas. Of these the author only recognizes J. granosa, J. products, J. delicatula, J. jeniei, Jeffersonia sp. 1 and Jeffersonia sp. 2 as fitting within the concept of Jeffersonia. Of the excluded species, J. missouriensis probably represents a new genus as its pygidium lacks pleural ribs and has an extremely wide, convex-upward posterior border rather than a narrow, flat to concave-upward posterior border; J. mediacrista is elsewhere (this study, p. 146) designated the



type species of the new genus Parapeltabellia; and J. crassimarginata is herein assigned to Peltabellia. With respect to the Cullison species included in Jeffersonia the author regards Jeffersonia sp. 1 and Jeffersonia sp. 2 as conspecific. The two species, which are represented by one pygidia each, are identical except for a small difference in longitudinal profile; this is probably due to their slight size difference (compare Cullison, 1944; pl. XXXV, figs. 7, 8 to figs. 9, 10). Of the Cullison species J. jenii Cullison (1944, plate XXXV, figures 17-22) most closely resembles J. angustimarginata. The distinguishing difference is that the pygidial border of J. jenii is much narrower.

Poulsen (1946, plate XXIII, figure 10) illustrated an incomplete pygidium from the Canyon Elv Formation (Peel and Cowie, 1979) at Scoresby Bay, Ellesmere Island which the author herein assigns to J. angustimarginata as it possesses the characteristic four well defined axial rings and narrow posterior border. Poulsen (1946; pl. XXIII, figs. 6-9) also illustrated a cranidium, librigena, and two flattened pygidia from other beds exposed at Cape Steven, southwest of Scoresby Bay and north of Bache Peninsula. This he included in the same species as the Scoresby Bay pygidium. However, the author regards the Cape Steven species as a different, possibly new species of Jeffersonia as its pygidium only has three, rather than four, well defined axial rings and a wide, rather than narrow, posterior border.

Bathyrina sp. indet. (Fortey, 1979a, p. 78; pl. 28, figs. 8, 10, 11) is herein assigned to J. angustimarginata as its pygidium has the

characteristically developed four well defined axial rings and narrow posterior border.

Jeffersonia timon (Billings, 1865)

(not figured)

- 1865 Bathyrus timon (n. sp.) - Billings, p. 261; Fig. 244.
- 1925 Petigurus timon (Billings) - Raymond, p. 164.
- 1969 "Bathyrus" timon Billings - Whittington and Kindle, p. 658.
- 1979a Bathyrina timon (Billings) - Fortey, p. 76-78; Fig. 12; pl. 25, figs. 1-10.

Diagnosis: Lateral lobes on occipital ring. Pygidium of moderate convexity. Axial lobe with three well defined axial rings. Posterior border broad, flat or slightly downsloping; median acumination lacking. Prosopon of coarse tubercles except for almost smooth posterior border; postaxially prosopon of fine tubercles. Modified and expanded from Fortey (1979a, p. 76).

Stratigraphic range: Lower-limestone sequence of Catoche Formation, 2.41 to 16.73 m above the base of Cape Norman measured section.

Material: Four (4) cranidia; seven (7) librigenae; seven (7) pygidia.

Holotype: Pygidium, G.S.C. 636, from the Catoche Formation on Port au Choix Peninsula (the original of Billings, 1865; Fig. 244 - by monotypy, Fortey, 1979a).

Description: Fortey (1979a) has already provided a detailed description of J. timon which is not repeated.

Genus Parapeltabellia nov.

Type species: Jeffersonia mediacrista Gullison, 1944 from the Rich Fountain Formation (Jefferson City Group) of Missouri - northern Arkansas (designated herein).

Diagnosis: Glabella convex, straight- and parallel-sided, subrectangular, anteriorly gently rounded. Occipital ring sagittally narrow, subrectangular. Preglabellar, occipital and axial furrows well defined. Fixigenae narrow, palpebral area relatively large, low, located posterior to glabellar midpoint. Facial suture extends directly forward from palpebral lobe almost to anterior margin, abaxially curving where it intersects anterior border. Anterior border narrow, convex, abaxially tapering. Pygidium convex, semicircular. Axial lobe weakly convex, posteriorly tapering and abruptly rounded. Five axial rings including terminal ring. Four pairs of pleural and interpleural furrows. Posterior border poorly defined, relatively wide. Prosopon smooth.

Derivation of name: From para (Greek), near and peltabellia, referring to the similarity of Parapeltabellia to the genus Peltabellia.

Assigned species: Jeffersonia mediacrista Cullison and Parapeltabellia boatharbourensis sp. nov. (both described in this study) are the only two species the author currently recognizes as belonging to Parapeltabellia nov.

Remarks: Parapeltabellia nov. most closely resembles Paraplethopeltis Bridge and Cloud, 1947 and Peltabellia Whittington, 1953. The differences are discussed below.

The glabella of Parapeltabellia is parallel-sided whereas that of Paraplethopeltis is anteriorly tapering. In addition, the pygidial posterior border is wider.

The cranidial anterior border of Parapeltabellia is less distinct, narrower and less convex than that of Peltabellia. In addition, the glabella of Parapeltabellia is anteriorly gently rounded whereas that of Peltabellia is abruptly rounded. Furthermore, the pygidium of Parapeltabellia lacks the well developed pleural ribs characteristic of Peltabellia.

Parapeltabellia is less convex and more effaced than both Paraplethopeltis and Peltabellia; in particular, the pygidial posterior border of Parapeltabellia is less distinct.

Parapeltabellia mediacrista (Cullison) D

✓ (Pl. 12, fig. 7; pl. 13, figs. 1, 3)

1944 Jeffersonia mediacrista n. sp. Cullison, p. 74-75; pl. XXXIV, figs. 25-27.

Diagnosis: Two pairs of lateral glabellar furrows, weakly defined. Anterior border well defined. Palpebral lobes relatively large, narrow, semicircular.

Stratigraphic range: Rich Fountain Formation (Jefferson City Group), 10 to 29 m above the base, Missouri - northern Arkansas (Cullison, 1944; pl., II).

Material: One (1) cranidium; one (1) pygidium.

Holotype: Cranidium, U.S.N.M. 155393, from the Rich Fountain Formation of Missouri - northern Arkansas (the original of Cullison, 1944; pl. XXXIV, figs. 25, 26 - by monotypy).

Paratype: Pygidium, U.S.N.M. 155394 from the Rich Fountain Formation of Missouri - northern Arkansas (the original of Cullison, 1944; pl. XXXIV, fig. 27 - by monotypy).

Description: The following is a redescription of the specimens originally described by Cullison (1944, p. 74-75; pl. XXXIV, figs. 25-27) based on examination of the original material.

Glabella convex, transversely broadly vaulted, straight- and parallel-sided, subrectangular, anteriorly gently rounded, with faint median longitudinal ridge; it extends about seventeen-twentieths total cranial length. Occipital ring sagittally narrow, subrectangular. Preglabellar, occipital and axial furrows well defined. Two pairs of lateral glabellar furrows, weakly defined, shallow, posteriorly directed; anterior pair anterior to palpebral lobe, posterior pair opposite palpebral lobe midpoint. Preglabellar field narrow, convex, anteriorly steeply downsloping, about one-tenth total cranial length. Anterior border well defined, narrow, convex, abaxially tapering, in anterior view horizontal. Anterior fixigenal areas narrow, convex, anteriorly steeply downsloping. Anterior portions of facial suture extend directly forward from palpebral lobes almost to anterior margin, abaxially curving where they intersect anterior border. Palpebral fixigenal areas relatively large, about twice width of anterior fixigenal areas, low, abaxially gently downsloping, sagittally anteriorly gently downsloping, located just behind glabellar midpoint. Palpebral lobes large, long - exsagittal length about two-thirds sagittal glabellar length, narrow, semicircular. Palpebral furrow distinct. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas not preserved. Prosopon smooth.

Hypostoma, librigenae, and thorax unknown.

Pygidium convex, semicircular, length about eight-ninths maximum width. Axial lobe weakly convex, transversely gently arched,

posteriorly tapering and abruptly rounded. Five axial rings, including terminal ring, posteriorly of decreasing distinctiveness. Four pairs of pleural and interpleural furrows weakly defined, posteriorly of decreasing distinctiveness. Posterior border furrow extremely faint. Posterior border poorly defined, wide, weakly convex. Prosopon smooth.

Parapeltabellia boatharbourensis sp. nov.

(Pl. 12, fig. 8; pl. 13, figs. 2, 4)

Diagnosis: Lateral glabellar furrows not developed. Anterior border faintly defined. Palpebral lobes relatively small, narrow, crescentic.

Derivation of name: After the community of Boat Harbour where the species was discovered.

Stratigraphic range: Upper member of Boat Harbour Formation, 58.46 m above the base of Boat Harbour measured sequence.

Material: One (1) cranidium.

Holotype: Cranidium, NFM F-155, from BH-34 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Most of the description given for P. mediacrista (Cullison) also applies to this species and is not repeated. The discriminating differences are as follows:

1. Lateral glabellar furrows not developed.
2. Anterior border furrow weak. Anterior border faintly defined; less convex than that of P. mediacrista.
3. Palpebral lobes relatively small, narrow and crescentic; located more posteriorly than those of P. mediacrista. Prosopon smooth.

The hypostoma, librigenae, thorax and pygidium are unknown.

genus Peltabellia Whittington, 1953

Type species: Jeffersonia peltabella Ross, 1951 from the Garden City Formation of northeastern Utah.

Diagnosis: Cephalon strongly convex. Glabella straight- and parallel-sided, anteriorly abruptly rounded to pointed. Lateral glabellar furrows not developed. Anterior border extremely narrow and convex, of constant width. Anterior sections of facial suture slightly divergent. Genal spines short. Pygidium with posterior border broad, smooth, weakly to moderately convex. Prosopon punctate, smooth or tuberculate.

Peltabellia knighti sp. nov.

(Pl. 13, figs. 5-8; pl. 14, fig. 1)



1983 Peltabellia sp. nov. - Boyce in Stouge and Boyce; pl. 16, figs.

3-5.

Diagnosis: Glabella anteriorly effaced. Pygidium with two to three axial rings variably defined; only two pleural ribs. Posterior border relatively narrow. Prosopon smooth. Internal mould punctate.

Derivation of name: For I. Knight (Newfoundland Department of Mines and Energy) who originally collected this species and who has done much to unravel the Cambrian-Ordovician stratigraphy of western Newfoundland.

Stratigraphic range: Upper member of the Boat Harbour Formation, 73.62 to 79.39 m above the base of the Boat Harbour measured sequence.

Material: Fourteen (14) cranidia; eight (8) librigena; thirty-six (36) pygidia.

Holotype: Pygidium, NFM F-157 from BH-46 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidia, NFM F-112 from BH-46; cranidium, NFM F-156 from BH-47; librigena, NFM F-113 from BH-46; pygidium, NFM F-114 from BH-46; all in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella highly convex, transversely strongly vaulted, straight- and parallel-sided, anteriorly abruptly rounded and effaced; it extends about nine-tenths total cranial length. Occipital ring sagittally narrow, rectangular. Preglabellar furrow well defined, narrow deep, abaxially becomes shallow, indistinct. Axial furrows well defined, wide, deep; occipital furrow narrower. Lateral glabellar furrows not developed. Preglabellar field extremely narrow, convex, steeply anteriorly downsloping, about one-twentieth total sagittal cranial length. Anterior border furrow distinct, narrow, deep, convex-forward. Anterior border transversely long, extremely narrow and convex, of constant width in anterior view; transversely broadly arched in anterior view. Anterior fixigenal areas of moderate width, convex, anteriorly steeply downsloping. Palpebral fixigenal areas only slightly wider than anterior fixigenal areas, abaxially horizontal to very gently upsloping, sagittally anteriorly very gently downsloping. Palpebral lobes relatively large, long - exsagittal length about one-third sagittal glabellar length, wide, convex, semicircular. Palpebral furrow distinct, narrow. On internal mould palpebral lobe is extremely narrow and convex and palpebral furrow distinct, extremely wide, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas narrow, convex, posteriorly moderately steeply downsloping. Posterior border furrows distinct, narrow, deep. Posterior border strongly convex. Prosopon smooth. On internal mould, glabella finely punctate.

Hypostoma unknown.

Librigena with genal field highly convex. Lateral border furrow distinct, narrow, deep adjacent to facial suture, abaxially becomes less distinct, wider, shallower to posterior border furrow. Lateral border extremely narrow and convex, abaxially becomes substantially wider and less convex to posterior border. Posterior border furrow distinct, narrow, shallow. Posterior border wide, weakly convex. Genal spine long and narrow, flat to moderately convex. Proson smooth.

Thorax unknown.

Pygidium moderately convex, semielliptical, length about two-thirds maximum width at posterior end of articulating facets. Axial lobe highly convex, transversely strongly arched, posteriorly gently tapering, and abruptly rounded; it extends about three-quarters total pygidial length. Two to three axial rings variably defined, of constant sagittal width. Axial furrows and two pairs of pleural furrows distinct, wide, deep. Interpleural furrows not developed. Only two pairs of pleural ribs; these stop at posterior border. Posterior border weakly defined, relatively narrow, weakly to moderately convex, moderately steeply downsloping, anteriorly narrower than postaxially, in posterior view horizontal. Proson smooth. Internal mould finely punctate.

Remarks: P. knighti most closely resembles P. crassimarginata (Cullison, 1944, p. 75-76; pl. XXXV, figs. 13-16) and P. willistoni

Lochman (1966, p. 542; pl. 62, figs. 10, 11). However, the pygidia of the latter two species differ from that of P. Knighti in having four to five axial rings, three pleural ribs and posterior borders of constant width.

Peltabellia pseudopeltabella sp. nov.

(Pl. 14, figs. 2-5)

Diagnosis: Pygidial axial lobe composed of at least four axial rings of posteriorly decreasing distinctiveness. Posterior border weakly defined, extremely wide, convex. Prosopon smooth. Internal mould finely punctate.

Derivation of name: From pseudēs (Greek), false, and peltabella, referring to the similarity of this species to Peltabellia peltabella (Ross).

Stratigraphic range: Upper member of the Boat Harbour Formation, 76.50 m above the base of the Boat Harbour measured sequence.

Material: Three (3) pygidia.

Holotype: Pygidium, NFM F-159, from BH-49 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratype: Pygidium, NFM F-158, from the same horizon as holotype (designated herein).

Description: Cranidium, hypostoma, librigenae and thorax unknown.

Pygidium moderately convex, semicircular. Axial lobe strongly convex, transversely highly vaulted, cylindro-conical, almost parallel-sided, posteriorly gently tapering and abruptly rounded; it extends about one-half total pygidial length. At least four axial rings, excluding terminal ring, posteriorly becoming progressively indistinct but of equal sagittal width. Axial furrows well defined. Pleural furrows narrow, posteriorly becoming less distinct and shallower. Three axial rings of equal (sagittal) width becoming progressively indistinct posteriorly. Axial furrows well defined. Three pairs of pleural ribs, posterior pair almost nonexistent. Interpleural furrows not developed. Posterior border weakly defined - almost indistinct in large individual (pl. 14, fig. 3), extremely wide, convex, strongly downsloping. Prosopon smooth. Internal mould smooth except posterior border finely punctate.

Remarks: P. pseudopeltabella most closely resembles P. sibirica (Maximova 1955; pl. VIII, fig. 6) and the type species P. peltabella (Ross, 1951; pl. 17, figs. 19, 21). However the pygidia of the latter species are less effaced and have more posteriorly tapering axial lobes and narrower posterior borders. The prosopon of tubercles, less convex axis, and posteriorly less downsloping and convex posterior border also distinguishes P. peltabella from P. pseudopeltabella. The much wider

posterior border of P. pseudopeltabella also readily distinguishes it from Peltabella sp. B (Hintze, 1953; pl. IX, fig. 8), P. Knighti sp. nov. (pl. 13, fig. 8; pl. 14, fig. 1) and P. willistoni Lochman, 1966; pl. 62, figs. 10, 11).

Genus Petigurus Raymond, 1913

Type species: Bathyrus nero Billings, 1865, from the Catoche Formation (St. George Group) on Port au Choix Peninsula, western Newfoundland.

Diagnosis: Glabella straight-sided, anteriorly weakly expanding and strongly forward-protruding; it overhangs anterior margin. Posterior fixigenal areas long, narrow. Pygidium subtriangular to semielliptical with five axial rings including terminal ring well defined. Four to five pairs of pleural furrows strongly developed. Interpleural furrows variably developed. Prosopon of coarse tubercles.

Petigurus nero (Billings, 1865)

(Pl. 14, fig. 6)

1865 Bathyrus nero (n. sp.) - Billings, p. 260-261; Fig. 243.

1913 Petigurus nero (Billings) - Raymond, p. 58-59; pl. 7, fig. 8.

1925 Petigurus nero (Billings) - Raymond, p. 164.

1953 Petigurus nero (Billings) - Whittington, p. 658; pl. 66, figs. 18-20.

1959 Petigurus nero (Billings) - Whittington in Moore, p. 0378, 0379; Figs. 285-5a,b.

1979a Petigurus nero (Billings) - Fortey, p. 84-86; pl. 29, figs. 1-12, 15.

1980 Petigurus nero (Billings) - Boyce, pers. comm. in Knight and Saltman, p. 20.

1983 Petigurus nero (Billings) - Boyce in Stouge and Boyce; pl. 13, figs. 1, 2.

Diagnosis: Pygidial interpleural furrows abaxially obsolete. Prosopon of coarse tubercles. Modified from Fortey (1979a, p. 84).

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 76.85 to 93.60 m above the base of the Boat Harbour measured sequence; lower limestone sequence of the Catoche Formation, 7.43 to 16.73 m above the base of the Cape Norman measured sequence.

Material: Six (6) cranidia; nine (9) librigenae; five (5) pygidia.

Lectotype: Internal mould of glabella, G.S.C. 750, from the Catoche Formation (St. George Group) on Port au Choix Peninsula, western Newfoundland (selected by Whittington, 1953, p. 658).

Description: Fortey (1979a, p. 84, 86) has already provided a detailed description of P. nero which is not repeated.

Genus Strigigenalis Whittington and Ross in Whittington, 1953

Type species: Strigigenalis cassinensis Whittington, 1953, from the Fort Cassin Formation (Beekmantown Group) at Fort Cassin, Vermont.

Diagnosis: Cephalon weakly to moderately convex. Glabella straight- and parallel-sided to convex-sided. Lateral glabellar furrows not developed. Anterior border narrow, convex. Pygidium with posterior border broad, smooth, weakly to moderately convex. Posterior spine short to long.

Strigigenalis brevicaudata sp. nov.

(Pl. 14, figs. 7, 8; pl. 15, figs. 1-4)

1983 Strigigenalis sp. nov. - Boyce in Stouge and Boyce; pl. 16, fig. 6.

Diagnosis: Pygidial axial lobe convex-sided, posteriorly tapering and abruptly rounded. At least three axial rings of posteriorly decreasing



sagittal width. Posterior spine short, broadly triangular with median carina on internal mould.

Derivation of name: brevis (Latin), short and cauda (Latin) tail, plus ata (feminine), referring to the characteristic short posterior spine.

Stratigraphic range: Upper member of the Boat Harbour Formation, 71.80 to 82.57 m above the base of the Boat Harbour measured sequence.

Material: Sixteen (16) cranidia; seventeen (17) librigenae; twenty-six (26) pygidia.

Holotype: Pygidium, NFM F-163 from BH-67 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein). †

Paratypes: Cranidium, NFM F-160 from Bed 39 of Section BHS-6; librigena, NFM F-161 from Bed 39 of Section BHS-6; pygidium, NFM F-115 from BH-92; all from the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella highly convex, transversely moderately vaulted, straight- and parallel-sided to slightly convex-sided, anteriorly abruptly rounded; it extends about six-sevenths total cranidial length. Occipital ring sagittally narrow, rectangular. Preglabellar, axial and occipital furrows well defined, narrow, deep. Lateral glabellar furrows not developed. Preglabellar field extremely narrow, convex,

anteriorly steeply downsloping, about one-fourteenth total sagittal cranial length. Anterior border furrow distinct, narrow, deep, convex-forward. Anterior border transversely long, narrow - of constant width, convex, in anterior view transversely broadly arched. Anterior fixigenal areas of moderate width, convex, anteriorly steeply downsloping. Palpebral fixigenal areas only slightly wider than anterior fixigenal areas, abaxially very gently upsloping, sagittally anteriorly very gently downsloping. Palpebral lobes relatively large, long - exsagittal length about one-third sagittal glabellar length, wide, convex, crescentic. Palpebral furrow distinct, narrow. On internal mould, palpebral lobe extremely narrow, convex; palpebral furrow distinct, extremely wide, shallow. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas narrow, convex, posteriorly moderately steeply downsloping. Posterior border furrows distinct, narrow, deep. Posterior border strongly convex. Prosopon smooth.

Hypostoma unknown.

Librigena with genal field moderately convex. Lateral border furrow distinct, narrow, deep adjacent to facial suture, abaxially becomes less distinct, wider, shallower to posterior border furrow. Lateral border narrow, convex, abaxially becomes substantially wider and less convex to posterior border. Posterior border furrow distinct, narrow, shallow. Genal spine relatively long and narrow, flat to moderately convex. Prosopon smooth.

Thorax unknown.

Pygidium weakly to moderately convex, triangular, length about two-thirds maximum width at posterior end of articulating facets. Axial lobe highly convex, transversely strongly arched, convex-sided, posteriorly gently tapering and abruptly rounded; it extends about one-half total pygidial length. At least three axial rings of posteriorly decreasing sagittal width. Axial furrows distinct, narrow, deep. Three pairs of pleural furrows distinct, wide, shallow. One anterior pair of interpleural furrows almost indistinct. Three pairs of pleural ribs, posteriorly progressively less distinct; these stop at posterior border. Posterior border weakly defined, narrow, weakly to moderately convex, moderately steeply downsloping, narrower anteriorly than postaxially. Posterior spine short, broadly triangular, posteriorly horizontal to gently upsloping; on internal moulds spine carries median carina. Prosopon smooth.

Remarks: Young (1973; pl. 6, figs. 16, 19, 22) illustrated two pygidia from Zone H in the Fillmore Formation (Pogonip Group) of western Utah, which the author assigns to Strigigenalis. These pygidia closely resemble S. brevicaudata. However, their straight- to concave-sided axial lobes with only two distinct axial rings, less distinct pleural ribs, relatively wider posterior borders and differently shaped and variably developed posterior spines readily distinguish them from that species. These pygidia ("unassigned pygidia 8 and 11" of Young, 1973) the author assigns to Bathyurellus(?) teretus Young (1973; pl. 22, figs. 5, 8-10, 13, 14). Fortey (1979a, p. 92) attributed "unassigned

pygidium 9" of Young (1973; pl. 6, figs. 17-20) to this species. However, the author assigns this pygidium to Benthamaspis giberula (Billings), based on a comparison with pygidia of B. giberula illustrated by Fortey (1979; pl. 34, figs. 8, 10, 11, 13). Fortey (1979a, p. 92) referred Bathyurellus(?) teretus to Bathyurellus sensu stricto but the size and shape of the anterior border, glabella, occipital ring and palpebral lobe the author regards as more characteristic of Strigigenalis.

Strigigenalis brevicaudata and Peltabellia knighti closely resemble each other, the distinguishing difference being the greater degree of segmentation and the short posterior spine of the pygidium of the former. The two species are regarded as being as indirectly related. Evidence from collections made on the north side of Barbace Cove, Port au Choix Peninsula (Boyce, 1983; p. 13) suggests that both species were probably derived from Peltabellia cf. P. willistoni Lochman. Pygidia of this species resemble those of P. knighti with respect to overall size, shape and convexity, and the width and lateral profile of the posterior border. However, like S. brevicaudata, pygidia of this undescribed species have five axial rings and three pleural ribs (P. knighti pygidia have fewer axial rings and only two pleural ribs). Although Peltabellia cf. P. willistoni lacks a posterior spine, certain specimens display postaxial flattening; this is interpreted as the first stage in posterior spine development.

The author concludes that Peltabellia cf. P. willistoni and S. brevicaudata record the direct evolution of Strigigenalis from Peltabellia.

Strigigenalis caudata (Billings, 1865)

(Pl. 15, figs. 5, 6; pl. 16, figs. 1,2)

- 1865 Bathyurus caudatus (n. sp.) - Billings, p. 261, 262; Fig. 245.
- 1925 Goniurus caudatus (Billings) - Raymond, p. 164.
- 1944 Goniotelus semicircularis n. sp. - Cullison, p. 84; pl. XXXV, figs. 25-26.
- 1953 Gen. et sp. ind. (pygidium) - Whittington, p. 670; pl. 68, figs. 30-32.
- 1979a Strigigenalis caudata (Billings) - Fortey, p. 88-90; Fig. 12; pl. 30, figs. 1-10.
- 1983 Strigigenalis caudata (Billings) - Boyce in Stouge and Boyce; pl. 16, fig. 7.

Diagnosis: Glabella anteriorly pointed. Preglabellar field short, down-sloping. Anterior border not acuminate medially. Pygidium with posterior spine relatively long, triangular with median carina on internal mould. Prosopon smooth. Modified from Fortey (1979a, p. 88).

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 83.88 to 88.31(+?) m above the base of the Boat Harbour measured sequence.

Material: Seven (7) cranidia; one (1) librigena; two (2) pygidia.

Holotype: Pygidium, G.S.C. 635 from the Catoche Formation (St. George Group) on Port au Choix Peninsula, western Newfoundland (the original of Billings, 1865; Fig. 245 - by monotypy).

Description: Fortey (1979a, p. 88, 90) has already provided a detailed description of S. caudata which is not repeated here.

Remarks: Goniotelus semicircularis Cullison (1944; pl. XXXV, figs. 25, 26) is synonymized with Strigigenalis gaudata based on the comparable size and shape of 1) the pygidial axial lobes and 2) the posterior spines of the two species.

S. caudata is regarded as the direct sympatric evolutionary descendent of S. brevicaudata for the following reasons:

- 1) The two species strongly resemble each other; the distinguishing difference is the longer posterior spine of S. caudata.
- 2) S. caudata first appears 1.31 m above the last sampled occurrence of S. brevicaudata within the same environment in Bed 39 of Section BHS-6.

Subfamily BATHYURELLINAE Hupe, 1953

Genus Bathyurellus Billings, 1865

Type species: Bathyurellus abruptus Billings, 1865, from the Catoche Formation (St. George Group) on Port au Choix Peninsula and Keppel Island, western Newfoundland (designated by Raymond, 1905, p. 337).

Diagnosis: Cranidium resembles that of Punka Fortey, 1979a but glabella transversely not highly vaulted. Anterior border narrow. Librigenae exsagittally/convex. Lateral border narrow, rim-like. Pygidium with pleural fields hardly furrowed behind anterior segment. Posterior border broad, depressed. Modified from Fortey (1979a, p. 90).

Bathyurellus abruptus Billings, 1865

(not figured)

- 1865 Bathyurellus abruptus (n. gen. n. sp.) - Billings, p. 263, 264; Figs. 247, 250.
- 1905 Bathyurellus abruptus Billings - Raymond, p. 337.
- 1925 Bathyurellus abruptus Billings - Raymond, p. 71-72, 164; pl. 3, fig. 18.
- 1953 Bathyurellus abruptus Billings - Whittington, p. 660; pl. 69, figs. 26, 27.
- 1979a Bathyurellus abruptus Billings - Fortey, p. 92, 94; Fig. 12; pl. 32, figs. 1-12.

1983 Bathyrellus abruptus Billings - Boyce in Stouge and Boyce; pl. 14, figs. 6; pl. 15, figs. 1, 4.

Diagnosis: Prosopon of dense terrace-lines on preoccipital glabella and over most of librigenae. Pygidium with posterior border postaxially broad, concave-upward. Modified from Fortey (1979a, p. 92).

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 10.36 to 14.54 m above the base of Cape Norman measured section.

Material: Three (3) cranidia; one (1) hypostoma; two (2) librigenae; six (6) pygidia.

Lectotype: Pygidium, G.S.C. 648, from the Catoche Formation on Port au Choix Peninsula, western Newfoundland (selected by Whittington, 1953, p. 660).

Description: Fortey (1979a, p. 92, 94) has already provided a detailed description of B. abruptus which is not repeated.

? Genus Grinnellaspis Poulsen, 1948

Type species: Actinopeltis feildeni Poulsen, 1946, from the Cape Weber Formation at Scoresby Bay, Ellesmere Island.

Remarks: The type species Grinnellaspis feildeni (Poulsen), is known only from one pygidium (Poulsen, 1946, p. 324-325; pl. XXII, figs. 8,



9). The author (this study) also recognizes G. newfoundlandensis sp. nov. Based on their prosopon of terrace-lines and the fit of the cranidial and librigenal facial sutures it has been possible to associate cranidia, librigenae, and pygidia of this new species. Based on the new material described below, the generic diagnosis by Rasetti in Moore (1959, p. 0522, 0523; Fig. 412-7) has been revised and expanded.

Diagnosis: Glabella straight- and parallel-sided, anteriorly evenly rounded. Preglabellar area wide. Anterior border wide, strongly concave. Pygidium subelliptical to elliptical, flat. Axial lobe conical, short, composed of up to seven distinct axial rings. Three pairs of pleural ribs distinct, small, highly convex. Posterior border wide, almost flat. Four pairs of interpleural furrows, incomplete; postaxial ridge or furrow developed.

Grippnellaspis newfoundlandensis sp. nov.

(Pl. 16, figs. 3-8)

Diagnosis: Pygidium elliptical. Axial lobe composed of up to three axial rings of posteriorly decreasing distinctiveness. Postaxial furrow, wide, shallow, poorly defined. Prosopon of terrace-lines.

Derivation of name: For the province of Newfoundland where this species was discovered.

Stratigraphic range: Upper member of the Boat Harbour Formation, 71.80 to 80.98 (to possibly 81.29) m above the base of the Boat Harbour measured sequence.

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Material: Five (5) cranidia (incomplete); three (3) librigenae; eight (8) pygidia.

Holotype: Pygidium, NFM F-170, from BH-60 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-166 from BH-60; librigena, NFM F-167 from BH-60; pygidium, NFM F-168 from BH-40; pygidium, NFM F-169 from BH-49; pygidium, NFM F-171 from BH-69; all in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella transversely broadly vaulted, straight- and parallel-sided, anteriorly evenly rounded; it extends about five-sevenths total cranidial length. Occipital ring incompletely preserved but well defined, extends one-seventh total cranidial length. Preglabellar, axial and occipital furrows distinct, narrow, deep. Lateral glabellar furrows not developed. Preglabellar field wide, about one-seventh total cranidial length, anteriorly downsloping. Anterior border furrow indistinct. Anterior border wide about one-seventh total cranidial length - of constant width, strongly concave, in anterior view straight. Anterior fixigenal areas wide, anteriorly downsloping.

Anterior portions of facial suture display strongly convex-outward profile. Palpebral fixigenal areas wider than anterior fixigenal areas by about 1.5x, abaxially horizontal to gently upsloping, sagittally anteriorly gently downsloping. Palpebral lobes large, semicircular, long - exsagittal length about three-fifths total sagittal glabellar length. Palpebral furrow not developed. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas not preserved. Prosopon consists of terrace-lines on occipital ring. Prosopon not preserved on remainder of cranium.

Hypostoma not known.

Librigenae long, broadly triangular, strongly convex. Lateral border strongly concave, abaxially tapering. Prosopon smooth except for genal spine, where it consists of terrace-lines perpendicular to the lateral margin.

Thorax not known.

Pygidium elliptical, length about three-quarters maximum width. Axial lobe transversely broadly arched, straight-sided, posteriorly tapering and abruptly rounded; it extends about one-half total pygidial length. As many as three axial rings of posteriorly decreasing distinctiveness. Axial furrows distinct, narrow, deep. Pleural fields small, triangular, strongly convex in comparison to posterior border. Three pairs of pleural ribs. Three pairs of pleural furrows distinct, narrow,

deep, extend only to posterior border furrow. Posterior border furrow indistinct, wide, shallow. Posterior border wide, at least one-half total pygidial length, flat to weakly convex and posteriorly gently downsloping. Four pairs of interpleural furrows distinct, wide, shallow, incomplete - extend only from posterior border furrow to posterior margin. Postaxial furrow less distinct, wider; it extends from axis to posterior margin. Prosopon consists of terrace-lines parallel to posterior margin.

Remarks: The small number of axial rings and the development of a postaxial furrow rather than a ridge readily distinguishes G. newfoundlandensis from G. feildeni.

Grinnellaspis and Punka (Fortey, 1979a; pl. 33, figs. 1-10; pl. 35, figs. 12, 14, 15) share the following morphological features:

1. Anterior borders wide, concave.
2. Glabellas straight- and parallel-sided, anteriorly evenly rounded.
3. Palpebral lobes large, semicircular.
4. Librigenae long, broadly triangular; lateral border concave, abaxially tapering.
5. Pygidia subelliptical to elliptical.

6. Pygidial axial lobes short, straight-sided.
7. Pygidial pleural fields small, convex.
8. Posterior borders wide, flat.
9. Pleural and interpleural furrows incomplete.
10. Prosopons of terrace-lines.

On the basis of the above morphological similarities and the fact that Punka species stratigraphically succeed Grinnellaspis species in western Newfoundland, the author suggests that Punka evolved directly from Grinnellaspis. The following morphological changes are observed.

1. Glabella increases in length.
2. Librigenae become longer and narrower.
3. Maximum number of axial rings in the pygidium decreases from seven to five.
4. Pygidial pleural fields become less convex and the pleural ribs less distinct from the posterior border.
5. The postaxial ridge/furrow disappears.

The pygidia of Punka? sp. indet. of Fortey (1979a, p. 91; pl. 35, figs. 12, 14, 15) illustrates the last three changes above, while it retains the shape of G. newfoundlandensis. This species occurs stratigraphically between G. newfoundlandensis and P. flabelliformis at Eddies Cove West.

Genus Uromystrum Whittington, 1953

Type species: Bathyrellus validus Billings, 1865, from the Table Point Formation (Table Point Group) at Pointe Riche, western Newfoundland (designated by Whittington; 1953).

Diagnosis: See Whittington in Moore (1959, p. 0380).

Uromystrum affine (Poulsen, 1937)

(Pl. 17, figs. 1-4)

1937 - Bathyrellus affinis n. sp. - Poulsen, p. 55; pl. 7, figs. 6, 7.

1983 - Uromystrum affine (Poulsen) - Boyce in Stouge and Boyce; pl. 14, figs. 4, 5; pl. 15, fig. 3.

Diagnosis: Glabella weakly defined. Occipital ring not developed.

\ Pygidial axial lobe effaced. Posterior border wide, concave-upward.

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 86.76 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Two (2) cranidia; six (6) librigenae; eleven (11) pygidia.

Holotype: Pygidium, G.M. 3705, from the Cape Weber Formation on Ella Island in central East Greenland (the original of Poulsen, 1937; pl. 7, fig. 7 - by monotypy).

Paratypes: Cranidium, NFM F-95 from BH-101/BH-110; librigena, NFM F-104 from BH-101/BH-110; pygidium, NFM F-96 from BH-103; all in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Cranidium highly effaced, strongly convex. Glabella weakly convex, transversely broadly arched slightly above level of palpebral fixigenae, straight- and parallel-sided. Axial furrows almost indistinct, narrow, shallow, disappear at point along line jointing divergence points of anterior branches of facial suture. Preglabellar and occipital furrows not developed. Lateral glabellar furrows not developed. Anterior fixigenal areas and preglabellar field wide, convex, anteriorly steeply downsloping. Anterior border transversely long, sagittally wide, broadly convex-forward, gently concave-upward, smooth, abaxially gently tapering; defined by distinct, abrupt broadly convex-forward change in slope. Anterior branches of facial sutures strongly divergent. Palpebral fixigenal areas abaxially and sagittally steeply downsloping. Palpebral lobes not preserved. Posterior fixigenal



areas apparently very small, posteriorly steeply downslping. Posterior  
der furrows not developed. Prosopon smooth.

Hypostoma unknown.

Librigena with genal field strongly convex, extending directly  
backward into long, equally convex genal spine. Lateral border poorly  
defined, wide, gently concave-upward, abaxially disappears rapidly.  
Posterior border not developed. Prosopon smooth.

Thorax unknown.

Pygidium weakly convex, almost flat, semicircular, length about  
one-half maximum width -at posterior end of articulating facets.  
Anterior margin straight. Articulating half-ring sagittally narrow,  
almost nonexistent. Articulating facets sagittally narrow, parallel to  
anterior margin. Axial lobe almost indistinct, slightly concave-sided,  
posteriorly tapering and abruptly rounded. Axial furrows faint, almost  
nonexistent. Pleural field narrow, subtriangular displays obscure  
furrows. Posterior border wide, concave-upward - of nearly constant  
width, postaxially slightly wider than at anterior margin. Prosopon  
smooth.

Discussion: The wide, concave-upward pygidial border of U. affine  
readily distinguishes it from U. forteyi sp. nov. which, more than any  
other Uromystrum species, it most closely resembles.



Uromystrum forteyi sp. nov.

(Pl. 17, fig. 5)

Diagnosis: Pygidial axial lobe distinct. Posterior border narrow, concave-upward.

Derivation of name: For Dr. R.A. Fortey (British Museum) who originally collected the species.

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 15.09 m above the base of the Cape Norman measured section.

Material: One (1) pygidium.

Holotype: Pygidium, G.S.C. 56864, from the Catoche Formation on Port au Choix Peninsula, western Newfoundland (the original of Fortey, 1979a; pl. 37, fig. 10 - designated herein).

Paratype: Pygidium, NFM F-172 from CN-16 in the lower limestone sequence of the Catoche Formation at Cape Norman, western Newfoundland (designated herein).

Description: Cranidium, hypostoma, librigenae and thorax unknown.

Pygidium semicircular, length about one-half width. Axial lobe and pleural region effaced, but axial lobe quite distinct for Uromystrum.

Posterior border narrow - of even width, concave-upward. Less effaced individuals display the following features (see Fortey, 1979a, pl. 37, fig. 10).

- 1) Articulating half-ring almost nonexistent, sagittally narrow.
- 2) Articulating facets sagittally narrow, parallel to anterior pygidial margin.
- 3) Axial lobe almost indistinct slightly concave-sided, posteriorly tapering and abruptly rounded. Axial furrows faint; two anterior axial rings weakly defined.
- 4) One pair of furrows, faint, incomplete, in the median portion of the anterior pleural field.

The posterior border is more well defined and appears to exhibit a greater degree of concavity in the smaller, less effaced individuals.

Discussion: Fortey (1979a, p. 99, 100) has already pointed out the differences between U. forteyi and U. affine which the former more than any other Uromystrum species most closely resembles. At that time because the cranidia and librigenae of neither species were known he believed there was insufficient evidence to diagnose a new species from Newfoundland. The author has been able to consistently recognize both species' pygidia outside Fortey's original study area.

In the Boat Harbour - Cape Norman region U. forteyi appears stratigraphically later than U. affine and because of the similarity of the two species pygidia, is regarded as its direct evolutionary descendent.

Family LECANOPYGIDAE Lochman, 1953

Genus Benthamaspis Poulsen, 1946

Type species: Benthamaspis problematica Poulsen, 1946, from the Nunatami Formation(?) at Cape Steven, Ellesmere Island.

Diagnosis: Glabella straight- and parallel-sided to anteriorly gently tapering and broadly rounded. Palpebral lobes long, thin, crescentic. Cranidial prosopon of convex-forward terrace lines. Pygidium with axial lobe small, straight-sided, posteriorly tapering and abruptly rounded to truncated. Pygidial prosopon consists of convex-forward terrace lines on axial lobe and concave-forward terrace lines on pleural field.

Benthamaspis conica Fortey, 1979a

(not figured)

1960 "New genus related to Strigigenalis and Benthamaspis" - Berry;  
pl. 7, figs. 1, 3.

1966 ?Oculomagnus obreptus n. gen. n. sp. (in part) - Lochman, p. 541-542; pl. 62, figs. 1, 2, 4 only.

1979a Benthamaspis conica sp. nov. - Fortey, p. 102, 104; pl. 35, figs. 1-10.

Diagnosis: Preglabellar furrow defined. Occipital furrow extends almost to axial furrow (Fortey, 1979a, p. 102).

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 15.41 to 15.54 m above the base of the Cape Norman measured section.

Material: Two (2) pygidia.

Holotype: Cranidium, G.S.C. 56873, from the Catoche Formation (St. George Group) on Port au Choix Peninsula, western Newfoundland (the original of Fortey, 1979a; pl. 35, figs. 1, 3, 10, - by monotypy).

Description: Fortey (1979a) has already provided a detailed description of B. conica which is not repeated.

Benthamaspis hintzei sp. nov.

(Pl. 17, figs. 6-8; pl. 18, figs. 1-3)

1953 Undetermined gen. and sp. B - Hintze, p. 242; pl. XIII, fig. 17 only.

1953 Unassigned pygidium - Hintze, pl. XV, figs. 18a,b.

Diagnosis: Pygidium with five axial rings (including terminal ring) visible on internal mould. Pleural and interpleural furrows faint.

Derivation of name: For Dr. L.F. Hintze (Brigham Young University) who originally illustrated the species.

Stratigraphic range: Upper member of the Boat Harbour Formation and lower limestone sequence of the Catoche Formation, 80.82 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Three (3) cranidia; three (3) pygidia.

Holotype: Pygidium, NFM F-175 from BH-110 in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-173 from BH-101/BH-110; pygidium, NFM F-174 from BH-112; both in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein). Pygidium, NFM F-176 from BH-62 in the upper member of the Boat Harbour Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Glabella highly convex, transversely strongly vaulted, straight-sided, anteriorly gently tapering and broadly rounded to slightly truncated. Occipital ring sagittally wide, subrectangular.

Preglabellar, axial and occipital furrows distinct, narrow, shallow. Preglabellar and anterior fixigenal areas not preserved. Palpebral fixigenal areas wide, convex, anteriorly and abaxially steeply down-sloping. Palpebral lobes poorly defined, long - exsagittal length about two-thirds sagittal glabellar length, narrow, broadly crescentic. Palpebral furrows indistinct. Line through centers of palpebral lobes crosses glabellar sagittal line at about one-half glabellar length from posterior edge of occipital ring. Posterior fixigenal areas small, convex. Posterior border furrow distinct, narrow, shallow. Posterior border short, weakly convex. Glabellar prosopon consists of fine, dense, convex-forward terrace-lines. Fixigenal prosopon smooth.

Hypostoma, librigenae and thorax unknown.

Pygidium convex, semielliptical, length about three-quarters maximum width at posterior end of articulating facets. Axial lobe transversely strongly arched, posteriorly tapering and abruptly rounded to pointed; it extends one-half to two-thirds total pygidial length. Five axial rings (including terminal ring) of approximately equal sagittal width are observed on internal mould; these are only faintly reflected on external mould. Postaxial area and pleural fields wide, evenly convex, steeply down-sloping. Anterior pair of pleural furrows distinct. Anterior pair of interpleural furrows less distinct. Additional pairs of fainter, incomplete pleural and interpleural furrows are also developed. Posterior border not developed. Doublure of constant width, about one-half total pygidial length, parallel to posterior margin; inner dorsal surface flat to concave, steeply down-sloping. Pygidial

prosopon of fine, dense, convex-forward terrace lines on axial lobe and concave-forward terrace lines parallel to posterior margin on postaxial area, pleural fields and doublure.

Discussion: The pygidium illustrated by Hintze (1953; pl. XV, figs. 18a,b) has slightly better defined axial rings than the Newfoundland specimens but agrees closely in most other respects. the cranidium illustrated by Hintze (1953; pl. XIII, fig. 17 only) is assigned to B. hintzei because it has a similarly shaped glabella and a well defined occipital ring.

Superfamily PROETACEA Säger, 1864

Family DIMEROPYGIDAE Hupe, 1953

Genus Ischyrotoma Raymond, 1925

Type species: Ischyrotoma twenhofeli Raymond, 1925 from the Cow Head Group at Lower Head, western Newfoundland.

Ischyrotoma anataphra Fortey, 1979a

(Pl. 18, fig. 4)

1979a Ischyrotoma anataphra sp. nov. - Fortey, p. 104, 106; pl. 36, figs. 1-13.

Diagnosis: Glabella anteriorly slightly tapering. Preglabellar field sagittally short. Anterior border indistinctly defined. Prosopon of coarse tubercles on stratigraphically early forms; on stratigraphically later forms tuberculation less pronounced, especially on librigenae. Genal spines small. Modified from Fortey (1979a, p. 104).

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 2.41 to 13.50 m above the base of the Cape Norman measured section.

Material: Seven (7) cephalons; two (2) librigenae; one (1) pygidium.

Holotype: Cephalon, G.S.C. 56879, from the Catoche Formation on Port au Choix Peninsula, western Newfoundland (the original of Fortey, 1979a; pl. 36, figs. 1, 6 - by monotypy).

Description: Fortey (1979a, p. 104, 106) has already provided a detailed description of I. anataphra which is not repeated.

Ischyrotoma parallela sp. nov.

(Pl. 18, figs. 5-8)

1983 Ischyrotoma sp. - Boyce in Stouge and Boyce; pl. 13, fig. 3.

Diagnosis: Glabella straight- and parallel-sided, strongly forward-protruding. Anterior border furrow distinct. Anterior border transversely long, narrow, convex, in anterior view straight. Prosopon of coarse tubercles.



Derivation of name: parallelus (Latin), parallel, referring to the sides of the glabella (feminine).

Stratigraphic range: Lower limestone sequence of the Catoche Formation, 88.24 to 93.60 m above the base of the Boat Harbour measured sequence.

Material: Eleven (11) cephalons; three (3) librigenae.

Holotype: Cranidium, NFM F-178 from BH-101/BH-110 in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Paratypes: Cranidium, NFM F-86 from BH-100; cranidium, NFM F-179 from BH-112; both in the lower limestone sequence of the Catoche Formation at Boat Harbour, western Newfoundland (designated herein).

Description: Cephalon highly convex with broad anterior arch. Librigenae attached almost vertically to cranidium. Glabella highly convex, transversely strongly vaulted, straight- and parallel-sided, subrectangular, anteriorly gently rounded, forward protruding; it overhangs anterior border. Forward glabellar outline semicircular. Occipital ring sagittally narrow, rectangular. Preglabellar, occipital and axial furrows well defined, deep; occipital furrow wider than preglabellar and axial furrows. Two pairs of indistinct, anteriorly directed lateral glabellar furrows occur on the sides of the glabella at about mid-length of cephalon. Preglabellar field narrow, vertical, convex. Anterior border furrow distinct. Anterior border transversely

long, narrow, convex, in anterior view straight. Posterior fixigenal areas triangular, about four-fifths transverse width of occipital ring. Posterior border furrows well defined, deep. Posterior border narrow, convex. Anterior portions of facial suture converge slightly in front of eyes, strongly so in front of anterior border; posterior portions diverge at an angle of about 53 degrees. Librigenae with lateral border furrows well developed. Genal spines if present, not preserved. Eyes convex, placed at about cephalic mid-length. Prosopon of coarse tubercles except for anterior and lateral borders. Tuberculation reflected on internal moulds.

Hypostoma, thorax and pygidium unknown.

Remarks: I. parallela most closely resembles the stratigraphically early forms of I. anataphra Fortey (1979a; pl. 36, figs. 2-4, 7, 10, 12). The strongly forward-protruding, straight- and parallel-sided glabella and the well defined anterior border of I. parallela, however, readily distinguish the two species. The stratigraphically early forms of I. anataphra are viewed as intermediate forms on a direct evolutionary line between I. parallela and the stratigraphically late forms of I. anataphra. Ischyrotoma parallela differs from the (younger) type species I. twenhofeli Raymond (Whittington, 1963; pl. 7, figs. 1-13) in that the glabella is straight- and parallel-sided; the preglabellar field is slightly larger and the anterior border appears straight, rather than transversely arched, in anterior view.

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APPENDIX A

MEASURED STRATIGRAPHIC SECTIONS - BOAT HARBOUR

Seven sections were measured along the shore northeast of Boat Harbour. The base of the measured sequence is a 1.48 m bed containing distinctive chert-rimmed algal mounds which forms the base of the upper member of the Boat Harbour Formation (Knight, 1980b; Stouge, 1981). This bed is located in the village of Boat Harbour on the southern shore of the cove south of Boat Head. The top of the measured sequence is situated about 3.5 km northeast of the village at the top of a 15 m+ cliff landward of a wave-cut platform. The cumulative thickness of the measured sequence is about 94 m.

SECTION BHS-1: ASCENDING SECTION TO NORTHEAST FROM BOAT HARBOUR

Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
<u>St. George Group</u>			
<u>Boat Harbour Formation</u>			
<u>upper member</u>			
1	Lime mudstone and wackestone (dolomitic?), light gray (when fresh). Top 18 cm of bed consists of stromatolite mounds which are circular, distinctly laminated, composed of dolomite and rimmed by chert. Mounds are separate entities in early stages, later are linked. Silicified (chert) mound seen formed in the depression between the dolomitic mounds although most commonly chert forms ridges separating dolomitic mounds.	1.48	1.48
2	Cherty dolostone or dolomitic chert, dark gray weathering, draped over underlying mounds; preserves thin, irregular, wispy laminations. Vugs of prismatic quartz.	0.12(av.) 0.10-0.14	1.60
3	Dolostone, dark gray, white or very light gray weathering; thin, irregular, wispy algal lamination.	0.08	1.68
4	Dolomitic lime mudstone and wackestone, light blue-gray weathering, planar bedded, flaser and cross-laminated; extremely thin, buff, dolomitic laminae. A scour/channel of intraclastic blue-gray packstone and	0.37	2.05

grainstone occurs at the top of the bed and erodes down 1.2 cm into the highly laminated portion. The intra-clasts are subangular to subrounded and up to 2 cm in diameter. The scour/channel is about 100 cm wide. Adjacent to it is another scour/channel 4-5 cm thick and greater than 300 cm in lateral extent.

- |   |  |                        |      |
|---|--|------------------------|------|
| 5 | Dolomitic lime mudstone and wackestone, light blue-gray, thin and irregularly bedded, sparsely bioturbated. Fossil trails buff, dolomitized. Erosive base cuts down as much as 10 cm into underlying bed. <u>Hystriocurus oculilunatus</u> and planispiral gastropods collected 26 cm above base of bed (BH-1). Planispiral gastropods also collected 81-106 cm above base (BH-2).   | 1.06                   | 3.11 |
| 6 | Lime mudstone and wackestone, light blue-gray, thinner, less irregularly, more planar bedded; thin, buff weathering dolomitic laminae.   | 0.43                   | 3.54 |
| 7 | Dolomite packstone and grainstone, buff weathering, highly laminated and cross-laminated; occasional flasers of blue-gray lime mudstone and wackestone.  | 0.15(av.)<br>0.10-0.20 | 3.69 |
| 8 | Lime boundstone, stromatolitic and thrombolitic, blue-gray, rubbly weathering, massive. Mounds contain abundant buff weathering, irregular, wispy dolomitic laminae and quartz-lined vugs. Internal laminations in mounds suggest they are stromatolitic. Basal laminations are of LLH type; these change upward into SH-C and SH-V. Mound surfaces are irregularly pitted; the surface of the mound interfill is flat and smooth. Mound interfill consists of blue-gray lime mudstone and wackestone and buff dolomite packstone and grainstone which is thin and flaser-bedded rather than massive and rubbly weathering. Interfill extends to top of bed and caps smaller mounds. Interfill laminations turned up at mound edges. Orientation of interfill channels 314, 318. | 0.75                   | 4.44 |

Planispiral gastropods collected from mound interfill 6-10 cm above base of bed (BH-3).

- |   |  |      |      |
|---|--|------|------|
| 9 | Dolomitic lime mudstone and wackestone, dark gray, massive, extensively bioturbated-burrows dolomitized, more resistant to weathering. | 0.98 | 5.42 |
|---|--|------|------|

Planispiral gastropods collected from bed (BH-4).

- |    |   |      |      |
|----|---|------|------|
| 10 | Lime boundstone, stromatolitic and thrombolitic, gray weathering, massive. Basal 20 cm contains SH-C and SH-V lamination but rest of bed is structureless. Mounds are circular to irregular in shape, up to 100 cm in diameter and, except for weather pitting, have featureless top surfaces. Mound interfill consists of planar interbeds of coarse grained blue-gray lime packstone and grainstone, buff dolomite packstone and grainstone and dark gray dolomitic lime mudstone and wackestone. The darker color and buff dolomitic matrix of the mound interfill helps outline the mounds. | 1.31 | 6.73 |
|----|---|------|------|

Planispiral gastropods collected 36 cm above base of bed (BH-5). Curved (cyrtoconic) cephalopod as well as planispiral gastropods seen at top of bed (BH-6).

- |    |   |      |      |
|----|---|------|------|
| 11 | Dolomitic lime mudstone and wackestone, dark buff weathering, massive, internally thin bedded, extensively bioturbated-burrows, trails dolomitized. | 1.19 | 7.92 |
|----|---|------|------|

Planispiral gastropods collected near top of bed (BH-7).

- |    |   |      |      |
|----|---|------|------|
| 12 | Dolomitic lime mudstone and wackestone, dark gray, thin bedded, less extensively bioturbated-burrows, trails dolomitized. | 0.58 | 8.50 |
|----|---|------|------|

Planispiral gastropods collected near middle of bed (BH-8).

13

Basal 34 cm of bed consists of lime and dolomite boundstone, thrombolitic. Mounds are isolated, circular, up to 200 cm in diameter and up to 34 cm thick. Centers of mounds are generally elevated 18 cm above edges. Mounds cored by dark blue-gray dolomitic limestone and rimmed by buff weathering - vuggy pseudo-brecciated diagenetic dolostone; vugs contain rhombic dolomite, pseudo-breccia veins contain cryptocrystalline dolomite and purple fluorite. Mounds are replaced by massive, buff, diagenetic dolostone to NE.

2.07

10.57

Middle 55 cm of bed consists of well laminated and interbedded light blue-gray lime mudstone and wackestone and buff dolomite packstone and grainstone. Bottom 30 cm is massive, well laminated, buff dolomite packstone and grainstone; top 25 cm is mostly thin bedded, light blue-gray lime mudstone and wackestone with abundant thin, buff dolomite packstone and grainstone laminae. Bed of constant thickness, drapes over and follows contours of underlying mounds. Consequently, top of bed in one spot may be 18 cm above top close by.

Upper 118 cm of bed consists of lime boundstone, stromatolitic and thrombolitic, darker blue-gray, rubbly weathering, massive, internally thinly and wispily laminated. Mound interfill consists of lime mudstone, wackestone, packstone and grainstone, blue-gray, thin bedded, with more buff dolomitic laminae than present in mounds. A thin 1 cm layer of buff dolostone was seen between two mounds. An intraclastic packstone/grainstone dike(?) was seen penetrating 40 cm into the unit. Topographic imperfections even out progressively towards top of bed.

Hillyardina minuspustulata, Randaynia saundersi, the clarkellid brachiopod Diaphelasma and planispiral gastropods collected 134 to 187 cm above

base of bed (BH-9), Hillyardina minuspustulata, Randaynia saundersi, echinoderm fragments and planispiral gastropods collected from top of bed, cryptoconic cephalopod (?Bassleroceras) also seen (BH-10).

14	Lime mudstone and packstone (dolomitic?) dark blue-gray, light blue-gray weathering, thin bedded, well laminated; planar and irregular, buff dolomitic laminae. Thin layers of intraclastic (flat-pebble) packstone and grainstone also occur in bed; clasts are flat, subangular to subrounded, up to 3 cm in diameter, and lie flat, scattered over bedding plane surfaces.  Planispiral gastropods collected approximately 130 cm above base of bed (BH-11).	1.48	12.05
15	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, massive; buff dolomitic laminae.	0.27	12.32
16	Lime mudstone and wackestone (dolomitic?), massive, internally thinly laminated, bioturbated; laminae, burrows buff, dolomitized.	1.77	14.09
17	Lime mudstone and wackestone, blue-gray, massive, extensively bioturbated-burrows buff, dolomitized.	0.43	14.52
18	Dolomitic lime/limy dolomite mudstone and wackestone, dark gray, medium gray weathering, massive, internally thin and irregularly bedded; irregular, buff dolomitic laminae; sparsely bioturbated-burrows, trails buff to dark brown, dolomitized.	1.30	15.82
19	Lime mudstone and wackestone (dolomitic?), blue-gray weathering, massive, internally thin and irregularly bedded; thin, irregular, buff weathering dolomitic laminae; sparsely bioturbated-burrows, trails buff, dolomitized.	0.77	16.59



20	Dolomitic lime mudstone and wackestone to packstone and grainstone, blue-gray, more planar, thin bedded; buff dolomitized laminae, abundant dolomitized trails on bedding surfaces. Basal 10 cm consists of dolomite packstone and grainstone, buff to blue, cross-laminated.	0.40	16.99
21	Lime mudstone and wackestone to packstone and grainstone, blue-gray, thin and irregularly bedded; buff weathering dolomitic laminae; sparsely bioturbated (mostly horizontal bioturbation); symmetrical and interference ripple marks in upper part of bed. Bimodal ripple marks - 266, 308, 325, 326, 328, 352, 004.	0.77	17.76
22	Lime mudstone and wackestone, blue-gray, massive, internally thin bedded, bioturbated horizontally and vertically-burrows, trails buff, dolomitized. Beds of lime packstone and grainstone seen, well cross-laminated, bioturbated, very fine grained.  Planispiral gastropods seen in bioturbated beds. <u>Hystricurus oculilunatus</u> and planispiral gastropods collected 32 to 42 cm above base of bed (BH-12).	1.13	18.89
23	Dolomitic lime mudstone and wackestone to packstone and grainstone, dark gray, light blue-gray weathering, thin and irregularly bedded, sparsely bioturbated, vuggy - vugs buff, quartz- or chert-lined.  <u>Hystricurus oculilunatus</u> , <u>Hillyardina minuspustulata</u> , echinoderm fragments and planispiral gastropods collected 24 cm above base of unit (BH-13).	1.19	20.08

TOP OF SECTION BHS-1

20.08

Note:

Between Sections BHS-1 and BHS-2, there are two covered intervals with some intervening unfossiliferous pseudobreccia beds generally exposed only at low tide. The author has accepted Knight's (1977b, Fig. 6) thickness values for these intervals.

Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
TO TOP OF SECTION BHS-1			20.08
	Cover	5.00	25.08
	Dolomite boundstone, buff weathering, diagenetic pseudobreccia mounds.	2.88	27.96
	Cover	4.23	32.19

SECTION BHS-2: ASCENDING SECTION TO NORTHEAST

Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
TO BASE OF SECTION BHS-2			32.19
1	Lime mudstone and wackestone, dark gray (when wet), massive, extensively bioturbated-ramifying network of buff, dolomitic burrows cuts matrix.	2.20+	34.39
2	Lime mudstone and wackestone, blue-gray, thin and planar bedded; thin beds or laminae of buff, dolomitic material.	0.61	35.00
3	Lime mudstone and wackestone, blue-gray, massive; buff, dolomitic burrows. Top of bed slightly irregular due to presence of lime boundstone mounds, 50 to 80 cm in diameter, elevated 15 cm above rest of bed. Top of mounds taken as top of bed.  Planispiral gastropods collected 30 to 67 cm above base of bed; cephalopod (? <i>Bassleroceras</i> ) seen in a vertical orientation 39 cm above base also collected (BH-14).	0.67	35.67
4	Lime mudstone and wackestone, blue-gray, thin bedded, sparsely bioturbated although local patches of abundant organic traces occur on bedding plane surfaces; burrows, trails buff, dolomitic.  High-spired gastropods seen and planispiral gastropods and partly silicified cephalopod collected 54 cm	1.96	37.63

above base of bed (BH-15). Hystri-  
curus oculilunatus, Diaphelasma,  
echinoderm fragments and planispiral  
gastropods collected 82 to 115 cm  
above base (BH-16). High-spired  
gastropods seen 80 to 85 cm above  
base.

- 5 Dolostone, buff. Bioturbation evident near planar base. Top undulose, laminated, contains flasers of lime mudstone and wackestone, blue-gray. 0.22(av.) 37.85  
0.16-0.27

Planispiral gastropods collected from top of bed (BH-17).

- 6 Lime boundstone, stromatolitic, dark blue-gray, rubbly weathering, massive. Huge mounds, up to 300 cm diameter and averaging 120 cm in thickness. Two mound horizons. Lower mounds developed on topographic highs of underlying bed and highs formed of stacked up edgewise flat pebble-conglomerate (intraclastic packstone and grainstone); they are built up by colloform digitate stromatolites and outlined by occasional layers of black chert. On top of lower mounds circular rings of black chert 60 cm in diameter suggest that the large mounds are formed by smaller coalesced mounds. Lower mound interfill alternating blue-gray lime mudstone, and wackestone, packstone and grainstone and buff dolomitic material, thin bedded, planar laminated; chert also occurs in narrowest gaps between mounds. Upper mounds developed in depressions between lower mounds; they are built up by digitate stromatolites and also contain orange chert. Upper mound complexes isolated, distance between any two varying from 15 to 200 cm. Upper mound interfill lime mudstone, wackestone, packstone and grainstone, well bioturbated in wide intermound areas, vuggy (vugs lined by sparry calcite), and particularly fossiliferous. 2.09 39.94

Randaynia saundersi, Hystri-  
pseudoculilunatus, Parahystri-  
smithiae, Hillyardina levis,

Diaphelasma, cephalopods, and planispiral gastropods collected from mound interfill 109 to 159 cm above base of bed (BH-18). Randaynia saundersi, Hystricurus pseudoculilunatus, Hillyardina lewis, cephalopods, and planispiral gastropods collected 189 to 209 cm above base (BH-19).

7	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, thin, and irregularly bedded; thin, irregular, buff weathering dolomitic laminae; sparsely bioturbated - horizontal trails buff weathering, dolomitic. Planar top.	0.95	40.89
	High-spired and planispiral gastropods collected, one straight cephalopod seen 20 cm below top of bed (BH-20).		
	Cover	0.60	41.49
8	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, planar base and top, internally thin and irregularly bedded; thin, irregular, buff weathering dolomitic laminae.	0.30	4.79
	Cover	7.70	49.49
9	See description for Bed 12 of Section BHS-3	0.50(av.) 0.30-0.70	49.99
	TOP OF SECTION BHS-2		49.99

Note:

Sections BHS-2 and BHS-3 are apparently in normal fault contact, with the beds of BHS-3 (on the northwestern side of the fault) downthrown with respect to the beds of BHS-2. Both sides of the fault were examined in detail in order to find matching beds. Bed 9 of BHS-2 and Bed 12 of BHS-3 were found to be of essentially the same lithology and were, therefore, assumed to be the same bed. In addition, the top of Bed 9 of BHS-2 was assumed to be equivalent stratigraphically to the top of Bed 12 of BHS-3.

The largely covered interval between the tops of Beds 7 and 9 of BHS-2 was also measured and compared with the cumulative thickness of Beds 1-12 of BHS-3. This was done to check if Beds 1-12 of BHS-3 could be accommodated between Beds 7 and 9 of BHS-2, as would be expected.

This was found to be the case. The covered interval between the tops of Beds 7 and 9 of BHS-2 was calculated to be 9.10 m, while the cumulative thickness of Beds 1-12 of BHS-3 was measured as 7.32 m. This leaves a covered interval of only 1.78 m between Sections BHS-2 and BHS-3.

For the following Section BHS-3, the top of Bed 12 is assumed to be 49.99 m above the base of the measured Boat Harbour sequence (i.e. stratigraphically equivalent to the top of Bed 9 of BHS-2, as stated above).

SECTION BHS-3: ASCENDING SECTION TO NORTHEAST

Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
TO BASE OF SECTION BHS-3			42.67
1	Lime mudstone and wackestone, dark gray, massive, internally thin and irregularly bedded; thin, irregular, buff dolomitic laminae.  Planispiral gastropods collected from top of bed (BH-21).	1.00+	43.67
2	Dolomite mudstone and wackestone, light gray, massive, planar bedded, very thinly laminated.	0.28	43.95
3	Lime mudstone and wackestone, blue-gray, thin and planar bedded; thin, planar, buff dolomitic laminae become less regular towards top of bed, some thin dolomitic interbeds at base.	0.46	44.41
4	Lime mudstone and wackestone, blue-gray, massive, internally thin and irregularly bedded; thin, irregular, buff dolomitic laminae; abundant bioturbation-burrows, trails buff, dolomitized. Top of bed gently undulating.  <u>Randaynia saundersi</u> , <u>Hystericurus pseudoculilunatus</u> , <u>Parahystericurus smithiae</u> , <u>Diaphelasma</u> , orthid brachiopods, cephalopods, and planispiral gastropods collected 65 to 118 cm above base of bed (BH-22).	1.18	45.59
5	Lime mudstone and wackestone, blue-gray, thin bedded; thin, buff dolomitic laminae, abundant bioturbation-burrows, trails buff, dolomi-	0.24(av.) 0.22-0.27	45.83

tized. Bottom of bed slightly undulating. Top of bed depressed by overlying bed.

Fossils collected as in underlying bed (BH-23).

- |    |   |                        |       |
|----|---|------------------------|-------|
| 6  | Lime boundstone, stromatolitic. Mounds circular, up to 50 cm in diameter, 42 cm maximum thickness pustular looking in plan view, built up by colloform columnar (SH-C) stromatolites, internally well laminated. Larger mound complexes up to 100 cm in diameter composed of 15 to 30 cm diameter coalesced mounds. Distance between mound complexes up to 150 cm. Mounds/mound complexes developed in depressions of underlying bed. Mound/mound complex interfill blue-gray lime mudstone and wackestone and buff dolomitic material, thin and flaser-bedded. | 0.42                   | 46.25 |
| 7  | Lime mudstone and wackestone, blue-gray, thin and irregularly bedded; thin, irregular, buff dolomitic laminae; extensively bioturbated-burrows, trails on bedding plane surfaces, buff dolomitized. Planar top.   | 0.22                   | 46.47 |
| 8  | Lime mudstone and wackestone, rubbly weathering, massive, sparsely bioturbated.<br><br><u>Randaynia saundersi</u> , <u>Hystricurus pseudoculilunatus</u> , <u>Hillyardina levis</u> , cephalopods, and planispiral gastropods collected 18 to 63 cm above base of bed; <u>Paraplethopeltis seelyi</u> collected from top of bed only (BH-24).   | 0.63                   | 47.10 |
| 9  | Lime mudstone and wackestone. Base of bed essentially planar; top undulose, possibly stromatolitic.<br><br>Planispiral gastropods collected from bed (BH-25).   | 0.22(av.)<br>0.20-0.25 | 47.32 |
| 10 | Lime packstone and grainstone, blue-gray, thin, irregular and lenticular bedded; thin, interbedded buff dolomitic layers and laminae; extensively   | 0.62                   | 47.94 |

	bioturbated-burrows, trails buff dolomitized. Thickness measured over mounds of underlying bed.		
11	Dolomite mudstone and wackestone, buff weathering, thin and irregularly bedded, extensively bioturbated. Top undulose, mound-like.	0.52(av.) 0.24-0.80	48.46
12	Lime boundstone, stromatolitic and thrombolitic, dark blue-gray, rubbly weathering, massive. Mounds large, built up by digitate stromatolites and thrombolites; beef-calcite structures seen. Mounds fossiliferous, although fossils small, hard to find. Mound interfill blue-gray lime mudstone, wackestone, packstone and grainstone and buff dolomitic material, thinly interbedded, locally extensively bioturbated. Top of bed extensively bioturbated.	1.53(av.) 1.81-1.25	49.99
	<u>Randaynia saundersi</u> , <u>Hillyardina levis</u> , and orthid brachiopods collected; cross-section of large straight cephalopod seen 75 to 50 cm below top of bed (BH-26). Cephalopods and planispiral gastropods (some pyrite-filled) collected from top of bed (BH-27).		
13	Lime mudstone and wackestone, thin and irregularly bedded; thin, irregular buff dolomitic laminae; moderately bioturbated. Base and top of bed undulose.	1.30	51.29
	<u>Hystericurus oculilunatus</u> , <u>Parahystericurus smithiae</u> , <u>Diaphelasma</u> , echinoderm fragments, and high-spined and planispiral gastropods collected 87 to 65 cm below top of bed (BH-28).		
14	Dolomite mudstone and wackestone, buff to light gray weathering, massive, bioturbated.	0.64	51.93
15	Lime boundstone, stromatolitic and thrombolitic, blue-gray, rubbly weathering, massive - essentially the same lithologies present as in Bed 6 of BHS-2 except for chert rimming the mounds.	1.73	53.66

Randaynia saundersi, Hystricurus pseudoculilunatus, Parahystricurus smithiae, Hillyardina levis collected, planispiral gastropods seen 100 to 25 cm below top of bed (BH-29).

16 Lime mudstone and wackestone, light blue-gray, thin, planar bedded; thin, irregular, buff dolomitic laminae. 0.75 54.41

17 Lime mudstone, wackestone, packstone and grainstone, intraclastic, dark blue-gray, massive, hard, sparsely bioturbated. Intraclasts subrounded, up to 1.5 cm in diameter, lime mudstone and wackestone. Bed has hummocky surface. 0.90 55.31

Randaynia saundersi, Hillyardina levis, Parahystricurus smithiae, and planispiral gastropods collected 10 cm below top of bed (BH-30).

18 Dolomite mudstone and wackestone, light gray, thin, irregularly bedded. Dolomite boundstone, stromatolitic, 100 to 120 cm above base of bed - mounds LLH and approximately 30 cm in diameter. 1.33 56.64

19 Lime mudstone and wackestone, light blue-gray, rubbly weathering, massive; buff dolomitic laminae; extensively bioturbated. Basal 15 cm of bed boundstone, stromatolitic, light blue-gray, less massive, unbioturbated-mounds LLH, approximately 20 to 30 cm in diameter. This bed is stratigraphically equivalent to the lower 1.22 cm of Bed 1 of Section BHS-4. 1.22 57.86

Hystricurus pseudoculilunatus and Parahystricurus smithiae collected 25 to 80 cm above base of bed, Randaynia saundersi collected only at 80 cm above base (BH-31).

TOP OF SECTION BHS-3

57.86



SECTION BHS-4: ASCENDING SECTION TO NORTHEAST

Note:

Bed 1 of Section BHS-4 directly overlies Bed 18 of Section BHS-3, and is in part stratigraphically equivalent to Bed 19 of Section BHS-3, as stated above.

Bed/Unit	Description	Thickness (Metres)	
		Bed/Unit	Total

TO TOP OF BED 18 OF SECTION BHS-3 (BASE OF SECTION BHS-4)			56.64
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1	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, massive, overall planar bedded, internally thin and irregularly bedded; thin, irregular buff dolomitic laminae; extensively bioturbated-burrows, trails buff, dolomitized; abundant black chert, mostly yellow - but locally white-weathering, irregular nodules and occasional lenses parallel to bedding.	1.50	58.14
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Hystricurus pseudoculilunatus and planispiral gastropods collected 90 to 80 cm below top of unit (BH-32); Randaynia saundersi, Hystricurus pseudoculilunatus and Hillyardina levis collected 40 to 25 cm below top (BH-33).

Note concerning facies change:

Where Bed 19 of Section BHS-3 and Bed 1 of Section BHS-4 link up, there is an apparent abrupt facies change, as the sequence of beds is different. This difference is not attributed to faulting as both beds overlie Bed 18 of BHS-3. The following section is thus partly equivalent to Bed 19 of BHS-3 and Beds 1-3 of BHS-4. The details of the section are as follows:

SECTION BHS-4A: ASCENDING SECTION TO NORTHEAST

Bed/Unit	Description	Thickness (Metres)	
		Bed/Unit	Total

TO TOP OF BED 18 OF SECTION BHS-3 (BASE OF SECTIONS BHS-4 and BHS-4A)			56.64
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1a	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, massive, overall planar bedded, internally thin and irregularly bedded; thin, buff dolomitic laminae.	0.57	57.21
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1b	Lime mudstone, wackestone and boundstone, dark blue-gray, light blue-gray weathering; thin, irregular, buff dolomitic laminae. Undulose upper surface due to pustular stromatolites, circular, up to 40 cm in diameter, flanked by intraclastic (flat-pebble) lime packstone and grainstone.	0.20	57.41
1c	Lime boundstone, stromatolitic, as in Bed 3 of Section BHS-4. Mounds circular, well laminated. Stromatolite mounds diameters as follows:  1) 40 to 55 cm at 40 cm above base of unit (LLH) 2) 30 cm at 50 cm above base 3) 22 cm at 62 cm above base 4) 10 cm at 70 cm above base  Mound interfill oolitic lime packstone and grainstone which is silicified except from 58 to 80 cm above base of unit.	0.80	57.21
1d	Lime mudstone and wackestone, dark gray, rubbly weathering, massive.  <u>Randaynia saundersi</u> , <u>Parahystricurus smithiae</u> , <u>Hillyardina levis</u> , <u>Parapeltabellia boatharbourensis</u> , cyrtonic cephalopods and planispiral gastropods collected 0 to 25 cm above base of unit (BH-34).	0.55	58.76
TOP OF SECTION BHS-4A			58.76
SECTION BHS-4 (CONTINUED)			
Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
TO TOP OF BED 1 OF SECTION BHS-4			58.14
2	Lime mudstone and wackestone, light blue-gray; thin, irregular, buff dolomitic laminae; some intraclastic (flat-pebble) packstone and grainstone. Undulose top, probably stromatolitic.	0.12	58.26

3	Lime boundstone, stromatolitic, light blue-gray and extremely rubbly weathering, well laminated; abundant black chert. Mounds include LLH, SH-V and club-shaped forms (like those of Shark Bay, Australia). Some LLH stromatolites only 28 cm in maximum thickness, others 56 * 3 cm thick. SH-V stromatolites extend to top of bed. Some circular mounds, 40 cm in diameter. Mound interfill lime packstone and grainstone, oolitic, silicified; it caps the thinner stromatolites.	0.80	59.06
4	Lime boundstone, thrombolitic, dark blue-gray, rubbly weathering, massive. Mound complexes large, 200 to 300 cm in diameter, built of smaller circular mounds, up to 40 cm in diameter, in a honeycomb arrangement - each "cell" highlighted by silicified or buff, dolomitized, bioturbated rims, etc. Mound complex interfill lime mudstone, wackestone, packstone and grainstone, thin and essentially planar bedded.	2.30	61.36
	<u>Hillyardina levis</u> collected 38 cm above base of unit (BH-35). Planispiral gastropods seen 64 to 230 cm above base; <u>Hillyardina levis</u> , cephalopods, and planispiral gastropods collected 100 cm above the base (BH-36).		
	TOP OF SECTION BHS-4		61.36
	Covered interval.	2.00	63.36

Note:

Knight (1977b, Fig. 6) gives a thickness of 7.97 m for this covered interval, however, Pratt (1979, Appendix F, Unit 120) gives a thickness of 2.0 m. This second figure is believed to be more accurate and is therefore utilized.

SECTION BHS-5: ASCENDING SECTION TO NORTHEAST

TO BASE OF SECTION BHS-5		63.36	
Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
1	Lime mudstone and wackestone, light blue-gray, rubbly weathering, massive, extensively bioturbated-burrows, trails buff, dolomitized.	6.87	70.23
<p><u>Diaphelasma</u> collected 255 cm above base of unit (BH-37). <u>Hillyardina levis</u> and <u>Magnusnasus proprius</u> collected 285 cm above base (BH-38).</p>			
TOP OF SECTION BHS-5		70.23	

Note:

The top 2.20 m of Section BHS-5 is equivalent to Beds 1-5 of Section BHS-6. The top of Bed 5 of BHS-6 is, therefore, 70.23 m above the base of the measured Boat Harbour sequence and the base of Bed 1 of BHS-6 is 68.03 m above the base.

SECTION BHS-6: ASCENDING SECTION TO NORTHEAST

TO BASE OF SECTION BHS-6		68.03	
Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
1	Lime mudstone and wackestone, dark gray, massive, planar bedded, extensively bioturbated (horizontally). Bed contains planispiral gastropods.	0.40	68.43
2	Lime mudstone and wackestone, dark gray, massive, planar bedded, extensively bioturbated (vertically).	0.24	68.67
3	Lime mudstone and wackestone, dark gray, massive, planar bedded, sparsely bioturbated.	0.20	68.87
4	Lime mudstone and wackestone, dark gray, thin and planar bedded, extensively bioturbated (horizontally). Top 27 cm more massive, also has vertical bioturbation.	0.77	69.64

Planispiral gastropods collected 4 to 42 cm above base of bed (BH-39), also seen on top of bed.

5	Lime mudstone and wackestone, medium blue-gray, massive, essentially planar bedded, extensively bioturbated-burrows light gray, dolomitized. Numerous elongate, elliptical, circular and irregular patches of ultra-extensive bioturbation evident on top surface of bed, locally aligned. Largest patch 569 cm by 325 cm, another 112 cm by 50 cm. Orientation of patches' long axes as follows: 304, 318, 318, 322 and 340. Patches start 14 cm above base of bed, in general are 45 cm thick. Most are almost 100% diagenetic dolostone, the burrows having been dolomitized, although the smaller ones appear to be less so. The patches have slightly upturned rims. They became smaller and disappear to the NE, and the bed surface appears less extensively bioturbated..	0.59	70.23
6	Diagenetic dolostone, light blue-gray, buff weathering, rippled, bioturbated, finely crystalline. Straight symmetrical ripples - 060 bimodal direction. Bed thins slightly to NE (to 7 cm).	0.09	70.32
7	Diagenetic dolostone, light blue-gray, buff weathering, massive, planar bedded, bioturbated, finely crystalline.	0.39	70.69
8	Diagenetic dolostone, light blue-gray, buff weathering, massive, planar bedded, bioturbated(?), finely crystalline.	0.43	71.12
9	Diagenetic dolostone, light blue-gray, buff weathering, finely crystalline, containing a) subangular to well rounded, white vug - quartz clasts up to 3 cm in diameter, b) angular gray to black chert clasts up to 6 cm long, c) subangular to sub-rounded gray chert clasts containing tiny pyrite crystals, and d) pyrite nodule clasts up to 1 cm in diameter. Small, straight, symmetrical, bimodal ripples measuring 052 seen. Bed has irregular, undulose top.	0.06(av.) 0.05-0.06	71.18

This is the "pebble bed" of Knight (1978, p. 143) and Boyce (1978, p. 81, 83; 1979a, p. 8, 9).

10	Dolomite wackestone, argillaceous, dark gray, draped over undulose surface of "pebble bed".	0.01	71.19
11	Dolostone (diagenetic?), light blue-gray, buff weathering, massive, finely crystalline; rare, tiny, rounded black chert clasts up to 5 mm in size.	0.29	71.48
12	Dolostone (diagenetic?), medium blue-gray, dark gray weathering, planar bedded, finely crystalline. Tiny planispiral gastropods seen.	0.14	71.62
13	Lime mudstone and wackestone, light blue-gray, thin bedded; thin, irregular, buff to yellow weathering dolomitic laminae.	0.21	71.83
	<p><u>Grinnellaspis</u> <u>newfoundlandensis</u>,  <u>Strigigenalis</u> <u>brevicaudata</u>, and  <u>Jeffersonia</u> <u>angustimarginata</u>                      collected 3 cm below top of bed (BH-40).</p>		
14	Lime packstone and grainstone, intraclastic, light blue-gray; subangular to subrounded clasts up to 1 cm in diameter.	0.08	71.91
15	Lime mudstone and wackestone, light blue-gray, thin bedded; buff to yellow weathering dolomitic laminae.	0.09	72.00
16	Lime packstone and grainstone, intraclastic, light blue-gray, massive, cross-laminated; intraclasts up to 1 cm in diameter.	0.33	72.33
17	Lime mudstone and wackestone, light blue-gray, planar bedded, containing small, circular, algal(?) mounds which project up to 5 cm above top of bed.	0.05	72.38
18	Lime mudstone and wackestone, thin and irregularly bedded; thin, irregular, wispy, buff to yellow weathering dolomitic laminae.	0.24	72.62

Bolbocephalus convexus collected 10 to 15 cm above base of bed (BH-41).  
Gastropods seen at top of bed.

- |    |  |      |       |
|----|--|------|-------|
| 19 | Lime packstone and grainstone, light blue-gray.  | 0.22 | 72.84 |
| 20 | Lime packstone and grainstone, intra-clastic, light blue-gray. 26 cm long intraclast seen. Bed appears to grade 2 cm down into underlying bed. Fossil fragments seen.  | 0.05 | 72.89 |
| 21 | Lime mudstone and wackestone, light blue-gray, thin and irregularly bedded; buff dolomitic laminae; minor, thin (3 cm) lime packstone and grainstone beds also occur.  | 0.62 | 73.51 |
|    | <u>Bolbocephalus convexus</u> , orthid brachiopods, cephalopods, and high-spined and planispiral gastropods collected 19 cm above base of unit (BH-42); <u>Bolbocephalus convexus</u> also collected 57 cm above base (BH-48).   |      |       |
| 22 | Lime packstone and grainstone, light blue-gray.  | 0.14 | 73.65 |
|    | <u>Peltabellia knighti</u> , planispiral gastropods collected 11 cm above base of bed (BH-44).   |      |       |
| 23 | Lime mudstone and wackestone, light blue-gray, thin and irregularly bedded; buff dolomitic laminae.  | 0.36 | 74.01 |
|    | <u>Bolbocephalus convexus</u> and high-spined and planispiral gastropods collected 21 to 36 cm above base of bed.  |      |       |
| 24 | Lime packstone and grainstone, dark blue-gray, massive. Abundantly fossiliferous. "hash" bed contains straight cephalopods, high-spined and planispiral gastropods, and trilobites. <u>Peltabellia knighti</u> collected 0 to 33 cm above base of bed. <u>Bolbocephalus convexus</u> and <u>Randaynia langdoni</u> collected 28 to 33 cm above base (BH-46). | 0.33 | 74.34 |

- |    |   |                        |       |
|----|---|------------------------|-------|
| 25 | <p>Lime boundstone, stromatolitic, dark blue-gray. Mounds large, isolated, steep-sided, circular to slightly elliptical, up to 150 cm in diameter; mound tops taken as top of bed, elevated 43 cm above rest of bed. Mound interfill lime mudstone, wackestone, packstone, and grainstone, slightly lighter in color than mounds, thin bedded. Minor thin horizons of lime packstone and grainstone near base of bed.</p> <p>Bed abundantly fossiliferous; contains articulate brachiopods, curved and coiled cephalopods, high-spired and planispiral gastropods, and trilobites. <u>Bolbocephalus convexus</u> and <u>Randaynia langdoni</u> collected 0 to 155 cm above base of bed, <u>Peltabellia knighti</u> collected 0 to 127 cm above base; <u>Bolbocephalus stevensi</u> collected 110 cm above base; <u>Strigigenalis brevicaudata</u> collected 111 to 155 cm above base (BH-47).</p> | 1.55                   | 75.89 |
| 26 | <p>Lime mudstone and wackestone, light blue-gray, and boundstone, stromatolitic, dark blue-gray. Mounds rarely vuggy, range in diameter from 8 to 50 cm; maximum elevation above rest of bed is 11 cm.</p> <p>Bed contains high-spired gastropods; straight cephalopods and planispiral gastropods collected from top of bed (BH-48).</p>   | 0.11                   | 76.00 |
| 27 | <p>Dolomite packstone - grainstone and mudstone-wackestone, light blue-gray, buff weathering, mudcracked on top surface. Bottom and top surfaces of bed irregular. Bed ranges between 13 and 17 cm in thickness due to undulose top of underlying mound bed.</p>  | 0.15                   | 76.15 |
| 28 | <p>Lime mudstone and wackestone, blue-gray, massive, internally thin bedded; thin, buff weathering dolomitic laminae; scattered lenses of lime packstone and grainstone throughout. Bioturbation most common towards top of bed-burrows buff weathering, dolomitized. Bottom of</p>   | 0.90(av.)<br>0.85-0.95 | 77.05 |



bed irregular. Bed ranges from 85 to 95 cm in thickness from SW to NE, respectively; bed thickens and thins before gradually reaching maximum thickness - where thickest, 10 to 13 cm of darker blue-gray lime packstone and grainstone forms base of bed.

Bed contains articulate brachiopods and trilobites. Jeffersonia angustimarginata collected 25 to 90 cm above base of bed; Peltabellia pseudopeltabella collected 35 cm above base; Bolbocephalus convexus collected 63 to 90 cm above base, Petigurus nero collected 70 to 90 cm above base, and Grinnellaspis newfoundlandensis collected 80 cm above base (BH-49).

29 Lime mudstone and wackestone, blue-gray; slightly irregular surface displaying buff, dolomitized trails. 0.13 77.18

Bed contains cephalopods, high-spined and planispiral gastropods, and trilobites. Bolbocephalus convexus recovered 8 cm above base of bed (BN-50).

30 Lime mudstone and wackestone, blue-gray, thin bedded; thin, irregular buff dolomitic laminae, bioturbation more common towards top of bed. Top of bed boundstone, stromatolitic/thrombolitic; circular mounds up to 25 cm in diameter and up to 8 cm in elevation above top of bed. 0.35 77.53

Coiled cephalopods, gastropods seen in bed. Strigigenalis brevicaudata collected from top of bed, Bolbocephalus convexus, Bolbocephalus stevensi collected from mounds (BH-51).

31 Lime mudstone and wackestone, blue-gray, extensively bioturbated relative to underlying bed. 0.31 77.84

32 Dolomite mudstone and wackestone, dark gray, buff to gray weathering, thin bedded, finely laminated. Bed is 35 cm thick in extreme SW, 40 cm thick in extreme NE. EXCELLENT MARKER BED. 0.38(av.) 78.22  
0.35-0.40

- |    |   |                        |       |
|----|---|------------------------|-------|
| 33 | Lime mudstone and wackestone, blue-gray, massive; thin, irregular, buff dolomitic laminae; local patches of lime packstone and grainstone.  | 0.65                   | 78.87 |
|    | Bed contains brachiopods, cephalopods, gastropods, and trilobites. <u>Jeffersonia angustimarginata</u> and <u>Bolbocephalus convexus</u> collected from bed; <u>Strigigenalis brevicaudata</u> collected 20 cm above base (BH-52).  |                        |       |
| 34 | Lime packstone and grainstone, blue-gray, thin bedded; thin, irregular, buff dolomitic laminae.   | 0.52                   | 79.39 |
|    | Bed contains brachiopods, cephalopods, echinoderm debris, gastropods, and trilobites. <u>Jeffersonia angustimarginata</u> , <u>Bolbocephalus convexus</u> and <u>Peltabellia knighti</u> collected from bed; <u>Grinnellaspis newfoundlandensis</u> collected 25 cm above base (BH-53).   |                        |       |
| 35 | Dolomite boundstone, stromatolitic, buff weathering, blue-mottled. Mounds exceptionally well preserved (diameters of 8, 15 and 33 cm observed), truncated by overlying bed, disappear to NE. Mound interfill lime and dolomite packstone and grainstone, intraclastic, buff weathering, blue-mottled; intraclasts up to 10 cm long. | 0.10                   | 79.49 |
| 36 | Dolomite mudstone and wackestone, dark gray, thin and irregularly bedded. Bed disappears to NE.   | 0.05(av.)<br>0.04-0.06 | 79.54 |
| 37 | Lime mudstone, wackestone, packstone and grainstone, thin bedded; irregular, buff to yellow weathering dolomitic laminae up to 5 mm thick commonly enclosing lenses of matrix.  | 0.68                   | 80.22 |
|    | Trilobite cross-sections seen.  |                        |       |
| 38 | Lime packstone and grainstone, intraclastic, dark blue-gray; intraclasts subangular to subrounded, up to 3.5 cm in length and 2 cm in diameter, lime mudstone and wackestone, pink to reddish.  | 0.10                   | 80.32 |

Bed contains brachiopods, trilobites. Petigurus nero collected 6 cm above base (BH-54).

- 39 Lime mudstone, wackestone, packstone and grainstone, locally intraclastic, dark blue-gray; light blue-gray weathering, thin and irregularly bedded; thin, buff dolomitic laminae; some horizontal bioturbation; intraclasts flat pebbles up to 7 cm in diameter, 2 cm in thickness. Top of unit marked by thin, 10 cm marker bed of lime mudstone and wackestone, dark blue-gray, light blue-gray and recessive weathering. 4.24 84.56

The unit is abundantly fossiliferous, altogether the most fossiliferous in the Boat Harbour measured sequence. In the 424 cm of the unit, 41 fossiliferous horizons were sampled (BH-55 to BH-95). Isoteloides peri collected 5 to 424 cm above base (BH-55 to BH-95); Strigigenalis brevicaudata collected 16 to 225 cm above base (BH-56 to BH-91); Bolbocephalus convexus collected 34 to 98 cm above base (BH-59 to BH-82); Grinnellaspis newfoundlandensis collected 45 to 66 and possibly 97 cm above base (BH-60 to BH-69 and possibly BH-81); Petigurus nero collected 45 to 100 cm above base (BH-60 to BH-83); Benthamaspis hintzei collected 50 cm above base (BH-62); Jeffersonia angustimarginata collected 52 and 424 cm above base (BH-63 and BH-95); Bolbocephalus stevensi collected 85 to 424 cm above base (BH-76 to BH-95); a 27 cm thick blue and yellow weathering marker bed contains Isoteloides peri and articulate brachiopods 268 cm above base; Strigigenalis caudata (Billings) collected 356 cm above base (BH-94); Jeffersonia angustimarginata, Bolbocephalus stevensi, Isoteloides peri, and articulate brachiopods collected 414 to 424 cm above base (BH-95).

- 40 Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, and dolomitic mudstone and wackestone/dolomitic laminae, very thin 2.42 86.98

and planar interbedded, extremely laminated near top of bed. Laminations disrupted but not displaced by probable mudcracks; vertical contorted laminations indicative of shrinkage also seen. Top surface of bed mudcracked.

This bed forms the top of the upper member of the Boat Harbour Formation. The contact between the Boat Harbour and Catoche Formations occurs at the top of the bed.

Catoche Formation

lower limestone sequence

41	Lime mudstone and wackestone, dark gray, light blue-gray and rubbly weathering, massive, moderately bioturbated-burrows buff weathering, dolomitized; birdseye calcite and white, sparry calcite-lined fenestrae.	662+	93.60
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In the 662 cm of this unit, 18 fossil collections were made (BH-96 to BH-114), including 4 from various levels on the scree slope developed along the sides of the cliff formed by this unit on the underlying bed (BH-101, BH-109, BH-110 and BH-112). Because fossils had to be obtained from a vertical cliff face, collections were not as complete as would have been liked. Articulate brachiopods, cephalopods, gastropods, ostracods, and trilobites collected. Strigigenalis caudata collected 191 and 375 cm above base of bed (BH-96 and BH-102); Uromystrum affine collected 220 to 662 cm above base (BH-97 to BH-114); Petigurus nero and Jeffersonia angustimarginata collected 222 to 662 cm above base (BH-98 to BH-114); Isochytotoma parallela collected 368 to 662 above base of bed (BH-100 to BH-114); Bolbocephalus convexus collected 385 to 662 cm above base (BH-104 to BH-114); Benthamspis hintzei collected 562 to 662 cm above base (BH-108 to BH-114); Isoteloides peri

collected 585 to 662 cm above base  
(BH-112).

TOP OF SECTION BHS-6 AND MEASURED BOAT HARBOUR SEQUENCE

93.60

APPENDIX B

MEASURED STRATIGRAPHIC SECTION - CAPE NORMAN

A reconnaissance section was measured through the lower limestone sequence and the Diagenetic Carbonates of the Catoche Formation exposed on the shore below the lighthouse at Cape Norman. The base of the section was taken 16.86 metres below the stratigraphic contact of the lower limestone sequence and the Diagenetic Carbonates. Lower beds of the Catoche Formation present along the shore were not measured because of heavy seas. Unlike the beds of the Boat Harbour sequence, which dip to the northeast, the beds exposed at Cape Norman dip toward the southwest.

SECTION CNS-1: ASCENDING SECTION TO SOUTHWEST

Bed/Unit	Description	Thickness Bed/Unit	(Metres) Total
<u>St. George Group</u>			
<u>Catoche Formation</u>			
<u>lower limestone sequence</u>			
1	Lime mudstone and wackestone, dark blue-gray, light blue-gray weathering, thin and rubbly bedded, bioturbated; spectacular pipes and patches of diagenetic dolostone-pseudobreccia, white to light gray weathering - one pipe seen to flare out horizontally and replace top portion of a limestone bed. Immediately east of measured section stratigraphically equivalent beds totally dolomitized. This indicates that the stratigraphically succeeding Diagenetic Carbonates are transgressive to, as well as conformably overlying the lower limestone sequence.	6.18+	6.18
	<u>Ischyrotoma anataphra</u> and <u>Jeffersonia timon</u> collected 241 cm above base of unit (CN-1); <u>Isoteloides</u> sp. undet. and <u>Jeffersonia timon</u> collected 324 and 400 cm above base (CN-2 and CN-3).		
2	Diagenetic dolostone, gray weathering, massive.	0.85	7.03
3	Lime mudstone and wackestone, dark blue-gray, light blue-gray weather-	9.83	16.86

ing, thin and rubbly bedded, bioturbated; top of bed contains thin lenses of skeletal lime packstone and grainstone and spectacular patches of diagenetic dolostone-pseudobreccia, white weathering.

Unit 3 more fossiliferous than unit 1, especially near top in the thin lenses of skeletal lime packstone and grainstone. Petigurus nero and piloceroid cephalopods collected 40 cm above base of unit (CN-4); Jeffersonia timon collected 171 cm above base (CN-5); Petigurus nero collected 321 to 329 cm above base (CN-6); Jeffersonia timon, Petigurus nero and Bathyuirellus abruptus collected 333 cm above base (CN-7); Jeffersonia timon collected 373 to 402 cm above base (CN-8); Bathyuirellus abruptus collected 383 to 398 cm above base (CN-9); Ischyrotoma anataphra collected 401 cm above base (CN-10); Jeffersonia timon collected 428 cm above base (CN-11); Jeffersonia timon and Petigurus nero collected 508 and 520 cm above base (CN-12 and CN-13); Jeffersonia timon, Petigurus nero, and Bathyuirellus abruptus collected 547 cm above base (CN-14); Ischyrotoma anataphra, Jeffersonia timon, Petigurus nero, and Bathyuirellus abruptus collected 647 cm above base (CN-15); Petigurus nero and Uromystrum forteyi collected 806 cm above base (CN-16); Jeffersonia timon, Petigurus nero, Bathyuirellus abruptus, and Benthamaspis conica collected 838 and 851 cm above base (CN-17 and CN-18); Jeffersonia timon and Petigurus nero collected 911 and 970 cm above base (CN-19 and CN-20).

Whittington and Kindle (1969, p. 659) also report Carolinites sp. from this unit, probably the upper part where the lenses of skeletal lime packstone and grainstone are most common. Portey (1979a, p. 64) also identified Isoteloides peri, Punka flabelliformis, Bolbocephalus convexus, Benthamaspis cf. B. gibberula and Strotactinus insularis from collec-

tions obtained by Whittington and  
Kindle at Cape Norman.

Diagenetic Carbonates

4	Diagenetic dolostone, dark gray, light gray to yellow weathering, massive, medium to coarse crystal- line, chert-bearing.	6.00+	22.86+
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TOP OF SECTION CNS-1

22.86



APPENDIX C

LOCATION OF SAMPLED FOSSILIFEROUS HORIZONS-BOAT HARBOUR COMPOSITE SECTION

Horizon(s)	Distance Above Base of Section (Metres)	Distance Below Base of "Pebble Bed" (Metres)
BH- 1	2.31	68.81
2	2.86-3.11	68.26-68.01
3	3.75-3.79	67.37-67.33
4	4.44-5.42	66.68-65.70
5	5.78	65.34
6	6.73	64.39
7	7.92	63.20
8	8.21	62.91
9	9.84-10.37	61.28-60.75
10	10.57	60.55
11	11.87	59.25
12	18.08-18.18	53.04-52.94
13	19.13	51.99
14	35.30-35.67	35.82-35.45
15	36.21	34.91
16	36.49-36.82	34.63-34.30
17	37.85	33.27
18	38.94-39.44	32.18-31.68
19	39.74-39.94	31.38-31.18
20	40.69	30.43
21	43.67	27.45
22	45.06-45.59	20.06-25.53
23	45.59-45.83	25.53-25.29
24	46.65-47.10	24.47-24.02
25	47.10-47.32	24.02-23.80
26	49.24-49.49	21.88-21.63
27	49.99	21.13
28	50.42-50.64	20.70-20.48
29	52.66-53.41	18.46-17.71
30	55.21	15.91
31	56.89-57.44	14.23-13.68
32	57.24-57.34	13.88-13.78
33	57.74-57.89	13.38-13.23
34	58.21-58.46	12.91-12.66
35	59.44	11.68
36	59.70-61.36	11.42- 9.76
37	65.91	5.21
38	66.21	4.91
39	68.91-69.29	2.21- 1.83
PEBBLE BED	71.12-71.18	-----

Horizon(s)	Distance Above Base of Section (Metres)	Distance Above Top of "Pebble Bed" (Metres)
BH- 40	71.80	0.62
41	72.48-72.53	1.30- 1.35

Horizon(s)	Distance Above Base of Section (Metres)	Distance Above Top of "Pebble Bed" (Metres)
BH- 42	73.08	1.90
43	73.46	2.28
44	73.62	2.44
45	73.86-74.01	2.68- 2.83
46	74.01-74.34	2.83- 3.16
47	74.34-75.89	3.16- 4.71
48	76.00	4.82
49	76.40-77.05	5.22- 5.87
50	77.13	5.95
51	77.53	6.35
52	78.42, 78.22-78.87	7.24, 7.04- 7.69
53	79.12, 78.87-79.39	7.94, 7.69- 8.21
54	80.28	9.10
55	80.37	9.19
56	80.48	9.30
57	80.56	9.38
58	80.62	9.44
59	80.66	9.48
60	80.77-80.79	9.59- 9.61
61	80.80	9.62
62	80.82	9.64
63	80.84	9.66
64	80.87	9.69
65	80.89	9.71
66	80.90	9.72
67	80.92-80.94	9.74- 9.76
68	80.95	9.77
69	80.96-80.98	9.78- 9.80
70	81.01-81.02	9.83- 9.84
71	81.03-81.06	9.85- 9.88
72	81.07	9.89
73	81.09	9.91
74	81.10	9.92
75	81.12	9.94
76	81.17	9.99
77	81.19	10.01
78	81.20	10.02
79	81.22	10.04
80	81.27	10.09
81	81.29	10.11
82	81.30	10.12
83	81.32	10.14
84	81.34	10.16
85	81.37	10.19
86	81.42	10.24
87	82.27	11.09
88	82.42-82.43	11.24-11.25
89	82.50	11.32
90	82.53	11.35
91	82.57	11.39
92	82.76	11.58

<u>Horizon(s)</u>	<u>Distance Above Base of Section (Metres)</u>	<u>Distance Above Top of "Pebble Bed" (Metres)</u>
BH- 93	83.84	12.66
94	83.88	12.70
95	84.46-84.56	13.28-13.38
96	88.89	17.71
97	89.18	18.00
98	89.20	18.02
99	89.24	18.06
100	90.66	19.48
101*	90.66	19.48
102	90.73	19.55
103	90.78	19.60
104	90.83	19.65
105	90.90	19.72
106	92.03	20.85
107	92.08	20.90
108	92.60	21.42
109*	92.60	21.42
110*	92.70	21.52
111	92.75	21.57
112*	92.85	21.67-22.42
113	92.85,93.60	21.67,22.42
BH-114	93.00-93.10	21.82-21.92

Note:

Collections by W.D. Boyce, summers 1976, 1977, 1978; \* indicates samples from float or talus.

APPENDIX D

LOCATION OF SAMPLED FOSSILIFEROUS HORIZONS - CAPE NORMAN SECTION

Horizon(s)	Distance Above Base of Section (Metres)	Distance Below Base of Diagenetic Carbonates (Metres)
CN- 1	2.41	14.45
2	3.24	13.62
3	4.00	12.86
4	7.43	9.43
5	8.74	8.12
6	10.24-10.32	6.62-6.54
7	10.36	6.50
8	10.76-11.05	6.10-5.81
9	10.86-11.01	6.00-5.85
10	11.04	5.82
11	11.31	5.55
12	12.11	4.75
13	12.23	4.63
14	12.50	4.36
15	13.50	3.36
16	15.09	1.77
17	15.41	1.45
18	15.54	1.32
19	16.14	0.72
CN-20	16.73	0.13

Note:

Collections by W.D. Boyce, September 1978.

APPENDIX E.

RANGES OF INDIVIDUAL TRILOBITE SPECIES - BOAT HARBOUR COMPOSITE SECTION

Trilobite Species	Range of Species Above Base of Boat Harbour Composite Section (Metres)
1. <u>Hystricurus oculilunatus</u> Ross	2.31-50.64
2. <u>Hillyardina minuspustulata</u> sp. nov.	9.84-19.13
3. <u>Randaynia saundersi</u> gen. et sp. nov.	9.84-58.46
4. <u>Hystricurus pseudoculilunatus</u> sp. nov.	38.94-57.89
5. <u>Parahystricurus smithiae</u> sp. nov.	38.94-58.46
6. <u>Hillyardina levis</u> sp. nov.	38.94-66.21
7. <u>Paraplethopeltis seelyi</u> (Whitfield)	47.10
8. <u>Parapeltabellia</u> <u>boatharbourensis</u> sp. nov.	58.46
9. <u>Magnusaeus proprius</u> gen. et sp. nov.	66.21
10. <u>Grinnellaspis newfoundlandensis</u> sp. nov.	71.80-80.98 (81.29?)
11. <u>Strigigenalis brevicaudata</u> sp. nov.	71.80-82.57
12. <u>Jeffersonia angustimarginata</u> sp. nov.	71.80-93.60
13. <u>Bolbocephalus convexus</u> (Billings)	72.48-93.60
14. <u>Peltabellia knighti</u> sp. nov.	73.62-79.39
15. <u>Randaynia langdoni</u> sp. nov.	74.29-75.89
16. <u>Bolbocephalus stevensi</u> sp. nov.	75.44-84.56
17. <u>Peltabellia pseudopeltabella</u> sp. nov.	76.50
18. <u>Petigurus nero</u> (Billings)	76.85-93.60
19. <u>Isoteloides peri</u> Fortey	80.37-93.60
20. <u>Benthamaspis hintzei</u> sp. nov.	80.82-93.60
21. <u>Strigigenalis caudata</u> (Billings)	83.88-83.31 (+?)
22. <u>Uromystrum affine</u> (Poulsen)	86.76-93.60
23. <u>Ischyrotoma parallela</u> sp. nov.	88.24-93.60

APPENDIX F

RANGES OF INDIVIDUAL TRILOBITE SPECIES - CAPE NORMAN SECTION

Trilobite Species	Range of Species Above Base of Cape Norman Section (Metres)
1. <u>Ischyrotoma anataphra</u> Fortey	2.41-13.50
2. <u>Jeffersonia timon</u> (Billings)	2.41-16.73
3. <u>Isoteloides</u> sp. undet. (not described)	3.24- 4.00
4. <u>Petigurus nero</u> (Billings)	7.43-16.73
5. <u>Bathyuirellus abruptus</u> Billings	10.36-15.54
6. <u>Uromystrum forteyi</u> sp. nov.	15.09
7. <u>Benthamaspis conica</u> Fortey	15.41-15.54

Plates 2-18

Plate 2

Leiostegium proprium sp. nov.

Upper member of the Boat Harbour Formation, Eddies Cove West. Both specimens from unit 9 of Pratt's (1979) section.

- Figure 1,2. Holotype cranidium, dorsal and lateral views, NFM F-110, x 4.  
3,4. Paratype pygidium, dorsal and lateral views, NFM F-111, x 6.

Isoteloides peri Fortey

Upper member of the Boat Harbour Formation, Boat Harbour. All from BH-94.

- Figure 5. Cranidium, dorsal view, NFM F-99, x 6.  
6. Librigena, dorsal view, NFM F-103, x 4.  
7. Pygidium, dorsal view, NFM F-102, x 5.  
8. Hypostoma, ventral view, NFM F-118, x 7.





Plate 3

Randaynia saundersi gen. et sp. nov.

- Figure 1. Paratype cranidium, dorsal view, NFM F-119, x 5, upper member of the Boat Harbour Formation, Boat Harbour, BH-18.
2. Paratype pygidium (latex cast of external mould), dorsal view, NFM F-120, x 3, upper member of the Boat Harbour Formation, Boat Harbour, BH-23.
3. Holotype dorsal shield (incomplete), dorsal view, NFM F-94, x 3, Boat Harbour Formation, Old Ferrolle Island, Brig Bay area.
4. Paratype pygidium, dorsal view, NFM F-121, x 6, upper member of the Boat Harbour Formation, Boat Harbour, BH-9.
5. Paratype librigena, dorsal view, NFM F-117, x 3, upper member of the Boat Harbour Formation, Boat Harbour, BH-30.
- 6,7. Paratype pygidium, dorsal and lateral views, NFM F-122, x 4, upper member of the Boat Harbour Formation, Boat Harbour, BH-30.



Plate 4

Randaynia langdoni sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour, All from BH-47.

- Figure 1. Paratype cranidium, dorsal view, NFM F-123, x 8.  
2. Paratype librigena (latex cast of external mould), dorsal view, NFM F-124, x 7.  
3,4. Holotype pygidium, dorsal and lateral views, NFM F-125, x 6.  
5. Paratype transitory pygidium retaining one thoracic segment, dorsal view, NFM F-126, x 8.

Hillyardina minuspustulata sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. All from BH-9.

- Figure 6. Holotype cranidium, dorsal view, NFM F-127, x 7.  
7,8. Paratype cranidium, dorsal and lateral views, NFM F-128, x 7.

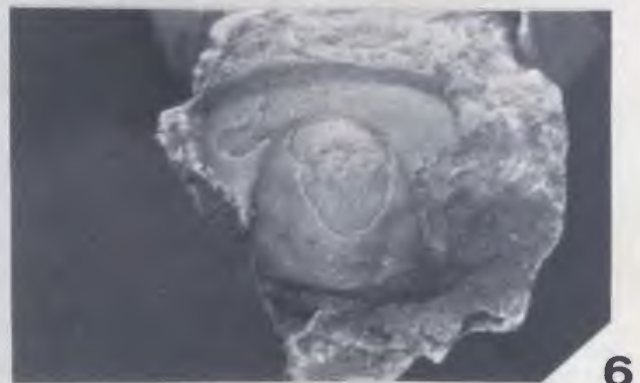


Plate 5

Hillyardina minuspustulata sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. All from BH-9.

- Figure 1. Paratype librigena, dorsal view, NFM F-129, x 8.  
2. Paratype pygidium, dorsal view, NFM F-130, x 8.

Hillyardina levis sp. nov.

- Figure 3. Paratype librigena (latex cast of external mould), dorsal view, NFM F-92, x 6, upper member of the Boat Harbour Formation, Boat Harbour, BH-18.  
4. Paratype dorsal shield (incomplete - latex cast of external mould), dorsal view, NFM F-131, x 4, Boat Harbour Formation, Old Ferrolle Island, Brig Bay area.  
5,7. Paratype cranidium, dorsal and lateral views, NFM F-93, x 6, upper member of the Boat Harbour Formation, Boat Harbour, BH-18.  
6. Paratype librigena, dorsal view, NFM F-132, x 6, upper member of the Boat Harbour Formation, Boat Harbour, BH-18.

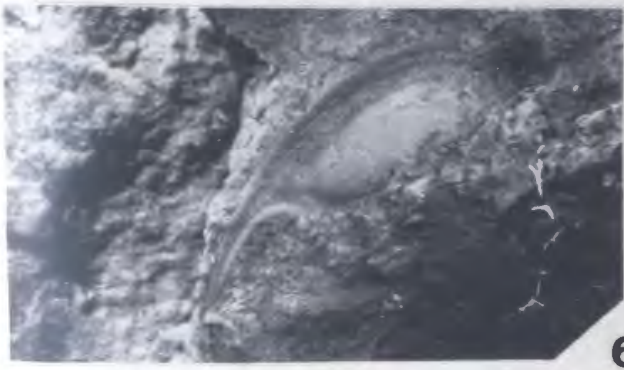


Plate 6

Hillyardina levis sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

- Figure 1. Paratype cranidium, dorsal view, NFM F-133, x 4, BH-23.
- 2. Holotype cranidium, dorsal view, NFM F-90, x 5, BH-18.
- 3. Paratype pygidium (latex cast of external mould), dorsal view, NFM F-91, x 8, BH-18.
- 4-6. Paratype pygidium, dorsal, posterior and lateral views, NFM F-134, x 8, BH-30.

Hystericurus oculilunatus Ross

Garden City Formation, northeastern Utah, U.S.A.

- Figure 7,8. Cranidium, dorsal and lateral views, Y.P.M. 18299 (the original of Ross, 1951; pl. 10, figs. 8, 9, 12), x 4.





Hystericurus oculilunatus Ross

- Figure 1,2. Cranidium (latex cast of external mould), dorsal and lateral views, NFM F-135, x 2.5, upper member of the Boat Harbour Formation, Boat Harbour, BH-28.
3. Cranidium, dorsal view, NFM F-80, x 4, upper member of the Boat Harbour Formation, Boat Harbour BH-28.
  4. Cranidium, dorsal view, A.M.N.H. 41335 (the original of Whitfield, 1889a; pl. 13, figs. 15, 16), x 2.5, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.
  5. Pygidium, dorsal view, NFM F-136, x 2.5, upper member of the Boat Harbour Formation, Boat Harbour, BH-16.
  6. Librigena, dorsal view, NFM F-137, x 2.5, upper member of the Boat Harbour Formation, Boat Harbour, BH-28.
  7. Pygidium (incomplete); dorsal view, NFM F-138, x 4, Boat Harbour Formation, Beach Point, Dog Peninsula, Brig Bay area.
  8. Pygidium, dorsal view, A.M.N.H. 41339 (the original of Whitfield, 1889a; pl. 13, figs. 20, 21), x 5, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.



Plate 8

Hystericurus oculilunatus Ross

- Figure 1,3. Pygidium, lateral and dorsal views $\beta$  NFM F-81, x 5, Boat Harbour Formation, Beach Point, Dog Peninsula, Brig. Bay area.
2. Pygidium, lateral view, A.M.N.H. 41339 (the original of Whitfield, 1889; pl. 13, figs. 20, 21), x 5, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.

Hystericurus pseudoculilunatus sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. All from BH-18.

- Figure 4. Holotype cranidium, dorsal view, NFM F-82, x 8.
5. Paratype librigena, dorsal view, NFM F-139, x 8.
6. Paratype cranidium, dorsal view, NFM F-140, x 4.
- 7,8. Paratype pygidium, dorsal and lateral views, NFM F-83, x 8.



Plate 9

Magnusnasmus proprius gen. et sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. Specimen from BH-38.

Figure 1-3. Holotype cranidium, dorsal, lateral and anterior views, NFM F-141, x 8.

Parahystricurus smithiae sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

- Figure 4. Holotype cranidium, dorsal view, NFM F-88, x 7, BH-30.  
5. Paratype cranidium, dorsal view, NFM F-142, x 8, BH-30.  
6. Paratype librigena, dorsal view, NFM F-143, x 8, BH-18.  
7. Paratype pygidium, dorsal view, NFM F-89, x 8, BH-30.  
8. Paratype librigena (latex cast of internal mould), dorsal view, NFM F-144, x 8, BH-30.



Plate 10

Paraplethopeltis cordai (Billings)

Levis Formation, Levis, Quebec.

Figure 1. Syntype cranidium, dorsal view, G.S.C. 836c, x 4.

Paraplethopeltis seelyi (Whitfield)

Figure 2. Cranidium, dorsal view, NFM F-105, x 2.5, upper member of the Boat Harbour Formation, Eddies Cove West, unit 9 of Pratt's (1979) section.

3. Syntype cranidium, dorsal view, A.M.N.H. 35504 (the original of Whitfield, 1889a; pl. 13, figs. 11, 12), x 2.5, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.

4. Cranidium, dorsal view, NFM F-106, x 4, Boat Harbour Formation, Moyrac Island, Brig bay area.

5. Cranidium (latex cast of external mould), dorsal view, NFM F-145, x 4, upper member of the Boat Harbour Formation, Eddies Cove West, unit 9 of Pratt's (1979) section.

6. Librigena (latex cast of external mould), dorsal view, NFM F-146, x 8, Boat Harbour Formation, Moyrac Island, Brig Bay area.

7. Syntype librigena, dorsal view, A.M.N.H. 35503 (the original of Whitfield, 1889a; pl. 13, fig. 10), x 3, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.





Plate 11

Paraplethopeltis seelyi (Whitfield)

- Figure 1. Pygidium, dorsal view, NFM F-107, x 1.5, upper member of the Boat Harbour Formation, Boat Harbour, BH-24.  
2. Syntype pygidium, dorsal view, A.M.N.H. 35505 (the original of Whitfield, 1889a; pl. 13, figs. 13, 14), x 5, Fort Ann (= lower Bascom) Formation, Plattsburgh, New York, U.S.A.

Bolbocephalus convexus (Billings)

- Figure 3. Cranidium, dorsal view, NFM F-108, x 4, upper member of the Boat Harbour Formation, Boat Harbour, BH-46.  
4. Pygidium, dorsal view, NFM F-147, x 6, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-101/BH-110.

Bolbocephalus stevensi sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour .

- Figure 5. Paratype cranidium, dorsal view, NFM F-148, x 5, BH-69.  
6. Holotype pygidium, dorsal view, NFM F-149, x 6, BH-95.  
7. Paratype pygidium (latex cast of external mould), dorsal view, NFM F-150; x 3, Bed 39 of Section BHS-6.  
8. Paratype pygidium, dorsal view, NFM F-151, x 8, BH-87.



Plate 12

Jeffersonia angustimarginata sp. nov.

- Figure 1,2. Paratype cranidium, dorsal and lateral views, NFM F-152, x 3, upper member of the Boat Harbour Formation, Boat Harbour, BH-40.
- 3,4. Paratype cranidium, anterior and lateral views, NFM F-153, x 2.5, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-112.
- 5,6. Holotype pygidium, dorsal and lateral views, NFM F-87, x 6, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-101.

Parapeltabellia mediacrista (Cullison) gen. nov.

Rich Fountain Formation, Missouri - northern Arkansas, U.S.A.

- Figure 7. Holotype cranidium (modelling clay cast of external mould); dorsal view, U.S.N.M. 155393 (the original of Cullison, 1944; pl. XXXIV, figs. 25, 26), x 6.

Parapeltabellia boatharbourensis sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. Specimen from BH-34.

- Figure 8. Holotype cranidium (latex cast of internal mould), dorsal view, NFM F-154, x 8.

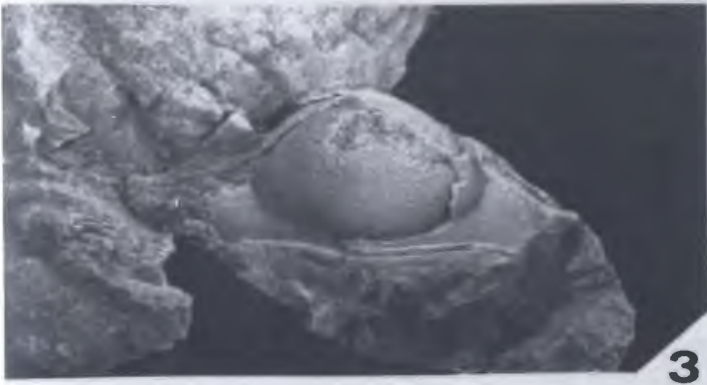


Plate 13

Parapeltabellia mediacrista (Cullison) gen. nov.

Rich Fountain Formation, Missouri - northern Arkansas, U.S.A.

Figure 1,3. Holotype cranidium (modelling clay cast of external mould), anterior and lateral views, U.S.N.M. 155393 (the original of Cullison, 1944; pl. XXXIV, figs. 25, 26), x 6.

Parapeltabellia boatharbourensis sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour, Specimen from BH-34.

Figure 2,4. Holotype cranidium (latex cast of internal mould), anterior and lateral views, NFM F-155, x 8.

Peltabellia knighti sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

- Figure 5. Paratype librigena, dorsal view, NFM F-113, x 3, BH-46.  
6. Paratype cranidium, dorsal view, NFM F-112, x 4, BH-46.  
7. Paratype cranidium, dorsal view, NFM F-156, x 5, BH-47.  
8. Paratype pygidium, dorsal view, NFM F-114, x 5, BH-46.

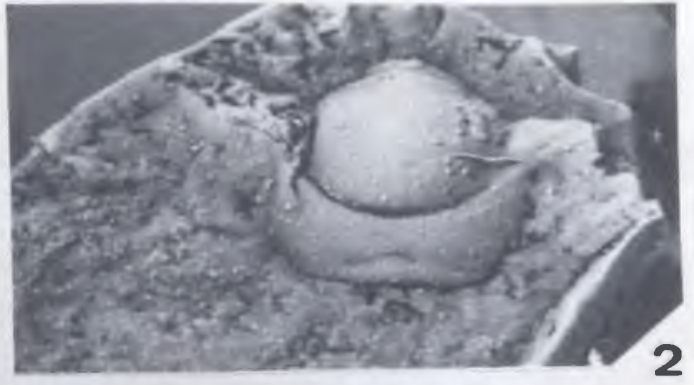


Plate 14

Peltabellia knighti sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. Specimen from BH-46.

Figure 1. Holotype pygidium, dorsal view, NFM F-157, x 8.

Peltabellia pseudopeltabella sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour, Specimens from BH-49.

Figure 2,4. Paratype pygidium, dorsal and lateral views, NFM F-158, x 3.

3,5. Holotype pygidium (latex-cast from internal mould), dorsal and lateral views, NFM F-159, x 2.5.

Petigurus nero (Billings)

Upper member of the Boat Harbour Formation, Boat Harbour. Specimen from BH-49.

Figure 6. Pygidium, dorsal view, NFM F-85, x 5.

Strigigenalis brevicaudata sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

Figure 7. Paratype cranidium, dorsal view, NFM F-160, x 6, Bed 39 of Section BHS-6.

8. Paratype pygidium, dorsal view, NFM F-115, x 6, BH-92.





Plate 15

Strigigenalis brevicaudata sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

- Figure 1. Paratype librigena, dorsal view, NFM F-161, x 8, Bed 39 of Section BHS-6.  
2. Paratype pygidium, dorsal view, NFM F-162, x 7, BH-59.  
3,4. Holotype pygidium, dorsal and lateral views, NFM F-163, x 4, BH-67.

Strigigenalis caudata (Billings)

- Figure 5. Pygidium, dorsal view, NFM F-164, x 3, upper member of the Boat Harbour Formation, Boat Harbour BH-94.  
6. Pygidium, dorsal view, Y.P.M. 17407 (formerly 17182 - the original of Cullison, 1944; pl. XXXV, figs. 25, 26), x 3, Cotter and lower Powell Formations, Missouri - northern Arkansas, U.S.A.

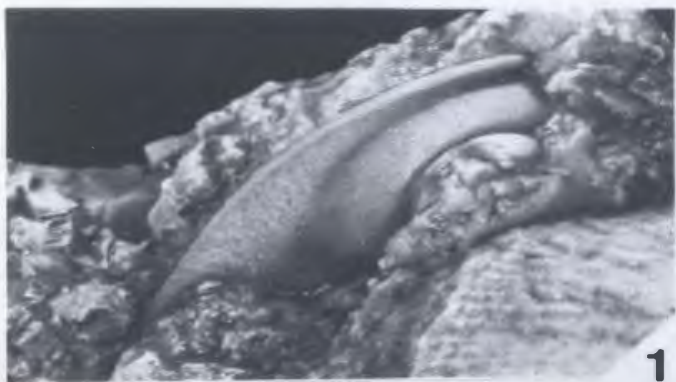


Plate 16

Strigigenalis caudata (Billings)

- Figure 1. Pygidium, lateral view, NFM F-165, x 3, upper member of the Boat Harbour Formation, Boat Harbour, BH-94.
2. Pygidium, lateral view, Y.P.M. 17407 (formerly 17182 - the original of Cullison, 1944; pl. XXXV, figs. 25, 26), x 3, low angle lighting, Cotter and lower Powell Formations, Missouri - northern Arkansas, U.S.A.

Grinnellaspis newfoundlandensis sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour.

- Figure 3. Paratype cranidium, dorsal view, NFM F-166, x 6, BH-60.
4. Paratype librigena, dorsal view, NFM F-167, x 4, BH-60.
5. Paratype pygidium, dorsal view, NFM F-168, x 5, BH-40.
6. Paratype pygidium, dorsal view, NFM F-169, x 4, BH-49.
7. Holotype pygidium, dorsal view, NFM F-170, x 4, BH-60.
8. Paratype pygidium, dorsal view, NFM F-171, x 3, BH-69.

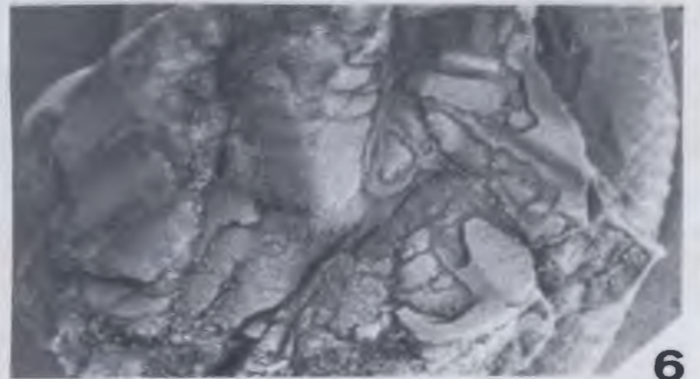


Plate 17

Uromystrum affine (Poulsen)

- Figure 1. Paratype cranidium, dorsal view, NFM F-95, x 6, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-101/BH-110.
2. Paratype librigena, dorsal view, NFM F-104, x 3, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-101/BH-110.
3. Paratype pygidium (latex cast of internal mould), dorsal view, NFM F-96, x 3, lower limestone sequence of the Catoche Formation, Boat Harbour, BH-103.
4. Holotype pygidium (latex cast of plaster mould), dorsal view, G.M. 3705 (the original of Poulsen, 1937; pl. 7, fig. 7), x 6, Cape Weber Formation, Ella Island, central East Greenland.

Uromystrum forteyi sp. nov.

Lower limestone sequence of the Catoche Formation, Cape Norman, Specimen from CN-16.

- Figure 5. Paratype pygidium, dorsal view, NFM F-172, x 3.

Benthamaspis hintzei sp. nov.

Lower limestone sequence of the Catoche Formation, Boat Harbour.

- Figure 6. Paratype cranidium, dorsal view, NFM F-173, x 8, BH-101/BH-110.
7. Paratype cranidium, dorsal view, NFM F-174, x 8, BH-112.
8. Holotype pygidium, dorsal view, NFM F-175, x 6, BH-110.



Plate 18

Benthamaspis hintzei sp. nov.

Upper member of the Boat Harbour Formation, Boat Harbour. Specimen from BH-62.

Figure 1-3. Paratype pygidium (latex cast of external mould), dorsal, posterior and lateral views, NFM F-176, x 8.

Ischyrotoma anataphra Fortey

Lower limestone sequence of the Catoche Formation, Cape Norman. Specimen from CN-10.

Figure 4. Cephalon, dorsal view, NFM F-177, x 6.

Ischyrotoma parallela sp. nov.

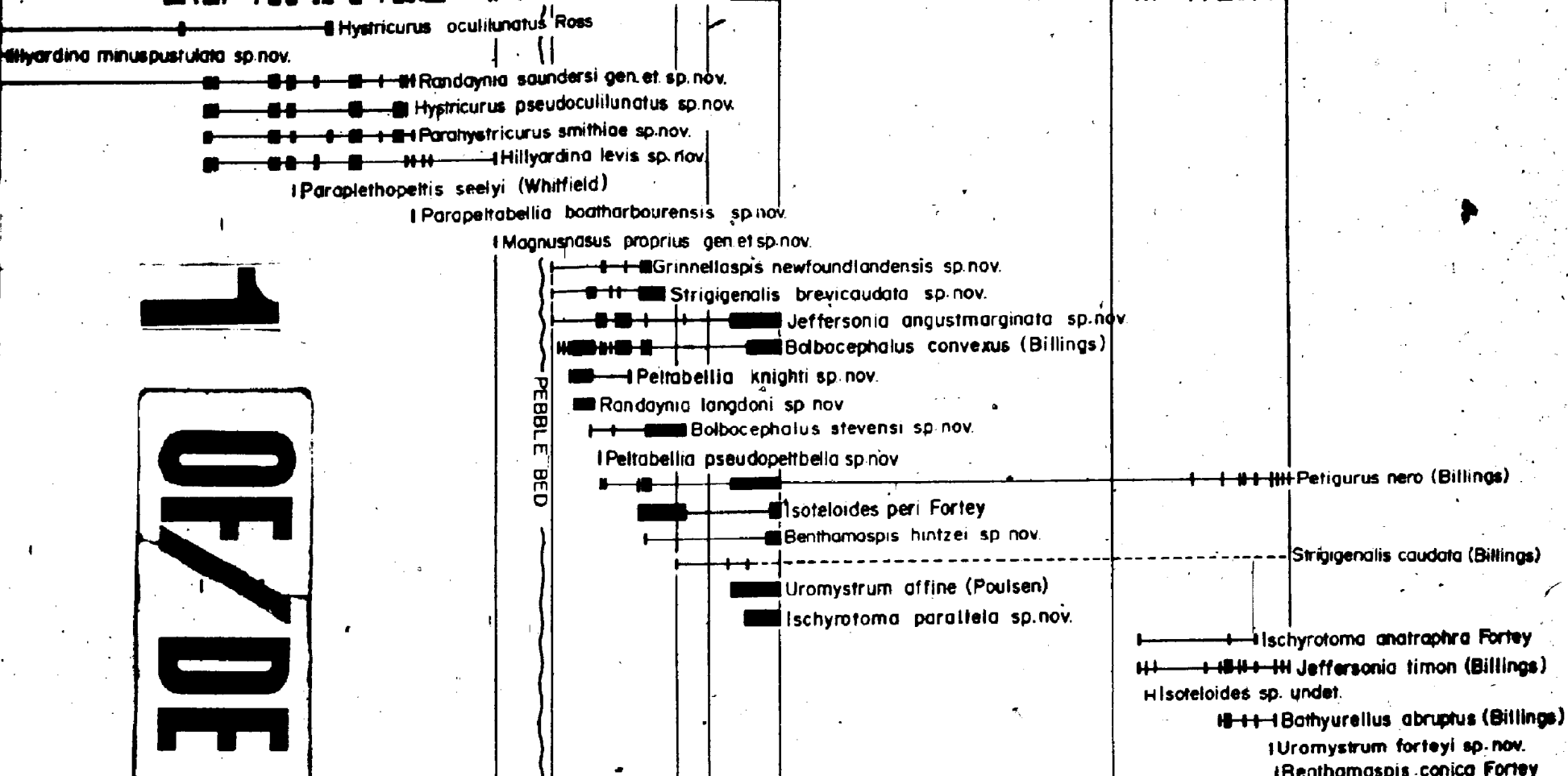
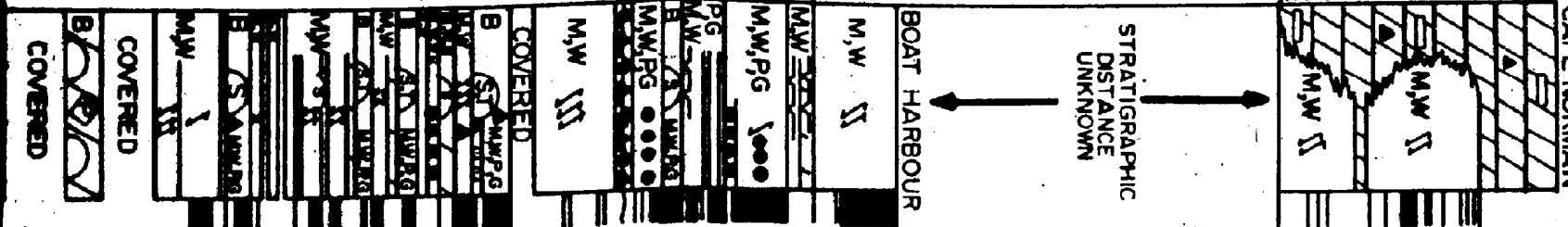
Lower limestone sequence of the Catoche Formation, Boat Harbour.

Figure 5. Paratype cephalon, dorsal view, NFM F-86, x 6, BH-100.  
6, 8. Holotype cephalon, dorsal and lateral views, NFM F-178, x 8, BH-101/BH-110.  
7. Paratype cephalon, anterior view, NFM F-179, x 8, BH-112.





ST GEORGE CATHOLIC FORMATION LOWER L-ESTONE SWEDEN



1 OF 1 DE

| Ischyrotoma analaphra Forley  
 | Ischyrotoma analaphra Forley (Billings)  
 | Isoteloides sp. undari.  
 | Bathyurellus abruptus (Billings)  
 | Uromystrum forteyi sp. nov.  
 | Benthamospis conica Forley





Strigigenalis caudata  
 (Range) Zone  
 - undetermined  
 higher level

Ischyrotoma parallela sp. nov.






	Strigigenalis caudata (Range) Zone - basal portion
	Strigigenalis brevicaudata (Range) Zone
	Barren Interzone II
DE	Randaynia saundersi (Assemblage) Zone

## LEGEND



### CARBONATE ROCK TYPES

-  Dolostone
-  Dolostone, limy
-  Limestone
-  Limestone, dolomitic





### PRIMARY DEPOSITIONAL TEXTURES

-  Mudstone
-  Wackestone
-  Packstone
-  Grainstone
-  Boundstone

### DIAGENETICALLY ALTERED TEXTURES




-  Crystalline
-  Sucrosic

### PARTICLES




-  Ooids
-  Intraclasts
-  Tabular pebbles (conglomerates)
-  Chert

### BIOTURBATION



(including burrows, trails, etc.)

-  Sparsely bioturbated
-  Moderately bioturbated
-  Extensively bioturbated




### ORGANIC BUILDUPS

-  Algal mounds
-  Stromatolite mounds
-  Thrombolite mounds

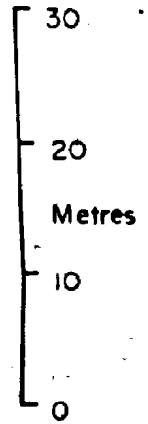
### FOSSIL COLLECTIONS

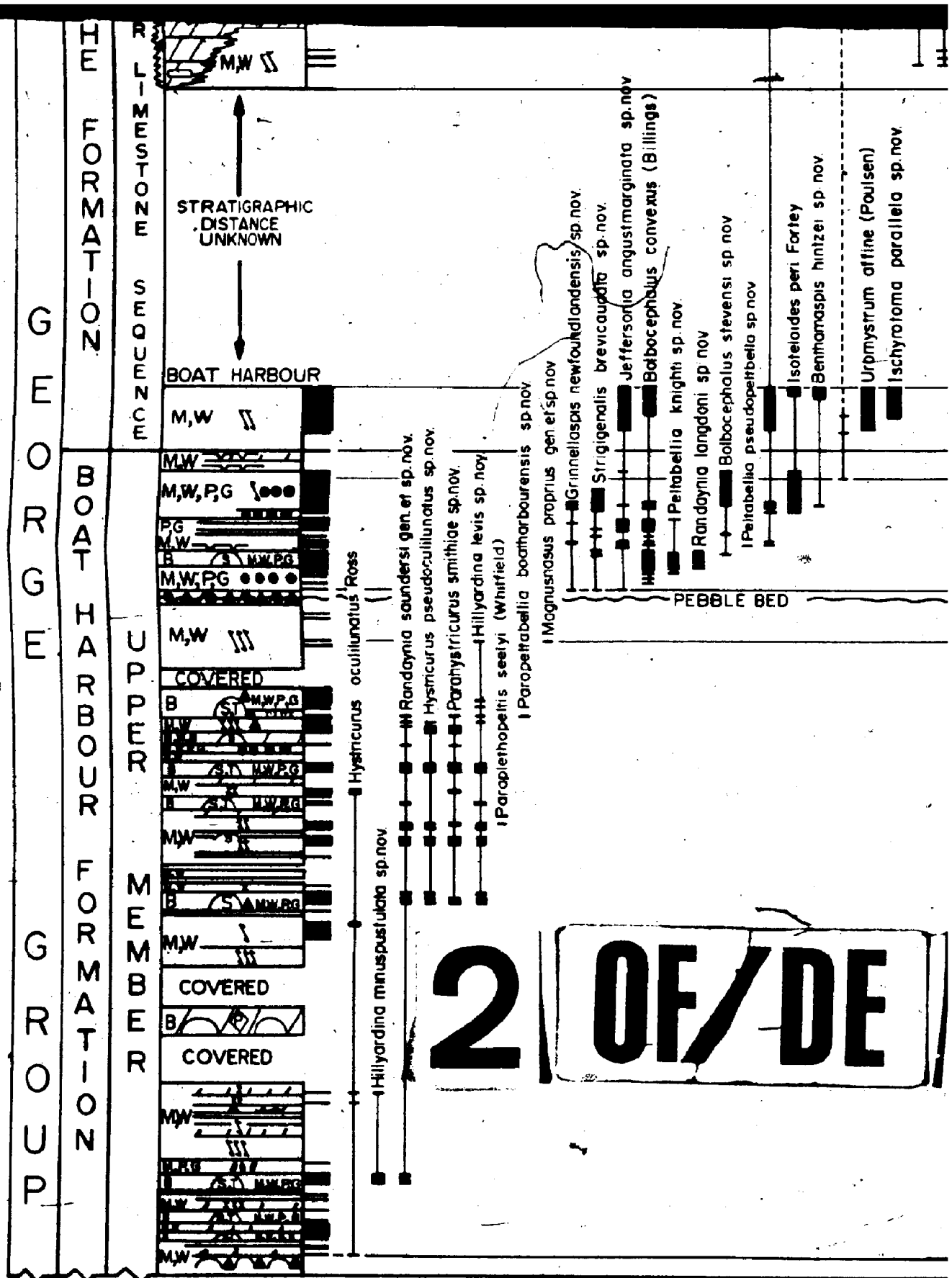
-  Single sampled horizon
-  Sampled interval

### SEDIMENTARY STRUCTURES

-  Interference ripples
-  Symmetric ripples
-  Mud cracks

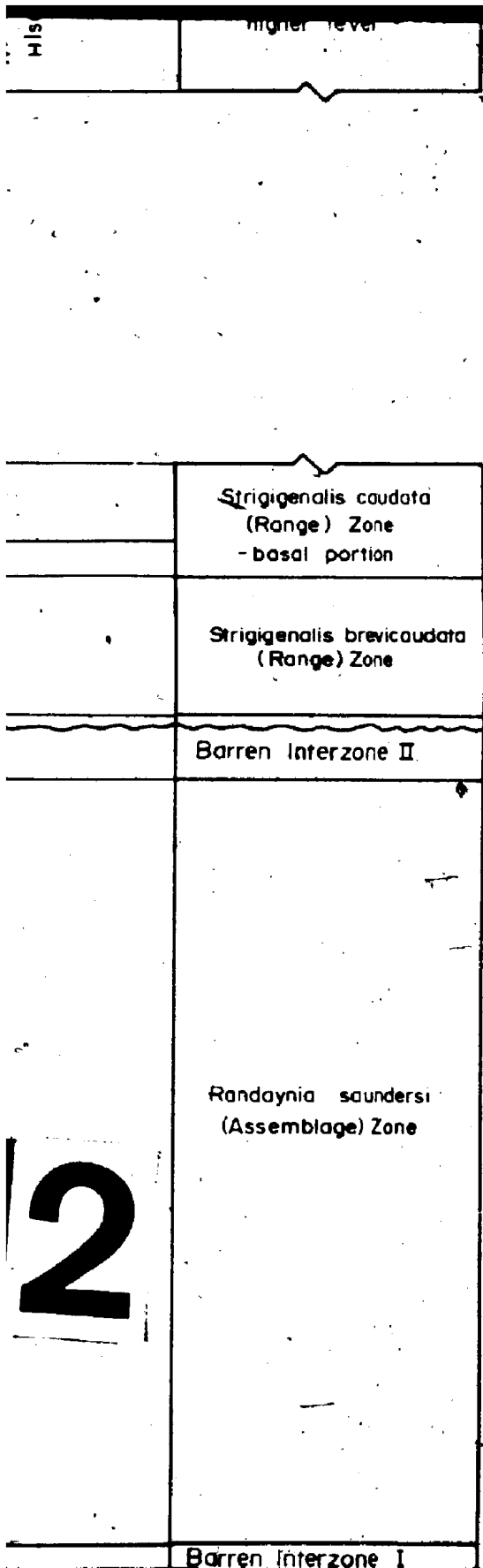
### EPIGENETIC STRUCTURES





2 OF/DE

Figure 3.1. Biostratigraphic zonation of the Boat Harbour and Catoche Formations in the Boat Harbour (1979a, Fig. 11) for stratigraphic ranges of trilobites in the upper part of the Strigigena the Catoche Formation on Pott au Choix Peninsula. Legend modified from Levesque (1979a).



- M** Mudstone
- W** Wackestone
- P** Packstone
- G** Grainstone
- B** Boundstone

**DIAGENETICALLY ALTERED TEXTURES**

- X** Crystalline
- Sucrosic

**PARTICLES**

- Ooids
- Intraclasts
- Tabular pebbles (conglomerates)
- Chert

**BIOTURBATION**

(including burrows, trails, etc.)

- Sparsely bioturbated
- Moderately bioturbated
- Extensively bioturbated

**ORGANIC BUILDUPS**

- Algal mounds
- Stromatolite mounds
- Thrombolite mounds

**FOSSIL COLLECTIONS**

- Single sampled horizon
- Sampled interval

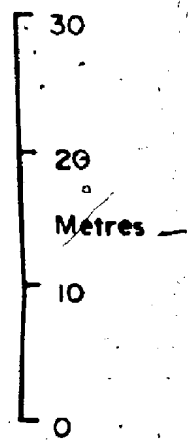
**SEDIMENTARY STRUCTURES**

- Interference ripples
- Symmetric ripples
- Mud cracks

**EPIGENETIC STRUCTURES**

- Pseudobreccia

DISCONFORMITY.



**Note:**

Major lithologies indicated on left side of column; minor/associated lithologies indicated on right side.

2 - Cape Norman study area: See Forley *Ilis caudata* (Range) Zone as developed in 77, Fig. 81.

IBEX, UTAH			
FM	TRILOBITE ZONES	CONODONT INTERVALS	
F I L L M O R E	↑	Jumudontus gananda	
	H	? Reutterodus andrus	
	G <sub>2</sub>		Oepikodus communis
			"Microzarkodina" marathonensis
	G <sub>1</sub>		Acodus deltatus
			Macerodus diana
	F		
	E		"Scolopodus" quadraplicatus
	?		aff. Scolopodus
	D		rex

\_\_\_\_\_ Hystericurus oculilunatus  
 \_\_\_\_\_ Benthamospis gibberula  
 \_\_\_\_\_ Benthamospis hintzei  
 \_\_\_\_\_ Carolinites genacinaca nevadensis  
 \_\_\_\_\_ "Scolopodus" quadraplicatus  
 \_\_\_\_\_ "Scolopodus" gracilis  
 \_\_\_\_\_ Drepanodus gracilis  
 \_\_\_\_\_ Tropodus comptus  
 \_\_\_\_\_ Oepikodus communis  
 \_\_\_\_\_ Macerodus diana

Figure 3.3. Range comparison of trilobite and conodont species common to [unclear] (1953), Terrell (1973) and Young (1973); conodont data from [unclear] (1979 a,b, 1983, this study), Fortey (1979a) and Boyce [unclear] Stouge and Boyce (1983).

WESTERN NEWFOUNDLAND			
FM	MBR	TRILOBITE ZONES	CONODONT FAUNAS
CATCOHE	LOWME	Strigigenalis caudata Zone	Fauna 4
BOATHR	DOLAR	Strigigenalis brevicaudata Zone	Fauna 3
		Barren Interzone II	
		Randaynia saundersi Zone	Fauna 2
			Fauna 1

Barren Interzone I

- *Hystericurus oculilunatus*
- *Benthomaspis hintzei*
- *Caralinites genocinaca nevadensis*
- *Benthomaspis gibberula*
- *Macerodus dianae*
- *Scotopodus* "gracilis"
- *Scotopodus* "quadraplicatus"
- *Drepanodus gracilis*
- *Tropodus-comptus*
- *Oepikodus communis*

ex, Utah and western Newfoundland. Ibsxian trilobite data from Hintze  
 npton and Clark (1981). Western Newfoundland trilobite data from Boyce  
 nd Boyce (1983); conodont data from Stouge (1982) and Stouge in Stouge

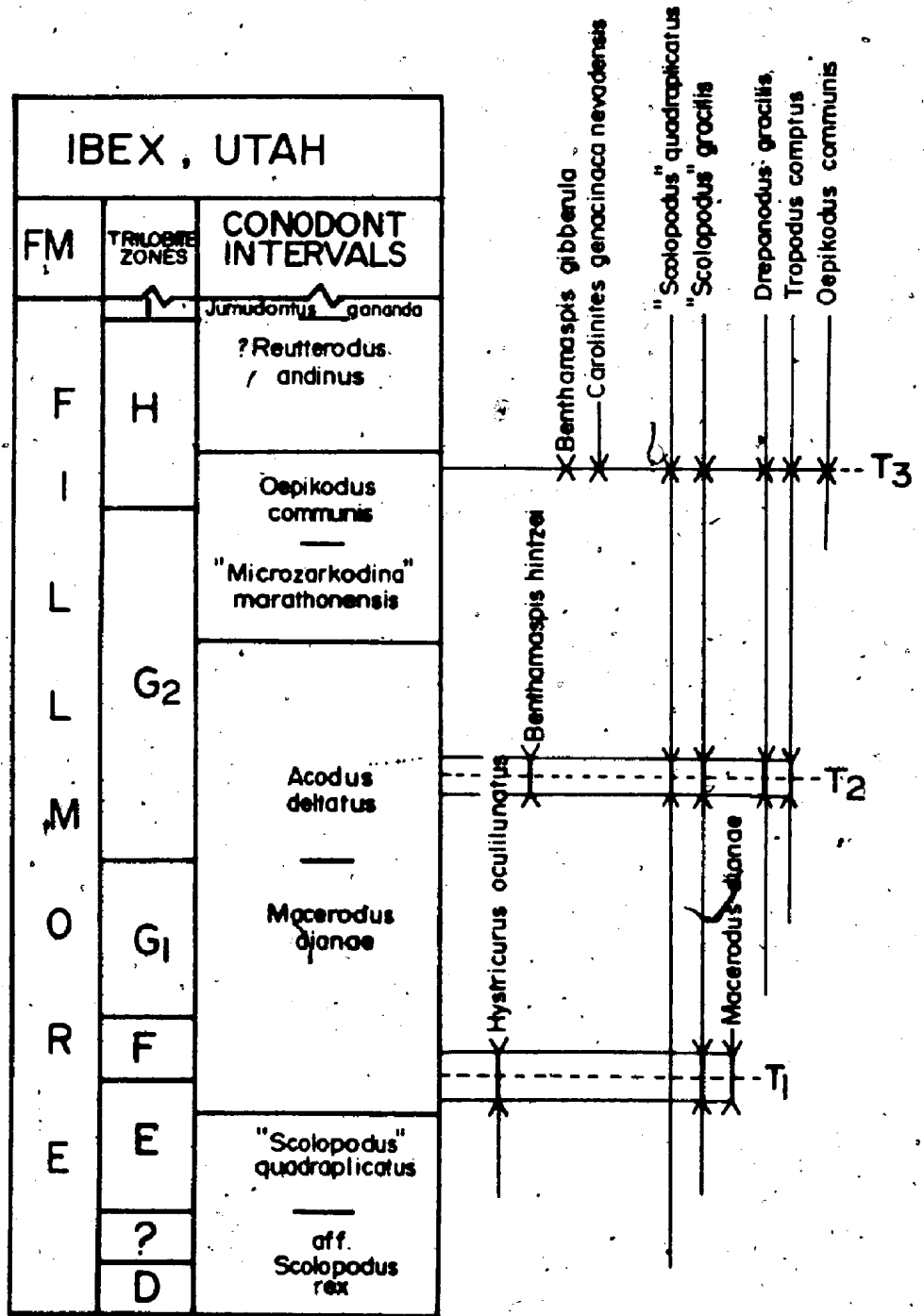
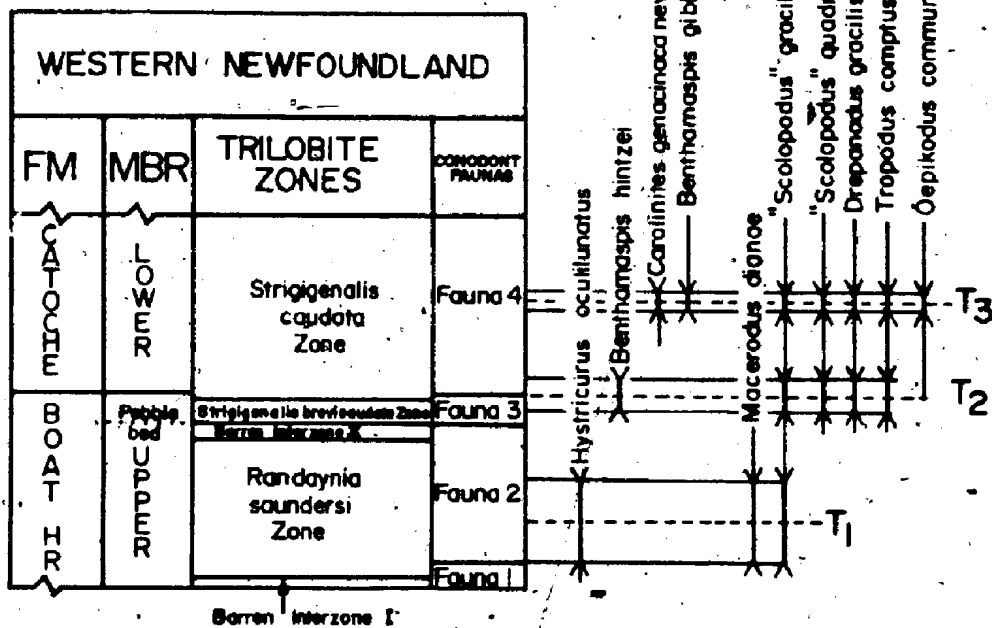


Figure 3.4. Correlation of trilobite-conodont species associations common to Ibex





- V - UPPER LIMIT OF TRILOBITE-CONODONT SPECIES ASSOCIATION
- STRATIGRAPHIC INTERVAL OF TRILOBITE-CONODONT SPECIES ASSOCIATION
- ^ - LOWER LIMIT OF TRILOBITE-CONODONT SPECIES ASSOCIATION
- T<sub>0</sub> - STRATIGRAPHIC MIDPOINT OF TRILOBITE-CONODONT SPECIES ASSOCIATION

Rah and western Newfoundland.

IBEX, UTAH			WESTERN NEWFOUNDLAND						
FM	TRILOBITE ZONES	CONODONT INTERVALS	FM	MBR	TRILOBITE ZONES	CONODONT FAUNAS	CEPHALOPOD ZONES		
F I L L E M O R E D	H	<i>Jurudontus</i> <i>genensis</i>	C A T O C H E	J O R D O N E — S U P — O Z I U M C O C C U R U	Strigigenalis caudata Zone	Fauna 4	Cassinoceras wortheni		
		Reutterodus andinus							
	Oepikodus communis								
	"Microzarkodina" marathonensis								
	G <sub>2</sub>	Acodus deltatus	B O A T H A R B O U R	U. M.	Strigigenalis brevicaudata Zone	Fauna 3	Pycnoceras apertum		
		Macerodus dianae						HIATUS	
	G <sub>1</sub>		S U S C A U D A C A U S	J O R D O N E S U P O Z I U M	Barron Interzone II	Fauna 2	Bassleroceras— Lecanospira		
	F	"Scolopodus" quadruplicatus						Randymia saundersi Zone	
	E	etf. Scolopodus rex						Barron Interzone I	Not zoned
	?							Not zoned	Not zoned
D									

Figure 3.5. Chart showing correlation of western Newfoundland trilobite zones, conodont faunas and cephalopod zones with the standard trilobite zones and conodont intervals of Ibex, Utah.

NEW YORK-VERMONT			
SERIES	STAGES FLOWER (1964) (1978)	FM	MBR
CANADIAN	CASSINIAN	FT CASSINIAN	PROV ISLAND DST.
			SCIOTA MEMBER
			WARD DST.
BERGIAN	FT ANN	LST.	

--- *Hysiricurus oculilunatus*  
 --- *Paraplethopeltis seelyi*  
 - - - *Strigigenalis caudata*  
 - - - *Benthomaspis gibberula*

WESTERN NEWFOUNDLAND		
FM	MBR	TRILOBITE ZONES
CAHOON	LOWR	<i>Strigigenalis caudata</i> Zone
BOATHE	DUDR	
	Pebble bed	<i>Strigigenalis lobocaudata</i> Zone
		<i>Randynia saundersi</i> Zone

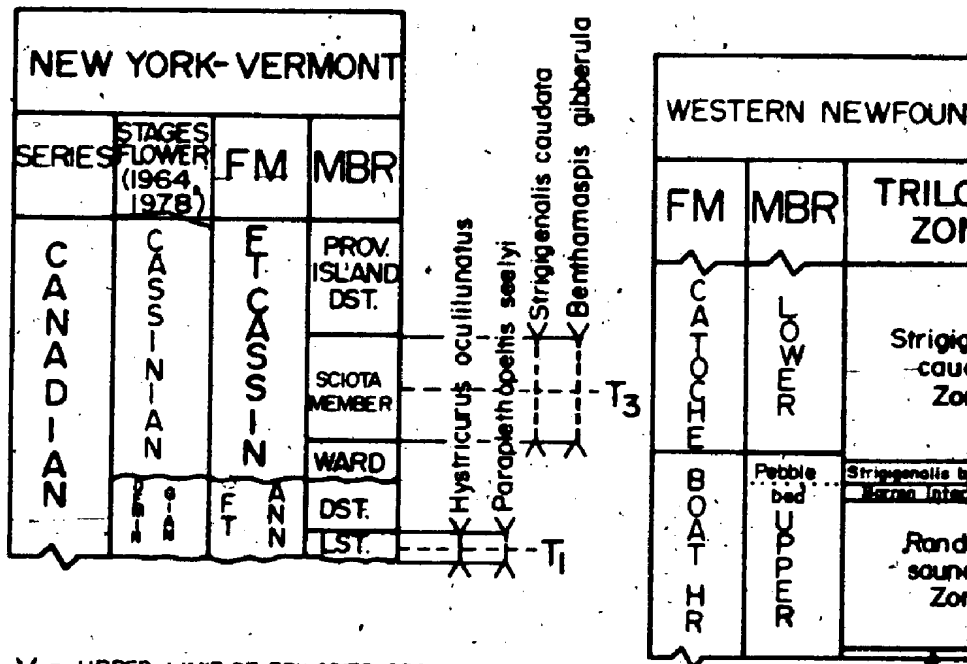
Barren Interzone I

--- *Hysiricurus oculilunatus*  
 X *Paraplethopeltis seelyi*  
 --- *Strigigenalis caudata*  
 --- *Benthomaspis gibberula*

MISSOURI - NORTHERN ARKANSAS				
SERIES	STAGES FLOWER (1964)	STAGES FLOWER (1978)	FM	MBR
CANADIAN	JEFFERSONIAN	CASSINIAN	POWELL	
			COTLER	
	WILLERSONIAN	WILLERSONIAN	WILLERSON CITY	BLACK-JACK KNOB
			WILLERSON CITY	LUTIE

--- *Peltabellia crassimarginata*  
 --- Genus(?) sp(?)  
 --- *Strigigenalis caudata*

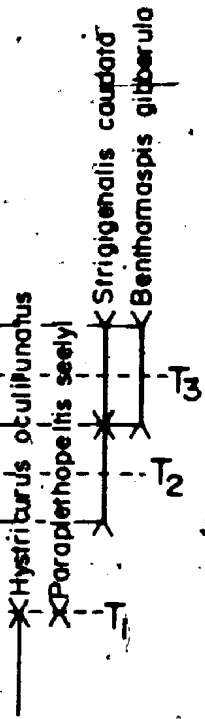
Figure 3.6 Range comparison of trilobite species common to New York - Vermont, Missouri - northern Arkansas and western Newfoundland. New York-Vermont data from Flower (1968c), Whitfield (1889a, 1897) and Whittington (1953); Missouri-northern Arkansas data from Cullison (1944); western Newfoundland data from Boyce (this study, unpublished), Boyce in Stouge and Boyce (1983) and Fortey (1979a).



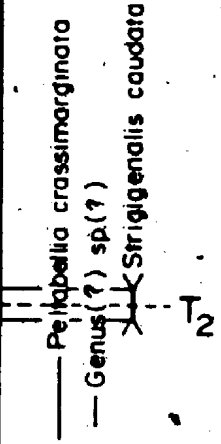
- V - UPPER LIMIT OF TRILOBITE SPECIES ASSOCIATION
- - - STRATIGRAPHIC INTERVAL OF TRILOBITE SPECIES ASSOCIATION
- ^ - LOWER LIMIT OF TRILOBITE SPECIES ASSOCIATION
- T<sub>0</sub> - STRATIGRAPHIC MIDPOINT OF TRILOBITE SPECIES ASSOCIATION

Figure 3.7. Correlation of trilobite species associations common to New York and Western Newfoundland.

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 caudata Zone  
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MISSOURI - NORTHERN ARKANSAS				
SERIES	STAGES FLOWER (1964)	STAGES FLOWER (1978)	FM	MBR
CANADIAN	ZAN-SON	ZAN-SON	LOWELL	
			WILSON	
	WILSON	WILSON	BLACK-JACK KNOB	
	WILSON	WILSON	LUTIE	



k - Vermont, Missouri - northern Arkansas and western Newfoundland.

NEW YORK-VERMONT			
SERIES	STAGES FLOWER (1964 1978)	FM.	MBR.
CANADIAN	CASSINAN	FT CASSIN	PROV ISLAND DST.
			SCIOTA MEMBER
			WARD
			DST.
			LST.

*Styaticurus oculilundus*  
*Benthomaspis gibberula*  
 T<sub>3</sub>  
 T<sub>1</sub>

- V - UPPER LIMIT OF TRILOBITE SPECIES RANGE
- STRATIGRAPHIC RANGE OF TRILOBITE SPECIES
- Λ - LOWER LIMIT OF TRILOBITE SPECIES RANGE
- T<sub>0</sub> STRATIGRAPHIC MIDPOINT OF TRILOBITE SPECIES RANGE

IBEX, UTAH		
SERIES	TRILOBITE ZONES	CONOD INTER
I B E X I A N	H	Jumudongia
		? Reutter andir
	G <sub>2</sub>	Oepiko comm
		"Microzai maratho
	G <sub>1</sub>	Acoc delta
		Macerc dian
	F	
	E	"Scolop quadrap
	?	of Scolop re
	D	

FIGURE 3.9. Correlation of range of trilobite species common to New York-Vermont data from Flower (1968c), Whitfield (18 Cullison (1944); Ibex, Utah data from Hintze (1953), Terr

		GREAT BRITAIN - SCANDINAVIA		NORTH AMERICA					
SYSTEM	SERIES	GRAPTOLITE ZONES	SERIES	STAGES	GRAPTOLITE ZONES	TRILOBITE ZONES	CONODONT INTERVALS		
O R D O V I C I A N	A R E N I G	<i>Didymograptus nitidus</i>	I B E X I A N	C A S S I N I A N	<i>Didymograptus brotobitidis</i>	H	<i>Jumudontus gananda</i>		
		Didymograptus deflexus			Tetragraptus fruticosus (3 and 4 branched)		? Reutterodus andinus		
		T R E M A C O D D A			Tetragraptus approximatus	Tetragraptus fruticosus (4 branched)	G <sub>2</sub>	G <sub>1</sub>	Oepikodus communis
					Adelograptus hunnebergensis — Clonograptus tenellus	Tetragraptus approximatus			Acodus deltatus — Macerodus dianeae
	D E M I N G I A N	D E M I N G I A N		Clonograptus flexilis — Adelograptus victoriae	D E M I N G I A N	D E M I N G I A N	F	"Scolopodus" quadruplicatus	
							E	— aff. Scolopodus rex	
?									
					D				

Figure 3.11. Correlation of Canadian and Ibebian Series with standard Ordovician graptolite zones of Great Britain-Scandinavia and North America. Correlation of graptolite zones after Skevington (1968, 1973).

• CHEWTONIAN

		GREAT BRITAIN		SCANDINAVIA		AUSTRALIA		
SYSTEM	SERIES	GRAPTOLITE ZONES	STAGES	GRAPTOLITE ZONES	SERIES	VICTORIAN GRAPTOLITE ZONES		SERIES
ORDOVICIAN	ARENIG	<i>Didymograptus rufidus</i>	LATORP	<i>Phyllograptus densus</i>	* C	Ch. 1	<i>Didymograptus protobifidus</i>	IBEXIAN
		<i>Didymograptus deflexus</i>		<i>Didymograptus balticus</i>	BENDIGONIAN	Be4	<i>Tetragraptus fruticosus</i> (3 branched)	
						Be3	<i>Tetragraptus fruticosus</i> (3 and 4 branched)	
						Be2	<i>Tetragraptus fruticosus</i> (4 branched)	
	Be1	<i>Tetragraptus approximatus</i> <i>Tetragraptus fruticosus</i>						
	TREMADOC		<i>Adelograptus hunnebergensis</i> — <i>Clonograptus tenellus</i>	CERATOPYGEE BEDS	<i>Adelograptus hunnebergensis</i> — <i>Clonograptus tenellus</i>	WARRENDIAN	La3	<i>Tetragraptus approximatus</i>
La2								

Figure 3.12. Correlation of late Tremadoc-early Arenig regressive-transgressive episodes in the four major other correlations by the author.



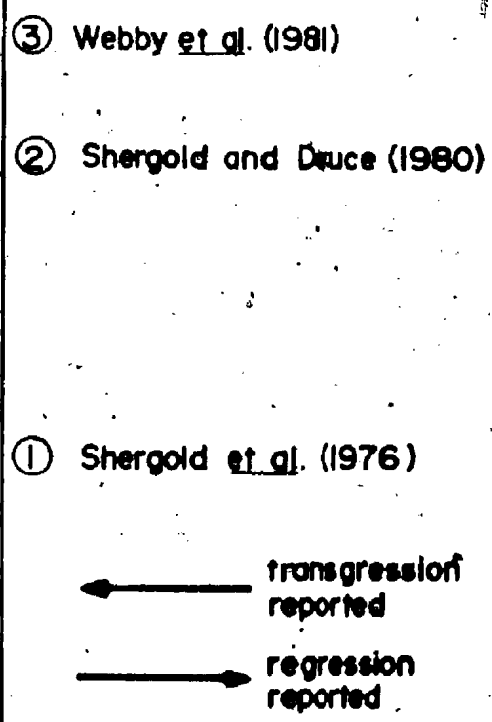
NORTH AMERICA					FAUNAL BATHYURID					SE. ONTARIO	
ES	STAGES	GRAPTOLITE ZONES	TRILOBITE ZONES	CONODONT INTERVALS	FM	MBR	TRILOBITE ZONES	CONODONT FAUNAS	CEPHALOPOD ZONES	FORMATION	
CANADIAN	CASSINIEN	<i>Ordymograptus protobilidus</i>	I	<i>Jumudontus ganonda</i>	CATOCHE	JORDAN 1-5 SWI-OZU MCCORMICK	Strigigenalis caudata Zone	Fauna 4	Cassinoceras wortheni	OXFORD	
		Tetragraptus fruticosus (3 and 4 branched)	H	? Reutterodus andinus						←	
		Tetragraptus fruticosus (4 branched)	G <sub>2</sub>	Oepikodus communis							
	Tetragraptus approximatus	"Microzarkodina" marathonsensis									
	JEFFERSONIAN	Tetragraptus approximatus	G <sub>1</sub>	Acodus deltatus	BOATHARBOR	LUMBER BAY	HIATUS	Fauna 3	Pycnoceras apertum	HIATUS	
				Macerodus dianae							
	DEMINGIAN	Clonograptus flexilis	F	"Scolopodus" quadruplicatus	SUSSEX	SUSSEX	Barren Interzone I	Fauna 2	Bassleroceras - Leconospira	MARCH	
			E	"Scolopodus" aff. Scolopodus rex							Barren Interzone II
		?		Randayna saundersi Zone							
		D		Not Zoned							Not Zoned

Early Ordovician faunal provinces of the world. Correlation of graptolite zonation of Great Britain, Scandinavia, Australia and North America.

CA		FAUNAL BATHYURID							AS	
		WESTERN NEWFOUNDLAND					S.E. ONTARIO	NEW YORK - VERMONT		NI
TRILOBITE ZONES	CONODONT INTERVALS	FM	MBR	TRILOBITE ZONES	CONODONT FAUNAS	CEPHALOPOD ZONES	FORMATION	FORMATION	FC	
	<i>Jumudontus gananda</i>	CATOCHE	LOWER MICHOCHE SUBZONE				OXFORD	FT. CASSIN (UPPER BASCOM)		
H	? <i>Reutterodus andinus</i>				Strigigenalis caudata Zone	Fauna 4	Cassinoceras wortheni	←	←	
	<i>Oepikodus communis</i> — "Microzarkodina" marathonensis									
G <sub>2</sub>	<i>Acodus deltatus</i> —	BOATHARBOUR	LOWER BOATHARBOUR SUBZONE	Strigigenalis brevicaudata Zone	Fauna 3	Pycnoceras apertum	HIATUS	HIATUS	LA	
G <sub>1</sub>	<i>Macerodus diana</i>				HIATUS					
F						Borren Interzone II <i>Randaynia saundersi</i> Zone	Fauna 2			
E	" <i>Scolopodus</i> " <i>quadruplicatus</i> — aff. <i>Scolopodus rex</i>			Borren Interzone I	Not Zoned	Bassleroceras - Leconaspira	MARCH	FT. ANN (LOWER BASCOM)	PA	
?				Not Zoned	Not Zoned					
D										

of the world. Correlation of graptolite zonation of Great Britain, Scandinavia, Australia and North America after

P R O V I N C E					
	ASAPHID	SELENOPELTIS		ASAPHOPSIS	
UNIT	NORTHERN ESTONIA	WALES	MOROCCO	BOHEMIA	AUSTRALIA
FORMATION	FORMATION	FORMATION	FORMATION	FORMATION	FORMATION
LATORP	LLYFNANT FLAGS and EQUIVALENTS	SCHISTES DES FEZOUATA SUPÉRIEUR	KLABAVA	KELLY CREEK	
	HIATUS	HIATUS	HIATUS	HIATUS	
PAKERORT	AMNODD SHALES and EQUIVALENTS	SCHISTES DES FEZOUATA INFÉRIEUR	MILINA	KELLY CREEK	



after Ross et al. (1982), Skevington (1968, 1969, 1973) and Webby et al. (1981);



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