CONODONTS AND PHOSPHATIC PROBLEMATICA FROM THE CAMBRO-ORDOVICIAN COOKS BROOK AND MIDDLE ARM POINT FORMATIONS, BAY OF ISLANDS, WESTERN NEWFOUNDLAND

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CONODONTS AND PHOSPHATIC PROBLEMATICA FROM THE CAMBRO-ORDOVICIAN COOKS BROOK AND MIDDLE ARM POINT FORMATIONS, BAY OF ISLANDS, WESTERN NEWFOUNDLAND

BY

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A thesis submitted to the school of Graduate
Studies in partial fulfillment of the
requirements for the degree of
Master of Science

Department of Earth Sciences
Memorial University of Newfoundland
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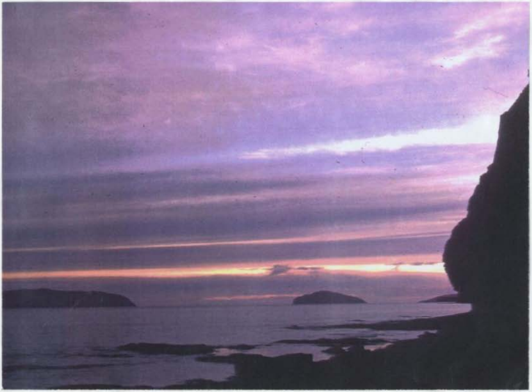

FRONTISPIECE

Sunset at Bay of Islands

End of another day in the field

ABSTRACT

The Cooks Brook and Middle Arm Point formations, situated in Bay of Islands, western Newfoundland mainly consist of deep-water carbonates and shales ranging in age from middle Cambrian to early Ordovician. Previous studies have shown that these rocks were deposited as a "base-of-slope sediment apron", downslope from a carbonate platform.

A total of 143 samples from five sections spanning the Cooks Brook and Middle Arm Point formations were collected for conodonts and other microfossils. Of these, 38 samples yielded identifiable conodonts and 19 samples yielded various types of phosphatic problematica. Systematic study of the conodonts have resulted in the identification of 68 species which are assignable to 36 genera. Three new unnamed genera have been described.

The conodont fauna permits the recognition of six standard uppermost Cambrian-lowermost Ordovician conodont zones within the Cooks Brook Formation. These zones are: (i) Proconodontus tenuiserratus Zone, (ii) Proconodontus muelleri Zone, (iii) Eoconodontus Zone, (iv) Cordylodus proavus Zone, (v) Cordylodus angulatus Zone and the (vi) Loxodus bransoni Interval.

The conodonts from the lower part of the Middle Arm Point Formation are assigned to Fauna D of Ethington and Clark (1971) while conodonts from the uppermost Middle Arm Point Formation are assigned to the Prioniodus elegans Zone.

Based on the conodont fauna the age of middle and upper Cooks Brook Formation ranges from uppermost Franconian to middle(?) Tremadocian. The Middle Arm Point Formation, on the other hand, ranges in age from middle(?) Tremadocian to lower Arenigian. Within the Cooks Brook Formation, the Cambro-Ordovician Boundary can be placed either at the base of the Cordylodus proavus Zone or at the base of the Cordylodus angulatus Zone.

The abundance and distribution of conodonts within the Cooks Brook and Middle Arm Point formations show strong environmental control and suggest that most of these conodonts were benthic or nektobenthic in habit.

The phosphatic problematica recovered from the Cooks Brook and Middle Arm Point formations exhibit a variety of morphologies and have been divided into four broad, informal groups, namely (i) phosphatic plates and related microfossils, (ii) spherical microfossils, (iii) tubular microfossils, (iv) miscellaneous microfossils and (v) nauplius-like larvae. This large fauna, most of which is

previously undescribed, have been described in detail using open nomenclature. Of the previously described forms, three new types (species?) of *Anatolepis* Bockelie and Fortey are described and the significance of this type of fossil in the earliest history of vertebrates is discussed. The presence of nauplius-like larvae in the Middle Arm Point Formation is of special interest as this is the first reported find of such fossils in North America.

(KEY WORDS: Conodonta, Cambro-Ordovician, Bay of Islands, western Newfoundland, Cooks Brook Formation, Middle Arm Point Formation, Curling Group, Biostratigraphy, Cambro-Ordovician Boundary, Paleoecology, Taxonomy, Phosphatic problematica, Nauplius-like larvae)

Dedication

To My Parents

Who still do not understand why I became a paleontologist, but have continued to support me in my endeavors anyway.

ACKNOWLEDGEMENTS

This project could not have been undertaken without the advice, encouragement and criticism of my supervisor Lars E. Fåhraeus who was always there to answer my questions and to listen to all of my outrageous and not so outrageous ideas. I take this opportunity to express my sincerest gratitude to him. Jack W. Botsford not only introduced me to the various sections, but also shared his knowledge of the Bay of Islands area as well as his sedimentologic data, thereby making the task a lot easier for me. I am extremely grateful to him for all the help. Sincere thanks are also due to R. K. Stevens for offering encouragement and sharing his vast knowledge in various fields.

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I would also like to thank Aubrey and Ted Sheppard and family of Cox's Cove for providing invaluable assistance and hospitality during fieldwork.

My friends and fellow students at Memorial have not only provided moral support and comraderie but through regular discussions involving a wide range of topics over countless bottles of beer have certainly helped improve the quality of this work. I would particularly like to thank James Waterfield, Rob Grenier, Chris Ryley, Peggy Harrigan, Nathaniel Ostrom, Kerry Sparkes, Ewan Cumming, Mike Gipp, Louise Quinn, Sheila Stenzel, Günter Suhr and Jeroen van Gool and the past and present occupants of Decadence Alley and Death Row for making my stay in St. John's extremely memorable.

I would also like to acknowledge the continued moral and financial support from my family over the years which has certainly made life a lot easier for me.

Finally, in a project like this there are so many people involved that it is impossible to acknowledge everybody individually. So to all those people directly or indirectly involved in this project and not mentioned here, thank you too.

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CHAPTER 1

INTRODUCTION

1.1 Introductory remarks

The Cooks Brook and Middle Arm Point formations situated in Bay of Islands, western Newfoundland consist of an allochthonous deep-water carbonate sequence ranging in age from middle Cambrian to early Ordovician. A number of conodonts and phosphatic problematica recovered from this suite of rocks form the focus of this paleontologic study.

1.2 Regional Geology

The westernmost part of the Appalachian Orogen in Newfoundland is called the Humber Zone (Williams, 1979) and consists of a thick package of autochthonous miogeoclinal sediments of Lower Cambrian to Middle Ordovician age which is structurally overlain by two allochthons. These two allochthons are, (a) the Humber Arm Allochthon and (b) the Hare Bay Allochthon to the north. The Cooks Brook and Middle Arm Point formations are part of the Humber Arm Allochthon. According to Stevens (1970), the rocks of the Humber Zone record the growth and destruction of an Atlantic type continental margin on the northern side of the Iapetus Ocean. This zone is bordered on the eastern side by the Dunnage Zone which, according to Williams (1979), represents the remains of an ancient ocean. The Humber Arm and the

Hare Bay allochthons were emplaced during the Middle to Late Ordovician Taconic orogeny which is generally considered to mark the initial closing of the Iapetus Ocean.

The authochthonous succession within the Humber Zone consists of the Lower to Middle Cambrian Labrador Group, the Middle to Upper Cambrian Port Au Port Group (Chow, 1986), the Lower Ordovician St. George (Knight and James, 1987) and Table Head (Klappa _et al_., 1980) groups and the Mainland Sandstone (Schilleref and Williams, 1979) and its equivalents.

The Humber Arm Allochthon consists of the Humber Arm Super Group (Stevens, 1970) and the Bay of Islands Ophiolite Complex. Within the allochthon, structural slices of igneous and volcanic rocks occur locally (Botsford, 1988). The Humber Arm Allochthon exhibits structures related to three major tectonic events. The westward emplacement of the allochthon during the Taconic Orogeny is reflected structurally by dominant thrust imbrication (Botsford, 1988) which were modified by the Devonian Acadian Orogeny (Williams, 1979). It has been proposed (Williams, 1979, Bosworth, 1985, Waldron, 1985) that the high angle normal faults which affect the deformed sediments within the allochthon are the result of the Alleghanian Orogeny.

1.3 Stratigraphy

1.3.1 Previous Work

The first study dealing with the rocks in the Humber Arm area appears to be that of Murray who, in 1874, mapped them on a regional scale and subdivided them very broadly into the Levis Shales, Sillery Sandstones and "Serpentines etc.".

Schuchert and Dunbar (1934), in their comprehensive study of the sedimentary rocks of western Newfoundland, introduced, for the first time, the term "Humber Arm Series" for sedimentary rocks exposed in the Bay of Islands area. They described the type section of this series as : "(The Humber Arm Series) begins with a great thickness of dark shales, exposed near the mouth of the Humber River. These are followed on the west by another group of strata in which there are many zones of quartzite and a few limestone conglomerates interbedded in greenish shale, together with a few red shale zones. West of these the land is occupied for several miles by dark shales and thick zones of thin-bedded limestones, with prominent beds of limestone conglomerates." This crudely subdivided series was interpreted as a Middle to Upper(?) Ordovician package stratigraphically overlying the Lower Paleozoic carbonate sequence of western Newfoundland.

Walthier (1949) attempted a more detailed subdivision of the Humber Arm Series and recognized three lithological divisions. These were (i) the Lower Humber Arm shales, sandstones and conglomerates succeeded by (ii) the Cooks Limestone which in its turn was succeeded by (iii) the Upper Humber Arm black shales and sandstones. Although this subdivision is more detailed than that of Schuchert and Dunbar (1934), the Humber Arm Series was still interpreted as a sequence of Middle to Upper(?) Ordovician sedimentary rocks stratigraphically overlying the Lower Paleozoic carbonates of western Newfoundland. In fact, this misconception about the stratigraphic contact between the Lower Paleozoic carbonates and the Humber Arm Series was to persist for a long time until Rodgers and Neale (1963) finally proved the allochthonous nature of the Humber Arm rocks and proposed that these rocks are coeval with the Lower Paleozoic carbonate succession of western Newfoundland. .

Lilly (1963) gave group status to Schuchert and Dunbar's "Humber Arm Series" and divided this new Humber Arm Group into five separate divisions. From bottom to top these were, (i) Undivided shales (mainly dark shales) (ii) Penguin Arm quartzites (partly interbedded quartzites) (iii) Penguin Arm Limestone formation (thinly bedded limestones) (iv) Western Sandstone formation (shales with interbedded sandstones) and (v) Humber Arm volcanic rocks (a thick sequence of basalts, andesites and lesser amounts of rhyolites). As far as the relationship of this group with the underlying rocks was concerned, Lilly concluded, "This group overlies the main carbonate groups with great unconformity." (underlining mine).

McKillop (1963) in a regional study also recognized a tripartite division of the Humber Arm Group consisting of (i) a dominantly shaly lower member (ii) a middle member composed of quartzitic conglomerates, sandstones and some interbedded shales and (iii) a mainly shale-rich upper member with lenticular calcirudites near the base.

The broad stratigraphic framework currently in use in the Bay of Islands area was first proposed by Stevens (1965). Although this original proposal of Stevens has undergone certain modifications over the years it still remains useful and forms the basis for the stratigraphic framework adopted in this study as discussed later. In this early study by Stevens, the Humber Arm Group was regarded as ranging in age from Early Cambrian to Middle Ordovician and was subdivided into five different formations which were separated by transition zones. From bottom to top these were (i) Summerside Formation, (ii) Meadows Formation, (iii) Cooks Formation, (iv) Middle Arm Point Formation and (v) Woods Island Formation.

The studies of Stevens (1965) and Brückner (1966) contributed immensely to the understanding of the allochthonous nature of the "Humber Arm Group". The stratigraphic scheme in the study by Brückner (1966) is similar to that of Stevens (1965) for the most part. The six formations proposed by Bruckner were, from bottom to top, (i) Summerside Formation, (ii) Irishtown Formation, (iii) Cooks Brook Formation, (iv) Middle Arm Point Formation, (v) Blow-Me-Down Brook Formation and (vi) Humber Arm Volcanics.

The terminology was further modified when Stevens, in a 1970 paper, proposed the name Curling Group for the transported sediment packages underlying the Bay of Islands ophiolite sequence. The name Curling Group thus replaced the name "Humber Arm Group" of earlier workers. In that particular study the name Humber Arm Supergroup was also invoked, for the first time, to refer to all the transported sediment packages belonging to the Curling Group and the Cow Head Group to the north.

The most recent study dealing with the stratigraphy of the Bay of Islands area is by Botsford (1988). In this comprehensive study, he used the name Curling Group to refer to the mainly clastic sequence of the Summerside and Irishtown formations. A new name, Northern Head Group, was introduced for the limestone and shale dominated Cooks Brook and Middle Arm Point formations of Stevens (1965) while the easterly-derived flysch underlying the Bay of Islands Igneous Complex was given the name Eagle Island Formation.

1.3.2 Curling Group, a few comments

It is clear from the above discussion that although the basic stratigraphic framework applicable to the transported sedimentary sequences of the Bay of Islands area remains essentially similar to that proposed by Stevens (1965), the nomenclatorial scheme is still in a state of flux. Until this confusion over nomenclature is formally resolved it is difficult to follow any one stratigraphic scheme while working in the area. The stratigraphic scheme used in this study is derived from Stevens (1970) and Botsford (1988). The definitions of Cooks Brook and Middle Arm Point formations used in this study are from Botsford (1988) and these definitions are believed to be valid and preferable over the earlier definitions. However, Botsford, as stated before, invoked the informal name Northern Head Group for Cooks Brook and Middle Arm Point formations. In my opinion the introduction of this new division is not really necessary as the two formations in question can quite easily be placed under the Curling Group (sensu Stevens (1970)), as has traditionally been done. The Eagle Island Formation, as defined by Botsford, consists only of the easterly-derived flysch and hence is preferable over the Blow-Me-Down Brook Formation which included the flysch as well as some of the tectonic melange. Thus the term Curling Group in this study consists of five formations namely, (i) Summerside Formation, (ii) Irishtown Formation, (iii) Cooks Brook Formation, (iv) Middle Arm Point Formation and (v) Eagle Island Formation.

The focus of this particular study is on the Cooks Brook and Middle Arm Point formations and hence these have been dealt with in more detail in the following sections. For a detailed description of the other formations within the Curling Group see Stevens (1970) and Botsford (1988).

Due to the deformed nature of the rocks in the Bay of Islands area, continuous sections spanning the Cooks Brook and Middle Arm Point formations are absent. The stratigraphy, thus, has to be assembled by piecing together structurally isolated sections spanning various parts of the two formations. This task has been done quite admirably by Botsford (1988). The following descriptions are based mainly on Botsford's work supplemented by the authors personal field observations. Due to the nature of this study, it is neither possible nor necessary to include an extremely detailed discussion of all the different units present in the area. A generalized discussion of the two formations and the six sections studied is presented here and the interested reader is referred to Botsford (1988) for a detailed treatment of the subject.

1.3.3 Cooks Brook Formation

The Cooks Brook Formation is best exposed between Halfway Point and Giles Point in the form of the "Cooks Brook Syncline" from where it derives its name. It is also exposed along the north shore of the Middle Arm (Appendix A), in isolated fragments within the "Rattler Window" and on the opposite shore of the Humber Arm. The Cooks Brook Formation is underlain by the Irishtown Formation and overlain by the Middle Arm Point Formation. The contact between Cooks Brook and Middle Arm Point formations is transitional. The base of the Cooks Brook Formation, according to Botsford (1988), "is placed at the first carbonate bed which appears above the black shale-dominated interval of the uppermost Irishtown". Due to its deformed nature, the total thickness of the Cooks Brook Formation is difficult to ascertain. The total composite thickness of the formation has been estimated to be approximately 350 metres by Botsford (1988).

The lowermost part of the Cooks Brook Formation has been termed the Irishtown/Cooks Brook transition interval by Botsford (1988). This fairly distinctive interval is best exposed at the type section at Halfway Point. Among the sections studied here, the interval is present at Northern Head. At Northern Head this interval has been disrupted by faulting (Appendix B).

The lithology of this transition interval is a mixture of carbonates and shales. The carbonate part includes granule to pebble conglomerates and isolated beds of grainstone, which commonly are dolomitic. The lower part of the interval is dominated by grey or black shales interbedded with carbonates while the upper half is dominated by black/green/dolomitic banded shale (Botsford, 1988).

Although the transitional basal interval of the Cooks Brook Formation is generally similar in all the sections, it is overlain in different sections by units of different ages. According to Botsford (1988) this "suggests a localized and variously punctuated onset of carbonate sedimentation."

At the type section of Cooks Brook Formation, the lowermost interval is overlain by the conglomerate dominated Halfway Point Member. However, this member is not well defined in the sections examined in this study and hence is not dealt with in detail here.

The Lowermost Cooks Brook Interval is overlain at Northern Head by the Brakes Cove Member (Botsford, 1988) (Appendix B). This member is also present in the Woman Cove section. The thickness of this unit has been estimated as 12 to 15 metres (Botsford, 1988). This member consists mainly of conglomeratic units interbedded with nodular to ribbon limestone. The conglomerates are dominated by pebble to cobble sized clasts and the units often have a lensoid appearance.

The Brakes Cove Member is conformably overlain by a ribbon lime grainstone interval at the Northern Head section (Appendix B). This lime grainstone interval is also partially present at the Woman Cove section. At Northern Head the thickness of this interval has been estimated as 100 metres. Isolated packages of parted lime grainstone are present in this interval. The carbonates of this interval are interbedded with green and grey shales. Thin lenses of platy conglomerates are also encountered within this interval. A zone of very chaotic folding occurs within this interval (fig. 1-1) and, according to Botsford (1988), this folding may be slump-related. The upper part of this ribbon lime grainstone interval, at Northern Head, contains rippled, dark lime grainstone beds 15 to 20 centimetres thick and some intraformational conglomerates. The topmost part of the section consists of parted limestone and some minor conglomerate beds. An important characteristic of the ribbon lime grainstone interval is the presence of abundant quartz sand-grains in the carbonates (Botsford, 1988). These sand grains are easily discernible in thin section but are not visible in the field. Most of the grainstones of this interval contain these well rounded, medium to fine grained quartz grains.

At Woman Cove section the Brakes Cove Member is overlain by a shale and mudstone dominated interval

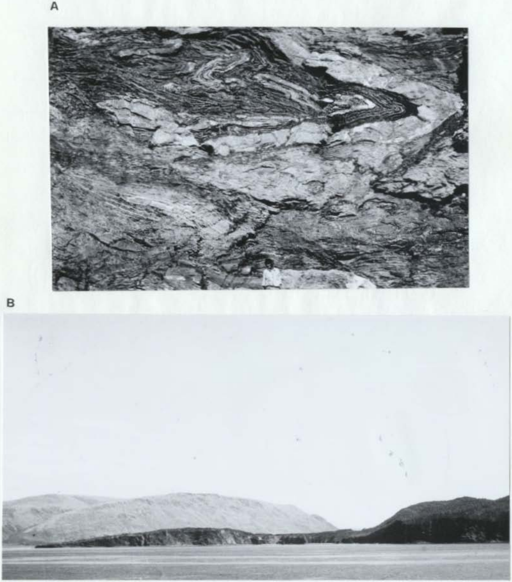


Figure 1-1. (A) Slump folding at Northern Head (B) North Arm Point section, general view.

(Botsford, 1988) in contrast with the lime grainstone interval at Northern Head. In addition, a second conglomeratic interval, somewhat similar to that at Northern Head, also occurs in this section (Appendix B).

At Northern Head, the lime grainstone interval is followed upwards by a prominent conglomerate occurring within a parted ribbon lime grainstone sequence (Appendix B). This has been termed the lowermost Ordovician conglomerate by Botsford (1988). The conglomerate consists of pebble- to boulder-sized clasts and is about 2 meters in thickness. The conglomerate unit exhibits planar boundaries and does not seem to have any internal grading. According to Botsford (1988) this conglomerate represents the youngest polymict conglomerate within the Curling (Northern Head of Botsford) Group.

The topmost part of the Cooks Brook Formation is dominated by a ribbon limestone interval (Tremadoc ribbon limestone interval of Botsford). This sequence is exposed in a number of sections. At Northern Head this interval has been disrupted by normal faulting but according to Botsford (1988) is in stratigraphic continuity with the underlying conglomerate described above (Appendix B). This sequence is also present at the core of a very complexly deformed anticline at Eagle Island south and at the base of the North Arm Point section (Appendix B). A highly deformed interval of similar lithology occurs at Woman Cove and has been correlated with this sequence by Botsford (1988). This interval is always either deformed or only partially exposed and hence its total thickness is extremely difficult to judge. A thickness of 30+ meters has been estimated by Botsford (1988), which seems to be reasonable. Although this interval is overlain by the basal member of the Middle Arm Point Formation (Woman Cove Member) the nature of the contact between the two is difficult to interpret due to the structural complexities. The lithology of this interval varies somewhat from section to section and because of the nature of exposures the mutual relationships of the sections containing this interval is not understood (Botsford, 1988). At Eagle Island south, this interval is present as interbeds of lime mudstone within a very tightly folded interval of black shales. At Northern Head the interval is fault bounded and consists of laminated black shales and interbedded lime mudstones. This interval occurs at the base of the section at North Arm Point and consists of finely laminated siliceous black shale interbedded with lime mudstone (Appendix B). The shale is often quite organic-rich and the lower part of the section also contains lensoid pebble conglomerates (Botsford, 1988). Here the topmost part of this interval contains a thin band of chert and passes upwards into sequence dominated by interbedded black and green shales.

1.3.4 Middle Arm Point Formation

The Middle Arm Point Formation stratigraphically overlies the Cooks Brook Formation. Stevens (1965) defined the base of this formation as the base of a yellow-weathering silty dolostone unit immediately overlying the uppermost Cooks Brook Formation (Appendix B). This dolostone unit is quite distinctive, easily mappable and forms a very good lithologic marker. The basal member of the Middle Arm Point Formation is termed the Woman Cove Member (Botsford, 1988). Exposures of this member are present at Woman Cove and North Arm Point (fig. 1-1). The type section of this member is at North Arm Point (Appendix B). A similar unit is also present at Eagle Island South (Appendix B), but the relationship of this unit is hard to determine due to its deformed nature (Botsford, 1988). As a whole, this unit is characterized by the presence of yellow-weathering silty dolostone beds which are often bioturbated and cross-laminated. Botsford (1988) interpreted the dolomite present in these units as "detrital dolomite" based mainly on petrographic evidence. The thickness of this member varies from about 12 metres at North Arm Point to about 17 metres at Woman Cove. This interval is underlain by units of somewhat different nature at North Arm Point and Woman Cove. At North Arm Point the Woman Cove Member overlies a sequence of interbedded black and green shale, ribbon limestone, lime mudstone and some conglomerates. The underlying unit at Woman Cove section is composed of ribbon limestone. At Woman Cove the dolomites are succeeded by a unit of green shale with thin beds of lime mudstone and minor granule conglomerate lenses while at North Arm Point a conglomerate consisting of pebble sized clasts immediately overlies the dolomites (Botsford, 1988). At Eagle Island South the dolostones are followed upwards by a shaly sequence which in turn is overlain by a pebble conglomerate.

At North Arm Point a sequence of parted lime grainstone appears above the shales overlying the Woman Cove Member (Appendix B). Exposures of this interval are also found on Eagle Island and in a cove just east of North Arm Point (Botsford, 1988). The exposures of this interval on both sides of North Arm Point have been interpreted as occuring on the opposite limbs of an isoclinally folded and sheared anticline (Botsford, 1988). The thickness of this unit is about 10 meters. At North Arm Point both the upper and lower contacts of the unit are sheared. However, these have been interpreted as sedimentary and not tectonic due to the gradual change of the lithology across these boundaries (Botsford, 1988). This sequence as a whole consists of dark coloured lime grainstone interbedded with black shale. The limestone is often bioturbated and exhibit infrequent ripples.

The lime grainstone interval is overlain by the North Arm

Point Member. The type section of this member is at North Arm Point and exposures also occur on Eagle Island. The total thickness of this unit is about 20 to 22 meters. This sequence is composed mainly of siliceous green shale (Appendix B). The shale contains thin interbeds of black shale and thicker packages of dolomite. The dolomites often exhibit cross-lamination. At North Arm Point this member is overlain by shales and red cherts. The upper part of the member shows evidence of shearing but again has been interpreted as transitional as it contains interbeds of the overlying red shale (Botsford, 1988).

The North Arm Point Member is succeeded by the uppermost Middle Arm Point Formation (Botsford, 1988). Exposures of this interval are common at North Arm Point, Eagle Island South and Eagle Island North among other places (Appendix B). This unit is dominated by red, black and green shales with some thin interbeds of carbonates. The shales of this interval are often silicified and occur as chert throughout the interval. Due to its shaly (cherty) nature this sequence has not been sampled and is outside the scope of this study.

As stated before, the Middle Arm Point Formation is succeeded upwards by the Eagle Island Formation which is dominantly clastic in nature and hence is not discussed here.

1.4 Depositional Model

The most comprehensive work on the depositional history of the Cooks Brook and Middle Arm Point formations is by Botsford (1988). In that study, he disputed the conventional notion of these two formations being the distal equivalents of the more famous Cow Head Group to the north and proposed a new depositional model for them. The following is an attempt to summarize the salient features of the model proposed by Botsford (1988).

The Cooks Brook and Middle Arm Point formations are generally interpreted as parts of a carbonate "base-of-slope" apron which was probably deposited downslope from a Lower Paleozoic carbonate platform. This carbonate apron is underlain by the clastic rocks of the Irishtown Formation which, according to this model, were deposited in a submarine fan environment. The style of sedimentation within the Cooks Brook and Middle Arm Point formations shows considerable variation through time and this has been interpreted to be the result of the changing nature of the platform margin itself.

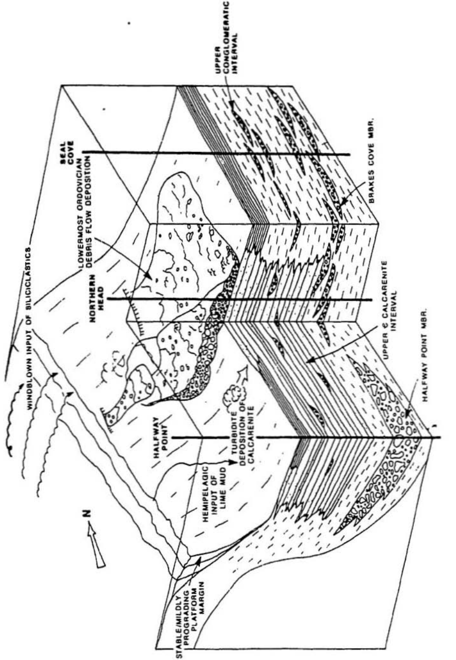
As a whole the Cooks Brook Formation appears to have been deposited in a poorly oxygenated and fairly deep water environment. This setting is characterized by the presence of hemipelagic black shales and resedimented carbonates, probably derived from the platform by gravity-transport mechanisms. The earliest sediments of the Cooks Brook

Formation were probably deposited at the mouths of submarine canyons and were later covered by extensive debris flow deposits and carbonate turbidites derived from the shallow-water platform margin occuring upslope from the depositional site (Fig. 1-2). The presence of gravity-transported carbonates within the Cooks Brook Formation appears to have decreased through time while hemipelagic sedimentation persisted longer.

The transition from Cooks Brook to Middle Arm Point Formation seems to be characterized by a major change in the style of deposition. Middle Arm Point Formation is more shale rich compared to the Cooks Brook Formation. The sediments of the Middle Arm Point Formation also contain abundant dolomite and frequently show evidence of reworking by bottom currents. These observations combined with the presence of extensive bioturbation, a "suboxic diagenetic regime" and a marked decrease in the presence of shelf and slope derived organic carbon has led to the postulation that the sediments of Middle Arm Point formation were deposited under more oxygenated conditions than that of the Cooks Brook Formation (see Botsford, 1988 for detailed discussion). According to Botsford's model, the style of deposition of the Middle Arm Point sediments seems to indicate the development of a new, "low-relief" carbonate platform margin upslope from the depositional site at that time (Fig. 1-3). This low relief platform margin continued

Figure 1-2

Schematic diagram showing the depositional setting of the Cooks Brook Formation during the Cambrian times (from Botsford, 1988).


WINDBLOWN INPUT OF SILICICLASTICS
LOWERMOST ORDOVICIAN DEBRIS FLOW DEPOSITION
SEAL COVE
UPPER CONGLOMERATIC INTERVAL
BRAKES COVE MBR.
NORTHERN HEAD
UPPER Є CALCARENITE INTERVAL
HALFWAY POINT MBR.
HALFWAY POINT
TURBIDITE DEPOSITION OF CALCARENITE
HEMIPELAGIC INPUT OF LIME MUD
N
STABLE/MILDLY PROGRADING PLATFORM MARGIN

until lower Ordovician (uppermost Tremadoc?) times when it gradually started collapsing. The last stage in this sequence of events is marked by the arrival of the sandstones of the Eagle Island Formation which finally burried the crumbling carbonate margin.

The depositional model proposed by Botsford (1988) offers quite an elegant explanation for the sequence of events observed in the rocks of Cooks Brook and Middle Arm Point formations and as discussed later seems to conform with the paleontologic data obtained in this study.

1.5 Methods

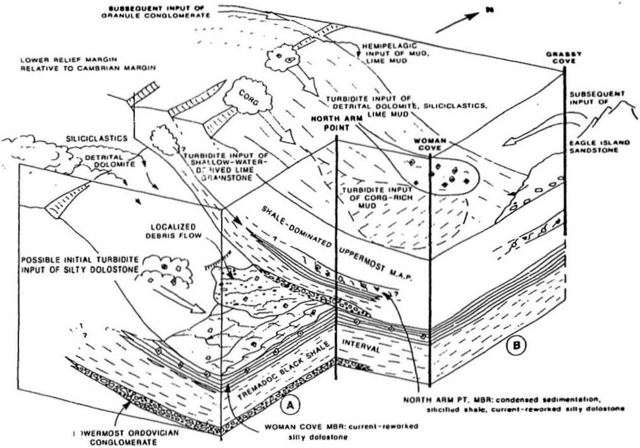
1.5.1 Field Methods

The fieldwork for this study was undertaken during the summer of 1987. In the Bay of Islands area, rocks belonging to the Cook's Brook and Middle Arm Point formations are exposed mainly along the shoreline (Appendix A) and hence are easily accessible by boat. Fieldwork was based out of the town of Cox's Cove on the southern shore of Middle Arm.

Samples were collected from five different sections spanning the Cook's Brook and Middle Arm Point formations (Appendix A). These sections are : (i) Northern Head, (ii) Woman Cove, (iii) North Arm Point, (iv) Eagle Island South and (iv) Eagle Island North. All these sections were logged in detail in a previous study by Botsford (1988). These stratigraphic logs were checked during this

Figure 1-3

Schematic diagram showing the depositional setting of the Middle Arm Point Formation during the Ordovician times (from Botsford, 1988).


SUBSEQUENT INPUT OF GRANULE CONGLOMERATE
N
HEMIPELAGIC INPUT OF MUD, LIME MUD
LOWER RELIEF MARGIN RELATIVE TO CAMBRIAN MARGIN
GRASSY COVE
CORG
TURBIDITE INPUT OF DETRITAL DOLOMITE, SILICICLASTICS, LIME MUD
SUBSEQUENT INPUT OF
NORTH ARM POINT
WOMAN COVE
EAGLE ISLAND SANDSTONE
SILICICLASTICS
DETRITAL DOLOMITE
TURBIDITE INPUT OF SHALLOW-WATER-DERIVED LIME GRAINSTONE
TURBIDITE INPUT OF CORG-RICH MUD
LOCALIZED DEBRIS FLOW
SHALE-DOMINATED UPPERMOST M.A.P.
POSSIBLE INITIAL TURBIDITE INPUT OF SILTY DOLOSTONE
INTERVAL
B
TREMADOC BLACK SHALE
A
NORTH ARM PT. MBR: condensed sedimentation, silicified shale, current-reworked silty dolostone
LOWERMOST ORDOVICIAN CONGLOMERATE
WOMAN COVE MBR: current-reworked silty dolostone

study and were found to be accurate. Hence Botsford's sections have been used for this study with some minor modifications (Appendix B). As this is the first major study of Cambro-Ordovician microfossils from the Cook's Brook and Middle Arm Point formations, efforts were made to sample all the different lithologies present. The sample size varied from 2 to 4 kilograms. Fifty-seven samples were collected from the Northern Head section, thirty- seven from the Woman Cove section, twenty-four from the North Arm Point section, twenty-four from the Eagle Island South section and one sample from the Eagle Island North section. The sample numbers can be interpreted as follows: the capital letters are abbreviations of the name of the section from which the sample was collected (e.g. NAP - North Arm Point) while the number following the abbreviation denotes the position of the sample in the section, a higher number representing a higher stratigraphic position (e.g. NAP 24 is stratigraphically higher than NAP 12).

The Bay of Islands area as a whole is highly tectonized and all the sections described in this study have suffered from extensive thrusting and complex folding. These structural complexities sometimes tend to obscure the stratigraphic relationships of different units. Efforts were made to resolve these problems in order to achieve as much stratigraphic control as possible under the circumstances. However, it should be recognized that most of the sections used in this study are composite sections and it is quite possible that there are some gaps or overlaps.

1.5.2 Laboratory methods

A total of 143 samples each ranging in weight from 2kg to 4kg were dissolved in 10% acetic acid. The residues were sieved under water and then separated using Sodium Polytungstate at a specific gravity of 2.81. The heavy residues were picked and sorted using standard methods. Samples which failed to dissolve in acetic acid were further treated with 10% formic acid solution. This procedure, however, failed to produce any appreciable results.

1.6 Purpose and Scope of the study

The purpose of this study is fourfold:

(i) To study the conodonts from the Cooks Brook and Middle Arm Point formations for the first time and to determine the ages of these rocks based on the conodont data.

(ii) To identify the position of the Cambro-Ordovician boundary in the sections, if possible.

(iii) To propose a biostratigraphic scheme for the Cooks Brook and Middle Arm Point formations based on conodont data to attempt a biostratigraphic correlation of the different sections used in the study.

(iv) To study in detail the large and diverse phosphatic problematica fauna recovered from the Cooks Brook and Middle Arm Point formations for the first time.

CHAPTER 2

BIOSTRATIGRAPHY

2.1 Cambro-Ordovician conodont zonation; a discussion

Cambrian conodonts were first described in detail by Müller (1959), who, in that pioneering paper, also discussed their potential biostratigraphic importance. Zonal schemes for late Cambrian conodonts were introduced by Müller (1973b) and Miller (1975). However, despite a number of later studies, the conodont zonation scheme for the Cambrian still remains quite coarse. The early studies dealing with the biostratigraphy of lower Ordovician conodonts of the North Atlantic Province are by Sergeeva (1964) and Lindström (1971). A more refined zonation scheme for lower Ordovician conodonts of the Baltoscandic area was subsequently proposed by Van Wamel (1974). This scheme, however, has proved only to be of local significance (Bergström, 1977). The first detailed zonation scheme for Cambro-Ordovician conodonts of the Midcontinent province was proposed by Druce and Jones (1971), while the first study dealing with conodont zonation for the Lower Ordovician of North America was by Ethington and Clark (1971). The search for the Cambro-Ordovician Boundary Stratotype has recently focused a lot of attention on the uppermost Cambrian and lowermost Ordovician conodont zonation which, as mentioned by Barnes (1988), is presently in a state of transition and undergoing extensive refinement. The coarse faunal assemblages of Ethington and Clark (1971) are no longer adequate and are gradually being replaced by a number of zones and subzones of shorter duration. It is not the premise of this discussion to argue that such refinement is undesirable as the ultimate aim of biostratigraphy is to achieve accurate global correlations. However, the point that is often forgotten is that any kind of biostratigraphic zonation has limitations of resolution imposed upon it by various other parameters and refinement is possible only up to a certain extent. If refinement is carried on beyond this limit the probability of identifying such short durations of time in any particular sequence of rock surpasses the limits of any degree of precision (Fåhraeus, 1986). In our quest for refined Cambro-Ordovician biozonation we have probably come very close to this optimum resolution and a hard look at the nature of our standard zonation scheme for this interval is required before further refinements can be considered. I realize that this whole issue in itself should be the subject of a separate study and that the brief discussion attempted here cannot do proper justice to the subject. However, since this zonation scheme is being widely used in a number of studies (including the present one) a discussion regarding its limitations is relevant and it is hoped that this would prompt further debate regarding this issue.

There are two aspects of uppermost Cambrian-lowermost

Ordovician conodont biozonation that need to be examined carefully. These are (i) the nature of the zones being used and (ii) the implied resolution of such zones. Here I intend to first take a critical look at the nature of the zonation scheme and then discuss the question regarding the resolution of such zones.

Recently Miller (1988a) has proposed a refined conodont zonation for uppermost Cambrian-lowermost Ordovician. Although this zonation is based mainly on conodonts from western North America, comparisons with other areas have been provided as well. According to this scheme, the uppermost Cambrian-lowermost Ordovician strata can be divided into 9 conodont zones with 7 subzones (see fig. 2-1). This paper by Miller (1980) appears to be the most comprehensive account of uppermost Cambrian-lowermost Ordovician conodont biozonation available and hence have formed the basis of the present discussion. Various other recent studies including those by Barnes (1988), Bruton, Koch and Repetski (1988), Chen and others (1988) and Apollonov and others (1988) have also dealt with Cambro-Ordovician conodont zonation. These studies, however, will not be considered in detail here as (i) they are of more local interest and (ii) some of them (e.g. Barnes, 1988) seem to use a modified version of Miller's (1988) zonation.

According to Miller (1988) the uppermost Cambrian-lowermost Ordovician conodont zones and subzones "are intervals between biohorizons defined at successive lowest occurrences of taxa in a phylogeny (sensu Johnson, 1979), and the units thus conform to the concept of interval zones (Hedberg, 1976)". Hedberg (1976), in discussing the characteristics of an interval zone, states that "it may have no more overall significance than that of position between two identifiable biohorizons". In other words the concept of interval zone implies that the precision of identifying the zone depends entirely on the precision of identifying the two biohorizons enclosing it. Hence to use an interval zone for meaningful correlation the biohorizons enclosing it should be chosen in such a manner that they would be least affected by paleoecological and other external factors- a point that does not seem to have been considered by Miller (1988) while defining the Cambro-Ordovician zones. As stated before, the recognition of any particular biohorizon of Miller (1988) is based on the lowest occurrence of a taxon in a phylogeny. There are two serious problems associated with this approach. The first is concerned with the usefulness of phylogenies in biostratigraphy and the second deals with the issue of using first appearances to define biostratigraphic horizons used for extensive correlations.

Eldredge and Gould (1977) have discussed, in detail, the role of phylogeny in biostratigraphy. According to them although there are two ways of expressing phylogenies, namely (i) in terms of ancestor descendant relationships or (ii) in terms of sister taxa (sensu Schaeffer et al., 1972), neither of these seem to be very useful in biostratigraphy. The ancestor descendant relationship is,in most cases almost impossible to verify, and although it is tacitly assumed in a number of biostratigraphic studies that ancestors precede descendants, it is now well known that ancestors can be coeval with descendants and in certain cases may even outlive them. In other words, for a speciation event to be useful biostratigraphically, it has to be shown convincingly that the mode of speciation is sympatric and not allopatric (Fahraeus, 1982b, 1986). A task that is rather formidable in itself. Secondly as Schaeffer et al. (1972) and Eldredge and Tattersall (1975) have pointed out, in a number of cases, interpretation of ancestor-descendant relationships relies heavily on the relative stratigraphic position of the taxa and an acceptance of phyletic gradualism. Any biostratigraphic correlation based on such relationships, as correctly pointed out by Eldredge and Gould (1977) runs a heavy risk of falling into a circular argument.

The concept of sister taxa does not appear to have much to offer in biostratigraphy either as (i) it is very difficult to establish true sister taxa and (b) the existence of sister species does not always imply that they were the products of a single split in an ancestral species (see Eldredge and Gould, 1977 for discussion of these points).

It is especially difficult to apply the concept of phylogeny in uppermost Cambrian-lowermost Ordovician conodont biostratigraphy as, at present, there is considerable debate in the literature regarding the taxonomy of these conodonts. Since sound taxonomic knowledge is a prerequisite for the construction of meaningful phylogenetic lineages it is probably more prudent not to incorporate phylogenetic concepts into uppermost Cambrian-lowermost Ordovician conodont biozonation until such time as the taxonomic debate is settled.

It is often a common practice in biostratigraphic studies to tacitly assume a sympatric mode of speciation and hence to use first appearances of taxa as distinctive biohorizons for correlation. As Fahraeus (1986) has pointed out, such practice is acceptable only if the resolution of the biostratigraphic zonation is coarse enough. First appearance data should never be used to construct a biostratigraphic zone if the time covered by the zone approximates the lifespan of the fossil taxa whose first appearance defines the zone. A number of uppermost Cambrian lowermost Ordovician conodont zones seem to violate this premise as the time covered by these zones closely approximates the lifespan of the taxon whose first appearance defines the zone (e.g. P. tenuiserratus zone, H. simplex subzone). It is widely acknowledged that the first appearance of a new species is controlled by ecological and evolutionary parameters and is, by definition, diachronous (Eldredge and Gould, 1977, also see discussion in Fahraeus, 1986). This diachronity is especially accentuated when correlation is attempted between different basins and across continents. This contention is especially true for a group like the conodonts which exhibits very strong ecologic controls in its distribution. In fact, it is well known that a number of key species of the zonation scheme under discussion are confined to the warm, shallow water facies and are very rare or absent in the slope facies(e.g. species of Fryxellodontus and Clavohamulus, see Miller, 1988). This rather strong segregation not only seems to suggest a benthic mode of life for these conodont species, but also emphasizes the dangers of using first occurrences in these cases.

Since the purpose of biostratigraphic zonation is to correlate coeval but geographically separated rock units, the usefulness of any zonation scheme is measured by the accuracy with which it can be applied for regional and global correlations. Fahraeus (1986) has argued that an inverse relationship exists between resolution of biostratigraphic zones and precision of correlation and that this inverse relationship is more accentuated in the older strata. In other words, for any biostratigraphic zonation to be meaningful a balance between resolution and precision has to be achieved. This question of balance is especially important in the Lower Paleozoic as it has been shown that rock accumulation rates decrease exponentially with increasing geological age with obvious effects on the precision of biostratigraphic correlations (see Fahraeus, 1986 for discussion and references). The implied resolution of the uppermost Cambrian-lowermost Ordovician conodont zonation, however, is not easy to determine. This is due to an extreme paucity of absolute age dates for this time period which makes an accurate estimation of how much time is involved very difficult. Secondly there is also the problem of correlation between North American and European stages and series as these are used interchangeably in different studies. To cite an example, according to the geological time table compiled by van Eysinga (1983), the North American Trempealeauan stage is directly overlain by the Canadian series the base of which correlates with the base of the Tremadoc series of Europe. The geologic time scale published by the Decade of North American Geology in 1983 (Map and Chart Series MC-50) also shows the Trempealeauan being directly succeed by the Tremadocian. On the other hand, according to the zonation schemes of Miller (1988) and Barnes (1988), the Trempealeauan is succeed by the Canadian, the base of which, however, is lower than the base of the Tremadocian, the difference being equivalent to slightly more than two and a half conodont subzones of Miller (1988) and more than two conodont zones of Barnes (1988). Since the correlation charts of Miller (1988) or

Barnes (1988) do not show any absolute ages, the time covered in these cases can only be roughly estimated by interpolation from other charts. According to the DNAG (1983) geologic time scale, the Tremadocian is 17 million years long. Although this scale does not exactly state where the base of Trempealeauan lies, its age can be roughly estimated as 6.3 million years. The time scale compiled by van Eysinga (1983), on the other hand, estimates the span of Tremadocian as roughly 12 million years and that of Trempealeauan as about 5 million years. The base of the lowermost conodont zone (i.e. _P_. _tenuiserratus_ zone) of Miller (1988) lies just below the base of Trempealeauan in the uppermost Franconian. The top of the _C_. _angulatus_ zone, as shown by Miller (1988) lies somewhere between the base of the Tremadoc and the boundary between Upper and Lower Tremadoc. Based on the figures given above, the time covered by this zonation scheme can be roughly estimated as between 15 to 18 million years. It should be pointed out that this estimate is rather liberal and in reality we may be dealing with less time. The total number of conodont zones and subzones proposed for this interval by Miller (1988) is 12 (8 zones and 7 subzones). The implied resolution of each zone or subzone, on the average, is, thus, slightly more than a million year. In the same interval there are also at least 3 trilobite zones with 8 subzones (Stitt, 1977 cited in Miller, 1988, fig.1). Since the conodont and trilobite zones do not correlate one to one, the implied resolution for cross-correlation appears, at least from Miller's (1988) figure, to be much less than a million year. This certainly poses a problem. As Fahraeus (1986) has discussed, the chances of identifying such short durations of time in the Lower Paleozoic is rather slim and the use of such high resolution zones is certainly not recommended for meaningful global correlations.

Although the discussion above has been rather critical of the existing uppermost Cambrian-lowermost Ordovician conodont zonation, this should not be taken to imply a total rejection of such zonation schemes. In fact, it has to be admitted that despite all the limitations mentioned above, at present, the uppermost Cambrian-lowermost Ordovician conodont biozonation proposed by Miller (1988) and Barnes (1988) remain the most useful of all such schemes and hence has also been used in this study. The discussion above is simply a reminder of the fact that in order for these zones to be meaningful, their limitations will have to be kept in mind while applying them for large scale correlations and that problems of resolution will have to be carefully considered before any further refinement can be proposed.

2.2 Conodont Biostratigraphy of Cooks Brook Formation

The uppermost Cambrian-lowermost Ordovician conodont zones of Miller (1988) that can be recognized in the Cooks Brook Formation (fig. 2-1) are (i) *Proconodontus tenuiserratus* Zone (ii) *Proconodontus muelleri* Zone (iii) *Eoconodontus* Zone, (iv) *Cordylodus proavus* Zone and (v) *Cordylodus angulatus* Zone and (vi) *Loxodus bransoni* interval.

Proconodontus tenuiserratus Zone: According to Miller (1988) the base of the *P. tenuiserratus* Zone is defined by the lowest occurrence of *P. tenuiserratus*. In the Bay of Islands material, this species has been recovered from the Northern Head section (Appendix B). The lowest occurrence of this species is represented by the sample NH24 (fig.2-2). The only other sample that contains *P. tenuiserratus* is NH28. Based on this the range of this species in the Cooks Brook Formation appears quite short. The top of this zone, however, cannot be identified with certainty in the Northern Head section. According to Miller (1988) the top of the *P. tenuiserratus* Zone coincides with the base of *P. posterocostatus* Zone. *P. psoterocostatus* has not been positively identified in the Bay of Islands material. Fragmentary material assigned to ?*P. posterocostatus* occurs lower in the section, only in one sample (NH22). The *P. posterocostatus* Zone, thus appears to be missing in the Northern Head section. This is possibly due to paleoecologic factors as the samples from the level where this zone should

Figure 2-1

Conodont zonation for the Cooks Brook Formation (modified from Miller, 1988 and Barnes, 1988).

<table>
<tr><th colspan="4">CONODONT ZONATION</th><th>SERIES</th></tr>
<tr><td colspan="2">Miller (1988)</td><td colspan="2">This Study</td><td rowspan="11">CANADIAN</td></tr>
<tr><td>Subzone</td><td>Zone</td><td>Subzone</td><td>Zone</td></tr>
<tr><td colspan="2"><i>Loxodus bransoni</i> Interval</td><td colspan="2"><i>L. bransoni</i> Interval</td></tr>
<tr><td colspan="2"><i>Cordylodus angulatus</i></td><td colspan="2"><i>Cordylodus angulatus</i></td></tr>
<tr><td colspan="2"><i>Cordylodus lindstromi</i></td><td colspan="2">Not recognized</td></tr>
<tr><td><i>Clavohamulus hintzei</i></td><td rowspan="2"><i>Cordylodus intermedius</i></td><td colspan="2" rowspan="5"><i>Cordylodus proavus</i></td></tr>
<tr><td><i>Hirsutodontus simplex</i></td></tr>
<tr><td><i>Clavohamulus elongatus</i></td><td rowspan="3"><i>Cordylodus proavus</i></td></tr>
<tr><td><i>Fryxellodontus inornatus</i></td></tr>
<tr><td><i>Hirsutodontus hirsutus</i></td></tr>
<tr><td><i>Cambrooistodus minutus</i></td><td rowspan="2"><i>Eoconodontus</i></td><td><i>Eoconodontus notchpeakensis</i></td><td rowspan="2"><i>Eoconodontus</i></td><td rowspan="6">CROIXAN</td></tr>
<tr><td><i>Eoconodontus notchpeakensis</i></td><td><i>Eoconodontus alisonae</i></td></tr>
<tr><td colspan="2"><i>Proconodontus muelleri</i></td><td colspan="2"><i>Proconodontus muelleri</i></td></tr>
<tr><td colspan="2"><i>Proconodontus posterocostatus</i></td><td colspan="2">Not recognized</td></tr>
<tr><td colspan="2"><i>Proconodontus tenuiserratus</i></td><td colspan="2"><i>Proconodontus tenuiserratus</i></td></tr>
<tr><td colspan="4">NO ZONATION ESTABLISHED</td></tr>
</table>

have occurred are either barren or have very low yields. Other species which occur in this zone are *Proconodontus* sp., *Prooneotodus gallatini*, *Phakelodus tenuis* and *Prooneotodus* sp. A.

Proconodontus muelleri Zone: This zone can be identified quite confidently in the Northern Head section and its base is characterized by the first occurrence of *P. muelleri* (Miller, 1988) (fig. 2-2). Sample NH37 represents the base of this zone in the Northern Head section (Appendix B). The top of this zone coincides with the base of *Eoconodontus* Zone which is represented by sample NH40. This zone can also be recognized in the Woman Cove section where samples WC15 and WC16 can be assigned to this zone (fig. 2-3, Appendix B). Other species present in this zone are *Phakelodus tenuis*, *Prooneotodus* sp. A and "*Sagittodontus*" *eureka*.

Eoconodontus Zone: Barnes (1988) has divided the *Eoconodontus* Zone into three subzones, namely *E. notchpeakensis* Zone at the bottom, followed successively upwards by *E. alisonae* and *C. primitivus* subzones. Of the two *Eoconodontus* species, *E. alisonae* is short ranging while *E. notchpeakensis* is a long ranging species. It is difficult to apply this subzonal scheme in the Northern Head section as the first occurrence of *E. notchpeakensis* (NH40) is very close to the first occurrence of *E. alisonae* (NH40) in this section (fig. 2-2). Thus, in this study the *Eoconodontus* Zone has been divided into the lower *E. alisonae* Subzone

(NH40-NH41) based on the short range of *E. alisonae* followed upwards by the *E. notchpeakensis* Subzone (NH41-NH43). The top of the *Eoconodontus* Zone coincides with the bottom of *Cordylodus proavus* Zone of Miller (1988). Other common species in this zone include *Proconodontus muelleri* and *Teridontus nakamurai*.

Cordylodus proavus Zone: The base of this zone is defined by the first occurrence of *C. proavus* (Miller, 1988) (fig. 2-2) and is represented in the Northern Head section by sample NH44 (Appendix B). The other species present in this zone are *C. hastatus*, *C. andresi*, *C. oklahomensis*, *Teridontus nakamurai*, *T.* aff. *T. nakamurai* and *T.* sp. According to Miller (1988), the *C. proavus* Zone is followed successively upwards by the *C. intermedius* and *C. lindstromi* zones, both of which appear to be missing in the Northern Head section. In the Woman Cove section *C. lindstromi* and *C. intermedius* occurs (WC23-WC24) with *C. angulatus* and *C. proavus* in the *C. angulatus* Zone (fig. 2-3) and hence once again the intervals represented by these zones cannot be identified. Thus in the Cooks Brook Formation, *C. proavus* Zone is followed upwards by the *C. angulatus* Zone.

Cordylodus angulatus Zone: The base of *C. angulatus* Zone is defined by the first occurrence of *C. angulatus* (fig. 2-2) and is represented in the Northern Head section by sample NH54 (Appendix B). Some of the other species occurring in this zone in the Northern head section are *C.*

Figure 2-2

Ranges of conodont species in the Northern Head Section

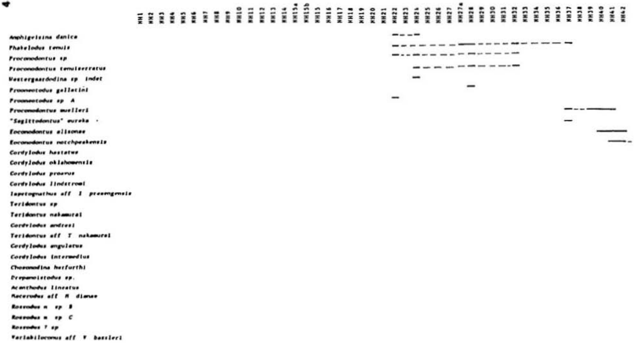
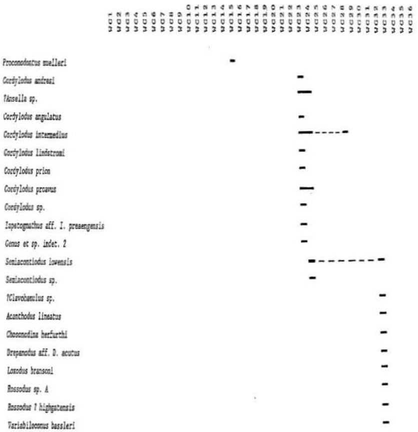

HH1
HH2
HH3
HH4
HH5
HH6
HH7
HH8
HH9
HH10
HH11
HH12
HH13
HH14
HH15a
HH15b
HH15
HH16
HH17
HH18
HH19
HH20
HH21
HH22
HH23
HH24
HH25
HH26
HH27
HH27a
HH28
HH29
HH30
HH31
HH32
HH33
HH34
HH35
HH36
HH37
HH38
HH39
HH40
HH41
HH42
Amphigeisina danica
Phakelodus tenuis
Proconodontus sp
Proconodontus tenuiserratus
Westergaardodina sp indet
Prooneotodus gallatini
Prooneotodus sp A
Proconodontus muelleri
"Sagittodontus" eureka
Eoconodontus alisonae
Eoconodontus notchpeakensis
Cordylodus hastatus
Cordylodus oklahomensis
Cordylodus proavus
Cordylodus lindstromi
Iapetognathus aff I preaengensis
Teridontus sp
Teridontus nakamurai
Cordylodus andresi
Teridontus aff T nakamurai
Cordylodus angulatus
Cordylodus intermedius
Chosonodina herfurthi
Drepanoistodus sp.
Acanthodus lineatus
Macerodus aff M dianae
Rossodus n sp B
Rossodus n sp C
Rossodus ? sp
Variabiloconus aff V bassleri

Figure 2-3

Ranges of conodont species in the Woman Cove Section

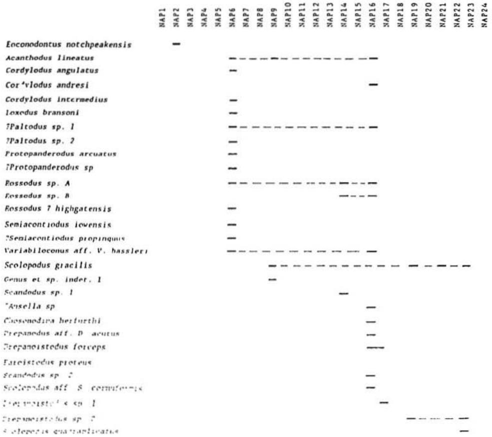

VCC1
VCC2
VCC3
VCC4
VCC5
VCC6
VCC7
VCC8
VCC9
VCC10
VCC11
VCC12
VCC13
VCC14
VCC15
VCC16
VCC17
VCC18
VCC19
VCC20
VCC21
VCC22
VCC23
VCC24
VCC25
VCC26
VCC27
VCC28
VCC29
VCC30
VCC31
VCC32
VCC33
VCC34
VCC35
VCC36
Proconodontus muelleri
Cordylodus andresi
?Ansella sp.
Cordylodus angulatus
Cordylodus intermedius
Cordylodus lindstromi
Cordylodus prion
Cordylodus proavus
Cordylodus sp.
Iapetognathus aff. I. preaengensis
Genus et sp. indet. 2
Semiacontiodus iowensis
Semiacontiodus sp.
?Clavohamulus sp.
Acanthodus lineatus
Chosonodina herfurthi
Drepanodus aff. D. acutus
Loxodus bransoni
Rossodus sp. A
Rossodus ? highgatensis
Variabiloconus bassleri

intermedius, C. proavus, Chosonodina herfurthi, Drepanoistodus sp. 3, Protopanderodus? sp., Rossodus sp. B, Rossodus? sp. and Variabiloconus aff. V. bassleri. The top of this zone cannot be identified in the Northern Head section as the samples near the top of the section either did not dissolve despite prolonged acid treatment or proved to be barren. The other samples assigned to this zone are WC23, WC24 from the Woman Cove section and NAP6 from the North Arm Point section (fig. 2-4).

Loxodus bransoni interval: This is the highest biostratigraphic division that can be recognized in the Cooks Brook Formation. The base of this interval is characterized by the first appearance of L. bransoni and is represented by sample WC32 in the Woman Cove section (fig. 2-3) and sample NAP6 in the North Arm Point section (fig. 2-4). Some of the other species common in this interval are C. herfurthi, Acanthodus lineatus, Protopanderodus arcuatus and Variabiloconus bassleri, V. aff. V. bassleri, Rossodus sp. A, Rossodus sp. B, Rossodus ? highgatensis, Semiacontiodus iowensis, and Semiacontiodus propinquus. The top of this interval most probably lies very close to the top of the Cooks Brook Formation. This, however, could not be verified as the interval in question is not only extremely deformed in the Woman Cove section, but also samples from this part of the Woman Cove and North Arm Point Formations failed to dissolve despite prolonged exposure to acid.

Figure 2-4

Ranges of conodont species in the North Arm Point section.


NAP1
NAP2
NAP3
NAP4
NAP5
NAP6
NAP7
NAP8
NAP9
NAP10
NAP11
NAP12
NAP13
NAP14
NAP15
NAP16
NAP17
NAP18
NAP19
NAP20
NAP21
NAP22
NAP23
NAP24
Eoconodontus notchpeakensis
Acanthodus lineatus
Cordylodus angulatus
Cordylodus andresi
Cordylodus intermedius
Loxodus bransoni
?Paltodus sp. 1
?Paltodus sp. 2
Protopanderodus arcuatus
?Protopanderodus sp
Rossodus sp. A
Rossodus sp. B
Rossodus ? highgatensis
Semiacontiodus iowensis
?Semiacontiodus propinquus
Variabiloconus aff. V. bassleri
Scolopodus gracilis
Genus et sp. indet. 1
Scandodus sp. 1
?Ansella sp
Chosonodina herfurthi
Drepanodus aff. D. acutus
Drepanoistodus forceps
Paroistodus proteus
Scandodus sp. 2
Scolopodus aff. S. cornuformis
Drepanoistodus sp. 1
Drepanoistodus sp. 2
? Glyptoconus quadraplicatus

From the discussion above it is evident that the conodonts recovered from the Cooks Brook Formation range in age from the uppermost Franconian to middle(?) Tremadocian. and the conodont data, for the first time, provides a definite age for the middle and upper Cooks Brook Formation. This age is consistent with that postulated by Botsford (1988) based on a very sparse macro-fauna. The lower part of this formation, however, is too old for conodonts and hence a specific age for this interval cannot be determined in this study. It should, however, be mentioned that inarticulate brachiopods are common in the lower part of Cooks Brook Formation and a detailed study of the brachiopod fauna will certainly help in our understanding of the age and depositional environment of this interval.

2.3 Conodont Biostratigraphy of Middle Arm Point Formation

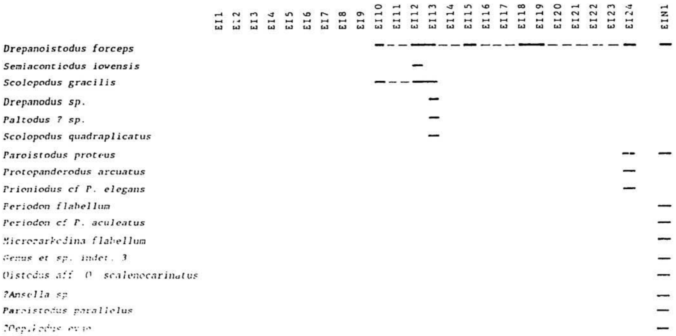
Unlike the lowermost Ordovician, the zonation for Upper Tremadocian-Lower Arenigian conodonts is still rather coarse and the relations between North Atlantic Province conodont zones and North Atlantic conodont zones is poorly understood (Bergström, 1977). No single zonation scheme has been found applicable to the conodonts recovered from the Middle Arm Point Formation. Hence in this study attempts have been made to tentatively correlate the conodonts recovered with zonations proposed by Ethington and Clark (1971) and

Bergström (1977).

The conodonts recovered from the lower part of Middle Arm Point Formation are equivalent to those of Fauna D of Ethington and Clark (1971) (Appendix B). Common species include *Scolopodus gracilis*, *Scolopodus* aff. *S*. *cornuformis*, *Scolopodus quadraplicatus*, *Acanthodus lineatus*, *Drepanoistodus forceps*, and *Variabiloconus* aff. *V*. *bassleri*. In the North Arm Point section *C*. *herfurthi* also occurs in this interval (NAP16) (fig. 2-4). This assemblage is represented by samples NAP9-NAP23 in the North Arm Point section and samples EI10-EI19 in the Eagle Island section (fig. 2-5). The conodont assemblage recovered near the top of the Middle Arm Point Formation (EI24) contains the species *Prioniodus* sp. cf. *P*. *elegans* and *Paroistodus proteus* (fig. 2-5) and most probably represent the *Prioniodus elegans* Zone of Bergström (1977). However, since *P*. sp. cf. *P*. *elegans* has been recovered only from sample EI24 the actual thickness of this zone cannot be determined. This, in fact, poses a problem. Botsford (1988) recovered Arenigian graptolites from the North Arm Point member as well as from the Uppermost Middle Arm Point Formation which seems to suggest that the top of the North Arm Point member correlates with *Didymograptus bifidus* Zone while the uppermost Middle Arm Point formation spans the *Isograptus victoriae lunatus* and *Isograptus victoriae victoriae* zones. Moreover, no graptolites representing the *Pendeograptus*

Figure 2-5

Ranges of conodont species in the Eagle Island South and Eagle Island North sections.


EI1
EI2
EI3
EI4
EI5
EI6
EI7
EI8
EI9
EI10
EI11
EI12
EI13
EI14
EI15
EI16
EI17
EI18
EI19
EI20
EI21
EI22
EI23
EI24
EIN1
Drepanoistodus forceps
Semiacontiodus iowensis
Scolopodus gracilis
Drepanodus sp.
Paltodus ? sp.
Scolopodus quadraplicatus
Paroistodus proteus
Protopanderodus arcuatus
Prioniodus cf P. elegans
Periodon flabellum
Periodon cf P. aculeatus
Microzarkodina flabellum
Genus et sp. indet. 3
Oistodus aff. O. scalenocarinatus
?Ansella sp
Paroistodus parallelus
?Oepikodus evae

fruticosus Zone of Williams and Stevens (1986) have been recovered from the Middle Arm Point Formation which prompted Botsford (1988, p. 84) to postulate that "the lower Arenig is condensed or missing within the Middle Arm Point Formation". The fact that Prioniodus sp. cf. P. elegans specimens recovered in this study occur above the North Arm Point member in the uppermost Middle Arm Point Formation and that the Prioniodus elegans zone correlates with the P. fruticosus graptolite zone (O'Brien and Szybinski, 1989) seems to disagree with Botsford's (1988) contention that lower Arenig is missing within the Middle Arm Point Formation. Instead, his hypothesis that the lower Arenig is condensed within this interval seems more reasonable and is supported by the very short and overlapping range of P. sp. cf. elegans and P. proteus (which occur in the same sample). However, an important point that should be kept in mind is that the species of Prioniodus recovered in this study differs in some respects from the typical Prioniodus elegans which characterizes the P. elegans Zone and hence the possibility that the former is slightly younger than the latter can not be ruled out altogether. Thus, although it seems likely that a somewhat condensed lower Arenig interval is present within the Middle Arm Point Formation, more data are required before such a contention can be conclusively proved. The youngest conodont assemblage recovered in this study comes from sample EIN1 (fig. 2-5) and includes

Paroistodus proteus, Drepanoistodus forceps, ?Oepikodus evae, Periodon flabellum, Periodon sp. cf. P. aculeatus and Microzarkodina flabellum. As discussed later (Chapter 4, Paleoecology) the stratigraphic relationship of this fauna with the rest of the Middle Arm Point material is not clear. However, the co-occurrence of these species in one sample again seems to indicate condensed sedimentation during the lower Arenig in the area. The age of this particular assemblage can also be estimated as early Arenig.

Thus, in summary, it can be concluded that the Middle Arm Point Formation ranges in age from middle (?) Tremadocian to early Arenigian and that the topmost part of this formation is characterized by condensed sedimentation.

CHAPTER 3

CAMBRO-ORDOVICIAN BOUNDARY

3.1 Introduction

"So gradually do the typical Cambrian and Ordovician faunas grade one into the other in most regions, and so convenient is it for mapping purposes to select a lithological break as the dividing line, that it will probably be found that for some years to come we must content ourselves in many districts with drawing an approximate boundary-line between the two." (Lapworth, 1902 in Henningsmoen 1973). Written more than eight decades ago, this comment proved to be more prophetic than even Charles Lapworth himself could probably have imagined. The Cambro Ordovician boundary is still being drawn at different levels in different places and despite significant efforts we are yet to reach a consensus regarding the position of the boundary. Since the Cooks Brook Formation is Cambro-Ordovician in age, the question of the Cambro-Ordovician boundary has to be addressed in this study. In this chapter I intend to first discuss briefly the historical aspects as well as the ongoing debates about the boundary problem and then attempt to discuss the nature of the Cambro-Ordovician transition in my sections.

3.2 Historical perspective

Over the years three different stratigraphic levels have been used as the base of the Ordovician. These are (i) the base of the Arenigian (ii) the base of the Tremadocian and (iii) the boundary between Upper and Lower Tremadocian (see Henningsmoen, 1973, Norford, 1988). This variation of about 10 million years is at least partly attributable to the manner in which Charles Lapworth originally defined the Ordovician System. According to this definition, the Ordovician System is comprised of the "Strata included between the base of the Lower Llandovery formation and that of the Lower Arenig" (Lapworth, 1879). As Henningsmoen (1973) has correctly pointed out, Lapworth followed Hicks's (1875) idea of the Arenig Group and hence his "Lower Arenig" included the Upper Tremadoc of Wales as well. Thus, it appears that from the historical perspective, the base of Ordovician should coincide with the base of Upper Tremadoc. However, a rather interesting point raised by Henningsmoen (1973) in this regard is the question about Lapworth's own concept of the Cambro-Ordovician boundary. It should be noted that from the paleontological point of view, the Ordovician System was defined to include the "faune seconde" mentioned by Barrande in 1846, which meant that the base of this System should coincide with the boundary between "faune primordiale" and "faune seconde", an option Lapworth himself considered (see Henningsmoen, 1973). In other words, historically it would be just as justified to put the base of the Ordovician System at the base of Lower Tremadoc as it would be to put it at the base of Upper Tremadoc.

3.3 IWGCOB and the Cambro-Ordovician Boundary

Since the establishment of the International Working Group on the Cambro-Ordovician Boundary in 1974, considerable work has been done in trying to settle the boundary question and it was decided in 1983 to place the boundary in a horizon close to the base of the Tremadoc Series of North Wales (Norford, 1988). However, the biostratigraphic problems associated with the boundary question are yet to be solved. Over the years a number of different fossil groups have been used to define the Cambro-Ordovician boundary in different parts of the world. For example trilobites have traditionally defined the boundary in North America, graptolites in Wales and conodonts in Australia (Miller, 1988). In order to facilitate global correlation the use of conodonts as the main fossil group along with planktic graptolites to define the boundary has been decided upon by the IWGCOB. At present, however, there are several problems regarding Cambro-Ordovician conodont zonation which has led to differences of opinion regarding the choice of the boundary horizon (see Miller, 1988 for discussion). Before discussing specific problems relating to conodont zonation one important point regarding the choice of the boundary needs to be addressed. The IWGCOB has decided to select the boundary point in such a way that it would correspond to a specific biostratigraphic horizon which can be correlated globally. This has been interpreted, in some studies, to mean that "such a biostratigraphic horizon can only be defined by a single species in one fossil group, so only one group can characterize the actual boundary" (Miller, 1988, p. 355). The zonal concept being implied in this particular case is that of interval zone (see Chapter 2, Biostratigraphy for discussion) and the boundary is being defined on the first appearance of one particular species. I personally feel that this is an extremely dangerous approach. As discussed in Chapter 2, the first appearance of any species is almost by definition diachronous and hence any boundary based only on such information will not only be diachronous in nature but it would be virtually impossible to estimate the amount of diachroneity involved. It should be noted that this discussion is not meant to be a criticism of the notion of the boundary horizon, but merely that of the methodological statements like the one mentioned above. The Cambro-Ordovician boundary is an extremely important boundary and any decision regarding this is bound to have implications for various other branches of earth sciences. Hence it is imperative that the methodologies involved in choosing this boundary be scrutinized carefully.

At present three biostratigraphic horizons are under consideration as the potential Cambro-Ordovician boundary (Miller, 1988). These three horizons are (i) the base of the Cordylodus proavus Zone, (ii) the base of the Cordylodus intermedius Zone and (iii) the base of the Cordylodus lindstromi Zone.

Cordylodus proavus is a cosmopolitan species of conodont that has been used to define the base of the Ordovician in Australia (Jones, Shergold and Druce, 1971). According to Miller (1988a, 1988b), the base of the C. proavus zone is a rather distinctive horizon as (i) it seems to coincide with changes in conodont and trilobite faunas, (ii) it seems to coincide with the base of the Lange Ranch Eustatic Event of Miller (1984) and hence important from the point of view of event stratigraphy and (iii) it seems to be characterized by magnetic and chemical (Cerium and Strontium) anomalies. I agree with Miller (1988a, 1988b) on the first point since it has been noted in this study that the base of C. proavus zone marks the disappearance of the genus Proconodontus and probably the disappearance of the Eoconodontus species E. alisonae. The other contentions of Miller are hard to judge due to the limited amount of published data. Also, contrary to the previously held belief, Taylor et al. (1988) have suggested that the first appearance of C. proavus is isochronous and can be traced from the Laurentian shelf margin into the slope of the Iapetus. Although this claim is at odds with the standard knowledge about the first appearances of taxa (see above), if it can be substantiated by data from other areas then this horizon will have to be given serious consideration as a potential Cambro-Ordovician boundary. The main objections against this horizon are (i) it would place the Cambro-Ordovician boundary considerably below the base of the Tremadocian into strata which have traditionally been considered Cambrian, (ii) this horizon is considerably older than the first occurrence of planktic graptolites and (iii) this horizon seems to be characterized by unconformities in the platform facies in several areas around the world. Thus although the base of the _C_. _proavus_ Zone is distinctive, its suitability as the Cambro-Ordovician boundary is still a debateable issue.

The base of the _C_. _intermedius_ Zone was used to define the Cambro-Ordovician boundary in China by Chen and Gong (1986). This zone, however, does not appear to be distinctive enough to merit the status of the Cambro-Ordovician boundary.

Of the three horizons mentioned above, the base of the _C_. _lindstromi_ Zone is closest to the base of the Tremadoc Series of Wales (Miller, 1988a, Barnes, 1988). This horizon also has the advantage over the other two in being only slightly below the first appearance of the planktic graptolites (see Miller, 1988a for references). On the other hand, there are some very good arguments against using the base of this zone as the Cambro-Ordovician boundary. Firstly, although this horizon is distinctive enough in the

North American platform facies, it is not so well demarcated in other areas (Miller, 1988). Secondly, the range of this species in the slope facies has not been well documented and there is a strong possibility that this range is not coeval with that in the platform facies (Miller, 1988). Finally, and most importantly, the status of C. lindstromi as a species has been questioned by several workers (see discussion in Chapter 5) and no consensus in this matter has been reached yet. Until this taxonomic question can be settled, it does not seem prudent to use this species to define an important horizon like the Cambro-Ordovician boundary.

3.4 Cambro-Ordovician Boundary within Cooks Brook Formation

Before this study, the only recent attempt to identify the position of the Cambro-Ordovician boundary in the Cooks Brook Formation was by Botsford (1988) based mainly on macrofossil data. Although he correctly postulated the presence of the boundary in the Northern Head and Woman Cove sections, Botsford had to conclude that "structural deformation and/or paucity of fauna do not permit accurate location of the boundary within the Northern Head Group" (Botsford, 1988, p. 103). The findings of this study suggest that despite very strong structural, paleoecologic and taphonomic overprints, the Cambro-Ordovician boundary can be identified in at least one section within the Cooks Brook

Formation based on conodonts and its presence can be inferred in another section.

Within the Cooks Brook Formation the Northern Head section exposes the only sequence where the Cambro-Ordovician transition is well documented. This section has yielded a number of biostratigraphically important conodont species, including P. muelleri, E. alisonae, C. proavus and C. angulatus. No specimens which can be definitely ascribed to C. lindstromi have, however, been recovered from this section. Two different biostratigraphic horizons seem to be quite distinctive in the Northern Head section. The first one of these is the first occurrence of C. proavus. This horizon is also characterized by (i) the first occurrence of C. hastatus and (ii) the disappearance of a number of Upper Cambrian species including P. muelleri and E. alisonae just below it. The second distinctive biostratigraphic horizon occurs near the top of the section and is marked by the first appearance of C. angulatus and C. herfurthi amongst others. Of these two horizons the first horizon represents the base of C. proavus zone while the second horizon marks the base of C. angulatus zone (see Miller, 1988). Thus of the three potential Cambro-Ordovician boundary horizons discussed above, only one can be recognized in the Northern Head section. This illustrates the problems involved in trying to apply the existing Cambro-Ordovician conodont zonation to the deeper water facies. This also brings up another point which is relevant to the boundary debate, namely that of the use of the base of C. angulatus zone as the potential Cambro-Ordovician boundary. C. angulatus is a biostratigraphically important species which occurs in both shallow and deep water rocks around the world and hence might prove to be useful in global correlation. Also, unlike C. lindstromi this species is morphologically very distinctive which reduces the chance of misidentification and hence miscorrelation. Admittedly, the base of C. angulatus zone is higher than the base of the Tremadoc Series but as discussed above, historically it is quite justified to place the Cambro-Ordovician boundary near the base of Upper Tremadoc rather than near the base of Lower Tremadoc. This possibility, however, has to be examined in more detail before such a claim can be substantiated and hence for the purpose of this study I have designated the base of the C. proavus zone as the Cambro-Ordovician boundary (Appendix B).

The only other section within the Cooks Brook Formation where the interval containing the Cambro-Ordovician transition is exposed is at Woman Cove. However, the boundary cannot be positively identified here as (i) some of the samples collected from this interval failed to dissolve even after extensive acid treatment and hence no conodonts could be recovered and (ii) the section is faulted near the inferred boundary and some of the section appears to be missing. Thus, the position of the boundary in this case has been tentatively inferred from the available data (Appendix B).

In conclusion, it appears that there are two distinctive horizons in the Northern Head section which can serve as potential Cambro-Ordovician boundary. These are (i) the base of the _C. proavus_ Zone and (ii) the base of the _C. angulatus_ Zone. Of these, the first one is under consideration by the IWGCOB as a potential boundary horizon and has been used as Cambro-Ordovician boundary in this study. The other horizon, although not under active consideration by the IWGCOB, seems to have definite advantages and merits careful examination in the future.

CHAPTER 4

PALEOECOLOGY

4.1 Introduction

The enigmatic nature of the conodont animal and a rather poor understanding of the function of the conodont elements makes interpretation of conodont paleoecology somewhat difficult (Aldridge, 1976). Despite claims to the contrary, modern paleoecologic studies, in a number of cases, rely heavily on the principle of uniformitarianism. Although such an approach produces rather remarkable results for a number of animal groups (e.g. see the classic study on deposit-feeding bivalves by Levinton and Bambach, 1975), it is more difficult to apply the same concepts to animals whose biological affinities are not clear. Hence, it is not surprising that so far there has been a rather limited number of studies dealing solely with the paleoecology of conodonts and that of these very few deal exclusively with Upper Cambrian-Lower Ordovician conodonts.

4.2 Paleoecologic models for conodonts

As mentioned by Aldridge (1976), due to the enigmatic nature of the conodont animal, ecological models proposed for conodonts have largely relied on a purely empirical approach of examining the distribution patterns of conodonts and correlating these patterns with some identifiable paleoenvironmental factors. At present there are two general models which attempt to explain the distribution pattern of conodonts. These are (i) the depth-stratification model of Seddon and Sweet (1971) and (ii) the lateral-segregation or nektobenthic model of Barnes and Fahraeus (1975).

The depth-stratification model of Seddon and Sweet (1971) attempts to explain the presence of distinct, laterally segregated conodont biofacies by postulating a pelagic, depth-stratified mode of life for the conodont animal. According to this model, "in their lifetimes, different conodonts inhabited different levels in the sea, in the manner of living chaetognaths" (Sweet, 1988, p. 151). This implies that if the conodontophorids were originally distributed uniformly in the water column, then a gradual increase in diversity would characterize samples from deeper waters (Sweet, 1988). On the other hand, if the original distribution of the conodontophorids was uneven in the water mass, then even adjacent biotopes may exhibit marked differences in biofacies (Sweet, 1988).

The nektobenthic model of Barnes and Fahraeus (1975) also recognizes the presence of laterally segregated conodontophorid communities and attempts to explain this distribution pattern by postulating a benthic or nektobenthic mode of life for the majority of Ordovician conodontophorids. This model recognizes only a few pelagic forms in the Ordovician. These are simple cone taxa which exhibit very simple symmetry transition series.

4.3 Paleoecology of conodonts in the Cooks Brook and Middle Arm Point Formations

4.3.1 Observations:

The conodont fauna recovered from the Cooks Brook and Middle Arm Point formations exhibit several interesting features with important paleoecologic implications. These characteristics are first summarized below and then a palaoecolgic interpretation is proposed based on the sedimentological and paleontological data.

The abundance of conodonts in the Cooks Brook and Middle Arm Point formations is rather variable. Of the 143 samples collected from five different sections, 38 have yielded identifiable conodonts. However, this 26.5% figure is rather misleading as in a number of cases the absence of conodonts is either due to the age of the sample or due to practical difficulties in extracting the conodonts from the rock. The age plays an important role in the Northern Head and Woman Cove sections, the lower parts of which are of Franconian or older age and hence do not yield any conodonts. Problems of extracting conodonts have been faced in all the sections to a greater or lesser degree. The dolostones, in a number of cases, have not dissolved despite prolonged acid treatment. The same problem has also been encountered in some limestones probably due to the presence of silica. This problem is especially prevalent in the Eagle Island South section. It is estimated that approximately 70 samples have not yielded any conodonts due to either of these two reasons. Thus about 54% of the rest of the samples have yielded conodonts in this study. The abundance of conodonts in individual samples is generally low to moderate except in a few samples where it is high. In fact, in some cases the numbers can be as low as 3 or 4 (e.g. sample NH39). The distribution of conodonts in the vertical sequence is, however, not uniform and fossiliferous samples are interspersed with barren ones. This patchy distribution of fossiliferous samples is especially apparent in the Cooks Brook Formation (Northern Head and Woman Cove sections) (see Appendix B).

Since all the carbonates of the Cooks Brook and Middle Arm Point formations have been deposited in a deep water setting as gravity deposits, they do not exhibit marked facies contrasts. The predominant lithologies are parted limestone (including grainstone and mudstone), ribbon limestone, conglomerate and dolostone. Apart from this, highly deformed calcarenites occur only in the Woman Cove section. Conodonts have been recovered from all of these different lithologies and as is to be expected in a setting like this, there does not seem to be any significant correlation between lithology and distribution of conodonts. It should, however, be noted that this observation is valid only for the carbonate rocks. The Cooks Brook and Middle Arm Point formations also contain black, green and red shales which have not been sampled in this study.

Although the abundance of conodonts in individual samples is generally good, the same cannot be said about diversity. The Cooks Brook Formation is generally characterized by low diversity of conodonts. A number of samples occurring below the C. proavus Zone are dominated by one or two species (e.g. sample NH41 contains abundant E. alisonae and few specimens of E. notchpeakensis) (Appendix C). Some samples from the C. proavus Zone and above (e.g. NH44, NH54) show increased diversity accompanied by a change in size of some specimens (see below). However, even in this interval the diversity values fluctuate from sample to sample and the overall diversity remains low. The diversity of conodonts in the Middle Arm Point Formation is high compared to the Cooks Brook Formation.

An extremely interesting feature exhibited by the conodonts from the Cooks Brook and Middle Arm Point formations is the presence of markedly different size fractions of conodonts often in the same sample. In the Cooks Brook Formation the samples with low diversity yield extremely small but nicely preserved conodonts. However, in the samples with relatively high diversity large, robust conodonts are generally present along with tiny and fragile conodonts. The large conodonts are generally broken, abraded and dark in colour while the small conodonts are generally much lighter in colour and better preserved. A good example of this phenomenon is found in sample NH44 which marks the base of the C. proavus Zone in the Northern Head section. In this sample, very large robust elements of C. hastatus are present along with much smaller and lighter coloured specimens of C. proavus as well as small specimens of T. nakamurai and T. sp. All the elements of C. hastatus are broken and are dark in colour (CAI approximately 4.5-5) while the smaller conodonts are much lighter (CAI 1.5-2) and better preserved. This variation of size, whenever present, gives a distinct impression of bimodality rather than a continuous variation. Although in most cases the bigger fauna is distinctly different from the smaller fauna, this variation in size can sometimes be documented for conodonts of the same genus in the same sample. In other cases conodonts of even the same species can exhibit marked variation in size in different samples. For example specimens of C. angulatus in sample NH54 is rather small while specimens of C. angulatus in samples WC23 and NAP6 are much larger. The specimens in NAP6 exhibit low CAI whereas the specimens in WC23 are quite dark (CAI 4.5-5). Similarly specimens of A. lineatus in specimen NAP6 are very large and robust while conodonts of the same species in sample NAP16 are much smaller. The specimens of A. lineatus in sample WC32 are moderate in size. The variation in size is also, almost always, accompanied by some change in morphology.

Thus although the overall morphology of a particular species remains the same, on a finer scale, the morphology of conodonts of the same species can vary somewhat from one sample to another.

4.3.2 Interpretation

Since at present there is no comprehensive paleoecologic model which can be applied to deep-water conodonts, the observations noted above have to be interpreted in the light of the available sedimentological data and depositional models for the area. As mentioned earlier, the Cooks Brook and Middle Arm Point formations dominantly consist of redeposited carbonates and shales which were most probably deposited as a "base of slope sediment apron" associated with a "by-pass margin" (Botsford, 1988). Of the two, the Cooks Brook Formation was probably deposited in a deep water, poorly-oxygenated basin while Middle Arm Point Formation was deposited under more oxygenated conditions. Sedimentological evidence also suggests that the Cooks Brook and Middle Arm Point formations contain components derived from the shallow water carbonate platform as well as from the slope itself (see Botsford, 1988 for detailed sedimentological discussion). As discussed below, most of the observations regarding the size, diversity, abundance and colour of the conodonts, mentioned above, can be explained within this depositional model.

The variation in size of the conodonts noted above can be interpreted in two ways, namely (i) this variation is dominantly ontogenic and (ii) the variation is environmentally controlled. Of these two possibilities the first does not seem very likely as the size variation neither appears to be continuous nor is confined within one species. In fact, in any particular sample, the sizes of individuals belonging to the same species tend to be more or less the same and the variation of size within a species is seen only when one compares populations from different, sometimes widely spaced, samples. The second possibility is that the variation is environmentally controlled provides a much more likely explanation. It should be pointed out that a number of different types of plants as well as invertebrates are known to exhibit variation in morphology ("phenotypic plasticity") in order to adapt to their microhabitats (Valentine, 1973). This type of variation, where the genotype can selectively produce any particular ontogeny out of a number of different ones depending on the environmental requirement has been termed "multiple-choice variation" by Bonner (1965). The variation in size exhibited by some species of conodonts recovered in this study (e.g. <u>Acanthodus lineatus</u>) most probably represents this type of variation where the large, robust specimens represent shallow water variety while the small specimens probably inhabited the deeper water environment. The same observation is also valid for C. angulatus where the variation in size is also accompanied by a slight variation in morphology. Thus the striking difference in size amongst different species in the same sample tends to indicate the influx of shallow water component represented by the species with the large robust elements amongst a deeper water fauna characterized by the species with very small elements. This interpretation is supported by the fact that the larger elements, in most cases, are also broken and abraded as a result of transportation from the shallower environments into deeper waters while the small elements generally tend to be nicely preserved (e.g. not a single complete element of C. hastatus has been recovered in this study but numerous, beautifully preserved, small elements of E. alisonae or T. nakamurai have been recovered).

At this stage it should be pointed out that variation in the size of organisms along environmental or depth gradients is a characteristic feature of benthic organisms. For example, as mentioned by Boucot (1975, 1981), for families or genera that live in both subtidal and intertidal regions, the intertidal species generally tend to be larger compared to the subtidal ones. The interpretation presented above, thus, provides a strong argument for the nektobenthic habit of the conodontophorid, more evidence in favour of which comes in the form of the diversity and abundance data. Both the diversity and abundance of conodonts in the Bay of

Islands material is highly variable. For most of the Cooks Brook Formation except near the top (NH54), the overall diversity of conodonts remains low. This is consistent with the expectations for benthic or nektobenthic organisms in highly stressed anoxic environments. Benthic organisms in highly stressed environments commonly exhibit low diversity but high abundance. Evidence of this is present in some of the Cooks Brook samples. For example, sample NH41 is dominated by numerous tiny, beautifully preserved elements of the species E. alisonae (Appendix C). The presence of a number of barren samples in the Cooks Brook Formation also appears to be related to the depth of water. Sedimentological evidence suggests a fluctuation of water depth within the Cooks Brook Formation (see Botsford, 1988 for details) and it is possible that the barren samples represent relatively high water levels when the environmental conditions were beyond the depth tolerance limits of the conodontophorid. With a subsequent shallowing and onset of more tolerable conditions, these habitats were probably reinvaded, resulting in fossiliferous samples.

The interspecific as well as intraspecific variation, so prominent in the Cooks Brook Formation, is not so strikingly evident in the Middle Arm Point Formation. The size variation still exists in some samples, but the difference is less marked compared to the Cooks Brook Formation. The diversity values rise considerably compared to the older ones and no single species tends to dominate the fauna. This change is directly related to sedimentological evidence suggesting the onset of more oxygenated conditions and decreased input of the shallow water derived components (see Botsford, 1988). The overall diversity, however, remains low compared to the published accounts of shallow water conodont faunas and is indicative of a continuing deep-water environment.

Within the Middle Arm Point Formation one particular sample has yielded a conodont fauna which is sufficiently distinct from the rest of the material recovered in this study to merit separate mention. Stratigraphically, this sample, EIN1, occurs near the top of the Middle Arm Point Formation (Appendix B). The sample comes from a highly bioturbated lime mudstone interval which exhibits numerous Palaeophycus Type D burrows on the bedding surface (fig. 4-1), (Botsford, 1988). This bioturbation style is rather distinctive and does not occur anywhere else within the Cooks Brook and Middle Arm Point formations. The conodonts recovered from this sample are quite fragile and extremely small in size. The fauna consists of Periodon flabellum, Periodon sp. cf. P. aculeatus, Microzarkodina flabellum, ?Oepikodus evae and Paroistodus proteus amongst others. Despite their fragile nature, these conodonts are nicely preserved and exhibit a CAI of 1 to 1.5. Abundance is high compared to most of the other fossiliferous samples from

Figure 4-1. Paleophycus Type D burrows on the bedding plane at Eagle Island North.

Cooks Brook and Middle Arm Point formations.

It is rather difficult to interpret the environmental significance of this particular conodont fauna which also happens to be the youngest recovered in this study. As mentioned before, the lime mudstone interval yielding this fauna occurs immediately below the flysch of the Eagle Island Formation and hence represents the last phase of destruction of the Cambro-Ordovician carbonate platform. The extremely small size and fragile nature of these conodonts seems to indicate a deep water habitat for these organisms and the homogeneous composition of the fauna as regards size and robustness of the elements tends to rule out the influx of any shallow water components in this particular habitat. The absence of shallow water components, so common in the rest of the Bay of Islands material, and the rather distinctive nature of these conodonts tends to indicate that the lime mudstone interval which yields this fauna represents a deep water allochthonous block emplaced within the uppermost Middle Arm Point Formation. This hypothesis easily explains the rather different nature of this fauna, as compared to the rest of the Cooks Brook and Middle Arm Point material. Field evidence suggests that the lime mudstone interval in question has been faulted in place, a fact which also seems to support this hypothesis. Finally, as mentioned before, the particular style of bioturbation present in this interval does not occur anywhere else within the Cooks Brook and Middle Arm Point formations (Botsford, 1988) and hence again indicates an allochthonous nature of this interval. However, at present the source of this block is not clear and further studies are required to settle the question.

CHAPTER 5

SYSTEMATIC PALEONTOLOGY OF CONODONTS

Phylum CONODONTA Pander, 1856

Class CONODONTATA Pander, 1856

Order CONODONTOPHORIDA Eichenberg, 1930

Genus ACANTHODUS Furnish, 1938

Type species: *Acanthodus uncinatus* Furnish, 1938

Remarks: The original description by Furnish (1938) is rather vague and hence not very useful. The Treatise defines the genus as "apparatus apparently composed only of nongeniculate coniform lamellar elements with reclined, laterally compressed cusp, portion of posterior margin of cusp serrate; basal cavity shallow" (Clark *et al*., 1981, p. W142-W143). It is quite evident that this definition needs to be revised as it does not specify the composition of the apparatus except in very generalized terms. *Acanthodus* should be defined as: apparatus consisting of nongeniculate coniform elements that include costate and non-costate symmetrical and asymmetrical forms; elements rounded to laterally compressed with proclined to reclined cusps.

ACANTHODUS LINEATUS (Furnish, 1938)

(Plate 1, figures 1-6)

Synonymy:

Drepanodus lineatus Furnish, 1938, p. 328, Pl. 41, figs. 33, 34, text-fig. 1H.

Acanthodus costatus DRUCE and JONES, 1971, p. 54-55, Pl. 5, figs. 1a-5c, text-fig. 19a; MÜLLER, 1973, p. 26, Pl. 8, figs. 10-12 only.

Acanthodus cf. uncinatus Furnish,' LINDSTRÖM, 1964, p. 137, fig. 47f.

Acanthodus lineatus (Furnish), ETHINGTON and CLARK, 1981, p. 17, Pl. 1, fig. 7; REPETSKI and ETHINGTON, 1977, p. 95-96, Pl. 1, fig. 7; REPETSKI, 1982, p. 10, Pl. 1, figs. 1, 3.

?Acanthodus costatus JONES, 1971, p. 42-43, Pl. 1, figs. 4a, b.

"Acanthodus" lineatus (Furnish, 1938), LANDING et al., 1986, p. 1935-1936, Pl. 3, figs. 11, 12, text-fig. 3J, R.

Acanthodus sp. REPETSKI, 1982, p.10, Pl. 1, fig. 2

Description: Apparatus consists of symmetric to slightly asymmetric non-costate and symmetric to asymmetric costate forms.

Symmetric costate element with long reclined cusp. Posterior margin of cusp bears small aborally pointing nodes giving serrated appearance. Cross-section of cusp circular to oval. Upper part of cusp lighter in colour compared to rest of element. Each lateral surface bears a prominent costa. Costae situated close to anterior margin in basal region, becoming more medial along cusp. In some specimens a less well developed costa is present posterior to main costa. Anterior and posterior margins keeled. Keels become less pronounced near base. Base quite small with circular to oval cross-section. Laterally compressed and rounded morphotypes present.

Asymmetric costate element exhibits two morphotypes. Morphotype I is similar in overall morphology to symmetric element except that only one lateral face is costate. In some specimens the asymmetry can also be produced by unequal development of costae on opposite sides. Morphotype II characterized by compressed, laterally twisted cusp. Cusp long and proclined. Anterior and posterior margins of cusp sharply keeled, keels not extending up to base. One lateral costa on each side extending upto basal margin. Basal opening circular to slightly oval.

Non-costate element symmetric to slightly asymmetric and laterally compressed with large base. Cross-section of cusp biconvex. Anterior and posterior margins sharply keeled. Base slightly extended posteriorly. This type of element is rare and represented only by broken fragments in the Bay of Islands material.

Remarks: The exact nature of the genus Acanthodus is still under debate. It has been found that the serration on the posterior margin of the cusp can be absent in many elements of Acanthodus and hence the usefulness of this feature in recognizing the genus has been questioned (see Landing *et al.*, 1986). Landing *et al.*(1986) postulated that "acanthodid serrations are a vicarious feature" and hence not a diagnostic criterion for the genus - a conclusion I disagree with. The presence of serrate and non-serrate forms most probably reflect the fact that both these forms are part of the Acanthodus apparatus and hence this feature is, by no means, vicarious. This would indicate that the Acanthodus apparatus is more complex than previously believed, a fact that has been discussed to some extent by Moskalenko (1972).

A. lineatus is a common species in Bay of Islands material and occurs in several different sections. The size of elements of A. lineatus in my samples varies from small to very large. In fact some of the specimens of A. lineatus represent the largest conodonts recovered from Bay of Islands. For a possible explanation of this size difference see Chapter 4, paleoecology.

Material: 4 non-costate elements; 27 costate elements. Specimens often broken.

Occurrence: WC32, NAP6, NAP9, NAP16, NH54.

Family AMPHIGEISINIDAE Miller, 1981

Remarks: Bengtson (1976) introduced the term "protoconodont" for long, slender Cambrian conodont-like elements exhibiting only basal-internal growth increments. Miller (in Clark *et al*. 1981) placed all conodont-like elements exhibiting protoconodont histology in the family Amphigeisinidae. Except for the presence of characteristic histology the nature and relationship of the conodont-like elements of this family is poorly understood. At present Amphigeisinidae consists of four genera: (a) *Amphigeisina* Bengtson, 1976, (b) *Protohertzina* Missarzhevsky, 1973, (c) *Gapparodus* Abaimova, 1978 and (d) *Phakelodus* Miller, 1984. These four genera are all very simple and rather similar in morphology and are differentiated mainly on the basis of the number and position of keels on the element (see Miller, 1984). Although this taxonomic scheme is commonly followed at present, whether the position and presence/absence of keels are sufficient criteria for differentiation at the generic level is certainly debatable. Moreover, the question whether these elements actually belong to the phylum Conodonta and if so whether a multielement taxonomic scheme can be applied to these simple cones also needs to be addressed.

Unfortunately, only a few of these cones have been recovered from the Bay of Islands samples and hence at present it seems prudent to go along with the existing scheme.

Genus AMPHIGEISINA Bengtson, 1976

Type species: *Hertzina*? *danica* Poulsen, 1966

AMPHIGEISINA DANICA (Poulsen)

(Plate 1, figure 23)

Synonymy:

Hertzina? *danica* POULSEN, 1966, p. 4-8, Pl. 1, figs. 1-8, text-figs. 1-2.

Description: Large, hollow, simple cones with thin walls. Anterior margin rounded, posterior margin concave. Two posterolateral costae present.

Remarks: The Bay of Islands specimens of *A. danica* are all broken. The fragments, however, agree fairly well with the description of Poulsen (1966).

Material: 5 broken specimens.

Occurrence: NH22, NH24

Genus ANSELLA Fahraeus and Hunter, 1985

Type species: _Belodella jemtlandica_ Löfgren, 1978

? ANSELLA SP.

(Plate 1, figures 20, 22)

Description: Laterally compressed geniculate element with one denticle. Cusp strongly recurved, blade-like and slightly to markedly twisted. Cusp well developed in some elements, poorly developed in others. One well developed, flattened denticle present at the junction of oral edge and posterior margin of cusp. Base large and more or less triangular. Oral margin straight or curved. Base generally slightly expanded laterally.

Remarks: Only a few specimens of this type have been recovered and the taxonomic affinity is not clear. The elements are very characteristic in being extremely compressed laterally and having a denticle. They are similar in overall morphology to the geniculate element of _A. jemtlandica_ (Löfgren) described by Fahraeus and Hunter (1985). However, the geniculate element of _A. jemtlandica_ (Löfgren) is not denticulate. Moreover, the present species occurs in lowermost Ordovician rocks while _Ansella_ is a middle Ordovician genus. Another species of similar morphology is O. selene s.f. Morphologically, this species can be derived from O. selene simply by the addition of a denticle. Infact, elements of this species are associated with those of O. selene in one sample (EIN1). Future studies with larger material are required to establish the relationship of this species.

Material: 11 specimens.

Occurrence: NAP16, WC23, WC24, EIN1.

Genus CHOSONODINA Müller, 1964

Type species: Chosonodina herfurthi Müller, 1964

Discussion: First described from the Lower Ordovician of South Korea in 1964 (Müller, 1964), this genus still remains somewhat enigmatic in nature. The similarity of this genus with Westergaardodina has led to the postulation that "there is probably a continuous link between the genera Westergaardodina, Chosonodina, and Coleodus" (Druce and Jones, 1971, p. 58). Conodonts belonging to the genus Chosonodina generally exhibit low abundance and appear to have a monoelemental apparatus (Barnes et al., 1979). Interestingly enough a recent revision of multielement classification by Sweet (1988) does not recognize Chosonodina as a member of phylum Conodonta.

CHOSONODINA HERFURTHI Müller, 1964

(Plate 1, figure 21)

Synonymy:

Chosonodina herfurthi MÜLLER, 1964, Pl. 13, figs. 3a-c; DRUCE and JONES, 1971, p. 59, Pl. 4, figs. 1a-6c, 9a-b, text-figs. 21b-c; ETHINGTON and CLARK, 1971, Pl. 1, fig. 10; LEE, 1980, Pl. 1, fig. 11; WANG, 1986, p. 213-214, Pl. IV, figs. 20,21, Pl. VI, figs. 21-24, Pl. X, figs. 18-21.

Description: Thin, symmetrical unit with two lateral and three medial denticles. Denticles have pointed tips. Basal cavity shallow and trough-like. Unit laterally compressed.

Remarks: My specimens are very similar to the ones described by Müller (1964) and Druce and Jones (1971). The abundance of this species is quite low in my samples.

Material: 6 specimens.

Occurrence: WC32, NAP16, NH54.

?Genus CLAVOHAMULUS Furnish, 1938

Type species: Clavohamulus densus Furnish, 1938

?CLAVOHAMULUS SP. Ethington and Clark, 1971 s.f.

(Plate 1, figure 14)

Synonymy:

?Trichonodella sp. MOUND, 1968, p. 420-421, Pl. 6, fig. 73.

?Clavohamulus sp. ETHINGTON and CLARK, 1971, Pl. 1, fig. 9.

Description: Unit small with recurved cusp and two well developed denticulated anterolateral processes. Cusp sharply recurved above base. Anterolateral processes confined to basal region and curved posteriorly. Margin of processes denticulate. Base fairly large compared to cusp. Base dark due to higher organic content.

Remarks: Generic assignment of this species is difficult. Conodonts belonging to the genus Clavohamulus are characterized by a bulbous base covered with tiny nodes. The present species has two well developed processes and does not exhibit prominent nodes and hence cannot be assigned to Clavohamulus without redefining the genus. Such a revision, however, has not been attempted in this study as only one specimen has been recovered. This species is characteristic of fauna C of Ethington and Clark (1971).

Material: 1 specimen

Occurrence: WC32

Genus CORDYLODUS Pander, 1856

Type species: Cordylodus angulatus Pander, 1856

Discussion: Originally described in 1856, the Cordylodus apparatus was regarded as monoelemental for a long time until Bergström & Sweet (1966) proposed the first multielement apparatus of the genus by grouping together C. angulatus Pander, 1856 s.f. and C. rotundatus Pander, 1856 s.f. The concept of the genus was later revised by Miller (1980) who proposed a bielemental apparatus for Cordylodus. According to this reconstruction, Cordylodus apparatuses "consist of simple, rounded and compressed, denticulate elements" (Miller, 1980, p.13). This apparatus scheme was followed by Landing et al., (1980) and Clark et al., (1981). A more complex apparatus plan for Cordylodus was proposed by Bagnoli et al., (1987). According to them, the rounded (p) elements in this type of apparatus exhibit a subtle symmetry transition series of laterally compressed symmetrical forms to highly asymmetrical forms which exhibit a low carina on the inner lateral face. The variation in the compressed (q) elements appears to be minor. This reconstruction has been confirmed by Viira _et al_., (1987) from northern East Baltic material and has also been followed by Barnes (1988). Viira _et al_., (1987) have also observed that the complexity of the _Cordylodus_ apparatus can be correlated with the evolutionary change within the genus. According to them the earliest representatives of this genus show relatively simple three element apparatuses which exhibit symmetry transition from rounded to twisted forms while more complex apparatuses characterize the later representatives of the _Cordylodus_ lineage.

Remarks: An examination of published material seems to indicate that the apparatus plan proposed for _Cordylodus_ by Bagnoli _et al_., (1987) is preferable to that of Miller (1980). However, considerable confusion still exists in the literature regarding the taxonomy of this genus. This is, in part, due to the fact that the morphologic variation within most species of _Cordylodus_ is quite extensive. Secondly, the shape of the basal cavity is considered as one of the most important criteria for identifying different _Cordylodus_ species, (Druce & Jones, 1971; Müller, 1973; Miller, 1969, 1980; Bagnoli _et al_., 1987; Viira _et al_., 1987 and Barnes, 1988, also see discussion under _C_. _lindstromi_). Although this feature is easily discernible in well preserved specimens, it is much less apparent in poorly preserved specimens and specimens with high CAI's.

Synonymy lists for species of this genus are difficult to construct. The wide range of intraspecific variation combined with the fact that published SEM illustrations do not show the shape of the basal cavity often makes it impossible to establish synonymy.

In this study efforts have been made to follow the apparatus plan proposed by Bagnoli et al. (1987). However, the number of specimens in my samples is quite small, which precludes the construction of complete apparatuses in most cases.

CORDYLODUS ANDRESI Viira et Sergeyeva, 1987

(Plate 1, figures 12, 13)

Synonymy:

Cordylodus sp. ANDRES, 1981, p. 23, 25, Figs. 11-18.

Cordylodus andresi VIIRA et al., 1987, p. 147-148, Pl. I, figs. 1-8, Pl. III, figs. 1, 2, 4, text-fig. 2, 18, 33-36, 42-59, text-fig. 4, 28; BARNES, 1988, p. 410-411, Figs. 13d-f, 14a.

Cordylodus proavus Müller, DRUCE and JONES, 1971, p. 120, Pl. 1, figs. 2a, b (only).

Cordylodus sp. cf. C. proavus Müller, NOWLAN, 1985, p. 111, Fig. 4.4, 4.6 (only).

Description: Elements small and delicate. Rounded and compressed morphotypes present.

Rounded element with recurved cusp and well developed posterior process. Unit as a whole somewhat compressed laterally but with rounded edges. Posterior process denticulated. Denticles discrete. Basal cavity large extending to mid-height of cusp. Anterior margin of basal cavity convex. Basal opening elongate oval.

Compressed element with suberect cusp and denticulated posterior process. Elements smaller than those of rounded morphotype and commonly broken. Cusp flattened laterally with sharp edges. Basal cavity large and extends above mid-height of cusp.

Remarks: As pointed out by Viira et al. (1987), the morphology of C. andresi is rather variable. In Bay of Islands material the species can be recognized by its delicate nature and characteristic basal cavity.

Material: 6 rounded elements; 3 compressed elements (broken)

Occurrence: NH45, NH49, NAP16, WC23 .

CORDYLODUS ANGULATUS Pander

(Plate 1, figures 7-11)

Synonymy:

rounded element-

Cordylodus angulatus PANDER, 1856, Pl. 2, figs. 28-31, Pl. 3, fig. 10; LINDSTRÖM, 1955, p. 551-552, Pl. 5, fig. 9, text-fig. 3G, non text-fig. 3E; ETHINGTON and CLARK, 1965, p. 189, Pl. 1, fig. 7; DRUCE and JONES, 1971, p. 66, Pl. 3, figs. 4-6, text-figs. 23a-b, non Pl. 3, fig. 7; JONES, 1971, p. 45, Pl. 8, figs. 3a-c; MÜLLER, 1973, p. 27-29, Pl. 11, figs. 1-7; non VAN WAMEL, 1974, p. 58-59, Pl. 1, figs. 5-7; MILLER, 1980, p. 13-16, Pl. 1, fig. 22 (only); LANDING and BARNES, 1981, p. 1614, Pl. 3, fig. 11, text-fig. 3(4); REPETSKI, 1982, p. 16-17, Pl. 4, fig. 9, text-fig. 4(L); TAYLOR and LANDING, 1982, text-fig. 5 (A); AN et al., 1983, p. 84, Pl. 8, figs. 1-2; NOWLAN, 1985, p. 108-109, text-fig.4 (10); BAGNOLI et al., 1986, p. 150-152, Pl. 1, fig. 20.

compressed element -

Cordylodus rotundatus PANDER, 1856, p. 33, Pl. 2, figs. 32, 33; LINDSTRÖM, 1955, p. 553, Pl. 5, figs. 17-20, text-fig. 3 (F); ETHINGTON and CLARK, 1971, Pl. 1, fig. 17; DRUCE and JONES, 1971, p. 71, Pl. 3, fig. 8 (only); JONES, 1971, p. 49, Pl. 2, figs. 10-11; MÜLLER, 1973, p. 36-37, Pl. 11, figs. 8-10, text-fig. 2 (H); VAN WAMEL, 1974, p. 60-61, Pl.

1, fig. 14; MILLER, 1980, p. 20-21, Pl. 1, fig. 24, text-fig. 4 (P); REPETSKI, 1982, p. 18, Pl. 5, fig. 3, text-fig. 4 (N); AN et al., 1983, p. 88-89, Pl. 8, figs. 3-7; NOWLAN, 1985, p. 111-112, text-fig. 4 (3); BAGNOLI et al., 1986, p. 150-152, Pl. 1, figs. 19, 21.

Description: Rounded element characterized by prominent cusp and well developed denticulated posterior process. Cusp gently recurved. Denticles well developed and fused near their bases. Cusp as well as the denticles oval in cross-section and have sharp edges. Cusp and denticles have pointed tips. Basal cavity moderately deep with concave anterior margin and recurved apex. Outline of basal cavity somewhat resembles that of a "phrygian cap".

Compressed element with large cusp and denticulated posterior process. Denticles generally discrete but can be fused near their bases. Cusp and denticles oval in cross-section. Base flared in some specimens. Basal cavity moderately deep and basal margin arched near center. Antero-aboral margin well rounded and bisected by basal cavity.

Remarks: The exact composition of the apparatus of C. angulatus Pander is still uncertain. Several authors, including Bergström and Sweet (1966), have combined C. angulatus Pander, 1856 s.f. and C. rotundatus Pander, 1856 into one multielement taxon. This reconstruction was criticized by Miller (1980) who considered _C. angulatus_ and _C. rotundatus_ as two different multielement species. Bagnoli _et al._, (1986) pointed out that such a differentiation is unwarranted given the comparable pattern of denticulation and shape of the basal cavity in the two form species. This is also supported by the nearly ubiquitous stratigraphic and geographic co-occurrence of the two elements. Consequently, I agree with their reconstruction and have treated _C. angulatus_ Pander, 1856 as the rounded element and _C. rotundatus_ Pander, 1856 s.f. as the compressed element of the multielement species _C. angulatus_ Pander.

Material: 12 rounded elements; 10 compressed elements.

Occurrence: WC23, NAP6, NH54.

CORDYLODUS HASTATUS Barnes, 1988

(Plate 1, figures 15-18)

Synonymy:

Cordylodus proavus Müller, CHEN and GONG, 1986, p. 130-133, Pl. 36, figs. 13, 17 (only); BAGNOLI, BARNES and STEVENS, 1987, p. 154-155, Pl. 1, figs. 1, 4, 6, 9 (only).

Cordylodus prion Lindström, DRUCE and JONES, 1971, p. 70, Pl. 2, fig. 4 (only); LANDING, 1983, Fig. 8 (only).

Cordylodus sp. cf. C. proavus Müller, DRUCE and JONES, 1971, p. 70-71, Pl. 2, fig. 4 (only).

Cordylodus hastatus BARNES, 1988, p. 411, Figs. 13 s-x, 14d.

Description: Two rounded and a compressed morphotype present. All elements broken.

Rounded morphotype I consists of large, sharp-edged cusp and small denticulated posterior process. Denticles well developed with pointed tips. Basal cavity fairly large with convex anterior margin. Carina present on lateral surfaces of some elements. In some elements lower part of lateral faces expanded to produce an oval basal opening.

Rounded morphotype II with prominent cusp and well developed posterior process. Cusp sharp-edged with a poorly defined carina on lateral face. Posterior process denticulated. Posterior process slightly twisted in some elements.

Compressed morphotype with prominent cusp and posterior process. Cusp with sharp-edges. Cusp slightly twisted laterally in some specimens. Posterior process denticulated and directed downward. Denticles discrete. Basal cavity large with convex anterior margin. Lower part of one lateral face expanded slightly or markedly.

Remarks: All of my C. hastatus specimens are broken probably because of their large size. However, the species is very distinctive and easy to identify. Barnes (1988) described four morphotypes in the apparatus one of which cannot be identified positively in my material. The elements of C. hastatus are much darker compared to the other Cordylodus species in the same sample. This is probably due to the higher organic content of these elements.

Material: 49 broken fragments.

Occurrence: NH44

CORDYLODUS INTERMEDIUS Furnish

(Plate 1, figure 19)

Synonymy:

Cordylodus intermedius FURNISH, 1938, p. 338, Pl. 42, fig. 31, text-fig. 2 (C); DRUCE and JONES, 1971, p. 68, Pl. 3, figs. 1a-3b, text-figs. 23 (f,g); JONES, 1971, p. 46, Pl. 2, figs. 2a-3c; MÜLLER, 1973, p. 30, Pl. 10, figs. 1-3; VAN WAMEL, 1974, p. 58, Pl. 1, figs. 6-7; MILLER, 1980, p. 17-18, Pl. 1, fig. 16, text-fig. 4 (L) only; ETHINGTON and CLARK, 1981, p. 32-33, Pl. 2, fig. 17 (only); *non* LANDING and BARNES, 1981, Pl. 2, fig. 19, text-fig. 3; REPETSKI, 1982, p. 17, Pl. 5, fig. 2, text-fig. 4 (M); *non* LANDING, 1983, text-fig. 7 (H) and 8 (E); NOWLAN, 1985, p. 109, text-figs. 4 (1,2); BAGNOLI *et al.*, 1986, p. 153-154, Pl. 1, figs. 15-18; VIIRA *et al.*, 1987, p. 148, Pl. III, figs. 9,10,13, text-figs. 3, ?23, 26.

Cordylodus angulatus Pander, DRUCE and JONES, 1971, p. 66-67, Pl. 3, fig. 7 (only).

Cordylodus proavus Müller, DRUCE and JONES, 1971, p. 70, Pl. 1, fig. 1 (only).

Cordylodus oklahomensis Müller, DRUCE and JONES, 1971, p. 69, Pl. 5, figs. 7a-c (only).

Description: Unit with prominent cusp and short, denticulate posterior process. Cusp commonly recurved with oval cross-section and sharp edges. Denticles discrete with circular to elliptical cross-section. Anteriormost denticle subparallel to cusp while posteriormost denticle directed away from cusp. In symmetric forms denticles lie in the plane of the cusp while in asymmetric forms denticles twisted laterally. Tips of cusp and denticles broken in most specimens. Basal cavity large with concave anterior margin. Tip of basal cavity directed towards anterior margin of element. Antero-basal margin rounded in some specimens.

Remarks: The most important feature for distinguishing this species is the shape of the basal cavity.

Viira _et al_.(1987) have observed that north-east Baltic collections of _C. intermedius_ Furnish contain two different morphotypes of the rounded element. One morphotype is similar to _C. proavus_ in overall shape but has a basal cavicy with a concave anterior margin. The other morphotype is similar to _C. angulatus_ Pander, 1856 s.f. in overall shape but exhibits a basal cavity which is recurved anteriorly. These two morphotypes can be differentiated in my samples as well despite the very small size of the collection. This observation may be significant as Druce and Jones (1971) and Miller (1980) have suggested that _C. intermedius_ is the "evolutionary intermediate" between _C. proavus_ and _C. angulatus_. The question, however, cannot be answered in the present study due to the paucity of specimens.

Material: 7 rounded elements; 6 compressed elements.

Occurrence: NH54, WC23, WC24, WC28, NAP6.

CORDYLODUS LINDSTROMI Druce and Jones

(Plate 1, figure 28)

Synonymy:

Cordylodus lindstromi Druce and Jones, BARNES, 1988, p. 410, Fig. 13, i-l, fig. 14c.

Description: Only rounded elements were recovered in this study. Unit with erect cusp and denticulate posterior process. Cusp and denticles oval in cross-section with sharp edges. Denticles curved posteriorly thereby forming a characteristic notch between cusp and anteriormost denticle. Basal cavity with convex anterior margin and generally small secondary apex extending under first denticle.

Remarks: C. lindstromi is an important index fossil. Its use to define the base of the Ordovician System is under consideration (see Barnes, 1988).

At present, there is a considerable amount of confusion in the literature regarding the nature of C. lindstromi and the validity of this species has been questioned over the years by a number of authors (see Müller, 1973, Landing, Ludvigsen and von Bitter, 1980, Fortey, Landing and Skevington, 1982, Landing, 1983 and Nowlan, 1985). C. lindstromi was originally described as "a cordylodid with a distinctive basal cavity with two or more apices" (Druce and Jones, 1971, p. 69). In that description it was also stated that "the unit is very similar to C. angulatus and C. prion, but the basal cavity is distinctive". As mentioned by Nowlan (1985), morphologically C prion is quite different from C. angulatus. Thus if one has to follow the criteria of Druce and Jones (1971), then any Cordylodus specimen with secondary apices of the basal cavity should be placed under this species. The taxonomic significance of the shape of the basal cavity is debatable despite the claim by a number of workers that the shape of the basal cavity is an evolutionary feature (see Druce and Jones, 1971, Müller, 1973, Miller, 1969, 1980, Bagnoli et al. 1987 and Viira et al., 1987). Moreover, it has been shown that other species of Cordylodus including C. proavus can exhibit secondary apices of the basal cavity under the posterior process (Nowlan, 1985, Viira et al., 1987). In the light of these observations it is evident that to define C. lindstromi based solely on the shape of the basal cavity is not proper from a taxonomic point of view. From a practical point of view it should also be mentioned that the basal cavity can be observed only in well preserved conodonts with low CAIs. It is extremely difficult, if not impossible, when working with thermally altered or badly preserved conodonts to correctly identify a species the definition of which is based solely on the shape of the basal cavity. This discussion about the taxonomy is important as it is related to another important issue, namely that of biostratigraphy. As stated before _C_. _lindstromi_ is very important biostratigraphically and a consensus regarding the nature of this species has to be reached since its use to define the Cambro-Ordovician boundary is under consideration (Barnes, 1988). I feel that the specimens described as _C_. _lindstromi_ by Barnes (1988, p. 410, Fig. 13, i-l) have a distinctive morphology and these conodonts should be used to define the interval known as _C_. _lindstromi_ zone. In this study I have used the name _C_. _lindstromi_ for specimens similar to those of Barnes (1988) only. In future studies, however, it is probably prudent to use another name for _C_. _lindstromi_ _sensu_ Barnes (1988), and the name _C_. _lindstromi_ should be considered as _nomen_ _dubium_.

Material: 4 broken specimens.

Occurrence: NH44, WC23.

CORDYLODUS OKLAHOMENSIS Müller s.f.

(Plate 1, figure 24)

Synonymy:

Cordylodus oklahomensis MÜLLER, 1959, p. 447-448, Pl. 15, figs. 15, 16, text-fig. 3A; MILLER, 1969, p. 423-424, Pl. 65, figs. 46-53, text-fig. 3I; ETHINGTON and CLARK, 1971, Pl. 1, fig. 24; NOWLAN, 1985, p. 110, Figs. 4.21-4.26. ?*Cordylodus* cf. *C. proavus* Müller, DRUCE and JONES, 1971, p. 71, Pl. 1, figs. 10a, b (only).

Description: Unit laterally compressed. Cusp large with sharp anterior and posterior margins, slightly bent laterally. Posterior process denticulated and well developed. Denticles reclined with sharp anterior and posterior margins, fused near base. Base large. Anterior margin of basal cavity slightly convex with tip situated near center.

Remarks: This species is rare in my samples and is represented by broken fragments only. Miller (1980) put *C. oklahomensis* in the apparatus of *C. proavus*. I, however, agree with Nowlan (1985) and consider these two species as separate.

Material: 2 specimens.

Occurrence: NH44.

CORDYLODUS PRION Lindström

(Plate 1, figure 25)

Synonymy:

Cordylodus prion LINDSTRÖM, 1955, p. 552-553, Pl. 5, figs. 14-16; DRUCE and JONES, 1971, p. 70, Pl. 2, figs. 1-3, 5-7, text-fig. 23i, k-o (non 4 - C. hastatus).

Cordylodus lindstromi DRUCE and JONES, 1971, Pl. 1, figs. 9a, b (only); MILLER, 1980, Pl. 1, fig. 19 (only).

Description: Element with suberect cusp and denticulated posterior process. Rounded and laterally compressed morphotypes occur. Anterior and posterior margins of cusp sharp, more so in laterally compressed specimens. Cusp can be slightly bent laterally. Denticles reclined with sharp anterior and posterior margins and pointed tips. Denticles generally small and often fused near bases. Basal cavity extends under posterior process. Aboral margin curved.

Remarks: The recovered specimens agree with Lindström's (1955) description of the species. The species, like most other Cordylodus species, exhibits a range of morphologic variation. Some elements of this species have been assigned to the apparatus of C. lindstromi by various authors (see discussion under C. lindstromi). However, I believe these two species to be distinct and hence have separated them in this study.

Material: 3 specimens.

Occurrence: WC23.

CORDYLODUS PROAVUS Müller

(Plate 1, figure 27; Plate 2, figure 1, 6)

Synonymy:

rounded element

Cordylodus proavus MÜLLER, 1959, p. 448-449, Pl. 15, figs. 11, 12, 18, text-fig. 3 (B); MILLER, 1969, p. 424-426, Pl. 65, figs. 37-45, text-fig. 3 (D); DRUCE and JONES, 1971, Pl. 1, figs. 2-6 (only); FAHRAEUS and NOWLAN, 1978, p. 453, Pl. 1, figs. 8,9; LANDING, 1983, text-figs. 7 (G), 8 (A), 9 (A-C); NOWLAN, 1985, p.111, text-fig. 5 (12, 13, 18, 17, 19); VIIRA et al., 1987, p. 149-151, Pl. II, figs. 1-6, Pl. III, figs. 3, 8, 12, Pl. IV, figs. 1-3, 9, 12, text-figs. 2 (1-3, 6-9, 11-15, 19-21, 23-29), 3 (3, 6, 7, 10, 11, 16, 17, 22), 4 (6-27).

multielement

Cordylodus proavus Müller, MILLER, 1980, p. 19-20, Pl. 1, figs. 14-15, text-figs. 4 (G,H); ETHINGTON and CLARK, 1981, p. 33-34, Pl. 2, figs. 18-19; BAGNOLI *et al*., 1986, p. 154-155, Pl. 1, figs. 7-9.

Description: Rounded element characterized by prominent cusp and large base extended as denticulated posterior process. Cusp reclined to recurved. Denticles large and discrete. Cross-sections of cusp and denticles generally oval but can be rounded. In most specimens tips of cusp and denticles broken. Basal cavity large and conical with convex anterior edge. Anterior edge of basal cavity parallel to anterior edge of element. Tip of basal cavity extends above base of anteriormost denticle. Majority of rounded elements recovered in this study are asymmetric. In asymmetric specimens posterior process twisted laterally and roundness of lateral surfaces unequal.

Compressed element with prominent cusp and large base. Posterior process better developed compared to rounded elements. Cusp generally recurved. Denticles well developed but less discrete compared to rounded elements. Basal cavity conical and extends into posterior process. Anterior margin of basal cavity parallel to anterior margin of element. Majority of elements asymmetric with laterally deflected posterior process. Convexity of lateral surfaces often unequal. Base strongly flared in at least one specimen.

Remarks: According to Miller (1980), Landing et al. (1980), An (1982) and Bagnoli et al. (1986), the apparatus of C. proavus consists of two distinct morphotypes, (rounded and compressed). Recently Viira et al. (1987) have suggested that this apparatus may include a third twisted element. Such an element, however, appears to be rare and has not been encountered in this study.

The range of intraspecific variation exhibited by C. proavus is extensive and as pointed out by Viira et al. (1987), this variation can be observed not only in time but also within a fauna.

Material: 18 rounded elements; 16 compressed elements. Material commonly broken.

Occurrence: NH44, NH45, NH49, WC23, WC24.

CORDYLODUS SP. s.f.

(Plate 1, figure 26)

Description: Element robust with large cusp and denticulated posterior process. Cusp with sharp anterior and posterior margins. Cross-section of cusp biconvex. Lateral surface of cusp seems to have poorly developed carina in basal part. Posterior process twisted laterally and exhibits at least six well developed denticles. Denticles with slightly convex and sharp anterior and posterior margins and pointed tips. Anteriormost denticle suberect and denticles become more reclined posteriorly. Junction between anterior part of aboral margin and basal part of anterior margin rounded. Aboral margin slightly curved. Base large with slight flaring under posterior end of process.

Remarks: This species is rather distinctive but rare. Its multielement association is not clear.

Material: 1 specimen

Occurrence: WC23

Genus DREPANODUS Pander, 1856

Type species: Drepanodus arcuatus Pander, 1856

DREPANODUS SP. aff. D. ACUTUS Pander, 1856, s.f.

(Plate 2, figure 2)

Synonymy:

aff. Drepanodus acutus PANDER, 1856, Pl. 2, fig. 9; DRUCE and JONES, 1971, p. 73, Pl. 20, figs. 5a-7c, text-fig. 24a.

Description: unit laterally compressed. Cusp sharply recurved with sharp anterior and posterior margins. Angle between cusp and base 90°. Cusp can be bent laterally. Base extended posteriorly, basal cavity moderate in size. Oral edge more or less straight. Basal funnel partially preserved in some specimens.

Remarks: This species differs from D. acutus in having a longer base and straighter oral edge.

Material: 5 specimens.

Occurrence: NAP16, WC32.

DREPANODUS SP. s.f.

(Plate 2, figure 5)

Synonymy:

Drepanodus pandus Branson and Mehl, MOSKALENKO, 1967, Pl. 23, figs. 2-4 (non Pl. 23, figs. 1-2).

Description: Recurved element with flared base. Cusp laterally compressed with sharp anterior and posterior margins. Cross-section of cusp biconvex. Base large. Oral margin concave, aboral margin convex in lateral view.

Material: 3 specimens

Occurrence: EI13

Genus DREPANOISTODUS Lindström, 1971

Type species: Oistodus forceps Lindström, 1955

DREPANOISTODUS FORCEPS (Lindström)

(Plate 2, figures 9-12)

Synonymy:

Acodus gratus LINDSTRÖM, 1955, p. 545, Pl. 2, figs. 27-29.

Oistodus forceps LINDSTRÖM, 1955, p. 574, Pl. 4, figs. 9-13, text-fig. 3M; ETHINGTON and CLARK, 1965, p. 194, Pl. 1, fig. 18; FAHRAEUS, 1966, p. 23, Pl. 3, figs. 1a-c.

Drepanodus homocurvatus LINDSTRÖM, 1955, p. 563, Pl. 2, figs. 23, 24, 39, text-fig. 4d; ETHINGTON and CLARK, 1964, p. 688, Pl. 113, figs. 13, 16; FAHRAEUS, 1966, p. 21-22, Pl. 2, figs. 11 a-b, text fig. 2E; UYENO and BARNES, 1970, p. 107, Pl. 21, fig. 9; JONES, 1971, p. 51-52, Pl. 8, figs. 4 a-c, non Pl. 3, figs. 2 a-c.

Drepanodus planus LINDSTRÖM, 1955, p. 565, Pl. 2, figs. 35-37, text-fig. 4a.

Drepanodus uberectus (Branson and Mehl) LINDSTRÖM, 1955, p. 568, Pl. 2, figs. 21, 22; ETHINGTON and CLARK, 1964, p. 688, Pl. 113, figs. 13, 16; FAHRAEUS, 1966, p. 23, Pl. 2, fig. 10; UYENO and BARNES, 1970, p. 107, Pl. 21, fig. 15; DRUCE and JONES, 1971, p. 75, Pl. 12, figs. 1a-2c; JONES 1971, p. 53-54, Pl. 8, figs. 6a-7c

Drepanoistodus forceps (Lindström) LINDSTRÖM, 1971, p. 42-43, figs. 5,8; SERPAGLI, 1974, p. 30-31, Pl. 10, figs. 8a-12c, Pl. 21, figs. 9-14; VAN WAMEL, 1974, p. 64-65, Pl. 2, figs. 14-22; FAHRAEUS and NOWLAN, 1978, p. 459, Pl. 1, figs. 22-25; LÖFGREN, 1978, p. 53-55, Pl. 1, figs. 1-6, text-fig. 26 A; BEDNARCZYK, 1979, p. 425, Pl. 4, fig. 8, Pl. 5, figs. 7, 17, Pl. 6, fig. 12; STOUGE, 1984, p. 53-54, Pl. 3, figs. 24-25.

Description: Homocurvatiform element characterized by recurved cusp with smooth lateral faces. Anterior and posterior margins of cusp sharp. In some laterally compressed elements margins of cusp may be drawn out as sharp edges. Basal cavity triangular with apex pointed towards anterior margin of cusp. Aboral margin curved while oral edge straight. Base can be flared in some elements.

Suberectiform element has erect cusp with sharp anterior and posterior margins. Lateral faces of cusp smooth. Oral edge straight and aboral edge curved. Angle between aboral margin and oral edge about 90°. Base slightly flared and basal cavity roughly triangular in outline.

Oistodiform element characterized by strongly reclined and straight cusp. Cusp exhibits sharp edges and a carina on one of lateral surfaces. Cusp fairly long and may be slightly twisted laterally. Angle between anterior and aboral margins about 45°. Basal cavity extends along the base up to the point where aboral margin meets oral margin. Basal cavity not very deep. Angle between posterior margin and oral edge quite small. In some elements anterior lower part of cusp and base are strongly laterally compressed and sharp margin of the cusp extended to resemble a very narrow anterior process.

Remarks: The homocurvatiform element of D. forceps is Drepanodus homocurvatus Lindström s.f. The suberectiform element is D. suberectus (Branson and Mehl) s.f. while the oistodiform element is O. forceps Lindström s.f. The Bay of Islands samples also contain a scandodiform element with a laterally twisted and expanded base which most probably belongs to D. forceps (see Fahraeus and Hunter, 1985). However, due to the small number of specimens I can not definitely confirm this hypothesis. Hence, in this study I have decided only to illustrate this element.

Material: 62 homocurvatiform elements; 30 oistodiform elements; 22 suberectiform elements; 10 scandodiform elements.

Occurrence: EI10, EI13, EI15, EI18, EI19, EI24, NAP16, NAP17, EIN1.

DREPANOISTODUS SP.1

(Plate 2, figures 3, 7)

Synonymy:

aff. Drepanodus n.sp. 6 s.f. REPETSKI, 1982, p. 24-25, Pl. 8, fig. 1 (only).

Description: Apparatus consists of drepanodiform and oistodiform elements.

Drepanodiform element: unit with recurved cusp and fairly large base. Cusp laterally compressed with sharp anterior and posterior keels which extend up to aboral margin. Outer lateral surface exhibits faint rounded carina. Base extended anteroposteriorly. Outer surface of base expanded. Basal cavity fairly large. Posterior margin of basal cavity concave in lateral view. Apex of basal cavity very close to anterior margin of element.

Oistodiform element: unit characterized by flared base. Cusp with sharp anterior and posterior margins. Anterior edge of cusp flexed laterally. Outer margin of cusp carinate, inner margin rounded. Angle between oral edge and posterior margin of cusp small. Oral edge curved. Basal opening roughly extended oval.

Remarks: The drepanodiform element is similar to D. n.sp. 6 of Repetski (1982). The main difference between the two is the size and shape of basal cavity.

Material: 2 drepanodiform elements; 1 oistodiform element.

Occurrence: NAP17.

DREPANOISTODUS SP.2

(Plate 2, figures 13-15)

Synonymy:

?aff. Drepanoistodus forceps (Lindström) LINDSTRÖM, 1971, p. 42-43, Figs. 5, 8.

?aff. Drepanodus suberectus (Branson and Mehl, 1933) LINDSTRÖM, 1955, p. 568, Pl. 2, figs. 21, 22.

?aff. Oistodus forceps LINDSTRÖM, 1955, p. 574-576, Pl. 4, figs. 9-13, text-fig. 3 M.

Drepanodus cf. D. planus Lindström, REPETSKI, 1982, p. 21, Pl. 6, fig. 8.

Drepanoistodus sp. cf. D. suberectus (Branson and Mehl), LANDING et al., 1986, p. 1936, Pl. 2, figs. 1, 3.

Drepanoistodus sp. LANDING et al., 1986, p. 1936, Pl. 2, fig. 9 (only).

Description: Apparatus consists of drepanodiform and oistodiform elements.

Drepanodiform element: unit characterized by reclined to suberect cusp with sharp anterior and posterior margins. Cusp more or less straight above base. Lateral surfaces of cusp rounded. Basal part of anterior margin generally curved anteriorly, straight in some specimens. Base expanded anteroposteriorly. Basal margin slightly flared except at anterior extension. Basal opening extended oval in shape with constricted anterior part. Oral margin straight. Angle between oral and aboral margins variable from about 60°-80°. Angle between aboral margin and basal part of anterior margin about 45° in most specimens. In scandodiform morphotypes, base can be slightly twisted relative to cusp.

Oistodiform element: unit consists of reclined cusp and flared base. Cusp twisted laterally. Anterior and posterior margins of cusp sharp. Anterior margin straight near base. Base relatively large, extended anteroposteriorly. Oral margin curved, aboral margin sinuous. Anteriormost part of aboral margin turned sharply upwards to meet the basal part of anterior margin at right angles.

Remarks: This species is rather problematic as is evident from the synonymy list. As mentioned by Landing _et al._ (1986) the elements of this species show similarities with _D_. _suberectus_ as well as _D_. _forceps_ but cannot be definitely assigned to either. I believe that this is a valid species distinct from either one mentioned above. The Bay of Islands specimens of this species are generally rather poorly preserved.

Material: 14 drepanodiform elements; 3 oistodiform elements.

Occurrence: NAP20, NAP23.

DREPANOISTODUS SP. 3

(Plate 2, figures 4, 8)

Description: Apparatus composed of coniform and oistodiform elements.

Coniform element with proclined to suberect cusp with large base. Scandodiform and drepanodiform morphotypes exist. Cusp laterally compressed with sharp anterior and posterior costae. Anterior costa extends up to aboral margin, posterior costa generally does not. Cusp slightly twisted laterally in scandodiform morphotypes. Posterior margin smooth curve in drepanodiform elements. Base large, basal cavity triangular in lateral view. Apex of basal cavity situated very close to anterior margin of element. Base flared in scandodiform elements. Oral margin straight to slightly curved, aboral margin straight in lateral view. Basal part of anterior margin curved anteriorly.

Oistodiform element: characterized by laterally twisted blade-like cusp. Anterior and posterior margins of cusp sharp. Angle between oral and posterior margin small. Lateral surface of cusp may be costate. Aboral margin of base sinuous in lateral view.

Remarks: The drepanodiform elements of this species are similar in general morphology to _D_. _numarcuatus_ Lindström, 1955, s.f. The basal cavity in D. numarcuatus is shallow while the basal cavity in the new species is quite large.

Material: 15 drepanodiform elements; 2 oistodiform elements.

Occurrence: NH54

Genus EOCONODONTUS Miller,1980

Type species: Proconodontus notchpeakensis Miller, 1969, s.f.

EOCONODONTUS ALISONAE

Landing, 1983, emend. herein

(Plate 2, figures 16-23)

Synonymy:

Eoconodontus alisonae LANDING, 1983, p. 1176, Figs. 7L-N, 11A-F, J, K.

Original diagnosis: " Conodont species with two-element apparatus consisting of non-costate scolopodiform elements with laterally to posterolaterally deflected base and costate drepanodiform elements; albid cusp strongly proclined, erect, or reclined" (Landing, 1983, p. 1176).

Emended diagnosis: Conodont species with apparatus consisting of scandodiform, costate drepanodiform and symmetric to slightly asymmetric, costate scolopodiform elements; compressed and rounded morphotypes of scolopodiform elements present.

Description: Scandodiform element characterized by strongly laterally compressed cusp and flared, triangular base. Cusp slightly to markedly recurved with keeled lateral margins. Keels fairly wide and continue onto base. Keels extend below basal margin in some specimens. Anterior margin broadly rounded in most elements, faintly carinate in some. Posterior margin carinate. Base large, triangular with flared margin. In nearly symmetrical element base situated medially. In asymmetric element base twisted laterally. Right-handed and left-handed specimens can be identified based on the direction of twist of the base.

Costate drepanodiform element: Curvature of cusp variable. Most units characterized by proclined to suberect cusp. Anterior and posterior margins of element sharply keeled. Keels quite wide. Keels may or may not extend up to basal margin. In some elements keels extend below basal margin. Aboral end of keels rounded. Lateral faces of element costate. Elements generally exhibit one or two prominent costae on each side. Main costa can be associated with one or two smaller lateral costae which can merge with the main costae. Costae may or may not extend onto base. In some elements costae extend below the basal margin. Base well differentiated in most elements of this type. Basal cavity moderate to large. In some elements unequal convexity of lateral surfaces give rise to slightly asymmetric forms.

Scolopodiform element: Curvature of cusp variable, recurved in most elements, proclined in some. Cusp well developed and fairly long. Sharp costae present on anterior and posterior margins of cusp. In some elements anterior and posterior costae fairly wide. One or two main costae present on each lateral face. Main costae associated with shorter secondary costae in the basal part. Main costae often merge with secondary costae. Total number of costae can be up to 6 or 8. Costae continue onto the base and in some specimens extend below the basal margin. Aboral terminations of costae rounded. Basal opening circular in rounded elements oval in asymmetric forms. Basal cavity moderate to large, apex situated medially near bend of cusp.

Remarks: The Bay of Islands specimens of E. alisonae exhibit more morphologic variation than described by Landing (1983). The apparatus of E. alisonae is complex and appears to includes at least one transition series from compressed scolopodiform elements to rounded scolopodiform elements. As mentioned by Landing (1983) the elements belonging to this species are quite small. The distribution of E. alisonae seems to be ecologically controlled as this species has so far been recovered only from the deeper water facies. This species also has a very short range and hence can be useful biostratigraphically.

Material: 30 scandodiform elements; 52 scolopodiform elements; 94 costate drepanodiform elements.

Occurrence: NH40, NH41, NH42.

EOCONODONTUS NOTCHPEAKENSIS (Miller)

(Plate 2, figure 24)

Synonymy:

Proconodontus notchpeakensis MILLER, 1969, p, 438, Pl. 66, figs. 21-29, text fig, 5G; MÜLLER, 1973, P. 43, Pl. 4, fig. 6.

Proconodontus carinatus MILLER, 1969, p. 437, Pl. 66, figs. 13-20, text-fig. 5I; LANDING, TAYLOR and ERDTMANN, 1978, text-fig. 2A.

<<Proconodontus>> carinatus Miller, LANDING, LUDVIGSEN and VON BITTER, 1980, p. 31-33, text-figs. 5C, F, 8D, H.

Eoconodontus notchpeakensis (Miller) MILLER, 1980, p. 22-23, Pl. 1, figs. 10-12, text-figs. 3D, E (includes synonymy up to 1979); LANDING, 1983, p. 1177, text-fig. 11P, Q; NOWLAN, 1985, text-figs. 5.7-5.9, 5.14-5.16; BAGNOLI, BARNES and

STEVENS, 1987, p. 155-156, Pl. 2, figs. 5-7.

Description: Simple cones with proclined cusp. Primitive elements laterally compressed with oval cross-section, advanced forms more rounded. Anterior and posterior margins costate. Costae well developed in primitive forms, less so in advanced ones. Symmetric and asymmetric morphotypes can be discerned, especially amongst primitive forms. Symmetric element exhibits rounded lateral faces. Asymmetric element characterized by one rounded and one flattened lateral face. Basal cavity fairly large with tip extending up to bend of cusp.

Remarks: According to Miller (1980) E. notchpeakensis apparatus includes "rounded" and "compressed" elements. The rounded element is represented by P. notchpeakensis Miller, 1969, s.f. and the compressed element is represented by P. carinatus Miller, 1969, s.f. The Bay of Islands material have yielded only the rounded element, which, according to Miller (1980), is the more abundant form. The size of the E. notchpeakensis specimens is variable from small to moderately large specimens.

Material: 27 specimens.

Occurrence: NH41, NH42, NH46, NH49, NAP2.

Genus GLYPTOCONUS Kennedy, 1980

Type species: Scolopodus quadraplicatus Branson and Mehl, 1933

GLYPTOCONUS QUADRAPLICATUS Branson and Mehl s.f.

(Plate 6, figure 3)

Synonymy:

Scolopodus quadraplicatus BRANSON and MEHL, 1933, p. 63, Pl. 4, figs. 14-15; MOSKALENKO, 1967, p. 114-115, Pl. 25, figs. 3-5; ETHINGTON and CLARK, 1971, p. 73, Pl. 2, fig. 5; REPETSKI and ETHINGTON, 1977, p. 96-97, 100, Pl. 2, fig. 15; REPETSKI, 1982, p. 50, Pl. 23, figs. 4, 5.

Glyptoconus quadraplicatus Branson and Mehl, KENNEDY, 1980, p. 61-63, Pl. 1, figs. 39-45.

Description: Cusp proclined, rather sharply recurved above cusp-base boundary. Cusp slightly bent laterally. Deep groove present on each side. Posterior margin broad with medial groove, two prominent posterolateral costae present. Anterior margin broadly rounded. Base slightly extended posteriorly. Basal margin slightly flared. Base darker compared to rest of element.

Remarks: G. quadraplicatus appears to be a common and abundant species in typical midcontinent collections (for example see Furnish, 1938, Repetski, 1982 amongst others). This species, however, is quite rare in my samples.

Material: 4 specimens.

Occurrence: NAP23, EI13.

Genus IAPETOGNATHUS Landing, 1982

Type species: _Pravognathus_ _aengensis_ Lindström, 1955, s.f.

IAPETOGNATHUS SP. aff. I. PREAENGENSIS

(Plate 2, figures 25-27)

Synonymy:

aff. _Iapetognathus_ _preaengensis_ LANDING, 1982, p. 124-126, Text-figs. 6, 8; BARNES, 1988, Fig. 13 y, z, aa-ee.

Description: Apparatus multielement, only partial apparatus with cordylodiform and iapetognathiform elements recovered.

Cordylodiform element with slightly recurved cusp and denticulated posterior process. Cusp deflected laterally. Cross-section of cusp circular. Posterior process with at least two well developed reclined denticles. Cross-section of denticles circular. Base flared laterally, basal cavity partially extending under posterior process.

Iapetognathiform element exhibits two morphotypes.

Morphotype I with cusp and denticulated lateral process. Cusp and denticles with sharp lateral margins and biconvex cross-sections. Cusp and denticles bend posteriorly. Base large and flared. Morphotype II represented by broken fragments in my samples and consists of cusp and denticulated process. Cusp and denticles about same in size, reclined and parallel. Margins of cusp and denticles sharp. Base well developeterolateral costae. Basal opening circular.

Remarks: The full apparatus of I. preaengensis Landing is yet to be described but apparently consists of a number of different types of elements (see Barnes, 1988). The Bay of Islands specimens of I. aff. I. preaengensis Landing are represented by broken elements in my samples and iapetognathiform elements are more common than cordylodiform elements.

Material: 26 iapetognathiform elements; 2 cordilodiform elements.

Occurrence: NH44, NH45, NH46, NH49, WC23.

Genus LOXODUS Furnish, 1938

Type species: <u>Loxodus</u> <u>bransoni</u> Furnish, 1938

LOXODUS BRANSONI Furnish s.f.

(Plate 2, figure 28)

Synonymy:

<u>Loxodus</u> <u>bransoni</u> FURNISH, 1938, p.339, Pl. 42, figs. 33-34, text-fig. 2A; ETHINGTON and CLARK, 1971, p. 72-73, Pl. 1, fig. 11; REPETSKI and ETHINGTON, 1977, p. 95-96, Pl. 1, fig. 2; REPETSKI, 1982, p. 27-28, Pl. 9, fig. 7; TAYLOR and LANDING, 1982, Text-fig. 5P; NOWLAN, 1985, Fig. 4.29; ORNDORFF, 1987, p. A13, Pl. 1, fig. 26.

Description: Laterally compressed elongate unit with denticulated upper margin. Denticles have convex margins. Tips of denticles lighter in colour compared to rest of element. Denticles fused except near tips. Anteriormost denticle suberect while remaining denticles become progressively more reclined towards posterior end. Basal margin straight posteriorly, slightly deflected inward anteriorly. Depth of basal cavity decreases posteriorly. Unit as a whole twisted towards the inside near its anterior margin.

Remarks: The specimens from Bay of Islands are quite similar to those described by Furnish (1938).

Material: 7 broken specimens.

Occurrence: WC32, NAP6.

Genus MACERODUS Fahraeus and Nowlan, 1978

Type species: *Macerodus dianae* Fahraeus and Nowlan, 1978

MACERODUS SP. aff. M. DIANAE Fahraeus and Nowlan

(Plate 2, figure 29)

Synonymy:

aff. *Macerodus dianae* FAHRAEUS and NOWLAN, 1978, p. 461, Pl. 1, figs. 26, 27; REPETSKI, 1982, p. 28, Pl. 15, figs. 10, 11.

Paltodus sp. C. ETHINGTON and CLARK, 1971, p. 73, Pl. 2, fig. 11.

Description: Slightly laterally compressed proclined simple cone. Cusp short compared to base. Base long and very slightly compressed laterally. Basal cavity deep, apex of basal cavity extends up to point of curvature of cusp. Oral margin slightly concave. Basal part of anterior margin more or less straight. Surface of element covered by fine longitudinal striations.

Remarks: The morphology of this species is very similar to that of *M. dianae*. However, the base of some specimens of *M.* sp. aff. *M. dianae* is less compressed compared to *M. dianae*. This species appears to be rare in the Bay of Islands material and only two broken specimens have been recovered.

Material: 2 specimens.

Occurrence: NH54.

Genus MICROZARKODINA Lindström 1971

Type species: *Prioniodina flabellum* Lindström 1955

MICROZARKODINA FLABELLUM (Lindström)

(Plate 6, figures 19-21)

Synonymy:

Microzarkodina flabellum (Lindström) LÖFGREN, 1978, p. 61-62, Pl. 11, figs. 27-36 (contains synonymy).

Remarks: Ozarkodiniform, trichonodelliform, cordylodiform and oistodiform elements of this species have been recovered. For more discussion on the oistodiform element see under *Periodon flabellum*. The Bay of Islands specimens agree well with the specimens of this species illustrated by Löfgren (1978). Elements of this species occur in only one of my samples.

Material: 22 ozarkodiniform elements; 8 trichonodelliform elements; 5 cordilodiform elements; (for oistodiform elements see under *P. flabellum*).

Occurrence: EIN1

Genus OEPIKODUS Lindstöm

Type species: *Oepikodus smithensis* Lindström, 1955 s.f.

?OEPIKODUS EVAE (Lindström)

(Plate 3, figures 9, 10, 16, 17)

Synonymy:

?*Oepikodus evae* (Lindström) FAHRAEUS and NOWLAN, 1978, p. 463-464, Pl. 3, figs. 15-17 (contains partial synonymy).

?*Prioniodus* (*Oepikodus*) *evae* Lindström, LÖFGREN, 1978, p. 79-80, Pl. 9, figs. 7-10.

?*Prioniodus evae* LINDSTRÖM, 1971, p. 52-53, Figs. 13, 14.

Description: Partial apparatus consisting of prioniodiform and ramiform (belodiform) elements. Prioniodiform elements exhibit well developed cusp and denticulated processes. The angles between the three processes variable, as in the case of P. cf. P. elegans. Only a few broken belodiform elements have been recovered. Posterior process of these elements fairly well developed and exhibit numerous, small, sharp tipped denticles.

Remarks: Only the prioniodiform elements of this species are well preserved and abundant. The prioniodiform and belodiform elements are very similar in morphology to the O. evae specimens illustrated by Fahraeus and Nowlan (1978). Positive identification, however, is difficult due to the broken nature and scarcity of the other elements and hence these conodonts are tentatively assigned to this species. No oistodiform element that can be definitely assigned to this species has been found. The oistodiform elements of this species illustrated by Lindström (1971) have some similarities with elements of Gen. et sp. indet. 3 described later in this study. I, however, consider the latter to be a separate species and hence have treated it as such.

Material: 26 prioniodiform elements; 3 broken belodiform elements.

Occurrence: EIN1.

Genus OISTODUS Pander, 1856

Type species: _Oistodus_ _lanceolatus_ Pander, 1856

OISTODUS sp. aff. O. SCALENOCARINATUS Mound

(Plate 3, figures 1-3)

Synonymy:

aff. _Oistodus_ _scalenocarinatus_ MOUND, 1965, p. 30, Pl. 4, figs. 6, 7, 10-12.

aff. _Oistodus_ _lanceolatus_ Pander, UYENO and BARNES, 1970, p. 119, Pl. 24, figs. 23, 24.

aff. _Oistodus_ _scalenocarinatus_ Mound, NOWLAN, 1976, p. 272-273, Pl. 8, figs. 1-4.

Description: Laterally compressed uni- or bicarinate geniculate coniform elements. Cusp well developed with sharp anterior and posterior margins. Oral margin convex. Aboral margin convex in bicostate elements, concave in unicostate ones.

Remarks: The elements described here are similar in morphology to geniculate elements of _Oistodus_ _scalenocarinatus_ Mound described by Nowlan (1976). The apparatus of _O_. _scalenocarinatus_ has oistodiform, acodiform and distacodiform elements and it is possible that the full apparatus of the present species is also similar. In this study, however, only the geniculate elements have been recovered. The main difference between the present species and _O_. _scalenocarinatus_ Mound appears to be in the shape of the aboral margin. The aboral margin of all the geniculate elements of _O_. _scalenocarinatus_ is convex while in case of the present species it can be concave in unicostate elements. As discussed by Nowlan (1976) elements of this type are similar to those of _O_. _lanceolatus_ Pander, the only difference being the absence of the lateral carinae in the former.

Material: 5 elements.

Occurrence: EIN1.

?OISTODUS TRIANGULARIS Lindström, 1955, s.f.

(Plate 3, figure 15)

Synonymy:

?_Oistodus_ _triangularis_ LINDSTRÖM, 1955, p. 581, Pl. 4, figs. 14-18.

Description: Unit with reclined cusp and posteriorly expanded base. Anterior and posterior margins of cusp sharp. Anterolateral costa present on one surface. Oral margin curved.

Remarks: Only a few very badly preserved specimens of this type have been recovered. These are, thus, tentatively assigned to O. triangularis s.f.

Material: 2 fragments.

Occurrence: NAP21

Genus PALTODUS Pander, 1856

Type species: Paltodus subaequalis Pander, 1856

?PALTODUS SP.1 s.f.

(Plate 3, figures 12, 13)

Description: Robust, asymmetric element with erect to proclined cusp. Anterior and posterior margins of element sharp. Anterior edge flexed laterally. Lateral costa present on one side, costa extending onto base. Base flared to one side, basal opening triangular.

Remarks: Only a few elements of this species have been recovered. No oistodiform element has been found in the Bay of Islands material and hence at present this species cannot be positively assigned to the multielement genus Paltodus.

Material: 4 specimens.

Occurrence: NAP6, NAP16

?PALTODUS Sp. 2

(Plate 3, figure 6)

Description: Nongeniculate, slightly to markedly asymmetric simple cones with erect to slightly recurved cusp.

Slightly asymmetric element rounded with a keeled posterior margin. Anterior margin broadly rounded. Two rounded anterolateral costae present. Base slightly extended posteriorly, basal cavity shallow.

Asymmetric element laterally compressed with an erect cusp. Posterior margin sharp. Basal part of element contains rounded anterior keel which becomes anterolateral along the cusp. One lateral keel may be present in some specimens. Basal cavity shallow. Inverted basal cavity appears to be present in some elements.

Remarks: Only a few elements of this type have been recovered and they probably do not represent the full apparatus. This makes generic assignment difficult. No oistodiform element of this species has, however, been found in the Bay of Islands material.

Material: 3 specimens.

Occurrence: NAP6

Genus PAROISTODUS Lindström, 1971

Type species: Oistodus parallelus Pander,1856

Remarks: Lindström (1971, p. 46) defined this genus as "Paroistodus includes drepanodid conodonts with drepanodiform and oistodiform elements. The basal cavity tends to become inverted anteriorly. Drepanodiform elements tend to develop a sharp, low costa on each side. Base of oistodiform elements is roughly square in side view and does not extend very far anteriorly". Van Wamel (1974) emended this definition to include a scandodiform element in the Paroistodus apparatus. However, this element has later proved to be a modified drepanodiform element (Löfgren, 1978).

PAROISTODUS PARALLELUS (Pander)

(Plate 3, figures 4, 5, 11)

Synonymy:

Oistodus parallelus PANDER, 1856, p. 27, Pl. 2, fig. 30; LINDSTRÖM, 1955, p. 579, Pl. 4, figs. 26, 30, 31, text-fig. 3 (O); ETHINGTON, 1972, p. 23, Pl. 1, fig. 21;

Acodus expansus GRAVES and ELLISON, 1941, p. 8, Pl. 1, fig. 6; ETHINGTON, 1972, Pl. 1, fig. 23;

Distacodus expansus (Graves and Ellison) LINDSTRÖM, 1955, p. 555, Pl. 3, figs. 13-17, text-figs. 2 g-i; ETHINGTON, 1972, p. 23, Pl. 1, fig. 23; REPETSKI, 1982, p. 19, Pl. 6, fig. 2.

Paroistodus parallelus (Pander) LINDSTRÖM, 1971, p. 47, figs. 8, 11; SERPAGLI, 1974, p. 61-62, Pl. 14, figs. 8-12b, Pl. 25, figs. 1-6, Pl. 30, fig. 5; VAN WAMEL, 1974, p. 79-80, Pl. 7, figs. 12-17; LÖFGREN, 1978, p. 68-69, Pl. 1, figs. 18-21; FAHRAEUS and NOWLAN, 1978, p. 460, Pl. 2, figs. 12, 13; BEDNARCZYK, 1979, p.431, Pl. 5, figs. 3, 8-9, 11.

Description: Drepanodiform element laterally compressed with prominent cusp. Cusp recurved and exhibits sharp anterior and posterior keels. In some specimens anterior keel extended to form a broad "knife-edge" which can be turned laterally. Cusp carries costa on each lateral face. Costae can be very poorly developed. Base expanded posteriorly. Oral edge curved and angle between oral and aboral margins about 30°. Anterior part of aboral margin subparallel to oral edge. Base generally thin and translucent. In some specimens the base slightly flared and twisted laterally.

Oistodiform element consists of strongly reclined cusp subparallel to posterior part of aboral margin. Cusp robust and exhibit sharp edges. Broad, rounded carinae present on lateral faces of cusp. In some elements cusp slightly twisted laterally. Oral edge quite sharp and makes an angle of about 30°-40° with aboral margin. Antero-basal angle about 90°.

Remarks: The drepanodiform elements of P. parallelus belong to the form species Distacodus expansus (Graves and Ellison) s.f. The oistodiform elements belong to Oistodus parallelus Pander, 1856 s.f. The only difference between the drepanodiform elements of P. parallelus and those of P. proteus is that the former has costae on the lateral faces of the cusp (see Löfgren, 1978). According to Lindström (1955), D. proteus s.f. is a highly variable species which can resemble D. expansus s.f. quite closely. Van Wamel (1974) has mentioned the presence of forms intermediate between D. expansus s.f. and D. proteus s.f. The distinction between P. parallelus and P. proteus in the Bay of Islands samples is very delicate. The drepanodiform elements vary from costate to non-costate forms and intermediate forms with faint costae can be found. The fact that both kinds occur together in one sample and that both species share the same oistodiform element complicates matters even further. I have assigned only the prominently costate forms to P. parallelus and have put the non-costate and very faintly costate forms under P. proteus. In the sample where the two species co-occur it is impossible to assign the oistodiforms to their respective species. Hence in this case the oistodiforms have been treated in bulk and listed under this species.

Material: 7 drepanodiform elements; see under P. proteus for oistodiform elements.

Occurrence: EIN1.

PAROISTODUS PROTEUS (Lindström)

(Plate 3, figures 7, 8)

Synonymy:

Drepanodus proteus LINDSTRÖM, 1955, p. 566-567, Pl. 3, figs. 18-21, text-figs. 2 a-f,i,j; REPETSKI, 1982, p. 21, Pl. 6, fig. 3.

Paroistodus proteus (Lindström) LINDSTRÖM, 1971, p. 46-47, figs. 8-10; BERGSTRÖM, EPSTEIN and EPSTEIN, 1972, p. D39, figs. 1a, c, d, e; FAHRAEUS and NOWLAN, 1978, p. 460, Pl. 2, figs. 17, 18; LÖFGREN, 1978, p. 68; BEDNARCZYK, 1979, p. 431, Pl. 5, fig. 12.

Paroistodus aff. proteus (Lindström, 1955) AN et al., 1983, p. 119-120, Pl. XIV, figs. 9, 10.

Oistodus parallelus Pander (for synonymy please see under P. parallelus)

Description: Drepanodiform element laterally compressed and consists of recurved cusp and posteriorly expanded base. Cusp has slightly rounded lateral faces and sharp anterior and posterior margins. In some elements anterior edge of cusp extended in the form of a "knife edge". Sharp edge can be slightly twisted laterally. Angle between oral and aboral edges is about 40°-45°. Base thin, transparent and slightly flared. Anterior part of aboral margin subparallel to oral edge.

Remarks: The drepanodiform element of P. proteus is D. proteus Lindström, 1955 s.f. According to Lindström (1955, p. 566), "this is a highly variable species that may be very like Oistodus parallelus on one hand, Distacodus expansus on the other". The main morphologic criterion that separates D. proteus from D. expansus appears to be the absence of lateral costae on the cusp of the former. Another difference observed by Lindström (1955) was that the oral edge of D. proteus is straight while that of D. expansus is curved.

This, however, does not appear to be a diagnostic feature as the oral edges of some of my D. proteus specimens also appear to be curved.

Material: 44 drepanodiform elements; 28 oistodiform elements.

Occurrence: EI24, EIN1.

Genus PHAKELODUS Miller, 1984

Type species: Oneotodus tenuis Müller, 1959

PHAKELODUS TENUIS (Müller, 1959)

(Plate 3, figures 14, 18)

Synonymy:

Oneotodus tenuis MÜLLER, 1959, p. 457, Pl. 13, figs. 11, 13, 14, 20.

Prooneotodus tenuis (Müller), MÜLLER, 1973, p. 45, Pl. 1, figs. 1-3a, b; LEE, 1975, p. 83-84, Pl. 1, figs. 14, 15, 17, text-fig. 2k; LEE, 1980, Pl. I, fig. 5; SZANIAWSKI, 1980, p. 115, Pl. 18, figs. 5, 6.

'Prooneotodus' tenuis (Müller), LANDING, 1977, p. 1073, Pl. 1, figs. 1-9, Pl. 2, figs. 1-11, text-fig. 1; LANDING, TAYLOR and ERDTMANN, 1978, p. 76, text-fig. 2B; MILLER, SUNDBERG, HARMA and WRIGHT, 1981, p. 192, Fig. 4P-T. *Phakelodus tenuis* MILLER, 1984, p. 65; CHEN and GONG, 1986, p. 157-158, Pl. 22, figs. 7, 8, 12, 14, 19, 21, Pl. 23, figs. 4-6, 8, 13, 15, 21, Pl. 24, fig. 3, text-fig. 59.

Description: Slender, elongate, symmetrical to slightly asymmetric simple cones. Cross-section round to oval. Posterior margin keeled in some specimens, anterior margin rounded. Basal cavity extends up to element tip. Elements dark in colour due to high proportion of organic matter.

Remarks: The Bay of Islands material contains individual elements as well as clusters of *P. tenuis*. The size of the elements is variable, individual elements generally tend to be larger than the elements in clusters.

Material: 28 elements (mostly broken); 12 clusters.

Occurrence: NH22, NH27a, NH28, NH32, NH37.

Genus PERIODON Hadding, 1913

Type species: Periodon aculeatus Hadding, 1913

PERIODON FLABELLUM (Lindström)

(Plate 3, figures 19-23)

Synonymy:

Periodon flabellum (Lindström) LÖFGREN, 1978, p. 72-74, Pl. 11, figs. 1-11 (includes synonymy up to 1976).

Periodon flabellum (Lindström) FAHRAEUS and NOWLAN, 1978, p. 462-463, Pl. 3, figs. 2-6.

Remarks: The multiramiform elements exhibit the typical cordylodiform - trichonodelliform symmetry transition series. Multiramiform, prioniodiniform and oistodiform elements of this species have been recovered in this study. I agree with van Wamel (1974) and Löfgren (1978) that the oistodiform element of this species is the form species O. selene. I further agree with Löfgren (1978) that the substantial morphologic variation exhibited by this element suggests that the form species O. selenopsis Serpagli, 1974 is also conspecific. The oistodiform elements of P. flabellum are quite similar to those of Microzarkodina flabellum and since the two species occur together in sample EIN1, the oistodiform elements have been treated here in bulk and are listed under the present species. In this context it should be mentioned that Löfgren (1978) has attempted to separate the oistodiform elements of the two previously mentioned species based on the shape of the aboral margin and the magnitude of the anterobasal margin. Although those variations can be observed in the Bay of Islands specimens I am not convinced that they represent intraspecific variation and hence have not used them to separate the oistodiforms. The Bay of Islands specimens of this species are very small and extremely fragile and probably represent a deep water variety.

Material: 75 multiramiform elements; 6 prioniodiniform elements; 38 oistodiform elements.

Occurrence: EIN1

PERIODON sp. cf. P. ACULEATUS Hadding

(Plate 3, figures 24-28)

Synonymy:

cf. Periodon aculeatus Hadding, LÖFGREN, 1978, p. 74-75, Pl. 11, figs. 12-16, 19-22.

cf. Periodon aculeatus Hadding, FAHRAEUS and NOWLAN, 1978, p. 46, Pl. 3, figs. 7-10, 13.

Remarks: The multiramiform elements recovered from Bay of Islands are similar in morphology to those of P. aculeatus Hadding. However, the posterior process in some of my specimens, is more twisted compared to typical P. aculeatus specimens. Although it is widely acknowledged that P. aculeatus evolved from P. flabellum there seems to be some confusion in the literature regarding the morphologic difference between the two species. Lindström (1964) regarded the nature of the denticles as well as the shape and inverted nature of the basal cavity as the characteristic features of P. aculeatus. Löfgren (1978) on the other hand placed considerable importance on the character of the oistodiform element. According to Löfgren, "the appearance of persistent denticulation in the oistodontiform element" should be used as the main criterion to distinguish P. aculeatus from P. flabellum. In practice, however, this criterion is difficult to apply as even

Löfgren (1978) mentions that in immature oistodiform elements the denticles may be missing. In fact the nature of the oistodiform element appears to change in *Periodon* faunas from different areas. For example, the oistodiform elements assigned to *P. aculeatus* and *P. flabellum* by Fahraeus and Nowlan (1978) from the Cow Head Group of western Newfoundland have a somewhat different morphology compared to those described by Löfgren (1978). The oistodiform elements assigned to *P. aculeatus*, in this study, have a fairly distinctive morphology but are adenticulate. It is possible that the variation is due to the presence of one or more subspecies(?) of *Periodon* and this question needs to be addressed in future. Interestingly enough, a somewhat similar situation also exists for *Prioniodus elegans* described later in this study.

Material: 12 multiramiform elements; 2 prioniodiniform elements; 4 oistodiform elements.

Occurrence: EIN1

Genus PRIONIODUS Pander, 1856

Type species: Prioniodus elegans Pander, 1856

Discussion: Lindström (1955, p. 589) defined the form genus Prioniodus Pander as: "to the genus Prioniodus belong compound conodonts with a subcentral cusp, from the base of which diverge three denticulate edges or processes, one posteriorly, one anteriorly and one laterally". According to Sweet and Bergström (1971, 1972), Prioniodus Pander consists of five different types of elements namely, prioniodiform, falodiform, belodiform, trichonodelliform and tetraprioniodiform. Conodonts belonging to different species of the genus Prioniodus Pander have traditionally been considered to have distinct prioniodiform and falodiform elements. Conodonts with two different types of prioniodiform elements are considered typical of the genus Baltoniodus. However, Fahraeus and Nowlan (1978) noted the presence of two different types of prioniodiform elements in the apparatus of P. elegans Pander which led them to suggest "the possibility that P. elegans contained two different prioniodiforms with one approaching the general morphology of the amorphognathiform and the other that of the ambalodiform, i.e., the Prioniodus apparatus was essentially of the same elemental composition as the Baltoniodus apparatus". They, however, did not formally modify the definition of the Prioniodus apparatus. Hunicken and Sarmiento (1980) also noted the presence of two types of prioniodiform elements in the apparatus of P. elegans. The Prioniodus specimens from Bay of Islands also exhibit two different types of prioniodiform elements. Secondly, the Bay of Islands samples also support the observation of Fahraeus and Nowlan (1978) and Bergström et al. (1972) that in the P. elegans apparatuses the number of prioniodiform elements is much larger than that of any other element type. In the light of these observations it is felt that the definition of the genus Prioniodus proposed by Fahraeus and Nowlan (1978) needs to be slightly modified to encompass the variability displayed by the prioniodiform element. Thus in this study conodont apparatus consisting of one or two morphotypes of denticulated prioniodiforms with free processes; fully developed symmetry-transition series of ramiforms; and anteriorly denticulated falodiforms are considered belonging to the genus Prioniodus.

PRIONIODUS SP. cf. P. ELEGANS Pander, 1856

(Plate 3, figures 29-32; Plate 4, figures 1-14, 18, 19)

Synonymy:

cf. Prioniodus elegans PANDER, 1856, p. 29, Pl. 2, figs. 22-23; LINDSTRÖM, 1955, p. 589, Pl. 5, figs. 26-29, text-fig. 5a; ETHINGTON, 1972, p. 23, Pl. 1, fig. 1; FAHRAEUS and NOWLAN, 1978, p. 464-466, Pl. 3, figs. 19, 20, 22-25, text-fig. 6, A-E; (?)LÖFGREN, 1978, p. 78-79, Pl. 9, figs. 1-6; HUNICKEN and SARMIENTO, 1980, p. 298-305, Pl. 1, figs. 1-11, Pl. 2, figs. 1-20.

cf. Belodus gracilis PANDER, 1856, p. 30, Pl. 2, fig. 21, Pl. 3, fig. 8.

cf. Prioniodus carinatus PANDER, 1856, p. 30, Pl. 2, fig. 25, Pl. 3, fig. 7.

cf. Gothodus costulatus LINDSTRÖM, 1955, p. 569, Pl. 5, figs. 23-25.

cf. Falodus prodentatus (Graves and Ellison) LINDSTRÖM, 1955, p. 569, Pl. 5, figs. 21,22,30.

cf. Tetraprioniodus robustus LINDSTRÖM, 1955, p. 597, Pl. 6, figs. 13-15.

cf. Oepikodus evae (Lindström) FAHRAEUS and NOWLAN, 1978, PL. 3, fig. 17 (only).

Description: prioniodiform element consists of cusp and three denticulated processes. Cusp short, flattened, suberect to slightly recurved with sharp edges and pointed tip. Side of cusp contains prominent costa which continues as lateral process. Posterior process straight and denticulate. Denticles flat and fused for most of their length. Tips of denticles free with convex margins and pointed tips. In smaller elements posterior process is slightly larger than anterior one while in larger elements both are about the same size. Anterior process curved. Degree of curvature variable based on which two different morphotypes can be distinguished. In morphotype 1 anterior process strongly curved laterally so that distal part of process makes an angle of about 90° with posterior process. In morphotype 2, anterior process slightly curved so as to make an angle of about 160°-170° with posterior process. Variation from morphotype 1 to morphotype 2 appears to be continuous. Angle between lateral and anterior processes also varies from acute to obtuse depending upon the curvature of the anterior process. In morphotype 1 anterior and lateral processes moderately inclined while in morphotype 2, anterior and lateral processes sharply inclined. The basal cavity shallow for all specimens. In larger specimens basal cavity forms a groove along length of posterior process and extends for some distance under lateral and anterior processes.

Falodiform element consists of long cusp with sharp edges and denticulated anterior margin. Cusp often exhibits a weak carina which can continue along posterior process. In some elements cusp slightly twisted laterally. Two different morphotypes of falodiform elements present. Type 1 has well developed denticulated anterior process extending below base. Denticles are small, fused but have discrete tips. Type 2 elements lack well developed anterior process. Posterior process in both morphotypes adenticulate with concave basal margin. Basal cavity flared on one side.

Belodiform element contains suberect to proclined cusp with sharp edges and two to three processes. Elements laterally compressed and vary from nearly symmetric to strongly asymmetric ones. Asymmetry produced by development of sharp lateral costa on one side of cusp. Lateral costa continues as short adenticulate lateral process below base. Variation from nearly symmetric to asymmetric forms is continuous and intermediate forms exist. Posterior process well developed with slightly concave basal margin and several denticles. Denticles fused for most of their length and have pointed tips and convex margins. In some elements distal margin of posterior process recurved laterally. Anterior process essentially a downward continuation of cusp. In some elements anterior process bears few small denticles near its end.

Trichonodelliform element also exhibits considerable morphologic variation. Unit consists of proclined cusp and three processes. Cusp bears three costae which transform into posterior and two lateral processes. Anterior margin of cusp rounded for most part and flat near base. Angle between posterior and lateral processes shows considerable variation. In one group of elements lateral processes straight and make an angle of about 90° with posterior process. In another group, the processes are curved posteriorly thereby making small acute angles with the posterior process. All three processes denticulate and inclined. Denticles fairly well developed, with sharp margins and pointed tips.

Tetraprioniodiform element with proclined cusp and four processes. Cusp with two lateral costae and rhomboidal cross-section. Lateral costae form two lateral processes which extend below base. Posterior as well as two lateral processes bear denticles. Denticles quite discrete, with sharp edges and pointed tips. Biggest denticles occur on posterior process. Anterior process does not carry any denticles. Posterior process generally broken and when complete is the largest of processes.

Remarks: From the works of Fahraeus and Nowlan (1978) and Hunicken and Sarmiento (1980) it was becoming increasingly clear that the apparatus of P. elegans is probably more complicated than generally believed. The Bay of Islands specimens of P. elegans are very similar to the ones illustrated by Pander. They are also very similar to the

South American specimens described by Hunicken and Sarmiento (1980), the western Newfoundland specimens described by Fahraeus and Nowlan (1978) and specimens from central Newfoundland (O'Brien and Szybinski, 1989). Most of the published accounts of P. elegans do not mention the morphologic variation observed in the prioniodiform elements from Newfoundland and South America. I believe that this morphologic variation is a characteristic feature of the P. elegans apparatus. However, at this stage the lack of data precludes ruling out the possibilities that this morphologic variation is either environmentally controlled or that the Newfoundland and South American specimens are somewhat different (?subspecies) from the Baltoscandic ones. Further research is needed to settle this question and hence for the present I prefer to assign my specimens to P. sp. cf. P. elegans.

Material: 92 prioniodiform elements; 27 falodiform elements; 35 belodiform elements; 18 trichonodelliform elements; 50 tetrapriniodiform elements. (Only the unbroken elements have been counted. In addition there exists more than 400 broken fragments).

Occurrence: EI24.

Genus PROCONODONTUS Miller, 1969

Type species: Proconodontus muelleri Miller, 1969

PROCONODONTUS MUELLERI Miller

(Plate 4, figure 29)

Synonymy:

Proconodontus mulleri mulleri MILLER, 1969, p. 437, Pl. 66, figs. 30-40, text-fig. 5H; ETHINGTON and CLARK, 1971, Pl. 1, fig. 25; FORTEY et al., 1982, Text-fig. 9K; NOWLAN, 1985, p. 114, Fig. 5.1.

Proconodontus muelleri muelleri MILLER, 1971, Pl. 2, fig. 18; FAHRAEUS and NOWLAN, 1978, p. 453, Pl. 1, figs. 1,2.

Coelocerodontus burkei DRUCE and JONES, 1971, p. 61-62, Pl. 11, figs. 9-11 (only), text-fig. 22a (only).

?Proconodontus muelleri MÜLLER, 1973, p. 42-43, Pl. 3, figs. 4-7 (only).

Proconodontus muelleri MILLER, 1980, p. 29-30, Pl. 1, fig. 7, text-fig. 4C; AN et al., 1983, p. 126-127, Pl. V, figs. 15, 16, 21-24.

Description: Thin-walled simple cones with erect to slightly proclined cusp. Lateral faces of cusp rounded while anterior and posterior margins sharply keeled. Keels may or may not extend up to base. Cross-section subrounded to oval.

Remarks: All the Proconodontus specimens from Bay of Islands, including P. muelleri, are broken. This is due to the extremely thin-walled nature of the elements which seems to be a characteristic feature of this genus.

Material: 16 specimens, all broken.

Occurrence: NH37, NH39, NH40, NH41, WC15.

PROCONODONTUS TENUISERRATUS Miller

(Plate 5, figure 1)

Synonymy:

Coelocerodontus burkei DRUCE and JONES, 1971, p. 61, Pl. 11, figs. 5,6 (only), text-fig. 22e.

Proconodontus tenuiserratus MILLER, 1980, p. 31-32, Pl. 1, figs. 1-3, text-fig. 4A; CHEN and GONG, 1986, p. 164, Pl. 29, figs. 1-16, Pl. 30, figs. 2, 5-7, text-fig. 63;

Description: Thin-walled erect to proclined simple cones. Cross-section round in most specimens, slightly oval in some compressed ones. Anterior margin of element rounded. Posterior margin keeled near top and broadly rounded near base. Posterior keel small and exhibit fine serrations. Basal cavity extends nearly up to tip of element.

Remarks: The Bay of Islands specimens are similar to those described by Miller (1980). According to Miller (1988) P. tenuiserratus is biostratigraphically important in the continental platform setting and so far has not been reported from deep-water environments in North America. The Bay of Islands specimens, probably for the first time, document the presence of this species in the deep water facies of North America. All of my specimens are fragile and have a very thin, translucent wall.

Material: 15 specimens, mostly broken.

Occurrence: NH24, NH28, NH32.

PROCONODONTUS SP.

(Plate 4, figures 15-17)

Description: Apparatus consists of nearly symmetrical and asymmetrical elements.

Nearly symmetrical element represented by thin-walled slightly proclined simple cone. Element rounded with circular cross-section. Two small posterolateral costae situated symmetrically on either side of posterior margin. One of the two costae very poorly developed. Both costae have serrated edges.

Asymmetric element similar in morphology to nearly symmetric element in that it also consists of thin-walled, proclined simple cone. Cross-section of element varies from circular to subcircular. Element characterized by presence of only one small costa. Costa begins at posterior margin near tip of element and continues as posterolateral costa making a small angle with posterior margin. Edge of costa serrated. Basal cavity fairly large.

Remarks: This species is very similar in morphology to P. tenuiserratus, the only difference between the two being the position of the serrated costa. In P. tenuiserratus the costa is situated posteriorly and is generally described as a "small posterior keel". In the Bay of Islands material P. sp. and P. tenuiserratus occur together in one sample. It is possible that P. tenuiserratus and P. sp. are conspecific and merely represent different elements of the same apparatus. However, Proconodontus is generally considered to have a monoelemental apparatus and hence further research with more abundant material is required before a multielement scheme for this genus can be proposed.

Material: 4 nearly symmetric element (broken); 8 asymmetric elements.

Occurrence: NH22, NH24, NH28.

Genus PROONEOTODUS Müller and Nogami, 1971

Type species: *Prooneotodus gallatini* Müller, 1959

PROONEOTODUS GALLATINI Müller and Nogami, 1971 s.f.

(Plate 4, figure 28)

Synonymy:

Oneotodus gallatini MÜLLER, 1959, p. 457, Pl. 13, figs. 5, 6, 8-10, 18 (*non* 7, 12).

Description: Simple cone with recurved cusp and large base. Cusp rounded and short compared to base. Tip of cusp pointed. Base large and expanded. Basal opening circular.

Remarks: The specimens agree closely with the original description by Müller (1959).

Material: 4 specimens.

Occurrence: NH28.

Genus PROTOPANDERODUS Lindström 1971

Type species: *Acontiodus rectus* Lindström, 1955

Original diagnosis: Lindström (1971, p. 50): "*Protopanderodus* includes panderodids with a cusp that is higher than the base. The longitudinal striations of the cusp may be inconspicuous. The cross-section of the cusp may be subcircular, comma-shaped, lanceolate, or *Acontiodus*-like. Most species include symmetrical as well as asymmetrical elements but there are no oistodiform elements".

Discussion: The original definition of the genus has been somewhat modified in later works (see Löfgren, 1978, Van Wamel, 1974, Stouge, 1984). *Protopanderodus* is now considered to include both symmetrical and asymmetrical acontiodiform and scandodiform elements. Moreover, laterally compressed drepanodiform elements of this species have also been recovered from Bay of Islands.

PROTOPANDERODUS ARCUATUS (Lindström)

(Plate 4, figures 20, 21, 23-25, 30)

Synonymy:

Acontiodus arcuatus LINDSTRÖM, 1955, p. 547-548, Pl. 2, figs. 1-4, text-fig. 3A; FAHRAEUS and NOWLAN, 1978, Pl. 2, fig. 7.

Protopanderodus arcuatus (Lindström) BERGSTRÖM, EPSTEIN and EPSTEIN, 1972, fig. 1j.

?*Protopanderodus* cf. *reclinatus* (Lindström) STOUGE, 1984 Pl. 3, fig. 7 (only).

?*Protopanderodus rectus* (Lindström) LÖFGREN, 197[illegible], Pl. 3, fig. 3 (only).

Scandodus pipa LINDSTRÖM, 1955, p. 593, Pl. 4, figs. 38-42, text-fig. 3P.

Description: The most characteristic acontiodiform element of this species is *A. arcuatus* Lindström, s.f. Unit consists of recurved cusp with sharply keeled anterior and posterior margins. Cusp contains two lateral costae on opposite sides of posterior keel. In some specimens costae continue on to base while in others they are very weakly developed or non-existent on base. Basal cavity fairly deep and roughly triangular outline. Angle between aboral and oral margin about 90°. Oral part of anterior margin slightly concave in some specimens.

Asymmetric acontiodiform element has well-developed postero-lateral and antero-lateral costae running along cusp and onto base. Cusp rounded compared to symmetric element. Base oval in outline.

Two types of scandodiform elements present. Type I has flared base and cusp with keeled anterior and posterior margins. Cusp bears two prominent lateral costae. Base expanded posteriorly and slightly twisted laterally. Oral margin slightly convex in some specimens. Angle between oral and aboral edges about 45°. Oral part of anterior margin slightly concave. Type II element is laterally compressed with reclined cusp. Cusp long, recurved basally, straight otherwise. Anterior and posterior margins of cusp bear sharp edges, lateral face carinate. Base drawn out posteriorly, laterally compressed. Angle between oral edge and posterior margin about 80°. This type of element has been described previously as S. pipa Lindström, 1955 s.f.

Drepanodiform element extremely compressed laterally and consists of large base and erect to suberect cusp. Anterior and posterior margins sharp. Cross-section of cusp biconvex with one face slightly more convex than other. In some elements cusp can be deflected laterally. Basal cavity large and extends up to base of cusp. Basal walls thin. Oral edge straight to slightly convex. Angle between oral edge and posterior part of aboral margin obtuse. Oral part of anterior margin straight.

Remarks: Prior to this study the status of A. arcuatus has been somewhat problematic. Van Wamel (1974) considered A. arcuatus s.f. to be a "rare variant" of Drepanodus arcuatus s.f. However, as discussed by Fahraeus and Nowlan (1978 p. 458), it is quite possible that A. arcuatus s.f. is quite different from D. arcuatus s.f. The Bay of Island specimens do not provide any evidence to suggest that A. arcuatus s.f. is a variant of D. arcuatus s.f. Hence until this question is satisfactorily resolved I prefer to follow Lindström in assigning elements with "acontiodus-like" cross-section of the cusp to the genus Protopanderodus.

Material: 9 acontiodiform elements; 7 drepanodiform elements; 3 scandodiform elements.

Occurrence: NAP6, EI24

?PROTOPANDERODUS SP.

(Plate 4, figures 22, 26, 27)

Synonymy:

?Scolopodus giganteus SWEET and BERGSTRÖM, 1962, p. 1247, Pl. 169, fig. 14, text-fig. 1, J; LEE, 1976, p. 173, Pl. 1, figs. 16, 17, text-fig. 2L.

?Protopanderodus cf. P. giganteus (Sweet and Bergström), BARNES and POPLAWSKI, 1973, p. 782, Pl. 1, fig. 4.

Description: Apparatus consists of nearly symmetric to asymmetric, nongeniculate coniform elements with or without lateral costae.

Laterally compressed, nearly symmetric to asymmetric simple cones with posteriorly expanded base and erect to proclined cusp. Cusp slightly twisted laterally in some specimens. Anterior and posterior margins of element keeled. In basal part of most elements anterior keel flexed laterally. Degree of flexure and width of keel variable. Lateral surfaces may or may not be costate. Costae poorly to well developed. Number of costae can vary from one to five on each surface and may not be developed equally on opposite surfaces. Costae generally follow curvature of element but in some cases may turn towards anterior margin in basal region. Multiple costae, when present, prominent on basal part, less so on cusp. In highly asymmetric element one lateral surface carinate, other nearly flat. In slightly asymmetric element convexity of lateral faces almost equal. Variation between these end members can occur. Basal cavity large with tip situated anteriorly. Oral margin straight. Angle between oral and aboral margin 45°. Base can be flared in some elements producing scandodiform morphotypes.

Remarks: Some of the multicostate elements of this species show similarity to S. giganteus Sweet and Bergström, s.f. The elements of ?P. sp., however, have a characteristic laterally flexed anterior margin, are laterally compressed and relatively small in size. Due to the nature of the apparatus generic assignment is difficult and the species is only tentatively assigned to Protopanderodus.

Material: 33 specimens.

Occurrence: NAP6, EI13.

Genus PROTOPRIONIODUS McTavish, 1973

Type species: Protoprioniodus simplicissimus McTavish, 1973

PROTOPRIONIODUS ARANDA

(Plate 7, figures 21-23)

Synonymy:

?Glabrodontus magnificus NOWLAN, (nomen nudum), 1976, p. 238-239, Pl. 8, figs. 8, 9, 11, 12. (includes partial synonymy).

Protoprioniodus aranda COOPER, 1981, p. 175-176, Pl. 30, figs. 1, 6, 7, 10, 12.

Description: Laterally compressed, slender ramiform elements with or without lateral process. Cusp well developed and extended downwards as "anticusp". Cusp broken in all specimens. Anterior and posterior margins of cusp and processes sharp. Slight varition in the curvature of the cusp can be observed. Oral margin strongly convex, aboral margin concave. Surface of element smooth.

Remarks: The elements described here are very similar to the ramiform elements of P. aranda Cooper.

Material: 10 specimens.

Occurrence: EIN1.

Genus ROSSODUS Repetski and Ethington, 1983

Type species: *Rossodus manitouensis*
Repetski and Ethington, 1983

ROSSODUS N. SP. A

(Plate 5, figures 2-11, 13)

Synonymy:

? *Acodina velva* Stauffer, MOSKALENKO, 1967, p. 100-101, Pl. XXII, fig. 1.

Acodus aff. *deltatus* Lindström, MOSKALENKO, 1967, p. 101-102, Pl. XXII, figs. 2-4.

Acodus oneotensis Furnish, MÜLLER, 1973, p. 26-27, Pl. 7, fig. 1, 3-8.

Description: Apparatus consists of a variety of costate, laterally compressed conical elements and an oistodiform element. Conical elements include a variety of "drepanodiform", "scandodiform" and "acodiniform" morphotypes. All elements characterized by dark base and albid cusp.

"Drepanodiform" element exhibits variable morphology, based on which three broad morphotypes can be discerned. Morphotype I characterized by laterally compressed proclined to erect simple cones. Cross-section of cusp bi-convex. Cusp weakly to strongly curved laterally above base. Anterior and posterior margins of element marked by broad, sharp costae. Costae widest at basal part, gradually to sharply tapering towards apex of cusp. One lateral or anterolateral carina present. Base relatively short and expanded posteriorly. Basal cavity roughly oval to teardrop-shaped. Morphotype II similar in morphology to Morphotype I except for presence of two prominent costae and intervening sulcus on one lateral face. Costae extending up to basal margin. Morphotype III consists of strongly laterally compressed simple cone with long cusp. Cusp suberect with roughly bi-convex cross-section. Cusp markedly curved laterally above base. Anterior and posterior margins of element exhibit broad, sharp costae. Costae widest in basal region, gradually tapering upwards. Posterior costa extends up to the basal margin. Anterior costa extends below basal margin in form of short process. One lateral surface bears rounded carina. Base short and somewhat extended posteriorly.

Scandodiform element characterized by symmetry transition series of laterally compressed proclined to erect simple cones with short bases. Cusp long and curved laterally above base. Anterior and posterior margins of element bear broad, sharp costae. Costae generally extend slightly below the aboral margin. Position of lateral costae relative to each other somewhat variable. In some elements both costae lie in one plane, in others they are flexed laterally. One lateral surface carinate, other rounded. Carina more prominent on base than on cusp. Base generally small and strongly expanded laterally on non-carinate side. Basal cavity shallow with apex generally situated anteriorly. Basal cone preserved in some scandodiform elements.

Acodiniform element small, anteroposteriorly compressed with recurved cusp and relatively large base. Cusp short with sharp tip; sharply curved posteriorly just above base, straight otherwise. Lateral margins of unit exhibit sharp, broad costae. Costae broadest at base, sharply tapering upwards. Costae flexed posteriorly. Sulcus may be present behind costa. In some elements costa have tendency to develop denticles. Anterior margin broadly rounded with medial carina. Base expanded anteroposteriorly.

Oistodiform element laterally compressed with sharply reclined cusp. Cusp flexed laterally. Margins of cusp sharply costate. Anterior costa can be flexed laterally. Carina present on inner face of cusp and continues along base. Outer face of cusp generally rounded. Angle between oral edge and posterior margin of cusp is small. Angle between aboral margin and basal part of anterior margin 45° or less. Base flared laterally, basal cavity generally shallow. Aboral margin sinuous.

Remarks: The apparatus described above is typical of the genus <u>Rossodus</u> (see Repetski and Ethington, 1983). Most of the elements described above are very similar to those of <u>R</u>.

manitouensis. However, the new species can be distinguished from the type species by the presence of the acodiniform and drepanodiform morphotype III elements.

Material: 20 drepanodiform elements; 2 acodiniform elements; 21 scandodiform elements; 8 oistodiform elements.

Occurrence: NAP6, NAP14, NAP16, WC32.

ROSSODUS N. SP. B

(Plate 5, figures 12, 14-16)

Description: Apparatus consists of laterally compressed drepanodiform, scandodiform and oistodiform elements.

Drepanodiform element strongly laterally compressed with slightly proclined to erect cusp. Anterior and posterior margins of element bear sharp costae. Costae extend up to aboral margin. Base small in extremely compressed elements, moderately big in less compressed elements. Base and cusp very poorly differentiated in extremely compressed elements. In less compressed elements oral and aboral edges more or less straight. Angle between oral and aboral edges about 90°; angle between basal part of anterior margin and aboral margin about 45°. Anterior margin of basal cavity straight, posterior margin concave. Apex of basal cavity situated very close to anterior margin of element near curvature of cusp.

Scandodiform element exhibits two morphotypes. Morphotype I consists of laterally compressed elements with proclined to reclined cusp and flared base. Anterior and posterior margins of element exhibit broad, sharp costae which extend up to aboral margin. Width of costae maximum in basal region gradually tapering upwards. Width of costae often greater than width of cusp. Costae can be slightly flexed laterally. Carina can be present on one lateral surface, other surface rounded. Carina well developed in basal part, less so on cusp and can extend slightly below aboral margin in some elements. In rare cases both lateral surfaces can be carinate. Base conical in outline, apex of basal cavity directed towards anterior margin. Morphotype II consists of laterally compressed elements with short base and fairly long cusp. Cusp curved laterally above base. Anterior and posterior margins of unit exhibit sharp, broad costae similar to morphotype I. One lateral surface contains well developed carina; position of carina variable. Base short, basal cavity shallow.

Oistodiform element laterally compressed with posteriorly extended base. Cusp fairly long and laterally flexed. Anterior and posterior margins of cusp sharply costate, costae extending up to aboral margin. Lateral surfaces of cusp rounded. Oral margin convex, aboral margin sinuous. Angle between oral and posterior margins variable but less than 90° in most cases. Base flared, basal cavity roughly triangular in lateral view. Apex of basal cavity directed towards anterior margin.

Remarks: Some of the elements of this species are somewhat similar to those of Utahconus tenuis Miller, 1980, s.f. Repetski and Ethington (1983) have reassigned U. tenuis to the genus Rossodus based on the presence of an oistodiform element. Elements of R. sp. B are extremely compressed laterally and are sufficiently distinctive to merit assignment to a separate species.

Material: 20 drepanodiform elements (4 of these broken); 15 scandodiform elements; 7 oistodiform elements.

Occurrence: NH54, NAP14, NAP16.

ROSSODUS N. SP. C

(Plate 5, figures 17-19)

Description: Drepanodiform element laterally compressed with reclined to suberect cusp. Morphology variable, but units commonly exhibit prominent anterior and posterior costae. Costae generally extend up to aboral margin. Base fairly small.

Scandodiform element with proclined to erect cusp and expanded base. All the elements exhibit prominent costae. Position and number of costae variable. In elements with three costae, two are lateral and the third is either anterior or posterior. Cross-section of cusp and aboral margin roughly triangular in these elements. In elements with two costae, position of costae lateral. Aboral margin rounded in this case.

Remarks: The elements described above most probably represent a partial Rossodus apparatus as no oistodiform element has been found associated with them. All the elements of this species are extremely small in size and are rather fragile. This species might be a precursor of R. sp.B which occurs in the sample immediately above.

Material: 9 drepanodiform elements; 12 scandodiform elements.

Occurrence: NH53.

?ROSSODUS HIGHGATENSIS Landing *et al*., 1986

(Plate 5, figures 20-22)

Synonymy:

Rossodus? *highgatensis* LANDING *et al*., 1986, Pl. 3, fig. 10, 13-26.

Description: Drepanodiform, suberectiform and scandodiform elements of this multielement species are present in my samples.

Drepanodiform element generally recurved, degree of curvature variable. Anterior and posterior margins of cusp sharp. Anterior flexed laterally. Flexure most prominent in the basal part. One surface of cusp can be carinate. Base fairly large, extended posteriorly. Angle between oral and posterior part of aboral margin nearly 90°. Scandodiform element with laterally compressed and twisted cusp. Anterior and posterior margins of cusp sharp, lateral faces slightly convex. Base expanded laterally.

Suberectiform element with laterally compressed blade-like erect cusp. Anterior and posterior margins of cusp exhibit sharp, broad edges. Base small compared to cusp, slightly extended anteroposteriorly and expanded laterally. Oral and aboral margins curved.

Remarks: The apparatus of *R*.? *highgatensis* as described by

Landing et al. (1986) is quite elaborate and includes a number of different types of elements. In this study, however, only three types of elements of this species have been found, hence the questioned assignment.

Material: 17 drepanodiform elements; 3 suberectiform elements; 4 scandodiform elements.

Occurrence: WC32, NAP6.

?ROSSODUS SP.

(Plate 5, figures 26-29)

Description: Apparatus consists of a variety of very small and laterally compressed coniform elements. Coniform elements exhibit "drepanodiform" "oistodiform" and "scandodiform" morphotypes.

Drepanodiform element: differentiated into two morphotypes based on presence or absence of prominent lateral costae. Morphotype I characterized by proclined to recurved cusp. Anterior and posterior margins exhibit sharp edges. Width and development of edges variable. Posterior edge in some specimens not well developed. Maximum width of anterior edge near base. In some specimens maximum width of anterior edge equal to maximum width of element. Basal cavity moderately deep, triangular in lateral view. Apex of basal cavity situated close to anterior margin of element. Morphotype II characterized by proclined cusp and sharp anterior and posterior margins. Anterior edge can be flexed laterally. Lateral surfaces exhibit prominent costae. Position of costae varies from anterolateral to medial. Costae extend up to aboral margin, anterolateral costae in some specimens extends below the aboral margin. Basal cavity fairly shallow.

Scandodiform element: Cusp proclined and curved laterally above base. Anterior and posterior margins of element sharp. One lateral margin can be carinate. Base expanded laterally.

Oistodiform element: characterized by slightly laterally flexed cusp and flared base. Anterior and posterior margins of cusp with sharply costate. Costae extend up to aboral margin. Lateral surfaces of cusp carinate, carina can extend onto base. Base fairly large and laterally expanded. Oral margin straight to slightly curved, aboral margin curved in lateral view. Angle between oral and posterior margins quite large.

Remarks: All elements of this apparatus are extremely small and strongly laterally compressed. Elements of <u>Rossodus</u> are generally albid above the base and this feature is noticeable in some elements of the species. The composition of the apparatus also seems to suggest assignment of this species to Rossodus.

Material: 14 drepanodiform elements; 8 scandodiform elements; 4 oistodiform elements.

Occurrence: NH54.

Genus SAGITTODONTUS Rhodes, 1953

Type species: Sagittodontus robustus Rhodes, 1953

? "SAGITTODONTUS" EUREKA Müller, 1959 s.f.

(Plate 5, figure 24)

Synonymy:

?Sagittodontus eureka MÜLLER, 1959, p. 461-462, Pl. 14, fig. 6.

Remarks: The specimen is corroded and badly preserved and hence positive identification is not possible.

Material: 1 specimen

Occurrence: NH37

Genus SCANDODUS Lindström, 1955

Type species: *Scandodus furnishi* Lindström, 1955

SCANDODUS SP. 1 s.f.

(Plate 5, figure 25)

Description: Robust element with reclined cusp. Cusp fairly long with sharp anterior and posterior margins. Cusp twisted relative to base. Posterolateral carinae present. Base flared, basal cavity fairly shallow. Aboral margin sinuous in lateral view.

Remarks: This species is rare in my samples and its multielement association is not clear.

Material: 1 specimen.

Occurrence: NAP14.

SCANDODUS SP. 2 s.f.

(Plate 5, figure 23)

Description: Asymmetric element with long cusp. Cusp suberect, strongly twisted relative to base. Cusp bears two sharp lateral costae which continue up to aboral margin.

Width of costae maximum in basal region, decreasing upwards. Base strongly compressed laterally and extended anteroposteriorly. Basal part of element triangular in outline.

Remarks: This species is very rare in Bay of Islands material. Its multielement association is not clear.

Material: 1 specimen

Occurrence: NAP16

Genus SCOLOPODUS Pander, 1856

Type species: Scolopodus sublaevis Pander, 1856

SCOLOPODUS SP. aff. S. CORNUFORMIS Sergeeva

(Plate 5, figures 30-33)

Synonymy:

aff. Scolopodus cornuformis Sergeeva, LÖFGREN, 1978, p. 105-107, Pl. 7, figs. 1-6, 9-12, Pl. 8, figs. 1-2, 4-6 (includes synonymy through 1978).

Description: Apparatus consists of a variety of small, slender, symmetrical and asymmetrical costate and non-costate coniform elements with short to long base and albid cusp. Morphology of elements variable. Costae can be rounded (cornuform element) or sharp.

Cornuform element exhibits symmetric and asymmetric morphotypes. Elements with variable curvature of cusp, generally proclined to suberect. Cusp, in symmetric element, rounded with two lateral or posterolateral grooves. Anterior margin rounded. Posterior margin generally convex but can be sharp. Base generally short. Asymmetric element similar in morphology to symmetric element except for asymmetric position of lateral grooves. Also base in asymmetric elements generally longer than symmetric elements.

Sharply costate element rounded. Curvature of cusp variable from proclined to erect. Symmetric and asymmetric morphotypes exist depending on the number and position of costae. Symmetric elements rare. Cusp in asymmetric elements generally twisted relative to base. Number of costae variable from one to four. Base generally long, basal cavity conical with apex near anterior margin. Basal opening roughly circular.

Non-costate element morphology simple but variable. Rounded and laterally compressed morphotypes present. Cusp weakly or strongly recurved. Cusp slightly twisted laterally in asymmetric elements. Base generally long, slightly extended posteriorly in compressed elements. Basal cavity conical with apex near anterior margin. Basal opening circular in rounded elements, oval in compressed ones.

Remarks: As is evident from the description above, the morphology of this species is quite variable. The morphology of the symmetric cornuform element is very similar to that of S. cornuformis s.f. The position of grooves, however, is more lateral in the present species. The apparatus of S. cornuformis as described by Löfgren (1978) is also similar to that of S. sp. aff. S. cornuformis although the former seems to lack the comparatively sharply costate elements present in the latter apparatus.

Material: 4 non-costate elements; 6 cornuform elements; 4 costate elements.

Occurrence: NAP16.

SCOLOPODUS GRACILIS Ethington and Clark

(Plate 5, figures 34, 35; Plate 6, figures 1, 2)

Synonymy:

Scolopodus gracilis ETHINGTON and CLARK, 1964, p. 699, Pl.115, figs. 2-4, 8, 9, text-fig. 2D, G; UYENO and BARNES, 1970, p. 116, Pl. 22, figs. 9, 10; ETHINGTON and CLARK, 1971, Pl.2, figs. 3, 9.

?Scolopodus gracilis Ethington and Clark, DRUCE and JONES, 1971, p. 92, Pl. 17, figs. 5a-7d, Pl. 18, figs. 5a-d, text-fig. 30C; JONES, 1971, p. 63-64, Pl. 6, fig. 2; BARNES and POPLAWSKI, 1973, p. 786-787, Pl. 3, figs. 6-8a, text-fig. 2G, H.

Scolopodus filosus ETHINGTON and CLARK, 1964, p. 699, Pl. 114, figs. 12, 17, 18, 19, text-fig. 2E; REPETSKI, 1982, p. 47, Pl. 22, fig. 2.

Scolopodus triangularis ETHINGTON and CLARK, 1964, p. 700, Pl. 115, figs. 6, 11, 13, 17, text-fig. 2,I.

Scolopodus triplicatus ETHINGTON and CLARK, 1964, p. 700-701, Pl. 115, figs. 20, 22-24, text-fig. 2C.

multielement

Scolopodus gracilis Ethington and Clark, REPETSKI, 1982, p. 48, Pl. 22, figs. 5, 8-11 (contains synonymy upto 1982).

Description: Apparatus consists of graciliform, filosiform and symmetric and asymmetric triangulariform elements.

Graciliform element: unit proclined to erect with long cusp and short base. Cusp laterally compressed in some specimens, rounded in others. Cusp in most specimens albid above base. Anterior margin rounded. Posterior margin broadly rounded with a medial sulcus. Sulcus deep and extends full length of element. Lateral margin of compressed specimens can exhibit very shallow sulcus. Basal cavity shallow, basal margin slightly expanded in some specimens.

Filosiform element: unit with proclined cusp. Cross-section of cusp circular. Cusp generally albid above base. Surface of element covered by fine longitudinal costae. Basal opening circular.

Symmetric triangulariform element: Small, slightly laterally compressed, coniform elements with proclined cusp. Cross-section of cusp triangular. Anterior margin rounded. Posterior margin wide with prominent sulcus. Each lateral surface exhibits a sulcus. Basal cavity conical, basal opening circular. Basal region much darker compared to cusp.

Asymmetric triangulariform element: unit laterally compressed with straight to slightly recurved cusp. Cusp twisted relative to base. Anterior and posterior margins of element bear sharp costae. Anterior costae may be flexed laterally. Lateral surfaces of cusp rounded. Base short, basal cavity shallow.

Remarks: The graciliform element of this apparatus is represented by *S. gracilis* Ethington and Clark, 1964, s.f. Some of the elements of this type also resemble *S. triplicatus* Ethington and Clark, 1964, s.f. The lateral trough characteristic of *S. triplicatus* Ethington and Clark, 1964, s.f. is not very well developed in the present species. The filosiform element is represented by *S. filosus* Ethington and Clark, 1964, s.f. The asymmetric triangulariform element appears to be the asymmetric version of *S. triangularis* Ethington and Clark, 1964, s.f. while the symmetric triangulariform element is *S. triangularis* Ethington and Clark, 1964, s.f. Repetski (1982) reconstructed the apparatus of *S. gracilis* with which I agree in general. However, unlike Repetski (1982) I consider *S. filosus* Ethington and Clark, 1964, s.f. part of the *S. gracilis* apparatus.

The Bay of Islands specimens of this species are very small and rather fragile. Preservation, thus, is often not very good. The complete apparatus is represented only in a few samples and specimens are mostly broken.

Material: 21 graciliform elements; 14 triangulariform elements; 23 filosiform elements.

Occurrence: NAP9, NAP19, NAP21, NAP23, EI10, EI12, EI13.

Genus SEMIACONTIODUS Miller, 1969, emend. Miller, 1969

Type species: _Acontiodus_ (_Semiacontiodus_) _nogamii_
Miller, 1969

SEMIACONTIODUS IOWENSIS (Furnish, 1938)

(Plate 6, figures 4-8)

Synonymy:

Acontiodus _iowensis_ Furnish, 1938, p. 326, Pl. 42, figs. 13-15, text-fig. 1L; LANDING and BARNES, 1980, p. 1614, Pl. 4, figs. 7, 11-14, 16, 18-21, fig. 3 (21, 22); REPETSKI, 1982, p. 14, Pl. 4, figs. 1, 3; NOWLAN, 1985, p. 105, fig. 4.12.

? aff. _Oistodus_ _mehli_ Furnish, 1938, p. 330, Pl. 42, figs. 7, 8.

"_Acontiodus_" _iowensis_ (Furnish), ETHINGTON and CLARK, 1981, p. 23, Pl. 1, fig. 15.

Semiacontiodus _iowensis_ (Furnish, 1938), LANDING _et_ _al_., 1986, p. 1942-1944, Pl. 1, figs. 4, 6, 10, text-fig. 3B, C, H.

Scolopodus _iowensis_ (Furnish, 1938), DRUCE and JONES, 1971, p. 93, Pl. 16, figs. 1a-7e, text-fig. 30d, e.

Description: Apparatus consists of symmetrical to asymmetrical acontiodiform elements and asymmetrical elements with flared base.

Symmetric acontiodiform element represented by A. iowensis Furnish, 1938, s.f. Slightly recurved unit compressed antero-posteriorly. Anterior margin generally rounded but can be carinate. Anterolateral costae and a posterior costae present. Costae broad and rounded. Posterior costa can be sulcate. Sulcus present in front of each anterolateral costa. Basal cavity shallow with apex near anterior margin. Basal opening flattened oval.

Asymmetric acontiodiform element similar in overall morphology to symmetric unit except that cusp twisted laterally relative to base. Base rounded. Basal opening circular to slightly oval.

Drepanodiform element with erect to reclined cusp and large base. Morphology variable from drepanodiform to scandodiform types depending on lateral twisting of cusp and anterior keel and flaring of base. Cusp slightly twisted laterally in drepanodiform elements, markedly so in scandodiform elements. Anterior and posterior margins sharply keeled. Posterior keel may or may not extend onto base. In some specimens anterior keel flexed laterally. Base large and flared. Parts of basal funnel preserved in some specimens

Remarks: Some of the drepanodiform elements of this species are somewhat similar in morphology to O. mehli Furnish, 1938, s.f. The overall variation exhibited by the drepanodiform elements in the Bay of Islands material seems to be wider than that described by Landing <u>et al</u>.(1986).

Material: 14 acontiodiform elements (5 of these represented by fragments); 4 drepanodiform elements.

Occurrence: NAP6, WC24, WC32, EI12.

?SEMIACONTIODUS PROPINQUUS (Furnish)

(Plate 6, figures 10-13)

Description: Apparatus consists of drepanodiform, scandodiform, symmetric and asymmetric acontiodiform and scolopodiform elements.

Drepanodiform element: robust unit with erect cusp and large base. Anterior margin rounded, posterior margin sulcate. A faint lateral sulcus can be present. Basal cavity circular.

Scandodiform element: unit with proclined to erect cusp and large base. Cusp twisted relative to base. Cross-section of cusp biconvex. Anterior and posterior margins of element sharply costate; costae do not extend onto base. Base somewhat extended posteriorly and flared.

Acontiodiform element: Symmetric and asymmetric morphotypes present. Symmetric element anterolaterally compressed with proclined cusp. The cusp is straight except for at its contact with base where it is sharply recurved. Posterior margin of element sulcate. Anterior margin broad and rounded with three very faint carinae. The anterior margin is expanded in the form of broad, rounded anterolateral costae. The costae are widest near the base and rapidly taper to merge with tip of cusp. The base is extremely compressed, shallow and elliptical. Asymmetric element with twisted recurved cusp. Cusp mainly straight except at its contact with base where it is sharply curved. Posterior margin sharp. Anterolateral carina present on one side. Faint lateral carina may be present on other side. Base fairly short, basal opening roughly triangular.

Scolopodiform element: characterized by large base and short proclined cusp. Cross-section of cusp nearly circular. One lateral face of element rounded, other face relatively flat. Rounded face exhibits a number of well developed rounded costae and intervening sulci. Flattened face exhibits deep sulcus. Base large and expanded. Basal opening oval.

Remarks: The symmetric acontiodiform element is represented by A. propinquus Furnish, 1938 s.f. Generic assignment of this species is difficult as the apparatus does not appear to fit into any recognized plan.

Material: 4 acontiodiform elements; 1 scolopodiform element;

2 drepanodiform elements.

Occurrence: NAP6.

SEMIACONTIODUS SP.

(Plate 6, figures 14, 15)

Description: Apparatus consists of drepanodiform and acontiodiform elements. Drepanodiform element with recurved cusp. Cusp rounded and twisted laterally. Base large, slightly extended posteriorly. Basal opening circular. Acontiodiform element asymmetric with deep posterolateral grooves and posterior carina. Cusp rounded. Posterior carina rounded. Base slightly expanded, basal opening circular.

Remarks: The acontiodiform element of this species is similar in morphology to elements of _A_. _iowensis_. The morphology of the drepanodiform element is different and no scandodiform element has been recovered.

Material: 4 drepanodiform elements; 2 acontiodiform elements.

Occurrence: WC24.

Genus TERIDONTUS Miller, 1980

Type species: *Oneotodus nakamurai* Nogami, 1967

TERIDONTUS NAKAMURAI (Nogami)

(Plate 6, figures 16, 17)

Synonymy:

Oneotodus sp. a MÜLLER, 1959, p. 458, Pl. 13, fig. 17.

Oneotodus nakamurai NOGAMI, 1967, p. 216, Pl. 1, figs. 9, 12 (only), text-figs. 3A,B (only); MILLER, 1969, p. 435, Pl. 63, figs. 1-10, text-fig. 5E; DRUCE and JONES, 1971, p. 82, Pl. 10, figs. 3, 4, 7, 8 (only), text-fig. 26i (only); JONES, 1971, p. 58, Pl. 4, figs. 1, 3 (only); MÜLLER, 1973, p. 41, Pl. 5, fig. 4.

Oneotodus datsonensis DRUCE and JONES, 1971, p. 80, Pl. 14, figs. 1-3 (only), text-fig. 26c; JONES, 1971, p. 56, Pl. 3, figs. 5, 7.

Teridontus nakamurai (Nogami), MILLER, 1980, p. 34-35, Pl. 2, figs. 15, 16, text-fig. 40; LANDING and BARNES, 1981, p. 1614, Pl. 1, figs. 15-17, 20, text-fig. 3 (16); AN et al., 1983, p. 156-157, Pl. VI, figs. 1-6; NOWLAN, 1985, p. 116, Figs. 5.26-5.32; CHEN and GONG, 1986, p. 192-193, Pl. 39, figs. 1, 3-9, 11-13, Pl. 40, figs. 1, 3, 5, 7, 9, 12-13, Pl. 47, figs. 7-8, Pl. 48, fig. 16, text-figs. 79-1-12, 15, 16; BAGNOLI, BARNES and STEVENS, 1987, Pl. 2, 15, 16, 17 (only).

Description: Simple cones with variable morphology. Most specimens erect to markedly proclined while some are reclined. Cross-section of cusp circular to slightly oval. White matter present in cusp. In some elements cusp slightly twisted laterally. Costa or carina absent. Cusp in most specimens broken just above the base. Base short to long. Outline of base circular, diameter of which is variable. Basal cavity roughly triangular in lateral view with apex near center. Base dark due to the presence of organic matter. Boundary between the darker base and white matter filled cusp sharp and near apex of basal cavity. Elements exhibit subtle curvature transition series.

Remarks: I have followed the revision of this species proposed by Miller (1980). However, the Bay of Islands specimens of _T_. _nakamurai_ exhibit a much wider range of morphologic variation both in the nature of the base and in the cusp-base relationship. The variability in cusp-base relationship, which has also been noted by Nowlan (1985), should be considered a characteristic feature of the _T_. _nakamurai_ apparatus.

Material: 69 specimens

Occurrence: NH41, NH44, NH45, NH46. NH48.

TERIDONTUS SP. aff. T. NAKAMURAI (Nogami) Nowlan, 1985

(Plate 6, figure 18)

Synonymy:

aff. Oneotodus nakamurai NOGAMI, 1967, p. 216-217, Pl. 1, figs. 9, 12 (only), text-figs. 3A, B (only).

aff. Teridontus nakamurai (Nogami), NOWLAN, 1985, p. 116, Figs. 5.40-5.43; ?BAGNOLI, BARNES and STEVENS, 1987, Pl. 2, fig. 18 (only); (see under T. nakamurai for complete synonymy of that species).

Description: Simple cones with proclined to erect cusp. Cross-section of cusp circular to slightly oval. Cusp fairly long and slender with pointed tip. In most elements anterior margin of cusp above base slightly concave, while posterior margin convex. White matter present in cusp. Cusp slightly twisted laterally in some specimens. Base expanded and triangular in outline. Basal opening circular. Basal cavity triangular, extending up to the bend of the cusp. Apex of basal cavity near center.

Remarks: In my samples this species occurs with together T. nakamurai. The first appearance of this species is, however, later than the first appearance of T. nakamurai. The morphologic variation exhibited by the two species are similar. The nature of the cusp and base is different from that of T. nakamurai. Nowlan's specimens of T. sp. aff. nakamurai Nowlan, 1985 differed from the elements of T. nakamurai "in being much more robust" (Nowlan, 1985, p. 116). In my case, the two species are about the same in size.

Material: 62 specimens.

Occurrence: NH45, NH49.

TERIDONTUS SP.

(Plate 7, figure 1)

Description: Element with expanded base and suberect to proclined cusp. Cusp-base relationship somewhat variable. Cross-section of cusp circular. Costa or carina absent. Number of small nodes can be present on the cusp. Basal opening circular in outline. Diameter of basal opening variable. Basal cavity large with apex extending up to bend of cusp. Basal part of element dark due to presence of organic matter.

Remarks: This species is not very abundant in the Bay of Islands material. When present it co-occurs with T. sp. aff.

T. nakamurai. The most characteristic feature of this species is the expanded margin of the base. The only other species of Teridontus with an expanded base is T. expansus Chen and Gong, 1986. However, the nature of the base in T. expansus is different and it does not appear to be conspecific with T. sp.

Material: 6 specimens

Occurrence: NH44, NH48.

Genus VARIABILOCONUS Landing et al., 1986

Type species: Paltodus bassleri Furnish, 1938

VARIABILOCONUS BASSLERI (Furnish, 1938)

(Plate 7, figures 7-14)

Synonymy:

Paltodus bassleri FURNISH, 1938, p. 331, Pl. 42, fig. 1.

Paltodus variabilis FURNISH, 1938, p. 331, Pl. 42, figs. 9, 10.

Oistodus pandus Branson and Mehl, FURNISH, 1938, p. 330, Pl. 42, fig. 5.

Acodus oneotensis FURNISH, 1938, p. 325, Pl. 42, figs. 26-29.

Variabiloconus bassleri LANDING et al., 1986, p. 1946-1947, Pl. 3, figs. 1-7, 9.

"Paltodus bassleri" Group NOWLAN, 1985, p. 118-120, Figs. 10.1-10.14.

Description: Complex multimembrate apparatus consisting of scandodiform and various types of costate and sulcate elements.

Scandodiform element: characterized by flared base and a proclined cusp. Cross-section of cusp oval. Anterior and posterior margins keeled, anterior keel not extending onto base. Basal cavity large.

Asymmetric unicostate element: unit with proclined to suberect cusp and slightly posteriorly expanded base. Cusp twisted laterally relative to base. Lateral surfaces of cusp rounded. Anterolateral costa present. Costa broad and flexed laterally. Posterior margin flat, often with shallow sulcus. Base laterally compressed, basal cavity fairly large.

Asymmetric bicostate element: cusp laterally compressed and recurved. Two broad lateral costae extending up to basal margin. Anterior and posterior margins rounded, poorly developed costae may be present on anterior margin. Basal opening circular.

Strongly asymmetric costate element: cusp recurved, slightly to strongly twisted relative to base. Posterior margin rounded or costate. Anterolateral costae present.

Posterior costa sharp, anterolateral costae broadly rounded. Base long or short. Basal cavity in long-based elements large, with anteriorly situated apex.

Asymmetric tetracostate element: characterized by recurved cusp and short base. Anterior, posterior and two anterolateral costae present. Anterior and posterior costa sharp and often poorly developed. Anterolateral costae rounded. Sulcus can be present infront of anterolateral costae. Basal opening circular.

Acontiodiform element: Symmetrical element with fairly large base and erect to recurved cusp. Cusp almost straight above base. Anterior and posterior margins rounded. Deep anterolateral or lateral sulci present in most elements. Posterior margin broadly rounded. Small posterior groove may be present. Base long or short, basal opening circular.

Remarks: As shown by Landing et al. (1986) the apparatus of V. bassleri include a number of previously described simple cone elements. I agree with their reconstruction in general. However, I do not think that Teridontus sp. aff. T. nakamurai (Nogami) Nowlan, 1985 belongs to the Variabiloconus apparatus simply because they do not coexist in my samples. I consider T. sp. aff. T. nakamurai (Nogami) Nowlan to be a valid species.

Most of the elements of V. bassleri exhibit one or more deep grooves (sulci) or costae. The costae are generally broad and rounded. The acontiodiform element of V. bassleri is P. bassleri. The size of the elements belonging to this species varies from small to large even in the same sample. The smaller elements tend to be lighter in colour while the bigger elements are comparatively darker. See Chapter 4, Paleoecology, for a possible explanation of this phenomenon.

Material: 74 costate elements; 18 scandodiform elements.

Occurrence: NAP6

VARIABILOCONUS SP. aff. V. BASSLERI

(Plate 7, figures 2-6)

Remarks: Apparatus similar to that of V. bassleri. Most elements of this species are much smaller than typical elements V. bassleri from Bay of Islands and have much longer bases. The bases of acontiodiform elements are especially long. The acontiodiform elements of this species are also strongly recurved. It is not clear whether the length of base and curvature of element are good enough criteria for division at species level. More likely these features are manifestations of ecophenotypic variation.

Material: 11 scandodiform elements; 11 acontiodiform elements; 60 costate elements.

Occurrence: NH54, NAP6, NAP16.

Genus WESTERGAARDODINA Muller, 1959

Type species: *Westergaardodina bicuspidata* Muller, 1959

WESTERGAARDODINA SP. INDET.

(Plate 7, figure 24)

Description: Specimens extremely poorly preserved and represented by phosphatic internal moulds. Unit u-shaped and rather slender.

Remarks: The specimens are morphologically similar to *W. fossa* Muller. However, the extremely poor preservation prevents positive identification.

Material: 3 poorly preserved internal moulds.

Occurrence: NH24.

GENUS et SP. indet. 1

(Plate 7, figures 15-17)

Description: Apparatus consists of symmetric acontiodiform and asymmetric scandodiform elements.

Scandodiform element characterized by flared base and recurved cusp. Cusp long, slender and laterally compressed. Cusp twisted relative to base. Anterior and posterior margins sharply costate. Anterolateral costa present on one side, posterolateral costa on other. Costae well developed and extend up to aboral margin. Base flared, oral and aboral margins curved.

Acontiodiform element exhibits two morphotypes. Morphotype I exhibits recurved cusp with two anterolateral costae. Costae fairly wide and extend up to aboral margin. Costae widest near basal margin and gradually tapers upwards. Posterior margin exhibits two sharp costae with sulcus in between. Anterior margin broadly rounded with faint medial carina. Base expanded posteriorly. Basal opening triangular. Morphotype II consists of slender cusp and large base. Cusp sharply curved posteriorly. Two anterolateral costae present. Costae broadest at aboral margin, sharply tapers upwards. Grooves present infront of the costae. Grooves deepest in basal region, becomes shallow along cusp. Posterior margin exhibits rounded keel, anterior margin broadly rounded. Base strongly expanded posteriorly. Basal opening triangular in outline.

Remarks: The composition of this apparatus is rather unusual which makes generic assignment difficult. Acontiodiform morphotype I somewhat resembles A. staufferi Furnish, 1938, s.f. There is a strong possibility that the reconstruction described here does not represent the full apparatus as only a few elements of this type have been recovered.

Material: 1 scandodiform element; 2 acontiodiform elements.

Occurrence: NAP9.

GENUS et SP. indet. 2

(Plate 7, figures 18-20)

Description: Apparatus composed of simple cones with prominent cusp and expanded base. Costate and non-costate morphotypes present.

Costate element laterally compressed. Cusp erect in most elements, slightly proclined in some. Cusp fairly long, tapering to a sharp point. Anterior and posterior margins of cusp bear sharp costae. Anterior costa may or may not extend below cusp-base junction. Posterior costa extends from tip of cusp to cusp-base junction. Shape of posterior costa slightly convex and very characteristic. Base laterally compressed or rounded slightly flared. Basal opening rounded or oval.

Non-costate element rounded with long cusp. Cusp erect and tapers to a sharp point. Cross-section of cusp roughly circular. Cusp very slightly curved with concave anterior edge. Base fairly big and expanded. Aboral margin convex in lateral view.

Remarks: This is a problematic apparatus. The posterior margin of the cusp in costate elements is very characteristic and similar to that illustrated by Dzik (1976, fig. 13 a) for some specimens of Scalpellodus laevis. Scolopodus bulbosus Löfgren, 1978, also exhibits a similar type of cusp as does some elements of Semiacontiodus cornuformis (Sergeeva) (see Löfgren, 1978, Pl. 8, figs. 6a-c and Dzik, 1976, fig.13g). It is not clear what the taxonomic significance of this feature is but is probably worth examining in future studies. The rounded element of this species has a cusp which is very similar to that of T. aff. T. nakamurai Nowlan. The differences between the two are in the nature of base and overall size of element. Genus A Sp.1 is younger than T. aff. T. nakamurai Nowlan and hence it is possible that the two species are related.

Material: 7 specimens

Occurrence: WC23.

CHAPTER 6

CAMBRO-ORDOVICIAN PROBLEMATICA

6.1 Introduction

In recent years there has been a renewed interest in the study of lowermost Paleozoic problematic fossils. While this has produced a number of important papers dealing with lower and middle Cambrian problematica (e.g. Rozanov, 1986; Bengtson et al. 1986; Hinz, 1987 and references therein), it has not contributed much to the knowledge of upper Cambrian-lower Ordovician phosphatic problematica. Although it is common knowledge that various kinds of phosphatic fossil fragments are generally associated with conodonts in acid resistant residues of upper Cambrian-lower Ordovician limestones, such fossils are rarely described in detail. This is mainly due to their enigmatic nature and uncertain taxonomic position. The lack of such a data base has, unfortunately, reduced the potential evolutionary and ecologic importance of these fossils and have relegated them to the position of being mere curiosities (see Bengtson, 1986a).

A large variety of small, fragmentary phosphatic fossils have been recovered from the Cooks Brook and Middle Arm Point formations in the course of this study. These fossils are described here in detail. The thesis argued here is that problematica are an important part of the lower

Paleozoic biota and hence are important from both evolutionary and paleoecologic points of view. Detailed studies of such fossils are, therefore, required before we can claim an understanding of lower Paleozoic life. It should be mentioned that this point has been argued by a number of workers over the years and hence is not new. However, a continuing lack of serious interest in fossils of uncertain taxonomic positions necessitates the reiteration of this idea.

6.2 Taxonomy of the problematica: an overview

In this study a "problematic fossil" is defined as "a fossil that cannot be recognized as belonging to a known phylum" (Bengtson, 1986, p. 3). As discussed by Bengtson (1977), problematic fossils, almost by definition, form a heterogeneous group, united not by biological characters but by taxonomic uncertainties. In other words, the existence of problematic fossils is a grim reminder of the limitations of our present taxonomic concepts.

The question of applying Linnaean taxonomic concepts to the fossil record has been the subject of debate in the paleontologic literature for a long time. As biological taxa are defined solely on the basis of living organisms some authors, including Croneis (1938), have suggested implementing a totally different system for classifying fossil organisms. The "Ordo militaris" concept of Croneis

(1938, 1941), for example, is independent of biological classification and based totally on morphologic criteria. While it has to be admitted that superficially the concept of "Ordo militaris" seems rather attractive especially for fossils of uncertain affinities as it proposes a simple classification based only on morphology (see Lindström, 1954) it is none-the-less unacceptable. This is because it treats biological entities as inanimate objects and hence totally disregards any evolutionary or ecologic relationships. The application of standard Linnaean concepts of classification to geologically old fossils, on the other hand is not without its share of difficulties. Recently Bengtson (1986), in an important paper, has discussed this question in detail and here I will only summarize a few salient points of this discussion. There has always been a tendency amongst paleontologists to classify fossils on the basis of "current zoological classification of living animals and their biohistorical predecessors despite the remoteness in time of the processes which produces them" (Glaessner, 1984, p.133). According to this approach, phyla, by definition, are extant and hence it is assumed that all the early evolutionary experiments can be incorporated into extant phyla. As pointed out by Bengtson (1986), Babcock (1986) and Gould (1983, 1984), amongst others, such an approach is inappropriate as it tends to obscure important phylogenetic information and hence provides a false or distorted picture of diversification patterns. The limitations of this approach become even more apparent when one takes into account the rather provocative but appropriate definition of phylum proposed by Bengtson (1986, p. 3): "A phylum is a group of organisms of uncertain taxonomic affinities, that is, a problematic taxon". The concept of phylum is thus hazy at the best of times and extrapolating it back in geologic time only worsens things. At this point it should be pointed out that there is a real biological reason for the fact that our current systematic concepts work reasonably well in the case of most fossil groups but seem to fail in the case of a large number of lower Paleozoic organisms. Stanley (1976), while discussing the radiation of early metazoans, states "At the start of adaptive radiation of a phylum or class, the great ancestral potential of generalized early members commonly permits the divergence of a wide variety of subtaxa. Commonly, however, many of the subtaxa suffer rapid extinction..... The general pattern of initial adaptive radiation ..... is sometimes described as evolutionary 'experimentation'..... These would seem to document 'experimentation' in animal evolution not merely at the level of order or class but, for the only time in geological history, at the level of phylum". This is a rather elegant explanation of the presence of a number of "would-be-phyla" in the lower Paleozoic and is, in fact, the primary reason why the conventional concept of phylum fails badly in the case of early Paleozoic problematica (Bengtson, 1977). This, however, should not be taken to imply that the solution of the problem lies in assigning the problematic fossils to a number of hypothetical extinct phyla. Such an approach is no less cosmetic a solution for a real problem than trying to fit problematic fossils into extant phyla (Bengtson, 1986).

The taxonomic approach adopted in this study is weighted heavily towards the descriptive side. I am convinced that a number of taxonomic problems associated with upper Cambrian-lower Ordovician problematica are simply the result of a severe lack of knowledge about them and hence creation of a large data base is of utmost importance. A case in point is the ongoing debate about the affinities of the problematic genus Anatolepis. This particular type of phosphatic plate fragment has been assigned to an early Ordovician vertebrate by Bockelie and Fortey (1976) while Peel (1979) suggested an arthropod affinity. An examination of the published literature reveals how scanty our knowledge of this fossil is. Since its first description by Nitecki et al. (1975) less than 10 studies of this fossil have been reported and some of these studies have merely illustrated the specimens (e.g. Fortey et al., 1982). As is shown later in this study, the morphology of Anatolepis plate fragments is more complex than previously believed and hastily assigning it to either vertebrates or arthropods may not be prudent. In fact the situation is somewhat similar to that of the conodonts, which were originally described as fish remains and subsequently were assigned to at least ten different phyla (Bengtson, 1977). It is only recently, and after studying them in extensive detail, that it has been realized that the conodonts do not belong to any extant phylum.

The objective of this study is, thus, neither to force the problematic fossils into the pigeon holes of existing phyla nor to create a host of hypothetical phyla for them. The objective is to use a rather open taxonomic framework to describe them in detail. It is hoped that such an approach will prompt future studies of similar material which will ultimately lead to meaningful classification of these fossils.

The phosphatic problematica recovered from the Cooks Brook and Middle Arm Point formations exhibit a wide variety of structures and morphologies. They can, however, be divided into five broad informal divisions. These are (i) phosphatic plates and related microfossils, (ii) spherical and sub-spherical microfossils, (iii) tubular microfossils, (iv) miscellaneous microfossils and (v) nauplius-like larvae. In this study each of these five divisions has been described and discussed separately. It should be pointed out that these artificial divisions have been used here simply for the ease of discussion and have no biological significance whatsoever. Most of the problematica featured here have either not been described before or have been described only in informal terms. This gives rise to a problem of terminology as different terms are often used in different studies to describe the same feature. The terminology used in this study has been derived from the existing literature as much as possible. For each of the five informal categories the terminology used has been defined at the beginning of the respective sections.

6.3 Phosphatic Plates and related microfossils

6.3.1 Introduction

At present the literature dealing with upper Cambrian-lower Ordovician phosphatic plates is rather scanty. While some of these fossils have been described in detail a host of other forms have been merely illustrated in studies dealing with other animal groups. The plates described in detail have generally been placed under a number of newly created generic and specific names whose taxonomic positions are just as enigmatic as the nature of the fossil itself. While it has to be admitted that this unfortunate situation is often unavoidable due to the enigmatic nature of the fossil and the scantiness of the available material, it should also be mentioned that in a number of these cases the use of open nomenclature would have been preferable over the creation of formal taxa. The lack of systematic descriptions certainly has not helped the taxonomic confusion surrounding the upper Cambrian-lower Ordovician plates either.

The majority of the upper Cambrian-lower Ordovician phosphatic plates described so far have been placed into four major taxonomic groups each thought to be of generic (or higher) status. These four so called genera are *Hadimopanella* Gedik, *Milaculum* Müller, *Utahphospha* Müller and Miller and *Anatolepis* Bockelie and Fortey. The early Cambrian *Lenargyrion* Bengtson is probably a junior subjective synonym of *Hadimopanella* Gedik (see Wrona, 1982) although to the best of my knowledge *Lenargyrion* has not been described from upper Cambrian-lower Ordovician rocks. Missarzhevsky (1977) created a monotypic genus *Mongolitubulus* for cylindrical phosphatic sclerites from Mongolia and Siberia. *Mongolitubulus* Missarzhevsky is rather similar in morphology to *Anatolepis* Bockelie and Fortey and might be congeneric. Another taxon that should be mentioned in this context is *Astraspis* Walcott which was originally described from isolated phosphatic plate fragments and is now considered to be one of the earliest fishes (see discussion later). In addition to the taxa mentioned so far, a few other types of upper Cambrian-lower Ordovician phosphatic plates have been illustrated in isolated studies by Westergard (1953), Grant (1965), Ethington (1981) and Fortey et al. (1982) amongst others. In these studies the authors have chosen not to assign the plates to any particular taxon due to their enigmatic nature. Some of these plates occur in my material and are discussed in more detail later.

6.3.2 Description of the fauna

Before the systematic description of the phosphatic plates is undertaken, a few words regarding the taxonomic approach as well as the terminology used to describe the morphology of these fossils is appropriate.

As stated before, lower Paleozoic phosphatic sclerites, in the majority of cases, are recovered as acid resistant residues after the enclosing limestone has been dissolved. Due to such rigorous methods of preparation, these fossils commonly occur as disarticulated, broken fragments. This has led to the serious taxonomic question whether the different morphotypes of these plates represent different species or whether a number of morphotypes are, in reality, conspecific (a situation reminiscent, again, of conodonts). It has been recognized for a long time that in most cases a number of different morphotypes of plates, in reality, belonged to the same organism. For example, Walcott (1892) realized that Astraspis desiderata included a number of plates exhibiting different types of ornamentation. Müller (1973), while describing various species of Milaculum, also included more than one type of sclerite in a single species (e.g. M. scandicum Müller). Recently, van den Boogaard (1988, p.2), working with exceptionally well preserved Milaculum material, has most convincingly shown that "the Milaculum-bearing animal had a scleritome composed of different types of plates". Some of the material recovered in this study has shown that the same conclusion can be drawn for some other types of plates as well. Due to this, efforts have been made in this study to combine different morphotypes of plates into morphologically meaningful groups. It is evident that such a task is not at all easy as, at the present state of our knowledge, it is hard to define objective criteria based on which such "multielement" classification of the plates can be undertaken. The criteria used for defining the taxa in this study include overall similarity in basic morphology, similar structure and co-occurrence.

All the phosphatic plates described in the study are characterized by prominent surface ornamentation in the form of various types of nodose structures. A variety of terms like "pustules", "prominencies", "tubercles", "studs" and "scales" have been used in different studies to describe these structures. All these terms are more or less synonymous and in this study the term "tubercle" has been used to denote these features as I feel that it provides the most appropriate description. The other problem encountered while describing these plates is concerned with the terminology of the opposite surfaces of the plate and in the past terms like "exterior" and "visceral" have been used to describe these surfaces. However, since very little about either the nature of the organism these plates belonged to or the function of these plates is known, it is preferable to avoid the use of such terms. Instead, purely descriptive terms like "upper" and "lower" have been used in this study to describe the two surfaces. The upper surface, as defined here, is simply the surface with the most prominent ornamentation while the lower surface is the surface with little or no ornamentation.

Genus ANATOLEPIS Bockelie and Fortey

Type species: *Anatolepis heintzi* Bockelie and Fortey, 1976

Remarks: Bockelie and Fortey (1976) proposed the genus *Anatolepis* for lower Ordovician phosphatic plates with imbricated scale-like tubercles on the surface. Similar types of plates have been described by Nitecki et al. (1975), Peel (1977, 1979), Repetski (1978) and Fortey et al. (1982). The sclerite described by Missarzhevsky (1977) as *Mongolitubulus squamifer* might also be congeneric. The genus *Anatolepis* has so far been confined to plates with rhomboidal to oval tubercles which commonly have an imbricated appearance. The specimens recovered in this study indicate that the surface ornamentation of *Anatolepis* plates may be much more diverse than previously illustrated. An individual probably had more than one type of tubercles on the plates (Pl.9, figs. 2, 7). Bockelie and Fortey (1976) noted that the size and shape of the individual tubercles on A. heintzi were variable and they postulated that this variation was probably controlled by the position of the fragments on the body of the animal. The present findings suggest that depending on the position of the sclerite on the body of the organism the shape and distribution of the tubercles can change rather remarkably. This observation is certainly not surprising since, as mentioned before, similar findings have been reported for another upper Cambrian-lower Ordovician sclerite genus Milaculum Müller (van den Boogaard, 1988). It should be mentioned that, unfortunately, this variation of surface morphology is not always taken into consideration while studying these fossils and often importance is placed on features of doubtful taxonomic significance. For example, Peel (1979) while describing Anatolepis fragments from Greenland placed importance on the overall shapes of the fragments as well as size of the tubercles and proceeded to doubt that the specimens from Greenland were congeneric with those described by Bockelie and Fortey (1976) from Spitsbergen and by Repetski (1978) from North America. If one takes into account the intraspecific variation observed in this study then it is very likely that the Greenland specimens are certainly congeneric with Anatolepis specimens described from elsewhere including the early Cambrian ones described from

Mongolia and Siberia by Missarzhevsky (1977). Although histologic investigations of Anatolepis have been undertaken by Repetski (1978) and Bockelie and Fortey (1976), none of the previously published studies on Anatolepis have mentioned the intricate structure of the tubercles themselves (see Pl. 8, figs. 3, 5, 6, 7, Pl. 9, figs. 4, 7, 9, Pl. 10, fig. 3, 5, Pl. 11, figs. 1, 4, 8, 9). This structure, described later, is extremely striking and common to all the Anatolepis material recovered in this study.

ANATOLEPIS SP. A

(Pls. 8, 9, 10, 11)

Description: This species consists of a variety of phosphatic plate fragments. The general morphology of all the fragments consists of a thin plate with raised tubercles on one or both the surfaces. The specimens can occur either as small flat pieces (Pl. 8, fig. 2, 5, Pl. 9, fig. 6, Pl. 11, figs. 1, 2, 6; or as fragments of hollow tubes or spines (Pl. 8, figs. 1, 3, 4, 9, Pl. 9, figs. 1, 2, 5, 8, Pl. 10, figs. 1, 2, 9, Pl. 11, figs. 3, 7). The upper surface of all the fragments exhibits prominent tubercles. The lower surface may or may not exhibit tubercles. The shape, size and distribution of tubercles on the upper surface is quite variable. Based on their general appearance, these tubercles can be divided into two broad types. Type I tubercles are quite large and vary in shape from oval (Pl. 8, fig. 4, Pl. 9, fig. 2, Pl. 10, figs. 1, 9, Pl. 11, figs. 1, 2, 7, 8) to elongated trapezoid with rounded edges (Pl. 8, figs. 1, 2, 3, 5). When intact, these tubercles have a smooth covering on top and along the sides (Pl. 8, fig. 4). However, in the majority of Bay of Island specimens the phosphatic covering on top has been partially removed (probably due to acid etching) to reveal the presence of numerous tiny rod-like structures inside the tubercles (Pl. 8, figs. 2, 3, 5, 6, 7, Pl. 9, fig. 7, Pl. 10, figs. 2, 3, 5, Pl. 11, figs. 4, 8). These densely packed rods are oriented nearly perpendicular to the plate surface near the center of the tubercle while near the edges, they make an angle of less than 90° thereby giving the visual impression of radiating away from the center (Pl. 8, figs. 5, 6, 7). In some instances the tips of these rod-like features have been broken revealing that they are hollow (Pl. 8, figs. 6, 7). Tubercles of this type, in a number of cases, are thicker on one side thereby giving an "imbricated" appearance (Pl. 8, figs. 1, 3). Type II tubercles are round to oval in shape and are entirely covered on the surface by small nodes (Pl. 9, figs. 2, 3, 4, 5, 7, 9). Closer observation reveals that these nodes are, in reality, extremely small rods not unlike those found in Type I tubercles. The upper surface of the specimens can be covered with either with one type of tubercle (Pl. 8, figs.

1, 2, 3, 4, 5, 9, Pl. 9, fig. 1, 5, 6) or can exhibit both types of tubercles (Pl. 9, figs. 2, 7). In plates exhibiting one type of tubercles, the size of the tubercles, in a number of cases, is variable (Pl. 8, figs. 2, 9, Pl. 11, fig. 1). Due to the fragmented nature of the specimens, it is not easy to detect any definite pattern of arrangement of the tubercles on the surface of the plates. In some specimens the tubercles seem to be arranged regularly (Pl. 9, fig. 1,) while in others the pattern is not so apparent (Pl. 8, fig. 2). The junction of the Type I tubercles with the surface of the plate can be characterized by the presence of numerous fine wrinkles or folds (Pl. 10, figs. 2, 3, 4, 5) which probably represent the fossilized remains of soft tissue (see below). This feature, however, is not present in the case of Type II tubercles which occur inside shallow pits on the plate surface (Pl. 9, fig. 9,). Another interesting feature found on some of the specimens is the presence of circular holes in Type I tubercles (Pl. 11, figs. 1, 4). These holes have a regular outline and extend into the tubercle but do not seem to reach the other surface. Interestingly enough, these holes seem to affect only the Type I tubercles as they have not been found to occur either on the surface of the plate or on Type II tubercles. The lower surface of the specimens of this species also exhibits considerable variation in morphology. In some specimens the lower surface exhibits shallow depressions or pits corresponding to tubercles on the other side (Pl. 10, fig. 8,). In other specimens, however prominent tubercles can be present on the under surface (Pl. 11, figs. 2, 5,). Although these tubercles are similar in shape to oval Type I tubercles they lack the top covering and the densely packed internal rods of the former. The size of these tubercles can be variable. Due to the extremely small size and brittle nature of the fragments, attempts to section the plates in order to study the wall structure have so far met with very little success. However, examinations of freshly fractured and etched surfaces under the SEM reveals that the plates are composed of three layers (Pl. 8, fig. 8, Pl. 10, fig. 7, Pl. 11, fig. 3). Of these the top and bottom layers appear to be laminar while the middle layer has a spongy appearance. In most specimens the bottom layers get eroded and hence only two layers are visible. The overall composition of the plates of this species is calcium phosphate, although the rods inside the tubercles seem to contain a little more silica as compared to the plate surface and the covering of the tubercles (Figs. 6-1, 6-2(A)).

Remarks: Some of the specimens described above are very similar in appearance to the specimens of A. heintzi Bockelie and Fortey, 1976 and probably belong to a related species. One of the interesting features of the Bay of

Islands specimens is the rather striking internal structure of the tubercles. This feature has not been described before and at present the functional significance of this feature remains unclear. It can be postulated that the tiny, hollow rods present inside the tubercles represent the fossilized remains of some kind of sensory organ. In fact the presence of the fine wrinkles at the base of the tubercles may suggest that the surface of the plate as well as the tubercles were originally covered with a membrane or soft tissue and the assemblage of tiny rods under this covering served some kind of subcuticular sensory purpose. Recently Gans and Northcutt (1983) and Northcutt and Gans (1983) have put forward rather convincing embryological evidence in favour of the hypothesis that "vertebrates have evolved from protochordate-like ancestors primarily by elaboration and differentiation of their epidermal nerve plexus and by muscularization of their hypomere" (Gans and Northcutt, 1983, p. 268). According to this hypothesis it is likely that those organs that are derived from the epidermal placodes and neural crests have developed phylogenetically from epidermal nerve plexus of earlier vertebrates. Thus it is quite likely that the early dermal armour was involved in sensory perception as well as in protection and ion storage (Northcutt and Gans, 1983). It is also possible to postulate that Type II tubercles are the early growth stages of Type I tubercles. Although purely speculative, this second hypothesis certainly needs further testing in future studies as morphologically it is quite easy to produce Type I tubercles just by adding an external covering to Type II tubercles. Another feature that remains enigmatic at this point is the presence of regular holes in some of the tubercles. The most convenient explanation that comes to mind is that these holes, which cut right through the internal structure, are the result of borings by other organisms. It is, however, more difficult to explain why the borings are present only on the tubercles and not on the surface of the plate itself. It is tempting to speculate that the tubercles, due to their fine internal structure, provided zones of weakness favored by the borers. Such a contention, however, is impossible to prove at the present state of knowledge. Also, the fact that these holes do not quite reach the other surface of the plate seems to provide a strong argument against the boring hypothesis.

This type of plate is common in the Bay of Islands material.

Occurrence: NH22, NH24, NH27a, NH28, NAP6.

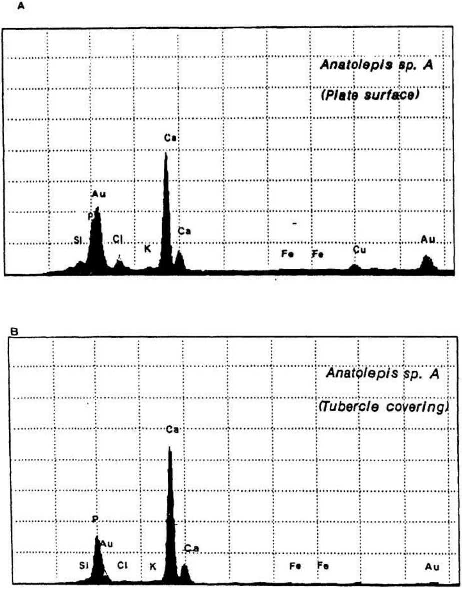


Figure 6-1. Qualitative plots of major element compositions of A. sp. A. (A) Plate surface (B) Tubercle covering.

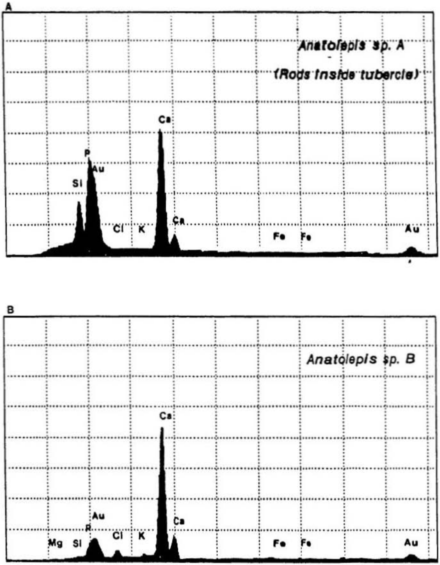


Figure 6-2. Qualitative plots of major element compositions of (A) *A*. sp. A, rods inside tubercle and (B) *A*. sp. B.

ANATOLEPIS SP.B

(Pl. 12)

Description: This species is represented in the Bay of Islands material by a number of tuberculate phosphatic plate fragments. The tubercles on the upper surface of the plates are circular to slightly oval in cross-section (Pl. 12, figs. 1, 2, 3, 4, 7, 10). Two types of tubercles are present. The bigger tubercles are similar to Type I tubercles of Anatolepis sp.A in that they have an external phosphatic covering which is often etched away to reveal a dense packing of tiny rods inside the tubercle (Pl. 12, fig. 5). The smaller tubercles, on the other hand, occur inside cylindrical pits and do not extend above the plate surface (Pl. 12, fig. 9). The tubercles appear to be distributed rather randomly on the plate surface although this observation is hard to substantiate as most of the specimens recovered in this study are small fragments. The lower surface of the plates can either be nearly smooth or can exhibit a number of rather small, closely spaced tubercles (Pl. 12, fig. 8). The wall structure consists of three layers (Pl. 12, figs. 4, 6). The top and bottom layers are laminar while the middle layer has a spongy appearance. The composition of this type of plate is calcium phosphate (Fig. 6-2(B)).

Remarks: The plates described above have been assigned to Anatolepis because of the characteristic internal structure of the tubercles. It is evident that due to the enigmatic nature of the material being described, delineation of species is rather arbitrary and may not be biologically meaningful. However, the overall morphology of the plates assigned to Anatolepis sp.B appears to be sufficiently distinct from that of Anatolepis sp.A to merit separate species status.

Occurrence: NH22, NH24, NH28.

?ANATOLEPIS SP. C

(Pl. 13, figs. 1, 2)

Description: This species is represented by fragments of plates with a series of low, oval tubercles on the upper surface. Each tubercle is characterized by an outside rim and numerous small nodes which appear to have been recrystallized. Superficially the tubercles resemble type I tubercles of Anatolepis sp. A, but the well defined rod-like structures are missing. Regular openings are present in some tubercles. These openings are circular and generally situated at the edge of the tubercle. The wall appears to be composed of three discrete layers.

Remarks: This fossil has superficial similarity with the _Anatolepis_ specimens and hence has been tentatively assigned to this group. However, this plate is siliceous in composition (Fig. 6-3(A)) which distinguishes it from other _Anatolepis_ specimens. It is possible that this siliceous composition is secondary although conclusive proof is lacking. Only a few specimens of this type have been recovered in this study.

Occurrence: NH28

GEN. ET SP. INDET. 1

(Pl. 13, figs. 3-10)

Synonymy:

Problematicum II WESTERGARD, 1953, p. 467, Pl. V, figs. 16 a-b.

Problematicum II Westergård, FORTEY et al., 1982, Text-fig 9, T, U.

Description: The species is represented by a number of small tuberculate phosphatic plate fragments. The fragments occur mostly as flat pieces but in some cases they have curled

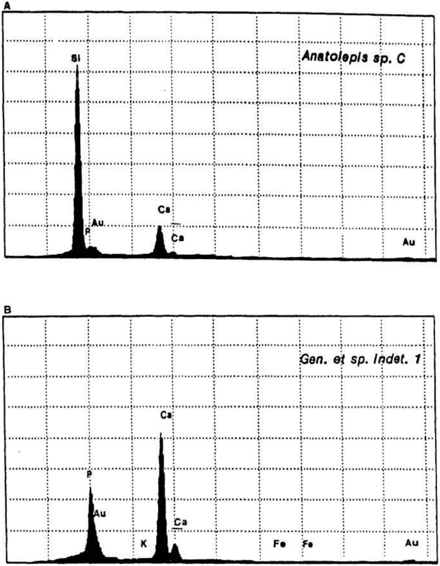


Figure 6-3. Qualitative plots of major element compositions of (A) *A*. sp. C and (B) Gen. et sp. indet. 1

edges (Pl. 13, fig. 7). The tubercles present on the upper surface of the plates are quite characteristic with circular cross-section (Pl. 13, figs. 3-9). The size of the tubercles is variable. In some specimens all the tubercles are nearly equal in size (Pl. 13, fig. 3) while in others they exhibit a bimodal (Pl. 13, figs. 4, 5, 6) or trimodal (Pl. 13, fig. 8) size distribution. The bimodality can be weakly or strongly developed. In some specimens the outer covering of the tubercles has been etched away and the interior seems to be filled with a granular mass (Pl. 13, fig. 9). This internal structure is quite different from the internal structure of the tubercles of _Anatolepis_. The upper surface of the plate itself is generally smooth but sometimes exhibits small folds or wrinkles (Pl. 13, figs. 3, 9). The plate wall is typically composed of three layers. The top and bottom layers appear to be laminar while the middle layer has a spongy appearance. The middle layer is often preferentially removed leaving a void (Pl. 13, fig. 10). Composition of this type of plate is calcium phosphate (Fig. 6-3(B).

Remarks: This type of phosphatic plate was first described by Westergård in 1953 from the upper Cambrian _Agnostus pisiformis_ zone of Sweden. In his description Westergård mentioned that his plates ("shell" according to him) were "black, glossy, apparently corneous, and flexible...". The Bay of Islands specimens of this type are also often organic rich and black in appearance. Fragments of this type have also been described from the Cow Head Group by Fortey et al. (1982). In the Bay of Islands material this type of plate has a wide stratigraphic range and has been recovered from a number of different sections. The affinity and taxonomic position of this type of plates remains uncertain at present.

Occurrence: NH22, NH24, NH28, NH37, NH53, NAP6, WC32.

GEN. ET SP. INDET. 2

(Pl. 14, figs. 4, 5)

Description: This species is represented by fragments of phosphatic plates, the top surfaces of which are covered by small pits or depressions. The depressions are oval in outline and are of approximately the same size (Pl. 14, fig. 5). These depressions have slightly raised rims and are in contact with adjacent depressions along these rims. The interior of the depressions have a very fine porous appearance. These depressions exhibit a fairly tight packing and have a honeycomb-like appearance. The specimens of this type are organic-rich and are dark in colour.

Remarks: This type of plate is rather rare in the Bay of Islands material and has so far been recovered only from one sample. A search of the relevant literature failed to produce any previous illustration of this type of material and at present the affinity of this type of plate remains uncertain.

Occurrence: NH41.

GEN. ET SP. INDET. 3

(Pl. 14, figs. 6, 8,)

Description: This species consists of a phosphatic plate with a number of rounded tubercles on the upper surface (Pl. 14, fig. 6). The tubercles are quite densely arranged on the plate surface. Two different sized tubercles are present, the smaller ones being more abundant than the larger ones. The wall structure of the plate has a fibrous appearance (Pl. 14, fig. 8) and seems to be composed of numerous individual rod-shaped crystals.

Remarks: This particular type of plate is rare in my material but is of interest because of its characteristic wall structure. Due to the small number of specimens of this type recovered, it is difficult to say whether the wall structure is primary or is a result of recrystallization.

Occurrence: NH39.

GEN ET SP. INDET. 4

(Pl. 14, figs. 1-3, 10)

Description: This species consists of phosphatic plate fragments, the upper surfaces of which exhibit a number of small pits. The pits are more or less elliptical in shape and exhibit some variation in size (Pl. 14, fig. 2). The specimens belonging to this species can be divided into two morphotypes. Specimens of morphotype I exhibit a tiny rod-shaped protrusion at the center of each pit (pl. 14, fig. 2). This protrusion seems to originate in a second pit inside the first one and does not extend up to the surface of the plate. The specimens of morphotype II exhibit pits as well as small rounded tubercles on the surface of the plate (Pl. 14, fig. 3). Most of the specimens of this morphotype recovered from Bay of Islands have been recrystallized and the secondary phosphate occurring on them obscure the finer morphologic patterns to some extent. The pits, in this case, have much larger nodose bodies inside them as compared to morphotype I. The internal nodes within the pits extend up to the surface of the plate itself. Plates of this morphotype also exhibit small rounded nodes on the surface, interspersed with the pits. The plate surface has a granular appearance due to the precipitation of secondary phosphate.

Remarks: To the best of my knowledge this type of plate has not been described before. The function of the pits on the surface of the plate remain enigmatic. However, a sensory function for the tiny rod-like protrusions inside the pits can probably be postulated. This type of plate seems to have been affected more by recrystallization and secondary phosphatization compared to other plates in the Bay of Islands material. Some of the specimens of this type are quite organic-rich and are dark in colour.

Occurrence: NH24.

GEN. ET SP. INDET. 5

(Pl. 14, fig. 7)

Description: Plate fragment with prominent ornamentation on the upper surface. The ornamentation is comprised of a number of small raised tubercles arranged in a row so as to create a ridge-like structure. A number of such ridges are arranged parallel to each other. The surface of the plate itself is more or less smooth.

Remarks: This type of plate is not very common in the Bay of Islands material and only a few fragments have been recovered.

Occurrence: NH24.

GEN. ET SP. INDET 6

(Pl. 14, fig. 9)

Description: Fragment of a rather robust plate. The upper surface of the plate exhibits rounded tubercles. The tubercles are fairly big compared to the size of the plate and are arranged linearly in a row. Two such rows are visible on the specimen, forming two ridges on opposite edges of the plate. The plate surface itself is more or less smooth but exhibits some broad folds adjacent to one of the ridges. The plate surface as well as the tubercles exhibit a number of minute perforations. The density of these perforations appears to increase somewhat near the edges of the plate.

Remarks: This type of plate is rare in my material and so far only a couple of specimens have been recovered from one particular sample. These specimens are slightly more robust compared to most of the other plates described herein. The presence of a number of tiny perforations is an interesting feature of this type of plate. Although Raasch (1939), has noted the presence of minute punctae around the tubercles on the plates of Cambrian Aglaspis spinifer the random distribution of the perforations on the present specimen seems to suggest that these are probably the result of microbial borings. This type of plate is composed of calcium phosphate (Fig. 6-4(A)) and show similarity with the composition of conodonts (Figs. 6-4(B), 6-5(A)).

Occurrence: NAP6.

GEN. ET SP. INDET. 7

(Pl. 15, figs. 1-6)

Description: This species consists of a number of phosphatic plate fragments with prominent tubercles on both surfaces. The tubercles are generally small and more or less uniform in size. Tubercles can be either rounded (Pl. 15, fig. 1) or conical (Pl. 15, figs. 5, 6). The density of tubercles on the plate surface is variable. Generally tubercles seem to be less densely distributed on the upper surface (Pl. 15, figs. 1, 5, 6) as compared to the lower surface (Pl. 15,

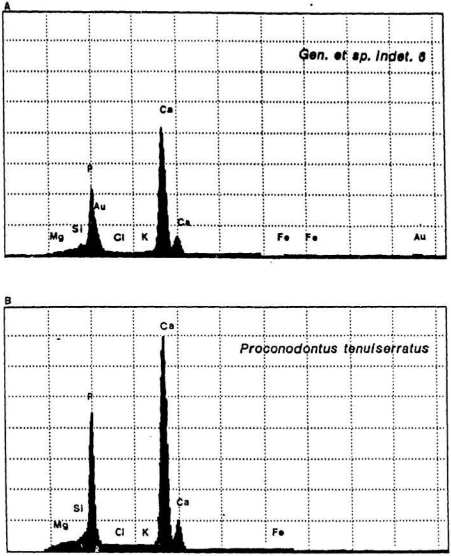


Figure 6-4. Qualitative plots of major element compositions of (A) Gen. et sp. indet. 6 and (B) <u>Proconodontus tenuiserratus</u>.

figs. 2, 4). In some specimens the tubercles on the lower surface tend to occur in clusters of two or three (Pl. 15, fig. 4) while those on the upper surface are discrete. The wall structure in specimens with rounded tubercles is uniform with very fine layering (Pl. 15, fig. 3). The tubercles originally might have been filled with a material different from that of the wall as sections of the plates often show voids under the tubercles (Pl. 15, fig. 3). In plates with conical tubercles, the wall structure shows at least two distinct layers, both of which appear to be laminar (Pl. 16, fig. 6). Overall composition appears to be calcium phosphate and is rather similar to that of conodonts (see figs. 6-5)

Remarks: Some of the fragments of this type have a very distinctive bluish white hue. Such bluish colour has also been noticed in plates of Cambrian Aglaspis integument by Raasch (1939). Fortey et al.(1982, text-fig. 9 Y) illustrated a plate fragment with somewhat similar surface patterns from the Cow Head Group. That fragment, according to Fortey et al., represented the "visceral" surface of their Anatolepis sp. The fragment described here, however, has a morphology sufficiently distinct from the Anatolepis specimens described herein to warrant distinction

Occurrence: NH28.

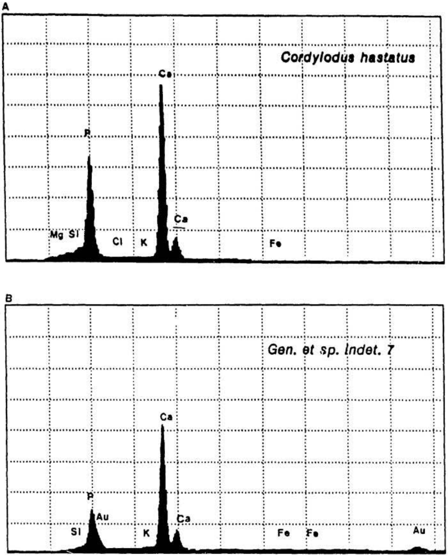


Figure 6-5. Qualitative plots of major element compositions of (A) Cordylodus hastatus and (B) Gen. et sp. indet. 7.

GEN. ET SP. INDET. 8

(Pl. 15, figs. 7-11, Pl. 16, figs. 1-4)

Description: This species consists of a variety of phosphatic plate fragments all of which exhibit small tubercles on one surface. The overall morphology of the fragments is variable. While most of the fragments occur as disarticulated flat pieces (Pl. 15, fig. 7) some are partially joined exhibiting two surfaces at right angles to each other (Pl. 16, figs. 1, 2). One of these surfaces is generally somewhat concave while the other is slightly convex. As a general rule, the convex surface is more strongly tuberculate compared to the concave surface (Pl. 16, figs. 1, 2), which exhibits very few tubercles. A number of fragments assigned to this species exhibit spines along their margins (Pl. 15, figs. 8, 9, Pl. 16, figs. 3, 4,). The spines can be either widely spaced, discrete for most of their length and few in number (Pl. 15, fig. 9) or closely spaced, fused along their bases and abundant (Pl. 15, fig. 8). The upper surfaces of the plates can be covered with a number of small tubercles (Pl. 15, figs 7-11). The tubercles have a circular cross-section with rather steep sides and can be appropriately described by using the term "pustules" or blisters used by Raasch (1939) to describe similar features on Cambrian merostomes. The top of each tubercle has a circular opening at the center (Pl. 15, fig. 11). The density of the tubercles on the plate surface is variable. In most fragments the density is quite high (Pl. 15, fig. 7). The partially joined specimens, on the other hand, show that while one surface is rather densely tuberculate, the other surface, may exhibit only a few tubercles (Pl. 16, fig. 1, 2). In fact in one of the specimens (Pl. 16, fig. 2) the tubercles are comparatively dense along the junction of the two surfaces and very sparse on the surfaces themselves. Also the density of the tubercles on fragment with few spines appears to be more than that of the fragments with a number of spines. Overall composition of this type of plate is calcium phosphate (Fig. 6-6(A)).

Remarks: This type of plate is fairly common in the Bay of Islands material and a large number has been recovered. Plate fragments of this type have been described from the Caryocaris shale of central Nevada by Ethington (1981). Raasch (1939) has also noted similar tubercles on the cuticle of Cambrian merostomes. The functional significance of the tubercles remains uncertain. However the presence of openings on the top of the individual tubercles may indicate that these were originally used to house cilia or some similar sensory organ. From the overall morphology and structure it appears that this type of plate has an arthropod affinity. However, detailed studies with larger

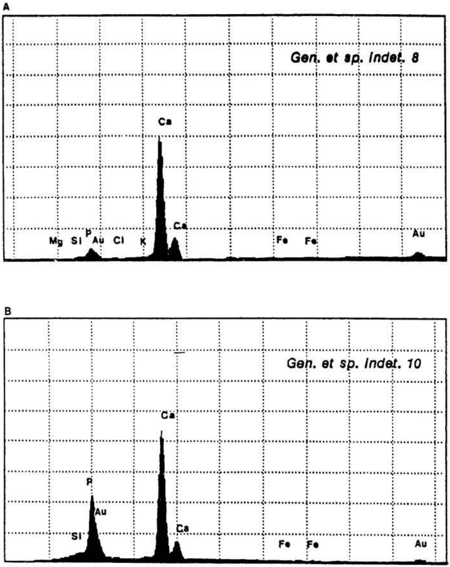


Figure 6-6. Qualitative plots of major element compositions of (A) Gen. et sp. indet. 8 and (B) Gen. et sp. indet. 10

materials are required before such a claim can be fully substantiated.

Occurrence: NAP6, NH54, NH24.

GEN. ET SP. INDET. 9

(Plate 16, figs. 5-7)

Description: Rather poorly preserved elongate fragment of a phosphatic plate with slightly curved edges. The upper surface of the plate exhibits a number of low, transverse ridges (Pl. 16, fig. 6). The ridges are parallel to each other and are composed of a number of small linearly arranged tubercles (Pl. 16, fig.7). The tubercles are flattened and circular in plan view. Due to recrystallization the surface of the plate has a granular appearance in most parts. The ridges, however, have been less affected by recrystallization compared to the surface and hence have a smoother appearance (Pl. 16, fig. 7). The wall appears to have been composed of at least two different layers. However, the original wall structure has been lost due to the recrystallization and replaced by a granular appearance (Pl. 16, fig. 5).

Remarks: Only a few small fragments of this type have been recovered from the Bay of Islands material.

Occurrence: NH28.

GEN. ET SP. INDET. 10

(Plate 16, figs. 8-10, Pl. 17, figs. 1-6)

Description: This species consists of a number of fragments of the phosphatic exoskeleton of an organism of unknown affinity. The fragments can occur in a variety of forms ranging from flat pieces with irregular edges (Pl.16, fig. 8, Pl. 17, fig. 4) to unevenly flattened tubular forms (Pl. 16, fig. 9, Pl. 17, fig. 3). In plan view, the upper surface of the plates exhibit numerous small crescentic openings (Pl. 16, figs. 8-10, Pl. 17, figs. 1, 4). Closer examination reveals that, in cross-section, these openings are actually circular but the presence of a small half-circular crystallite inside each of them imparts a crescentic appearance to the openings (Pl. 16, fig. 10, Pl. 17, fig. 1). These openings extend into the plate but do not reach the opposite surface. The openings are similar in size and are spread uniformly over the plate surface without any apparent arrangement. Apart from these openings the plate surface also exhibits numerous tiny pores occurring between the bigger openings (Pl. 17, fig. 1). In one of the specimens, this surface with openings is covered by another rather uneven layer which does not exhibit any ornamentation (Pl.17, fig 3). This covering layer, however, may not be primary and may have simply been formed due to the precipitation of secondary phosphate. In transverse section the internal structure of this specimen is rather remarkable in that it is composed of a number of thin lamellar layers interspersed with a large quantity of spongy material and numerous voids (Pl. 17, figs. 5, 6). The lamellar layers are rather complexly folded. The voids are very irregular in appearance and exhibit a large variation in size. The composition of this type of plate is similar to that of Gen. et sp. indet. 11 in that both are composed of calcium phosphate (Figs. 6-6(B), 6-7(A))

Remarks: This species is extremely interesting because of its remarkable internal structure. Although this type of plate is rather common in the Cooks Brook Formation, the majority of the specimens occur as small flat fragments and so far only one specimen with well preserved internal structure has been found.

Occurrence: NH22, NH24, NH28.

GEN. ET SP. INDET. 11

(Pl. 17, figs. 7-10)

Description: The species consists of phosphatic plate fragments both upper and lower surfaces of which bear tubercles. The upper surface exhibits a number of flattened tubercles which are circular in plan view and have rounded edges (Pl. 17, fig. 8). The top surfaces of the tubercles exhibit very fine wrinkles while a number of closely spaced longitudinal ridges are present along the sides of the tubercles (Pl. 17, fig. 8). The surface of the plate itself is covered by a thin top layer which exhibits a number of broad folds in between the tubercles (Pl. 17, fig. 8). The lower surface of the plate carries a number of closely spaced tubercles (Pl. 17, figs. 7, 9). These tubercles are broadly conical in shape often with hollow centers. Two or more of these tubercles can be arranged concentrically. The size of the tubercles is variable, the smaller tubercles being more abundant than the larger ones. A number of very fine laminations arranged in steps are often present near the bases of these tubercles (Pl. 17, fig. 7). The plates of this type appear to be composed of at least three distinct layers. The uppermost layer is very thin compared to the others and generally exhibits broad folds. The two other layers appear to be very finely laminated. Composition of these plates appear to be calcium phosphate.

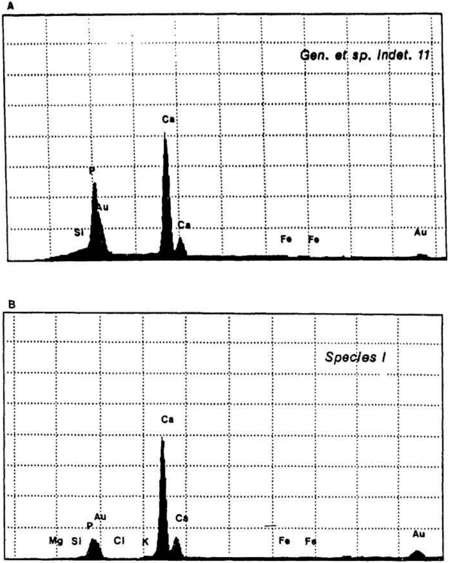


Figure 6-7. Qualitative plots of major element compositions of (A) Gen. et sp. indet. 11 and (B) Species I.

Remarks: So far only a few specimens of this type have been recovered. The surface ornamentation of this type of plate is rather similar to those of Astraspis desiderata illustrated by Walcott (1892, Pl. 3, figs. 8, 10). Superficial similarity of ornamentation, however, is not a good enough criterion for assigning the material at hand to the genus Astraspis Walcott. According to the revised diagnosis of the genus by Denison (1967), the tubercles of Astraspis "have a central pulp cavity, branched in the largest ones, and consist of orthodentine capped by durodentine, with tubules less than 1µ in diameter" (Denison, 1967, p. 164). Thus specimens should not be assigned to Astraspis unless the internal structure of their tubercles can be shown to be similar to that of Astraspis. Due to the small number of specimens recovered and the difficulty of sectioning such minute fragments, the internal structure of the tubercles of the plates illustrated here remains uncertain and hence I have preferred to use open nomenclature for these specimens.

Occurrence: NH28.

6.3.3 Affinities of phosphatic plates: a brief discussion

The extremely wide spectrum of morphologies exhibited by the phosphatic plates and related microfossils described here certainly indicates a wide range of affinities. While this means that ideally the question of affinity should be discussed separately for each particular type of plate, the lack of sufficient morphologic and histologic data in almost all the cases (Anatolepis being a notable exception) have prevented me from engaging in such rather speculative discussions. However, the question regarding affinities of these plates is critical and hence an attempt is made in this section to discuss it in general terms.

At present a rather thorny debate regarding the affinity of Anatolepis exists in the literature. One group of workers including Bockelie and Fortey (1976) and Repetski (1978) consider Anatolepis to be the remains of the oldest heterostracan fish while Peel and Higgins (1977) and Peel (1979) have proposed an arthropod affinity for this type of fossil. The argument for arthropod affinity is based mainly on the fact the Anatolepis specimens often occur as hollow cones which bear some superficial similarity to the telson spines of merostomes. However, given the fragmentary nature of the fossils, it is unfortunate that such emphasis is placed on the shape of the fragments especially when knowledge about the morphology of the earliest vertebrates is severely lacking. Another argument put forward by Peel

(1979) in support of the arthropod affinity is the three layered wall-structure of these fossils. While it is true that, as argued by Peel (1979), Raasch (1939) reported a three layered wall structure for Cambrian merostomes, later studies by Briggs and Fortey (1982) have shown that the histology of Anatolepis is quite different from that of the Cambrian merostomes. Moreover, this type of wall structure can also be easily interpreted as belonging to earliest vertebrates (see Bockelie and Fortey, 1976, Repetski, 1978). Thus at this point there does not seem to be any substantial evidence which identifies Anatolepis as an arthropod. The evidence in favor of vertebrate affinity, although somewhat stronger, is far from being conclusive. As noted by Dzik (1986), a chordate is defined neither by the presence of an internal skeleton nor by the phosphatic composition but by the characteristic internal structure of its skeletal material. The wall structure of Anatolepis does not appear to be comparable with that of other early vertebrates (Carroll, 1986). While this does not preclude a vertebrate affinity, it does put Anatolepis in a category of its own. Another fossil that exhibits surface ornamentation somewhat similar to that of Anatolepis is Arandaspis prionotolepsis Ritchie and Gilbert-Tomlinson, 1977. A partially articulated skeleton of this fossil is preserved as moulds in sandstone and has been interpreted as an heterostracan agnathan by Ritchie and Gilbert-Tomlinson (1977). The similarity of dermal ornamentations of Arandaspis and Anatolepis might indicate a relationship, although it should be mentioned that superficial similarity of ornamentation can often be misleading (see below). Since it is preserved as moulds, the histology of Arandaspis, unfortunately, cannot be determined and hence its wall structure cannot be compared with that of Anatolepis. Another problem regarding Anatolepis is that since it is known from isolated fragments its taxonomic status is uncertain. Although it is commonly considered to be a genus, the range of morphologic variation exhibited by this "genus" is poorly known mainly due to the lack of data. The specimens illustrated in this study show that the variation is definitely much more than previously believed. The other point that should be considered is that Mongolitubulus squamifer Missarzhevsky has a morphology very similar to that of Anatolepis. If Mongolitubulus is congeneric with Anatolepis and if the latter is indeed a vertebrate, then the range of vertebrates can be extended to the early Cambrian. The wall structure of Mongolitubulus, however, is not known at present and future studies are needed to settle this question.

As far as the affinities of the other phosphatic plates described herein are concerned, very little can be said at this time. Neither of the two readily observable morphologic features namely surface ornamentation and wall structure (as observed under the SEM along freshly fractured surfaces) are good enough criteria for judging affinities. Superficially the dermal or cuticular ornamentations of a number of lower Paleozoic vertebrates and arthropods are quite similar. For example, the tuberculate surface of Gen. et sp. indet. 8 is quite similar to that of the Cambrian merostome *Aglaspis spinifer* Raasch, 1939 on the one hand, and to some Devonian coccosteomorph arthrodires illustrated by Miles (1964) on the other. The three layered wall structure present in most of the specimens described in this study does not provide conclusive evidence for vertebrate affinity either, as a triple-layered wall structure with a middle "granular" layer has been noted in merostomes by Raasch (1939). Finally, the phosphatic composition, often cited as evidence of vertebrate affinity, is also not conclusive as arthropods (e.g. aglaspids) can also have phosphatic cuticles (Raasch, 1939).

The discussion above has highlighted the problems involved in determining the nature of the phosphatic plates and associated microfossils described here. The only conclusion that can be drawn from this discussion is that the present state of knowledge about these fossils does not permit any definite conclusions about their affinities. Detailed systematic and histologic studies are needed before this question can be settled and until such studies are available considerable caution should be exercised in proposing affinities for these fossils.

6.4 Spherical Microfossils

6.4.1 Introduction

The spherical microfossils recovered from the Cooks Brook and Middle Arm Point formations are either phosphatic or occasionally siliceous in composition and exhibit quite a wide range of morphologic variation. Although phosphatic and siliceous spherical microfossils of unknown affinities [illegible] often encountered in Lower Paleozoic rocks, like most other problematic fossils of that time period, they are very rarely described in detail. Hence, not only is the literature on these types of fossils scanty but also no taxonomic framework for describing these fossils exists.

A search of the relevant literature reveals that Lower Paleozoic phosphatic microspheres have been illustrated by Stauffer (1935), Ethington (1981), Aldridge and Armstrong (1981), Burrett (1985), Glenister et al. (1976) and Zhang (1987) while a type of siliceous microspheres have been described by Bengtson (1986). Landing et al. (1986) also illustrated wrinkled and pyritized spheres which they identified as tasmanitids. Since illustrations of this type of microfossils often occur as parts of studies dealing with other animal groups literature search is rather difficult and the list above is by no means complete. It does, however, represent the more recent studies and also illustrates the paucity of this type of data. The microspheres illustrated by Aldridge and Armstrong (1981) and Burrett (1985) and generally known by the informal name mazuelloid may also be related to the material described here. Spinose mazuelloids, however, have not been recovered from the Bay of Islands material. Smooth, phosphatic spheres similar to those excellently described by Ethington (1981) do occur in the Bay of Islands material and are described in this study. Microspheres described by Stauffer (1935) and later on termed "conodont pearls" by Glenister et al. (1976) are also similar to those described by Ethington (1981) as well as those recovered in this study.

6.4.2 Description of the fauna

GEN. ET SP. INDET. 12

(Pl. 18, figs. 1-3)

Description: This species consists of smooth-walled phosphatic microfossils the test of which resembles a short cylinder with rounded edges in shape. The maximum length of the specimens varies from 200 to 275 μm. All the specimens are cracked and broken which permits the examination of the inside. The tests appear to be hollow and devoid of any visible internal structure. Inside one specimen which has been broken in half, there are some irregular deposits which probably represent secondary phosphate (Pl. 18, fig. 2).

Most of the tests exhibit a small oval opening on the side which is probably a primary feature (Pl. 18, fig. 1). In some specimens this opening is surrounded by a shallow depression or dimple on the wall (Pl. 18, fig. 1). In fact, the same specimen also exhibits at least two other somewhat smaller dimples on its wall. Under high SEM magnification the wall structures of the specimens have a granular appearance with numerous euhedral to subhedral crystals. This type of wall structure appears to be the result of recrystallization.

Remarks: These specimens are moderately abundant and so far have been recovered from two samples from the Cooks Brook Formation. Zhang (1987) illustrated hollow spherical microfossils from the early Cambrian of China which he believed to be egg cases of unknown affinity. Although it is possible that the specimens illustrated here may also represent egg cases of some kind, such a speculation is impossible to verify at the present state of knowledge.

Occurrence: NH22, NH24

GEN. ET SP. INDET. 13

(Pl. 18, fig. 6)

Description: The overall morphology of the test resembles a short, somewhat flattened cylinder with rounded edges and circular cross-section. A hollow tube, about 230 μm long, joins two flattened surfaces of the test. The tube is about twice as long as it is wide. The surface of the test is smooth except for some deposits of what appears to be secondary phosphate. The wall structure of the test has a granular appearance and appears to have suffered recrystallization.

Remarks: The morphology of this specimen is rather interesting as superficially it bears a striking resemblance to the morphology of the imperforate inner float chambers of the recent foraminifer Neoconorbina (Tretomphaloides) concinna (Brady) illustrated by Banner et al. (1985). Although such similarity, by itself, does not imply any biological affinity whatsoever, it might imply a similarity of function. Given the late Cambrian age of the specimens such a speculation, if corroborated, can have far reaching implications. However, it is also possible that the specimen represents an algal segment (J. H. Lipps, personal communication, 1988) which was originally calcareous and has later been replaced with phosphate.

Occurrence: NH24

GEN. ET SP. INDET. 14

(Pl. 18, figs. 4, 5)

Description: The specimens are smooth-walled and have a crudely spherical shape. A number of specimens have a crumpled appearance and the wall of the test appears to have collapsed inwards (Pl. 18, fig. 4). This has imparted a thoroughly wrinkled appearance to the test. The diameter of the tests varies from about 100 to 230 μm. One of the specimens (Pl. 18, fig. 4) has a small (about 22 μm long), rather irregular opening on one side. It is not clear whether this is a primary feature or not. X-ray microanalysis reveals that the composition of the walls of the specimens is mainly calcium phosphate.

Remarks: Microfossils of similar morphology from the Tremadocian of Quebec have been described as tasmanitids by Landing et al. (1986), despite the absence of characteristic pore-canals on the outer surface. The main difference between the specimens of Landing et al. (1986) and the present specimens is that while the Quebec specimens were organic-walled with a pyrite infill, the present specimens are phosphatic in composition. This phosphatic composition combined with the absence of the characteristic pore canals has prevented me from assigning my specimens to the tasmanitids.

Occurrence: NH22, NH54.

GEN. ET SP. INDET. 15

(Pl. 18, fig. 7)

Description: A small spherical microfossil the outer surface of which is covered with numerous small "plates". The diameter of the test is about 133 μm. It is not clear whether these "plates" have been produced due to the cracking up of the original surface or whether they represent the original morphology. In fact, there is a third possibility that these "plates" may represent secondary deposits. The individual "plates" have a smooth surface and exhibit extensive variation in shape and size. A number of these "plates" are concave outwards and are in contact with the surface of the sphere only near their centers. In places where the plates have been peeled off, the inner surface of the sphere also appears to be smooth. At least one small, circular opening is present on the side of the sphere and is surrounded by several plates. This regular opening appears to be a primary feature. The surface of the plate as well as the plates on top appear to be siliceous in composition with some calcium and small amounts of phosphorus.

Remarks: This type of microfossil is extremely rare in my samples and so far only one specimen has been recovered. It is possible that the specimen may represent a primitive protist. However, more specimens of similar nature need to be studied in order to test such a speculation.

Occurrence: NH32.

GEN. ET SP. INDET. 16

(Pl. 18, figs. 9-12, Pl. 19, figs. 1-4)

Description: This species consists of a number of spherical to nearly spherical microfossils with smooth outer walls. The size of the specimens is variable and ranges from about 75 μm to about 200 μm in diameter. The specimens assigned to this species exhibit a variety of internal structures. Some tests (Pl. 18, figs. 10, 11) appear to be composed of two concentric spherical bodies. The inner sphere, in some specimens, has an irregular mass which can either be a secondary deposit or may represent original soft parts (Pl. 18, figs. 11-12). The wall of outer sphere of these specimens appears to be thicker than that of the inner sphere. A second type of specimen represented by Pl. 19, fig. 2, has a wall which appears to be composed of at least two distinct layers separated by space in between. The outer wall is more or less smooth whereas the inner layer has a recrystallized appearance. Rather poorly preserved inside the test is what appears to be the remnants of some kind of partition originally dividing the test into segments. The insides of the other specimens assigned to this species are generally filled with irregular deposits of what appears to be secondary phosphate. This has masked the original internal structures of these specimens. Most of the specimens, however, give an impression of having a complex internal structure and some of them might even have been chambered (Pl. 19, figs. 1, 4, for example).

Remarks: Since nothing is known about the affinity of these microfossils it is difficult, if not impossible, to classify them in a biologically meaningful way. Instead a number of different types of tests, which probably represent a variety of different taxa, have been described together. The main aim here is simply to illustrate these previously undescribed enigmatic microfossils and it is hoped that this will prompt future descriptions of more fossils of this type, which will finally lead to an understanding of their structure and nature.

Occurrence: NH22, NH28, NH45, NH54.

GEN. ET SP. INDET. 17

(Pl. 18, fig. 8)

Description: A phosphatic fossil fragment with a circular cross-section. The top of the fragment is flat with a raised rim around it. The diameter of the fossil is smallest at the top and increases downwards. A number of ridges with rounded tops are present around the side. The spaces in between the ridges are occupied by rather broad depressions or sulci. No other surface ornamentation is visible.

Remarks: Only a small fragment of this type has been recovered and hence the shape of the whole organism is uncertain at present.

Occurrence: NH24.

GEN. ET SP. INDET. 18

(Pl. 19, figs. 5-7)

Description: Small spherical microfossils without any prominent surface ornamentation. The diameter of the spheres varies from about 90 to about 175 μm. The spheres are mainly composed of calcium phosphate although small amounts of silica can be found in some specimens. The surfaces of the spheres are smooth, often rather shiny and appear to be devoid of any natural openings. In some specimens a shallow depression can be found on the side of the sphere (Pl. 19, fig. 5). The spheres are generally translucent to opaque. Most of the spheres appear to be hollow but have a small shapeless mass at the center (Pl. 19, fig. [illegible]). This central inclusion is best seen under the light microscope. The wall of the spheres generally has a granular appearance under high SEM magnification.

Remarks: The presence of small spherical microfossils in acid resistant residues of lower Paleozoic limestones has been noted in a number of different studies. Glenister et al. (1976) proposed that these spherical bodies are related to conodonts in that these were produced by the conodont animal in the same way as pearls are produced by oysters. This hypothesis, although interesting, is purely speculative and does not explain the presence of numerous hollow spheres such as described here. Although the internal structure of the present specimens is different from that of the so called "conodont-pearls", they, like the specimens of Glenister et al. (1976), are similar in composition to the conodonts and are generally associated with them. Unlike Glenister et al. (1976) I, however, do not consider similarity of composition and co-occurrence as good enough evidence to postulate any affinity and hence do not consider these spheres to be related to conodonts. Spheres very similar to the ones described here have been described by Ethington (1981) from the Caryocaris shale of central Nevada. Zhang (1987) illustrated hollow microspheres from the lower Cambrian of China which he considered to be egg cases. I have found a number of similar spheres in a sample from the Middle Arm Point Formation which not only yielded conodonts but also a few specimens of nauplius-like larvae (described later). One of those spheres exhibits protruding appendages interpreted as belonging to a nauplius-like larvae on its way out of the egg (for detailed description see below). This discovery certainly shows that at least some of these spheres represent eggs or larval stages of primitive organisms. However, whether all such spheres had similar functions is still an open question. In this study I have considered the spheres in immediate association with the nauplius-like larvae as fossilized representatives of membranous sacs enclosing the larvae while the rest of the spheres (i.e. those coming from samples which do not contain any nauplius-like larvae) have simply been illustrated and no affinities are proposed for them. While I acknowledge the fact that such division is rather arbitrary, I do not feel that at present there is enough evidence to suggest that all these spheres had similar function or that they were associated with the same organism.

Occurrence: NAP6, NH22, NH24, NH28, NH45, NH54, WC32.

6.5 Tubular Microfossils

6.5.1 Introduction

In this section a number of elongate, tube shaped microfossils recovered from the Cooks Brook and Middle Arm Point formations are described in detail. Fossils such as those described here exhibit quite interesting morphologic features but have not been described before. The most common lower Paleozoic tubular fossils belong to the order hyolithelminthes. The fossils described here, however, have a characteristic morphology and are quite different from known hyolithelminthes.

6.5.2 Description of the fauna

GEN. ET SP. INDET. 19

(Pl. 19, figs. 8-12, Pl. 20, figs. 1-3)

Description: Microfossils of this type are generally cylindrical in overall shape. The cylinder appears to be composed of a number of discrete layers which have been folded and rolled up (Pl. 19, figs. 8, 10, 11). The folds exhibited by some of the layers can be quite complex. Of all the layers the topmost layer is about 2 μm thick and is the thinnest. The other layers are about 7 to 8 μm in thickness (Pl. 19, fig. 10). The surfaces of most of the layers appear to be smooth except for the outermost layer with has a very faint reticulate pattern. The wall is composed of numerous lath-shaped crystals arranged in an interlocking fashion (Pl. 19, fig. 12, Pl. 20, figs. 1-3). The arrangement of these crystal laths is especially complicated near the hinges of the folded layers (Pl. 20, figs. 2, 3). X-ray microanalysis of the wall reveals the composition to be mainly calcium phosphate.

Remarks: The wall structure of this type of fossil is rather interesting although its significance is not clear. The overall morphology of these fossils is also rather peculiar due to its irregular nature and the question that needs to be asked in future studies of this type of fossil is whether these tubes represent the actual body parts of some organism or whether they are the remnants of tubes secreted by some tube dwelling organism. Tynan (1980, 1981, 1983) described a number of phosphatic tubes from the lower Cambrian of California which he regarded as skeletal remains of a very primitive group of anthozoa. Those tubes have some morphologic as well as compositional similarity with the ones described here. However, the two types do not appear to be related, as the tubes described by Tynan have a regular septate interior while the specimens at hand do not exhibit any such feature. Tubes of this type have so far been recovered only from one sample from the North Arm Point section where they occur in moderate abundance.

Occurrence: NAP6.

GEN. ET SP. INDET. 20

(Pl. 20, figs. 6-11, Pl. 21, figs. 1-7)

Description: Microfossils of this type are characterized by prominent net-like pattern on their outer surface. Most of the specimens are roughly cylindrical in overall morphology except in one case where the specimen is roughly rectangular in cross-section (Pl. 20, fig. 7). In some cases the cylindrical form can be enveloped in a rather irregular outer covering (Pl. 20, fig. 8). In other cases the specimen might be composed of two or more nested partial cylinders (Pl 20, fig. 5). The fossils have a multilayered wall. The outer surface of the tube generally exhibits a net-like pattern defined by very low ridges. The pattern is more or less regular and composed of a series of hexagons or pentagons joined together (Pl. 20, figs. 9, 10, Pl. 21, figs. 1, 3). The ridges have a rather irregular lumpy appearance and the point of intersection of two or more ridges is marked by a circular node. These nodes also have the same lumpy appearance as the ridges and often exhibit an opening at the center (Pl 21, fig. 7). In some specimens this reticulate surface appears to have been covered by another layer with smooth surface which has later been eroded away (Pl. 20, figs. 4, 6). This layer, however, appears to be absent in most specimens. Some specimens exhibit rounded edges which have a number of tubercles arranged linearly (Pl. 20, fig. 9, Pl. 21, fig. 6). These tubercles can either take the shape of flattened circles (Pl. 21, fig. 6) or can be elongate with rounded tips (Pl. 20, fig. 9). The individual layers in the walls of these fossils appear to be composed of interlocking lath-shaped crystals.

Remarks: Microfossils of this type are probably related to those described as Gen. et sp. indet. 19. This is indicated by the similarity of wall structure and overall morphology. The surface pattern so prominent on this type, however, is either absent or very faintly present in Gen. et sp. indet. 19. The regular nature of the pattern seems to suggest that it is a primary feature although the exact function of this type of structure is not known.

Occurrence: NAP6

GEN. ET SP. INDET. 21

(Pl. 21, figs. 9, 10)

Description: Tubular microfossils with a prominent net-like pattern on the outer surface. The reticulate pattern is defined by low ridges with flattened tops. The polygonal pattern exhibited by the specimens of this species is different from that of Gen. et sp. indet. 20 in that it lacks the nodes exhibited by the latter.

Remarks: This species is probably closely related to Gen. et sp. indet. 20.

Occurrence: NH53.

GEN. ET SP. INDET. 22

(Pl. 21, figs. 8, 11-13, Pl. 22, figs. 1-5)

Description: A variety of tubular microfosssils which are devoid of any prominent surface ornamentation are included in this type. The overall morphology varies from simple cylindrical forms with circular cross-section or flattened forms with biconvex cross-section to complex slightly conical forms consisting of two or more segments (Pl. 21, figs. 8, 12). The wall is composed of a number of discrete layers (Pl. 22, figs. 1, 3).

Occurrence: NAP6, NH28.

6.6 Miscellaneous microfossils

Family PHOSPHANNULIDAE Müller, Nogami and Lenz, 1974

Genus PHOSPHANNULUS Müller, Nogami and Lenz, 1974

Type species:

Phosphannulus universalis Müller, Nogami and Lenz, 1974

PHOSPHANNULUS UNIVERSALIS Müller, Nogami and Lenz, 1974

(Pl. 22, figs. 6-13)

Synonymy:

Phosphannulus universalis MÜLLER, NOGAMI AND LENZ, 1974, p. 90, Pl. 18, figs. 2, 4, 5, 6, 7, 8, 9.

Phosphannulus universalis Müller, Nogami and Lenz, FORTEY et al., 1982, Txt-fig. 9 S.

Phosphannulus universalis Müller, Nogami and Lenz, LANDING et al., 1986, Pl. 1, fig. 21.

Remarks: The specimens of P. universalis recovered from Bay of Islands are not very well preserved. This species occurs in both Cooks Brook and Middle Arm Point formations. The abundance, however, is low and only about 10 specimens have been recovered so far.

Occurrence: NH24, NH28, NAP6, WC32, EI18.

?Phylum PORIFERA Grant, 1872

?Class CALCAREA

Order, Family and Genus unknown

SPECIES A

(Pl. 23, figs. 1-3)

Description: Specimens are characterized by a skeleton made up of a number of beadlike segments. The individual beads generally have a circular cross-section. The size of the beads is variable. The outer surface of individual beads is smooth. The specimens are composed of calcium phosphate.

Remarks: The aspiculate, segmented and beadlike morphology of the specimens described above is very similar to that of sphinctozoan sponges (see Rigby, 1987). The sphinctozoan sponges are calcareous in composition and phosphatic skeletons are not known in that class. The phosphatic composition of the specimens described here is probably secondary. It, however, needs to be pointed out that framboidal apatite or phosphate can acquire a shape not unlike the shape of the present specimens and hence the biologic origin of these specimens is by no means certain.

Occurrence: NH44, NAP6.

SPECIES B

(Pl. 23, figs. 4, 5)

Description: Spindle-shaped pyritized bodies which probably represent monaxon sponge spicules. The spindles can be pointed at both ends or pointed at one end and rounded at the other.

Remarks: Pyrite spindles like the ones described above have been described from the Tremadocian of Quebec by Landing et al. (1986).

Occurrence: NAP14.

SPECIES C

(Pl. 23, fig. 6)

Description: Pyritized triaxon spicule. The specimen is highly corroded and only partially preserved. This type of spicule is rare in my material and only a couple have been recovered so far.

Occurrence: NAP14.

?Phylum ARTHROPODA

Class, Family and Order and genus unknown

SPECIES I

(Pl. 23, figs. 7, 8, 10)

Description: Terminal fragment of an appendage of unknown affinity. The proximal part of the appendage is cylindrical with circular cross-section (Pl. 23, figs. 7, 10) while the distal part is bulbous and terminates into three distinct digits. The surface of the appendage is smooth except for irregular pitting which is probably secondary in nature. The surface is exfoliated near the ends of the digits (Pl. 23, fig. 8). A small pore canal runs through the center of the appendage (Pl. 23, fig. 10). Composition of the appendage is calcium phosphate (Fig. 6-7(B)).

Occurrence: NAP6.

SPECIES II

(Pl. 23, figs. 9, 11)

Description: A fragment of a jointed appendage. The surface of the appendage lacks any ornamentation. The two segments of the appendage are circular in cross-section and similar in size.

Occurrence: NAP6

SPECIES III

(Pl. 24, figs. 3-7)

Description: Spinose phosphatic fragments. The fragments are generally small with comparatively long spines. The spines are circular in cross-section and commonly broken near the top. Based on the arrangement of the spines the fossils can be divided into two broad morphotypes. In type I specimens the majority of the spines are arranged in two closely spaced parallel rows (Pl. 24, figs. 5, 7). The individual spines are discrete but very closely spaced. These spines are more or less similar in size. A large spine is situated at one end of the specimen between the two rows. Type II specimens are characterized by a more random arrangement of the spines on the surface of the fossil (Pl. 24, figs. 3, 4, 6).

Remarks: This type of microfossils is rare in the Bay of Islands material and so far about 8 specimens have been recovered. It is possible that the specimens figured here may actually represent two or three different organisms.

However, due to the enigmatic nature of these specimens, it is probably more prudent at this point to describe them as a single type and refrain from splitting them any further until more data are available. It also needs to be pointed out that although the affinity of type I specimens is far from being clear, there is a possibility that the type II specimens may represent fragments of spinose brachiopod shells.

Occurrence: NAP23, EI13, EI18, NH41

Phylum, Class, Family and Order unknown

GEN. ET SP. INDET. 26

(Pl. 24, figs. 8-10)

Description: Conical fragments with or without surface ornamentation. The fragments are flattened laterally. The specimens are circular in cross-section near the apex of the cone while the rest has a biconvex cross-section. Two rounded keels are present along the edges of the specimens. The surface of the fossil can exhibit numerous small rather irregularly distributed nodes. The nodes are circular in cross-section. X-ray microanalysis reveals the composition of the fossils to be calcium phosphate.

Remarks: This type of fossil is rare in the Bay of Islands material and only five specimens have been recovered in this study.

Occurrence: NH54, NAP6.

GEN. ET SP. INDET. 27

(Pl. 23, figs. 13-15)

Remarks: The Bay of Islands material yielded a few fragments of phosphatic sclerites which, due to their enigmatic nature and very small numbers, cannot be assigned to any specific taxa. These fragments are simply illustrated here.

Occurrence: NAP6, EI13.

?Family LAPWORTHELLIDAE Missarzhevsky 1966

?Genus LAPWORTHELLA Cobbold 1921

Type species: Lapworthella nigra Cobbold 1921

?LAPWORTHELLA SP.

(Pl. 23, fig. 12)

Description: Fragment of a sclerite with circular cross-section. The outer surface of the sclerite covered by a number of very closely spaced transverse ridges. The ridges are rounded and carry numerous small nodes.

Remarks: Only two fragments of this type has been recovered.

Occurrence: NH54.

?Phylum ECHINODERMATA Klein, 1734

?Class PARACRINOIDEA Regnéll, 1945

Order, Family and Genus unknown

SP. 1

(Pl. 24, figs. 1, 2)

Description: Specimens are composed of a number of discrete plates joined together. The plates have a circular outline in plan view and are concave towards the outside. The composition of the specimens is dominantly calcium phosphate.

Remarks: Only two specimens of this type have been recovered. The morphology of the specimens seems to suggest an affinity with either the Order Varicata Jaekel, 1900 or the Order Brachiata Jaekel, 1900. Both of these orders are generally considered as middle Ordovician in age and are distinguished from each other based on the nature of the arms (see Kesling, 1967). As the specimens illustrated here are only partially preserved, positive identification is not possible.

Occurrence: NH28.

6.7 Nauplius-like Larvae

6.7.1 Introduction

Larval stages of organisms are very rarely encountered in the fossil record. This is due to their delicate nature and thus low preservation potential. This infrequent occurrence is especially evident in the Lower Paleozoic and so far only a few studies have reported such fossils from Cambro-Ordovician strata. The best known studies dealing with such material are by Müller and Walossek (1985, 1986) on exquisitely preserved Upper Cambrian arthropod larvae from anthraconite or "stinkstone" concretions in central Sweden and by Fortey and Morris (1978) on Lower Ordovician nauplius-like trilobite larvae from northern Spitsbergen.

In the course of this study specimens of Tremadocian (Early Ordovician) nauplius-like fossils have been discovered from the Middle Arm Point Formation. Two different types of larvae are described in this study. Specimens of Larva Type 1 are somewhat similar to a larval type (Larva A) described by Müller and Walossek (1986).

Larva Type 2 has been interpreted as a fossil nauplius-like larva in the process of hatching. This latter fossil consists of a spherical body with (probably) three appendages protruding through an opening. It is associated with the Type 1 larval specimens. This is the first reported find of such fossils outside Sweden.

6.7.2 Occurrence and preservation

All the specimens described here come from a single sample (NAP16, see Appendix B) from the North Arm Point section.

The specimens are steinkerns and they are phosphatic in composition (Fig. 6-8). It is not certain whether these fossils were originally phosphatic in composition or whether the presence of phosphate is a result of secondary phosphatization. Müller and Walossek (1985) have argued that the phosphate in the majority of the Upper Cambrian anthraconite fauna from Sweden (of which their nauplius specimens are a part) represent the result of secondary phosphatization. According to them the original composition of these fossils was probably chitinous. However, it should be pointed out that chitin in itself is a very stable substance and does not readily lend itself to replacement, as evidenced by the presence of fairly common Lower Paleozoic chitinous fossils (e.g. scolecodonts and Chitinozoa and, in my samples, fragments of crustacean

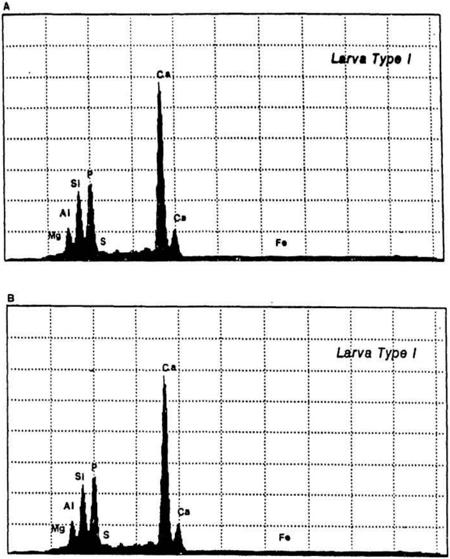


Figure 6-8. Qualitative plots of major element compositions of (A) Larve Type I and (B) Larva Type II.

exoskeletons). Secondly, arthropods with an original phosphatic composition (e.g. aglaspids and Phosphatocopina) are common in the fossil record. Thus as far as the phosphatic composition of the steinkerns described herein is concerned, the possibility that it was derived from an original phosphatic composition of these organisms cannot be ruled out altogether.

These larvae are very low in abundance and so far 3 kg kilograms of rock have yielded only 4 complete specimens and a few fragments of Larva Type 1 and only one specimen of Larva Type 2. The associated fauna and organic fragments consist of conodonts, enigmatic phosphatic plates (probably fragments of vertebrate armour), brachiopod fragments, tiny enigmatic phosphatic spherules, which might represent fossilized egg capsules (see discussion above) and some trilobite debris. Conodonts are fairly abundant in the sample and consist of a variety of simple cones as well as <u>Chosonodina herfurthi</u> Müller.

6.7.3 Morphology of Recent Crustacean Larva

The postembryonic development of crustaceans exhibits a wide range of variation. Some crustaceans (e.g. most Cladocera, Phyllocarida, Pancarida, Syncarida) have no larval stages morphologically distinct from the adult phase. The young in these cases resemble the adults except for their size and sexual immaturity (Williamson, 1982).

However, the vast majority of crustaceans hatch as larvae which go through metamorphoses during the ontogeny before finally transforming into the adult phase. The terminology which is generally used to describe crustacean larvae (see Williamson, 1982) defines different larval stages based mainly on the function of the limbs. According to this scheme, "Nauplius" is the larval stage where only three pairs of appendages exist and are used for propulsion. The larva is termed "metanauplius" if other appendages are present but are not used for propulsion. The "zoea" is the larval phase where thoracopods are used for propulsion while pleopods are used for propulsion in the phase called megalopa. The naupliar stage in crustaceans can either be a free-swimming stage or can be passed entirely inside the egg.

The larva, in the naupliar stage, generally has three pairs of functional appendages and a median eye. No external thoracic segmentation is present at this stage (Waterman & Chace, 1960). Of the three pairs of appendages, the antennules (1st pair) in the Nauplius are always uniramous while the antennae (2nd pair) and the mandibles (3rd pair) are characteristically biramous. However, in some Ostracoda, both the antennae and the mandibles can be uniramous (Williamson, 1982). The naupliar stage is also characterized, in most cases, by the presence of a very large and conspicuous labrum. The labrum serves for storage of yolk.

The mechanism of hatching in crustacean eggs is quite a complicated process. It appears that at least in some crustaceans the hatching of the larvae is controlled mainly by osmotic pressure. Davis (1959) studied the hatching process in some fresh-water copepod eggs and provided an excellent description. According to his observations, the embryo in these eggs is completely enclosed by two membranes. To initiate the hatching process the outer membrane breaks and the inner membrane containing the larva slips out. Due to the build up of internal pressure, the inner membrane at this point is quite enlarged and assumes a perfectly spherical shape. This sphere contains the larva which now assumes the normal swimming position with the appendages extended laterally. Finally this thin enclosing membrane bursts suddenly, apparently due to osmotic pressure and the Nauplius is forced out. Marshall and Orr (1954, 1955) observed the hatching of eucopepod eggs and described a process essentially similar that described by Davis. According to Marshall and Orr (1954, 1955) who studied Calanus finmarchicus the inner membrane breaks due to the activities of the Nauplius itself.

6.7.4 Systematic description

?Phylum ARTHROPODA

Class, Order, Family and Genus unknown

Larva Type 1

(Pl. 25, figs. 1-4, 8-11)

Description: The specimens are characterized by an ovoid body with three pairs of appendages. Of the three pairs, the anteriormost pair of appendages (antennules, Pl. 25, fig. 1) are the shortest; the other two pairs are similar in size, the second pair being slightly longer. The anteriormost pair of appendages are pointed slightly anteriorly while the posteriormost pair (mandibles, Pl. 25, fig. 1) is turned strongly posteriorly. All the appendages are concave towards the dorsal side, have a circular cross-section and are short and stumpy in appearance. The tips of the appendages have at least one pair of spinules although these are not preserved in most cases. All the appendages are uniramous. The anterior margin of the body is curved between the first pair of appendages. The body terminates in a pair of small, stubby caudal spines (Pl. 25, fig. 1) which are possibly attached to a short trunk bud. The ventral surface of the body bears a large, projecting labrum (Pl. 25, fig. 1). The labrum is knobby in appearance, has a flattened top and is a strikingly prominent feature. Immediately posterior to the labrum is a transverse fold which might indicate the position of the incipient mouth. The average diameter of the bodies of the fossils, excluding the outstretched appendages, is about 35μm.

Larva Type 2

(Pl. 25, figs. 5-7)

Description: The specimen consists of a sphere with projecting appendages. The spherical part of the fossil has no discernible surface ornamentation. The longer appendage is biramous with a well developed endopod. The tip of the endopod as well as the edges of both the endopod and exopod bear small projections or spinules. The appendage is quite robust. The shorter appendage is uniramous and is folded ventrally together with its counterpart. It bears four small spinules at its tip while no such spinules are visible on the edges. The space between the two appendages is partly taken up by what appears to be a thin membrane or webbing. The spherical part of the fossil has a diameter of about 50 μm.

6.7.5 Discussion

As mentioned before, the paleontological record of Early Paleozoic naupliar and nauplius-like larvae is extremely limited. Of the three papers dealing with Lower Paleozoic larvae mentioned above, the two by Müller and Walossek describe material which, I believe, are truly representative of fossil Nauplius larvae.

The paper by Fortey and Morris (1978) described button-shaped microfossils which they believed represented nauplius- like, pre-protaspis, phaselus larvae. Schram (1982) felt that such a claim was unjustified for what he termed "rather nondescript, caplike microfossils" (Schram, 1986).

The larval specimens described in this study agree very closely with the Nauplius body plan. One incongruity, however, is that all the limbs in the Type 1 specimens appear to be uniramous while, as discussed above, the antennae and mandibles in recent Nauplii are generally biramous. The probable explanation for this difference is that my specimens have been preserved as steinkerns and the endopods of the antennae, being quite tiny and fragile, were lost in the preservational process.

The reasons why I think that Larva Type 2 might represent a larva about to hatch out of an egg capsule are as follows. As discussed previously, in recent crustaceans, just before hatching the Nauplius resides inside a perfect sphere made up of the inner membrane of the egg capsule. The fossil specimen in question also has a spherical shape with laterally projecting characteristic 'naupliar' appendages. It is also associated with other nauplius-like larvae and spherical bodies I believe to represent fossilized egg capsules. It is quite possible that the complicated appendages of the specimen represent one antennule pair (with the appendages folded together) and a biramous antenna. This would mean that the limbs were folded together to facilitate the escape from the egg. Furthermore, the tips of the appendages are rather similar to the tips of the appendages found in Larva Type 1 in that they all bear small spinules. Finally, given the fact that before hatching the spherical membrane has a considerable internal pressure (Davis, 1959), which would certainly be released during hatching of the larva, the deflated size of the sphere agrees reasonably with that of a Type 1 larva folded together.

The spinules developed on Larva Type 1 and Larva Type 2 probably represent the fossilized bases of setae. Development of setae being typical of extant Nauplius larvae.

CHAPTER 7

CONCLUDING REMARKS

Based on the conodont fauna the age of the Cooks Brook Formation can be estimated as ranging from the uppermost Franconian to middle (?) Tremadocian. The age of the Middle Arm Point Formation is estimated as ranging from middle to upper Tremadocian to lower Arenigian.

Due to structural and sedimentologic complexities, it is difficult to identify the exact position of the Cambro-Ordovician boundary within the Cooks Brook Formation and hence only a tentative position has been suggested in this study.

The conodont fauna recovered from the Cooks Brook and Middle Arm Point formations shows a mixture of deep water and shelf-derived shallow water forms. The deep water conodonts are generally small, well preserved and exhibit low CAIs while the shallow water forms are much larger and are commonly broken and black in colour.

The Cooks Brook and Middle Arm Point formations have also yielded a variety of Cambro-Ordovician phosphatic problematica, most of which are previously undescribed. Notable amongst these are three new species of Anatolepis and some specimens of nauplius-like larvae.

REFERENCES CITED

ABAIMOVA, G. P. 1978. Late Cambrian conodonts of central Kazakhstan. Paleontological Journal, 12, pp. 493-503.

ALDRIDGE, R. J. 1976. Comparison of macrofossil communities and conodont distribution in the British Silurian. In Barnes, C.R. (ed.) Conodont Paleoecology, The Geological Association of Canada Special Paper Number 15, pp. 91-104.

ALDRIDGE, R. J. and ARMSTRONG, H. A. 1981. Spherical phosphatic microfossils from the Silurian of North Greenland. Nature, 292, pp. 531-533.

AN TAIXIANG 1981. Study on the Cambrian conodonts from North and Northeast China. University of Tsukuba Science Reports of the Institute of Geoscience, Section B, v. 3, pp.113-159.

AN TAIXIANG 1982. Study on the Cambrian and Ordovician conodonts from north and northeast China. Science Reports Institute Geoscience, Univ. Taukuba, Sec. B, v. 3, pp. 113-159.

AN TAIXIANG, ZHANG FANG, XIANG WEIDA, ZHANG YOUQIU, XU WENHAO, ZHANG HUIJUAN, JIANG DEBIAO, YANG CHANGSHENG, LIN LIANDI, CUI ZHANTANG and YANG XINCHANG 1983. The Conodonts of North China and the adjacent regions. Beijing Science Press, 223, 33 plsp.

ANDRES, D. 1981. Beziehungen zwischen kambrischen Conodonten und Euconodonten(vorlaufige Mitteilung). Berliner Geowissenschaftliche Abhandlungen (A), 32, pp. 19-31.

APPOLLONOV, M. K., CHUGAEVA, M. N., DUBININA, S. V. and ZHEMCHUZHNIKOV, V. G. 1988. Batyrbay Section, South Kazakhstan, U.S.S.R - potential stratotype for the Cambrian-Ordovician Boundary. Geological Magazine, v. 125, no. 4, pp. 445-449.

BABCOCK, JACK A. 1986. The puzzle of alga-like Problematica, or rummaging around in the algal wastebasket. In Antoni Hoffman and Matthew H. Nitecki (eds.), Problematic Fossil Taxa, Oxford University Press, New York, pp. 12-26.

BAGNOLI, GABRIELLA BARNES, CHRISTOPHER R. and STEVENS, ROBERT K. 1986. Lower Ordovician (Tremadocian) conodonts from Broom Point and Green Point, Western Newfoundland. Bollettino della Societa Paleontologica Italiana, 25, no.2, pp. 145-158, 2 pls.

BANNER, F. T., PEREIRA, C. P. G. and DESAI, DAMINI. 1985. "Tretomphaloid" float chambers in the Discorbidae and

Cymbaloporidae. Journal of Foraminiferal Research, 15, no.3, pp. 159-174, 6 pls.

BARNES, C. R. 1988. The proposed Cambrian-Ordovician global Boundary stratotype and point (GSSP) in Western Newfoundland, Canada. Geological Magazine, 125, no.4, pp. 381-414, 1 pl., 1 txt. fig.

BARNES, CHRISTOPHER R., KENNEDY, DAVID J., McCRACKEN, ALEXANDER D., NOWLAN, GODFREY S. and TARRANT, GLEN A. 1979. The structure and evolution of Ordovician conodont apparatuses. Lethaia, 12, pp. 125-151, 9 txt-figs.

BARNES, C. R. and FAHRAEUS, L. E. 1975. Provinces, communities and the proposed nekto-benthic habit of Ordovician conodontophorids. Lethaia, v. 8, pp. 133-149.

BARNES, C. R. and POPLAWSKI, M.L. SILVANA 1973. Lower and Middle Ordovician conodonts from the Mystic Formation, Quebec, Canada. Journal of Paleontology, 47, no.4, pp. 760-790, 5 pls.

BEDNARCZYK, W. 1979. Upper Cambrian to Lower Ordovician conodonts of Leba Elevation, NW Poland, and their stratigraphic significance. Acta Geologica Polonica, 29, pp. 409-448.

BENGTSON, S. 1976. The structure of some Middle Cambrian conodonts, and the early evolution of conodont structure and function. Lethaia, 9, pp. 185-206.

BENGTSON, STEFAN 1977. Aspects of problematic fossils in the early Paleozoic. Acta Universitatis Upsaliensis, Abstracts of Uppsala Dissertations from the Faculty of Science, 415, 71p.

BENGTSON, STEFAN 1986a. Introduction: The problem of the Problematica. *In* Antoni Hoffman and Matthew H. Nitecki (eds.), Problematic Fossil Taxa, Oxford University Press, New York, pp. 3-11.

BENGTSON, STEFAN 1986b. Siliceous microfossils from the Upper Cambrian of Queensland. Alcheringa, 10, pp. 195-216.

BENGTSON, STEFAN, CROSBIE MATTHEWS, S. and MISSARZHEVSKY, VLADIMIR V. 1986. The Cambrian netlike fossil *Microdictyon*. *In* Hoffman, Antoni and Nitecki, Matthew H. (eds.), Problematic Fossil Taxa, Oxford University Press, N.Y., pp. 97-115.

BERGSTRÖM, STIG M. 1971. Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and Eastern North

America. Geological Society of America Memoir, 127, pp. 83-161.

BERGSTRÖM, STIG M. 1977. Early Paleozoic conodont biostratigraphy in the Atlantic borderlands. In Swain, F. M. (ed.) Stratigraphic Micropaleontology of Atlantic Basin and Borderlands, Elsevier Scientific Publishing Company, Amsterdam, pp. 85-110.

BERGSTRÖM, S. M. and SWEET, W.C. 1966. Conodonts from the Lexington Limestone (Middle Ordovician) of Kentucky and its lateral equivalents in Ohio and Indiana. Bulletin of American Paleontology, 50, pp. 271-441, 8 pls.

BERGSTRÖM, STIG M., EPSTEIN, ANITA G. and EPSTEIN, JACK B. 1972. Early Ordovician north Atlantic province conodonts in eastern Pennsylvania. U.S. Geological Survey Professional Paper 800-D, pp. D37-D44.

BOCKELIE, T. and FORTEY, R. A. 1976. An early Ordovician vertebrate. Nature, 260, pp. 36-38.

BONNER, J T. 1965. Size and cycle, an essay on the structure of biology. Princeton University Press, Princeton, N.J., 219p.

BOSWORTH, W., 1985. East-directed imbrication and oblique-slip faulting in the Humber Arm Allochthon of Western Newfoundland; structural and tectonic significance. Canadian Journal of Earth Sciences, v. 22, pp. 1351-1360.

BOTSFORD, JACK W. 1988. Depositional history of Middle Cambrian to Lower Ordovician deep-water sediments, Bay of Islands, western Newfoundland. Unpublished Ph.D. thesis, Department of Earth Sciences, Memorial University of Newfoundland, 509p.

BOUCOT, A. J. 1975. Evolution and Extinction Rate Controls. Elsevier, Amsterdam, 427p.

BOUCOT, A. J. 1981. Principles of Benthic Marine Paleoecology. Academic Press, New York, 463p.

BRANSON, E. B. and MEHL, M.G. 1933. Conodont studies. University of Missouri Studies, 8, 349 p., 28 pls.

BRIGGS, DEREK E. G. and FORTEY, RICHARD A. 1982. The cuticle of the aglaspidid arthropods, a red-herring in the early history of the vertebrates. Lethaia, 15, pp. 25-29.

BRÜCKNER, W. D. 1966. Stratigraphy and structure of west-central Newfoundland. In Poole, W.H. (ed.), Guidebook -

Geology of parts of Atlantic provinces. Annual Meeting, Geological Association of Canada and Mining Association of Canada, pp. 137-151.

BRUTON, D. L., KOCH, L. and REPETSKI, J. E. 1988. The Naersnes section, Oslo Region, Norway: trilobite, graptolite and conodont fossils reviewed. Geological Magazine, v. 125, pp. 451-455.

BURRETT, CLIVE 1985. Problematic, phosphatic microspheres (mazuelloids) from the Ordovician of Tasmania, Australia. Alcheringa, 9, pp. 158.

CARROLL, ROBERT L. 1988. Vertebrate Paleontology and evolution. W. H. Freeman and Company, New York, 698 p.

CHEN, JUN-YUAN and GONG WEI-LI. 1986. Conodonts. In Chen Jun-Yuan (ed.) Aspects of Cambrian-Ordovician Boundary in Dayangcha, China. China Prospect Publishing House, Beijing, pp. 93-223, 38 pls., 58 txt. figs.

CHEN JUN-YUAN, QIAN YI-YUAN, ZHANG JUN-MING, LIN YAO-KUN, YIN LEI-MING, WANG ZHI-HAO, WANG ZONG-ZHI, YANG JIE-DONG and WANG YING-XI. 1988. The recommended Cambrian-Ordovician global Boundary stratotype of the Xiaoyangqiao section (Dayangcha, Jilin Province), China. Geological Magazine, v. 125, no. 4, pp. 415-444.

CHOW, N. 1986. Sedimentology and diagenesis of Middle and Upper Cambrian platform carbonates and siliciclastics, Port au Port Peninsula, western Newfoundland. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 458p.

CLARK, DAVID L., SWEET, WALTER C., BERGSTROM, STIG M., KLAPPER, GILBERT, AUSTIN, R.L., RHODES, F. H. T., MULLER, KLAUS, ZIEGLER, WILLI, LINDSTROM, MAURITS, MILLER, JAMES F., and HARRIS, ANITA G. 1981. Conodonta. In Robison, R. A. (ed.), Treatise on Invertebrate Paleontology, Part W Miscellanea, Supplement 2 Conodonta. The Geological Society of America, Inc. and The University of Kansas, Boulder, Colorado, and Lawrence, Kansas, 202p.

COBBOLD, E. S. 1921. The Cambrian horizons of Comley and their Brachiopoda, Pteropoda, Gasteropoda etc. Quart. Journal Geological Society of London, 76, pp. 325-387.

COOPER, B.J. 1981. Early Ordovician conodonts from the Horn Valley siltstones, Australia. Paleontology, v. 24, p. 147-183.

COOPER, R. A. and DRUCE, E.C. 1975. Lower Ordovician sequence and conodonts, Mount Patriarch, Northwest Nelson, New Zealand. New Zealand Journal of Geology and Geophysics, 18, pp. 551-582.

CRONEIS, C. 1938. Utilitarian classification for fragmentary fossils. Journal of Geology, 46, pp. 975-984.

CRONEIS, C. 1941. Micropaleontology - past and future. Bulletin of the American Association of Petroleum Geologists, 25, pp. 1208-1255.

DAVIS, CHARLES C. 1959. Osmotic hatching in the eggs of some fresh-water copepods. Biological Bulletin, 116, pp. 15-29.

DENISON, ROBERT H. 1967. Ordovician vertebrates from Western United States. Fieldiana Geology, 16, no. 6, pp. 131-192.

DONG XI-PING 1987. Late Cambrian and Early Ordovician Conodonts from Chuxian, Anhui. Nanjing Institute of Geology and Paleontology, Academia Sinica (eds.), Collection of postgraduate theses, no.1, pp. 135-184, 5 pls.

DRUCE, E. C. and JONES, P.J. 1971. Cambro-Ordovician conodonts from the Burke River Structural Belt, Queensland. Australia Bureau of Mineral Resources, Bull. 110, 159 p., 20 pls.

DZIK, JERZY 1976. Remarks on the evolution of Ordovician conodonts. Acta Palaeontologica Polonica, 21, no.4, pp. 395-455, 4 pls., 36 txt. figs.

DZIK, JERZY 1986. Chordate affinities of the conodonts. In A. Hoffma et al. (eds.) Problematic Fossil Taxa, Oxford University Press, New York, pp. 240-254.

EICHENBERG, W. 1930. Conodonten aus dem Culm des Harzes. Palaon. Ztsch. v. 12, pp. 177-182, 1 pl.

ELDREDGE, NILES and GOULD, STEPHEN JAY. 1977. Evolutionary Models and Biostratigraphic Strategies. In Kauffman, E. G. and Hazel, J. E. (eds.), Concepts and Methods of Biostratigraphy, Dowden, Hutchinson and Ross, Inc. Pennsylvania, pp. 25-40.

ELDREDGE, NILES and TATTERSALL, I. 1975. Evolutionary models, phylogenetic reconstruction, and another look at hominid phylogeny. In Szalay, F. S. (ed.), Approaches to Primate Paleobiology, Contrib. Primat. 5, pp. 218-242.

ETHINGTON, R. L. 1972. Lower Ordovician (Arenigian) conodonts from the Pogonip Group, central Nevada. Geologica et Paleontologica , Sonderband 1, pp. 17-28, 1 pl.

ETHINGTON, R. L. 1981. Conodonts and other microfossils and age of the Caryocaris shale, central Nevada. Journal of Paleontology, 55, no.4, pp. 780-787.

ETHINGTON, R. L. and CLARK, D.L. 1964. Conodonts from the El Paso Formation (Ordovician) of Texas and Arizona. Journal of Paleontology, 38, no.4, pp. 685-704, 3 pls., 2 txt. figs.

ETHINGTON, R. L. and CLARK, D.L. 1965. Lower Ordovician conodonts and other microfossils from the Columbia Ice fields section, Alberta, Canada. Brigham Young University, Geology Studies, 12, pp. 185-205, 2 pls.

ETHINGTON, R. L. and CLARK, D. L. 1971. Lower Ordovician Conodonts in North America. Geological Society of America Memoir 127, pp. 63-82, 2 pls.

ETHINGTON, R. L. and CLARK, D. L. 1981. Lower and Middle Ordovician conodonts from the Ibex area, western Millard County, Utah. Brigham Young University Geology Studies, v. 28, no. 2, 160p.

FAHRAEUS, LARS E. 1966. Lower Viruan (Middle Ordovician) conodonts from the Gullhogen quarry, southern central Sweden. Sveriges Geologiska Undersokning C, 610, pp. 1-40, 4 pls.

FAHRAEUS, LARS E. 1982a. Recognition and redescription of PANDER's (1856) Scolopodus (form-)species - Constituents of multi-element taxa (Conodontophorida, Ordovician). Geologica et Palaeontologica, 16, pp. 19-22, 3 pls.

FAHRAEUS, LARS E. 1982b. Allopatric speciation and lineage zonation exemplified by the Pygodus serrus - P. anserinus transition (Conodontophorida, Ordovician). Newsletter Stratigr., 11, pp. 1-7.

FAHRAEUS, LARS E. 1986. Spectres of biostratigraphic resolution and precision: Rock accumulation rates, processes of speciation and paleoecological constraints. Newsletter Stratigr., v. 15, pp. 150-162.

FAHRAEUS, L. E. and HUNTER, D.R. 1985. Simple-cone conodont taxa from the Cobbs Arm Limestone (Middle Ordovician), New World Island, Newfoundland. Canadian Journal of Earth Sciences, 22, no.8, pp. 1171-1182, 3 pls., 7 txt-figs.

FAHRAEUS, LARS E. and NOWLAN, GODFREY S. 1978. Franconian (Late Cambrian) to Early Champlainian (Middle Ordovician) conodonts from the Cow Head Group, Western Newfoundland. Journal of Paleontology, 52, no.2, pp. 444-471, 3 pls., 6 txt. figs.

FORTEY, R. A., and MORRIS, S. F. 1978. Discovery of nauplius-like trilobite larvae. Paleontology, 21, pp. 823-833.

FORTEY, R. A., LANDING, E. and SKEVINGTON, D. 1982. Cambrian-Ordovician boundary sections in the Cow Head Group, western Newfoundland. In Bassett, M.G. and Dean, W.T. (eds.), The Cambrian-Ordovician boundary: sections, fossil distributions, and correlations. National Museum of Wales, Geological Series No. 3, Cardiff, pp. 95-129, 9 txt. figs.

FURNISH, W. M. 1938. Conodonts from the Prairie Du Chien (Lower Ordovician) beds of the Upper Mississippi Valley. Journal of Paleontology, 12, no.4, pp. 318-340, 2 pls., 2 txt. figs.

GANS, CARL and NORTHCUTT, R. GLEN. 1983. Neural Crest and the Origin of Vertebrates: A New Head. Science, 220, pp. 268-274.

GLAESSNER, M. F. 1984. The Dawn of Animal Life. A Biohistorical Study. Cambridge University Press, Cambridge, 244p.

GLENISTER, BRIAN F., KLAPPER, GILBERT and CHAUFF, KARL M. 1976. Conodont Pearls? Science, 193, pp. 571-573.

GOULD, S. J. 1983. Nature's great experiments. Natural History, July, pp. 12-22.

GOULD, S. J. 1984. The Ediacaran experiment. Natural History, February, pp. 14-23.

GRANT, RICHARD E. 1965. Faunas and stratigraphy of the Snowy Range Formation (Upper Cambrian) in southwestern Montana and Northwestern Wyoming. Geological Society of America, Memoir 96, 171p.

GRAVES, R. W. and ELLISON, S.P., Jr. 1941. Ordovician conodonts of the Marathon Basin, Texas. University of Missouri School of Mining and Metallurgy, Bulletin, Technical Series, 14, no.2, pp. 1-26, 3 pls.

HADDING, A. 1913. Undre Dicellograptusskiffern I Skane Jamfe Nagre Darmet Ekivalenta Bildninger. Lunds Univ. Arsk. n.f. Avd. v. 9, no. 15, pp. 1-90.

HEDBERG, H. D. 1976. International Stratigraphic Guide. New York, John Wiley, 200p.

HENNINGSMOEN, G. 1973. The cambro-ordovician boundary.

Lethaia, v. 6, pp. 423-439.

HICKS, H. 1875. On the succession of the ancient rocks in the vicinity of St. David's, Pembrokeshire, with special reference to those of the Arenig and Llandeilo Groups, and their fossil content. Quaterly Journal of the Geological Society of London, v. 31, pp. 167-195, pls. 8-11.

HINZ, INGELORE 1987. The lower Cambrian microfauna of Comley and Rushton, Shropshire/England. Palaeontographica Abt. A, 198, pp. 41-100, 15 pls.

HUNICKEN, MARIO A. and SARMIENTO, GRACIELA N. 1980. The Baltoscandian conodont Prioniodus elegans Pander (Lower Arenigian) from the San Juan Formation of the Precordillera Guandacol River, La Rioja, R. Argentina. Boletin de la Academia Nacional de Ciencias, 53, pp. 293-306, 2 pls.

JONES, P. J. 1971. Lower Ordovician conodonts from the Bonaparte Gulf Basin and the Daly River basin, northwestern Australia. Australia Bureau of Mineral Resources, Bulletin, 117, 80 p., 8 pls.

JONES, P. J., SHERGOLD, J. H. and DRUCE, E. C. 1971. Late Cambrian and Early Ordovician stages in western Queensland. Journal of the Geological Society of Australia, v. 18, pp. 1-32.

JOHNSON, J. G. 1979. Intent and reality in biostratigraphic zonation. Journal of Paleontology, v. 53, pp. 931-942.

KALJO, D. HEINSALU, H., MENS, K., PUURA, I. and VIIRA, V. 1988. Cambrian-Ordovician Boundary beds at Tonismagi, Tallinn, North Estonia. Geological Magazine, 125, no.4, pp. 457-463, 2 pls., 1 txt. fig.

KENNEDY, DAVID J. 1980. A restudy of conodonts described by Branson and Mehl, 1933, from the Jefferson City Formation, Lower Ordovician, Missouri. Geologica et Palaeontologica, 14, p. 45-76, 2 pls.

KLAPPA, C. F., OPALINSKI, P.R., and JAMES, N.P. 1980. Middle Ordovician Table Head Group of Western Newfoundland: a revised stratigraphy. Canadian Journal of Earth Sciences, 17, pp. 1007-1019.

KNIGHT, I. and JAMES, N.P. 1987. The stratigraphy of the Lower Ordovician St. George Group, Lower Ordovician, Western Newfoundland: the interaction between eustasy and tectonics. Canadian Journal of Earth Sciences, v. 24, pp. 1927-1951.

LANDING, E. 1977. "Prooneotodus" tenuis (Muller, 1959) apparatuses from the Taconic allochthon, eastern New York: Construction, taphonomy, and the protoconodont "supertooth" model. Journal of Paleontology, v. 51, pp. 1072-1084.

LANDING, E. 1982. Conodont biostratigraphy and thermal alteration indices of the upper St. Charles and lower Garden City Formations, Bear River Range, northern Utah and southeastern Idaho. Denver: U.S. Geological Survey Open-File Report, 81-720, 29p.

LANDING, ED 1983. Highgate Gorge: Upper Cambrian and Lower Ordovician continental slope deposition and biostratigraphy, Northwestern Vermont. Journal of Paleontology, 57, no.6, pp. 1149-1187, 4 pls., 7 txt. figs.

LANDING, E. TAYLOR, M.E. and ERDTMANN, B. D. 1978. Correlation of the Cambrian-Ordovician boundary between the Acado-Baltic and North American faunal provinces. Geology, 6, pp. 75-78.

LANDING, E. LUDVIGSEN, R. and VON BITTER, P.H. 1980. Upper Cambrian to Lower Ordovician conodont biostratigraphy and biofacies, Rabbitkettle Formation, District of Mackenzie. Contr. Life Sci. Div. R. Ont. Mus. 126, pp. 1-42.

LANDING, ED and BARNES, CHRISTOPHER R. 1981. Conodonts from the Cape Clay Formation (Lower Ordovician), southern Devon Island, Arctic Archipelago. Canadian Journal of Earth Sciences, 18, no.10, pp. 1609-1628, 4 pls., 3 txt. figs.

LANDING, ED, BARNES, CHRISTOPHER R. and STEVENS, ROBERT K. 1986. Tempo of earliest Ordovician graptolite faunal succession: conodont-based correlations from the Tremadocian of Quebec. Canadian Journal of Earth Sciences, 23, pp. 1928-1949, 3 pls., 3 txt. figs.

LAPWORTH, C. 1879. On the tripartite classification of the Lower Paleozoic rocks. Geological Magazine, New Series, Decade 2, v. 6, pp. 1-15.

LEE, HA-YOUNG 1975. Conodonten aus dem Unteren und Mittleren Ordovizium von Nordkorea. Palaeontographica A, 150, no.4-6, pp. 161-186, 2 pls.

LEE, HA-YOUNG 1980. Lower Palaeozoic conodonts in South Korea. In Kobayashi, T., Toriyama, R., Hashimoto, W. and Kanno, S. (eds.), Geology and Palaeontology of southeast Asia, 21, pp. 1-9, 2 pls.

LEVINTON, JEFFREY S. and BAMBACH, RICHARD K. 1975. A comparative study of Silurian and recent deposit-feeding bivalve communities. Paleobiology, v. 1, pp. 97-124.

LILLY, H. D. 1963. Geology of the Hughes Brook - Goose Arm Area, Western Newfoundland. Memorial University of Newfoundland, Department of Geology, Report No. 2, 123p.

LILLY, H. D. 1967. Some notes on stratigraphy and structural styles in Central-Western Newfoundland. Geological Association of Canada, Special Paper No. 4, pp. 201-212.

LINDSTRÖM, MAURITS 1954. Conodonts from the lowermost Ordovician strata of southcentral Sweden. Geoliska Foreningens i Stockholm, Forhandlingar 76, pp. 517-604, 7 pls.

LINDSTRÖM, MAURITS 1957. Two Ordovician conodont faunas found with zonal graptolites. Geol. Foren. Stockholm Forh., 79, pp. 161-178.

LINDSTRÖM, MAURITS 1964. Conodonts. Elsevier Publishing Company, Amsterdam, London, New York, 195p.

LINDSTRÖM, MAURITS, 1970. A suprageneric taxonomy of the conodonts. Lethaia, v. 3, pp. 427-445.

LINDSTRÖM, MAURITS 1971. Lower Ordovician conodonts of Europe. In Sweet, W.C. and Bergstrom, S.M. (eds.) Symposium on conodont biostratigraphy, Geological Society of America, Memoir 127, pp. 21-61, 1 pl.

LÖFGREN, ANITA 1978. Arenigian and Llanvirnian conodonts from Jamtland, northern Sweden. Fossils and Strata, no.13, 129p., 16 pls.

MARSHALL, S. M. and ORR, A. P. 1954. Hatching in Calanus finmarchicus and some other copepods. Journal of Marine Biological Association U. K. , 33, pp. 393-401.

MARSHALL, S. M. and ORR, A. P. 1955. Biology of a Marine Copepod, Calanus finmarchicus (Gunnerus). Oliver and Boyd, Edinburgh, 188p.

McKILLOP, J. H. 1963. Geology of the Corner Brook Area, Newfoundland, with emphasis on the carbonate deposits. Memorial University of Newfoundland, Department of Geology, Report No. 1, 102p.

McTAVISH, ROBERT A. 1973. Prioniodontacean conodonts from the Emanuel Formation (Lower Ordovician) of Western Australia. Geologica et Palaeontologica, 7, pp. 27-51, 3 pls.

MILLER, JAMES F. 1969. Conodont fuana of the Notch Peak Limestone (Cambro-Ordovician), House Range, Utah. Journal of Paleontology, 43, no.2, pp. 413-439, 4 pls., 5 txt. figs.

MILLER, JAMES F. 1975. Conodont faunas from the Cambrian and lowest Ordovician of western North America. Geological Society of America, Abstract with Program, 7:7, pp. 1200-1201.

MILLER, JAMES F. 1980. Taxonomic revisions of some Upper Cambrian and Lower Ordovician conodonts with comments on their evolution. The University of Kansas Paleontological Contributions, Paper 99, 39 p., 2 pls.

MILLER, J. F. 1984. Cambrian and earliest Ordovician conodont evolution, biofacies, and provincialism. Geological Society of America Special Paper 196, pp. 43-68.

MILLER, J. F. 1988a. Conodonts as biostratigraphic tools for redefinition and correlation of the Cambrian-Ordovician Boundary. Geological Magazine, 125, no.4, pp. 349-362.

MILLER, J. F. 1988b. The base of the *Cordylodus proavus* zone as a potential horizon for defining the Cambrian-Ordovician Boundary. Vth Int. Symposium on the Ordovician System, program and abstracts, pp. 60.

MILLER, R. H., SUNDBERG, F.A., HARMA, R.H. and WRIGHT, J. 1981. Late Cambrian stratigraphy and conodonts of southern Nevada. Alcheringa, 5, pp. 183-196.

MISSARZHEVSKY, V. V. 1966. The first finds of *Lapworthella* in the Lower Cambrian of the Siberian Platform. Paleontol. zh., v. 2, pp. 13-18.

MISSARZHEVSKY, V. V. 1973. Konodontoobraznye organizmy iz pogranichnykh sloev kembriya Sibirskoy platformy i Kazakhstana (Conodont-shaped organisms from the Precambrian and Cambrian boundary strata of the Siberian Platform and Kazakhstan). *In* Zhuravleva, I.T. (ed.), Problemy paleontologii i biostratigrafii nizhnego kembriya Sibiri i Dal'nego vostoka (Paleontologic and biostratigraphic problems of the Lower Cambrian of Siberia and the Far East). Moscow, Trudy Instituta Geologii i Geofiziki Akademii Nauk SSSR, Sibirskogo Otdeleniya, 49, pp. 53-58.

MISSARZHEVSKY, V. V. 1977. Conodonts (?) and phosphatic problematica from the Cambrian of Mongolia and Siberia. *In* Tatarinov, L. N. et al. (eds.), Besposvonotschnye Paleosoja Mongolii. Akad. Nauka SSSR, Moskva, pp. 10-19.

MOSKALENKO, T. A. 1967. Konodonty Tsunskova yarusa (Nizhnii

Ordovik) rek Moiero u Podkamennaya Tunguska. [Conodonts from the Tsunsky Stage (Lower Ordovician) of the rivers Moiero and Podkamennaya Tunguska, pp. 98-116, 4 pls.] In Ivanovskii, A. B. and Sokolov, B. S. (eds.), Novye dannye po biostratigrafii Nizhnevo Paleozoya Sibirskoi Platformy [New data on the biostratigraphy of the Lower Paleozoic deposits of the Siberian Platform]. Akad. Nauk. SSSR, Sib. Otdel., Inst. Geol. Geofiz.

MOSKALENKO, T. A. 1972. Ordovician conodonts of the Siberian Platform and their bearing on multielement taxonomy. Geologica et Paleontologica, 1, pp. 47-56.

MOUND, M. C. 1965. A conodont fauna from the Joins Formation (Ordovician), Oklahoma. Tulane Studies in Geology and Paleontology, 4, pp. 1-45, 4 pls.

MOUND, M. C. 1968. Conodonts and biostratigraphy of the lower Arbuckle Group (Ordovician), Arbuckle Mountains, Oklahoma. Micropaleontology, 14, no.4, pp. 393-434, 6 pls.

MÜLLER, K. J. 1959. Kambrische Conodonten. Z. deutsch. geol. Ges., 111, no.2, pp. pp. 435-485, 5 pls., 10 txt. figs.

MÜLLER, K. J. 1964. Conodonten aus dem unteren Ordovizium von Sudkorea. Neus Jahrbuch fur Geologie Palaontologie, Abhandlungen 119, pp. 93-102, 2 pls.

MÜLLER, K. J. 1973a. Milaculum n.g., ein phosphatisches Mikrofossil aus dem Altpalaozoikum. Palaont. Z., 47, pp. 217-228.

MÜLLER, KLAUS J. 1973b. Late Cambrian and Early Ordovician Conodonts from Northern Iran. Geological Survey of Iran, Report No. 30, pp. 5-77, 11 pls., 11 txt. figs.

MÜLLER, KLAUS J. and NOGAMI, Y. 1971. Uber den Feinbau der Conodonten. Memoir Faculty of Science, Kyoto Univ. Ser. Geol. and Min., v. 38, no. 1, pp. 1-87, pls. 1-22.

MÜLLER, KLAUS J., NOGAMI, YASUO and LENZ, HELGA. 1974. Phosphatic rings as microfossils in the lower Paleozoics. Palaeontographica A, 146, pp. 79-99, 4 pls.

MÜLLER, KLAUS J., and WALOSSEK, DIETER. 1985. A remarkable arthropod fauna from the Upper Cambrian "Orsten" of Sweden. Transactions of the Royal Society of Edinburgh, 76, pp. 161-172.

MÜLLER, KALUS J., and WALOSSEK, DIETER. 1986. Arthropod larvae from the Upper Cambrian of Sweden. Transactions of the Royal Society of Edinburgh, 77, pp. 157-179.

NITECKI, MATTHEW H., GUTSCHICK, RAYMOND C. and REPETSKI, JOHN E. 1975. Phosphatic microfossils from the Ordovician of the United States. Fieldiana Geology, 35, no.1, pp. 1-9.

NOGAMI, Y. 1967. Kambrische Conodonten von China, Teil 2: Conodonten aus den hoch oberkambrischen Yencho-Schichten. Kyoto University College of Science Memoirs, Series B, v. 33, pp. 211-219, 1 pl.

NORFORD, B. S. 1988. Introduction to papers on the Cambrian-Ordovician Boundary. Geological Magazine, v. 125, pp. 323-326.

NORTHCUTT, R. GLEN and GANS, CARL. 1983. The genesis of neural crest and epidermal placodes: a reinterpretation of vertebrate origins. The Quarterly Review of Biology, 58, no. 1, pp. 1-28.

NOWLAN, GODFREY S. 1976. Late Cambrian to late Ordovician conodont evolution and biostratigraphy of the Franklinian miogeosyncline, eastern Canadian Arctic Islands. Unpublished Ph.D. thesis, University of Waterloo, 591 p., 18 pls.

NOWLAN, GODFREY S. 1985. Late Cambrian and Early Ordovician conodonts from the Franklinian Miogeosyncline, Canadian Arctic Islands. Journal of Paleontology, 59, no.1, pp. 96-122, 6 pls., 4 txt. figs.

O'BRIEN, F. H. C. and SZYBINSKI, Z.A. 1989. Conodont faunas from the Catchers Pond and Cutwell Groups, central Newfoundland. Current Research (1989) Newfoundland Department of Mines, Geological Survey of Newfoundland, Report 89-1, pp. 121-125.

ORNDORFF, RANDALL C. 1987. Latest Cambrian and Earliest Ordovician Conodonts from the Conococheague and Stonehenge Limestones of Northwestern Virginia. U.S. Geological Survey Bulletin 1837-A, pp. A1-A18, 2 pls.

PANDER, C. H. 1856. Monographie der fossilen Fische des Silurischen Systems der Russisch-Baltischen Gouvernements. St. Petersburg, Akademie de Wissenschaften, i-x, pp. 1-91.

PEEL, JOHN S. and HIGGINS A. K. 1977. *Anatolepis* - a problematic Ordovician vertebrate reinterpreted as an arthropod. Rapp. Gronlands geol. Unders., 85, pp. 108-109.

PEEL, JOHN S. 1979. *Anatolepis* from the Early Ordovician of East Greenland - not a fishy tail. Rapp. Gronlands geol. Unders., 91, pp. 111-115.

POULSEN, V. 1966. Early Cambrian Distacodontid conodonts from Bornholm. Kongelige Danske Videnskabernes Selskab. Biologiske Meddelelse, 23, no.15, pp. 1-9, 1 pl.

RAASCH, GILBERT O. 1939. Cambrian Merostomata. Geological Society of America Special Papers, Number 19, 146p.

REPETSKI, JOHN E. 1978. A fish from the Upper Cambrian of North America. Science, 200, pp. 529-531.

REPETSKI, JOHN E. 1982. Conodonts from El Paso Group (Lower Ordovician) of westernmost Texas and southern New Mexico. New Mexico Bureau of Mines and Mineral Resources, Memoir 40, 121p., 28 pls.

REPETSKI, J. E. and ETHINGTON, R.L. 1977. Conodonts from graptolite facies in the Ouachita Mountains, Arkansas and Oklahoma. In C.G. Stone (ed.), Symposium on the geology of the Ouachita Mountains, Arkansas Geological Commission. 92-106, 2 pls,

REPETSKI, J. E. and ETHINGTON, R.L. 1983. Rossodus manitouensis (Conodonta), a new early Ordovician index fossil. Journal of Paleontology, 57, no.2, pp. 289-301, 5 figs.

RHODES, F.H.T. 1953. Some British Lower Paleozoic conodont faunas. Philosophical Transactions of the Royal Society of London, Ser. B, no. 647, v. 237, pp. 261-334, pls. 20-23.

RIGBY, J. KEITH 1987. Phylum Porifera. In Boardman, R. S., Cheetham, A. H. and Rowell, A. J. (eds.), Fossil Invertebrates, Blackwell Scientific Publications, pp. 116-139.

RITCHIE, ALEXANDER and GILBERT-TOMLINSON, JOYCE. 1977. First Ordovician vertebrates from the Southern Hemisphere. Alcheringa, 1, no. 4, pp. 351-368.

RODGERS, J. and NEALE, E. R. W., 1963. Possible "Taconic" klippen in Western Newfoundland. American Journal of Science, v. 261, pp. 713-730.

ROZANOV, A. YU 1986. Problematica of the Early Cambrian. In Antoni Hoffman and Matthew H. Nitecki (eds.), Problematic Fossil Taxa. Oxford University Press, New York, pp. 87-96.

SCHAEFFER, B., HECHT, M. K. and ELDREDGE, N. 1972. Phylogeny and paleontology. In Dobzhansky, Th. et al. (eds.), Evolutionary Biology, Appleton-Century-Crofts, New York 6, pp. 31-46.

SCHILLEREFF, S. and WILLIAMS, H. 1979. Geology of Stephenville Map Area, Newfoundland. Current Research, Part A, Geological Survey of Canada, Paper 79-1A, pp. 327-332.

SCHRAM, FREDERICK R. 1982. The fossil record and evolution of Crustacea. In The Biology of Crustacea, Vol. I. Edited by L. G. Abele. Academic Press, New York, pp. 93-147.

SCHRAM, FREDERICK R. 1986. Crustacea. Oxford University Press, New York, 606 p.

SCHUCHERT, C. and DUNBAR, C. O., 1934. Stratigraphy of Western Newfoundland. Geological Society of America Memoir 1, 123 p.

SEDDON, G. and SWEET, W. C. 1971. An ecologic model for conodonts. Journal of Paleontology, v. 45, pp. 869-880.

SERGEEVA, S. P. 1964. On the significance of the lower Ordovician conodonts in the Leningrad region. Leningrad Univ. Vestnik, Ser. Geologiya i Geografii, 12, pp. 56-60 (in Russian).

SERPAGLI, E. 1974. Lower Ordovician conodonts from Precordilleran Argentina (Province of San Juan). Bollettino della Societa Paleontologica Italian. , 13, no.1-2, pp. 17-98, 25 pls., 26 txt.-figs.

STANLEY, S. M. 1976. Fossil data and the Precambrian-Cambrian evolutionary transition. American Journal of Science, 276, no.1, pp. 56-76.

STEVENS, R. K. 1965. Geology of the Humber Arm area, west Newfoundland. Unpublished M. Sc. thesis, Memorial University of Newfoundland, 121p.

STEVENS, R. K. 1970. Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a proto-Atlantic Ocean. Geological Association of Canada, Special Paper No. 7, pp. 165-177.

STOUGE, S. S. 1984. Conodonts of the Middle Ordovician Table Head Formation, western Newfoundland. Fossils and Strata No. 16, pp. 1-145, 18 pls.

SWEET, WALTER C. 1988. The Conodonta: Morphology, Taxonomy, Paleoecology, and Evolutionary History of a Long-Extinct Animal Phylum. Clarendon Press, Oxford, 212p.

SWEET, W. C. and BERGSTRÖM, S. M. 1962. Conodonts from the Pratt Ferry Formation (Middle Ordovician) of Alabama. Journal of Paleontology, v. 36, pp. 1214-1252.

SWEET, W. C. and BERGSTRÖM, S. M. 1972. Multielement taxonomy and Ordovician conodonts. Geologica et Paleontologica, Sonderband 1, pp. 29-42.

SWEET, WALTER C., ETHINGTON, RAYMOND L. and BARNES, CHRISTOPHER R. 1971. North American Middle and Upper Ordovician Conodont Faunas. Geological Society of America, Memoir 127, pp. 163-193, 2 pls.

SZANIAWSKI HUBERT 1980. Conodonts from the Tremadocian Chalcedony Beds, Holy Cross Mountains (Poland). Acta Paleontologica Polonica, 25, no.1, pp. pp. 101-121, 4 pls.

TAYLOR, M. E. and LANDING, E. 1982. Biostratigraphy of the Cambrian-Ordovician transition in the Bear River Range, Utah and Idaho, western United States. In Bassett, M.G. and Dean, W.T. (eds.) The Cambrian-Ordovician boundary: sections, fossil distributions, and correlations. National Museum of Wales, Geological Series No. 3, Cardiff, pp. 181-191, 2 pls.

TAYLOR, JOHN F., KENNEDY, DAVID J., MILLER, JAMES F. and REPETSKI, JOHN E. 1988. Base of the Cordylodus proavus zone: a reliable datum for intercontinental correlation. Vth Int. Symposium on the Ordovician System, program and abstracts, pp. 102.

TYNAN, MARK C. 1980. A probable new phylum and associated microfauna from the lower Cambrian, White and Inyo Mountains, California. Geological Society of America Abstracts with Programs, 12, pp. 539.

TYNAN, MARK C. 1981. Microfossils from the Lower Cambrian Campito and Poleta formations, White-Inyo Mountains. In M. E. Taylor (ed.), Short papers for the second International Symposium on the Cambrian System, 1981. United States Geological Survey Open-file Report, 81-743, pp. 231.

TYNAN, MARK C. 1983. Coral-like microfossils from the lower Cambrian of California. Journal of Paleontology, 57, no.6, pp. 1188-1211.

UYENO, T. T. and BARNES, C.R. 1970. Conodonts from the Levis Formation (zone D1) (Middle Ordovician), Levis, Quebec. Geological Survey of Canada, Bulletin 187, pp. 99-123, 4 pls.

VALENTINE, JAMES W. 1973. Evolutionary paleoecology of the Marine Biosphere. Prentice-Hall, Inc., New Jersey, 511p.

VAN DEN BOOGAARD, M. 1988. Some data on Milaculum Müller, 1973. Scripta Geologica, 88, pp. 1-25.

VAN EYSINGA, F. W. B. (compiler) 1983. Geological Time Table. Elsevier Scientific Publishing Company, Amsterdam.

VAN WAMEL, W. A. 1974. Conodont biostratigraphy of the Upper Cambrian and Lower Ordovician of north-western Oland, south-eastern Sweden. Utrecht Micropaleontological Bulletin 10, 126p., 7 pls.

VIIRA, VIIVE, SERGEEVA, S. and POPOV, L. 1987. Earliest representatives of the genus Cordylodus (Conodonta) from Cambro-Ordovician Boundary beds of North Estonia and Leningrad region. Proceedings of the Academy of Sciences of the Estonian SSR. Geology, 36, no.4, pp. 145-153, 4 pls., 3 txt. figs.

WALCOTT, C. D. 1892. Notes on the discovery of a vertebrate fauna in Silurian (Ordovician) strata. Bull. Geol. Soc. America, 3, pp. 153-172, 3 pls.

WALDRON, J. W. F., 1985. Structural history of continental margin sediments beneath the Bay of Islands Ophiolite, Newfoundland. Canadian Journal of Earth Sciences, v. 22, pp. 1618-1632.

WALTHIER, T. N., 1949. Geology and mineral deposits of the area between Corner Brook and Stephenville, western Newfoundland. Newfoundland Geological Survey, Bulletin No. 35, Part I, 54p.

WANG ZHI-HAO 1986. Late Cambrian and Early Ordovician conodonts from North and Northeast China with comments on the Cambrian-Ordovician boundary. In Stratigraphy and Paleontology of Systemic Boundaries in China: Cambrian-Ordovician Boundary (2). Nanjing Institute of Geology and Paleontology, Anhui Science and Technology Publishing House, pp. 195-258, 14 pls.

WATERMAN, T. H., and CHACE, F.A. JR. 1960. General crustacean biology. In The physiology of crustacea. Edited by T. H. Waterman. Academic Press, New York and London, pp. 1-33.

WESTERGARD, A. H. 1953. Two problematic fossils from the Cambrian in Sweden. Geol. Foren Forhandl., 75, no.4, pp. 465-470.

WILLIAMS, H. 1979. Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, 16, pp. 792-807.

WILLIAMSON, D.I. 1982. Larval morphology and diversity. In Biology of Crustacea, Vol. II. Edited by L.G. Abele.

Academic Press, New York, pp. 43-110.

WRONA, R. 1982. Early Cambrian phosphatic microfossils from southern Spitsbergen (Hornsund region). Palaeont. Pol., 43, pp. 9-16.

ZHANG, X. G. 1987. Moult stages and dimorphism of Early Cambrian bradoriids from Xichuan, Henan, China. Alcheringa, 11, pp. 1-19.

PLATE 1

Figures 1-6 Acanthodus lineatus (Furnish, 1938). (1) Small symmetric element, X130; NAP16; lateral view; (2) Large asymmetric costate morphotype II element, X60; NAP6; lateral view; (3) Asymmetric costate morphotype I element, X130; WC32; lateral view; (4) Symmetric costate element, X100; WC32; lateral view; (5) Asymmetric costate morphotype II element, X145; WC32; posterior view; (6) Non costate element, X133; WC32; lateral view.

Figures 7-11 Cordylodus angulatus Pander. (7) Compressed element, X86; NH54; lateral view; (8) Compressed element, X80; NAP6; lateral view; (9) Rounded element, X86; WC23; lateral view; (10) Compressed element, X130; NAP6; lateral view; (11) Rounded element, X180; WC23; lateral view.

Figures 12, 13 Cordylodus andresi Viira et Sergeyeva. All specimens from NH45 (12) Compressed element, X180; lateral view; (13) Rounded element, X262; lateral view.

Figure 14 ?Clavohamulus sp. Ethington and Clark, 1971 s.f., X317; WC32; posterior view.

Figures 15-18 Cordylodus hastatus Barnes, 1988. All specimens from NH44 (15) Rounded morphotype II, X80; lateral view (16) Rounded morphotype I, broken specimen, X80; lateral view; (17) Compressed morphotype, broken specimen, X56; lateral view; (18) ?Compressed morphotype, X75; lateral view.

Figure 19 Cordylodus intermedius Furnish. X187; NH54; lateral view.

Figures 20, 22 ?Ansella sp. (20) Specimen with well developed denticle, X 152; WC23; lateral view; (22) Specimen with poorly developed denticle, X141; WC24; lateral view.

Figure 21 Chosonodina herfurthi Müller, 1964, X204; NH54; lateral view.

Figure 23 Amphigeisina danica (Poulsen), X100; NH24; posterior view.

Figure 24 Cordylodur oklahomensis Müller, s.f., X110; NH44; lateral view.

Figure 25 Cordylodus prion Lindström, X161; WC23; lateral view.

Figure 26 Cordylodus sp., X58; WC23; lateral view.

Figure 27 *Cordylodus proavus* Muller, rounded element, X177; NH49; lateral view.

Figure 28 *Cordylodus lindstromi* Druce and Jones, X144; WC24; lateral view.

Pl. 1

PLATE 2

Figures 1,6 *Cordylodus proavus* Müller. (1) Compressed morphotype, X70; NH49; lateral view (6) Broken asymmetric element, X151; WC23; lateral view.

Figure 2 *Drepanodus* sp. aff. *D. acutus* Pander, 1856, s.f., X152; NAP16; lateral view.

Figures 3, 7 *Drepanoistodus* sp. 1. (3) Drepanodiform element, X100; NAP17; lateral view; (7) Oistodiform element, X100; NAP17; lateral view.

Figures 4, 8 *Drepanoistodus* sp. 3 All specimens from NH54 (4) Drepanodiform element, X238; lateral view; (8) Oistodiform element, X236; lateral view.

Figure 5 *Drepanodus* sp., X180; EI13; lateral view.

Figures 9-12 *Drepanoistodus forceps* (Lindström). All specimens from EI24 (9) Oistodiform element, X213; lateral view; (10) Suberectiform element, X120; lateral view; (11) Homocurvatiform element, X160; lateral view; (12) Scandodiform element, X125; slightly oral view.

Figures 13-15 *Drepanoistodus* sp. 2. All specimens from NAP23

(13) Oistodiform element, X106; lateral view; (14) Drepanodiform element, X105; lateral view; (15) Drepanodiform element, X93; lateral view.

Figures 16-23 Eoconodontus alisonae (Landing, 1983) All specimens from NH41 (16) Scolopodiform element, X240; lateral view; (17) Drepanodiform element, X200; lateral view; (18) Drepanodiform element, X200; lateral view; (19) Scolopodiform element, X255; slightly posterolaterl view; (20) Drepanodiform element, X200; lateral view; (21) Scolopodiform element, X192; lateral view; (22) Asymmetric scandodiform element, X186; posterior view; (23) Symmetric scandodiform element, X177; posterior view.

Figure 24 Eoconodontus notchpeakensis (Miller), X170; NH42; lateral view.

Figures 25-27 Iapetognathus sp. aff I. preaengensis. All specimens from WC23 (25) Iapetognathiform morphotype I element, broken specimen, X80; lateral view; (26) Iapetognathiform morphotype II element, X130; (27) Cordylodiform element, X123; lateral view.

Figure 28 Loxodus bransoni Furnish, s.f., X182; NAP6;

lateral view.

Figure 29 Macerodus sp. aff. M. dianae Fahraeus and Nowlan, 1978, X196; NAP20; lateral view.

Pl. 2

PLATE 3

Figures 1-3 *Oistodus* sp. aff. *O. scalenocarinatus* Mound. All specimens from EIN1. All lateral views (1) X196; (2) X192.5; (3) X166.

Figures 4, 11 *Paroistodus parallelus* (Pander) /*P. proteus* (Lindström) oistodiform element. All specimens from EIN1. Both lateral views. (4) X208; (11) X240.

Figure 5 *Paroistodus parallelus* (Pander), drepanodiform element, X200; EIN1; lateral view.

Figure 6 ?*Paltodus* sp. 2, X125; NAP6; lateral view.

Figures 7, 8 *Paroistodus proteus* (Lindström), drepanodiform elements. All specimens from EIN1. Both views lateral. (7) X260; (8) X200.

Figures 9, 10, 16, 17 ?*Oepikodus evae* (Lindström). All specimens from EIN1 (9) Multiramiform element, X169; lateral view; (10) Priniodiform element, X200; oblique top view; (16) Belodiform element, X150; lateral view; (17) Multiramiform element, X187; lateral view.

Figures 12, 13 ?*Paltodus* sp. 1. All specimens from NAP16.

Both lateral views. (12) X200; (13) 60.

Figures 14, 18 Phakelodus tenuis (Müller, 1959). Lateral views. (14) X112; NH27a; (18) Cluster, X87; NH28.

Figure 15 ?Oistodus triangularis, Lindström, 1955, s.f., X180; NAP21; lateral view.

Figures 19-23 Periodon flabellum (Lindström). All specimens from EIN1. All lateral views. (19) Oistodiform element, X180; (20) Cordylodiform element, X163; (21) X142 (22) Ramiform element, X158; (23) Oistodiform element, X192.

Figures 24-28 Periodon cf. P. aculeatus (Hadding). All specimens from EIN1. All views lateral. (24) Multiramiform element, X102; (25) Cordylodiform element, X104, (26) Multiramiform element, X142; (27) Oistodiform element, X140; (28) Cordylodiform element, X102.

Figure 29-32 Prioniodus sp. cf. P. elegans Pander, 1856. All specimens from EI24. All lateral views. (29) Belodiform element, X106; (30) Tetraprioniodiform element, X97; (31) Tetraprioniodiform element, X110; (32) Tetraprioniodiform element, X105.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Pl. 3

PLATE 4

Figures 1-14, 18, 19 Prioniodus sp. cf. P. elegans Pander, 1856. All specimens from EI24 (1) Tetraprioniodiform element, X116; lateral view; (2) Tetraprioniodiform element, X120; lateral view; (3) Broken tetraprioniodiform element, X105; lateral view; (4) Broken tetraprioniodifrom element, X78; lateral view; (5) Falodiform element, type 2, X111; lateral view; (6) Prioniodiform element, morphotype 1, X106; cblique top view; (7) Prioniodiform element, morphotype 2, broken specimen, X95; lateral view; (8) Prioniodiform element, morphotype 2, X157; lateral view; (9) Prioniodiform element, morphotype 1, X75; oblique top view; (10) Trichonodelliform element, X120; posterolateral view; (11) Trichonodelliform element, X156; posterior view; (12) Trichonodelliform element, X140; posterior view; (13) Falodiform element, type 1, X127; lateral view; (14) Falodiform element, type 1, X129; lateral view; (18) Falodiform element, type 2, X97.5; lateral view; (19) Falodiform element, type 1, X96; lateral view.

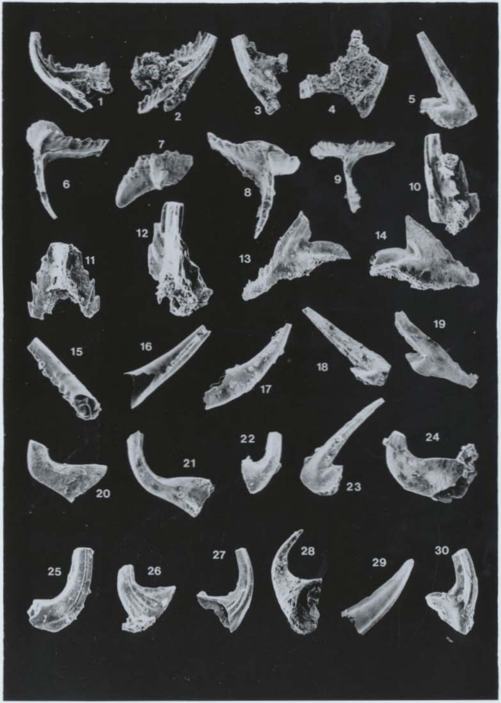
Figures 15-17 Proconodontus sp. All specimens from NH28 (15) Nearly symmetric element, X266; posterior view; (16) Asymmetric element, X106; posterolateral view; (17) Asymmetric element, X254; lateral view.

Figures 20, 21, 23-25, 30 *Protopanderodus arcuatus* (Lindström). All specimens from EI24. All lateral views. (20) Drepanodiform element, X93; (21) Asymmetric acontiodiform element, X112; (23) Scandodiform element, type II, X171; (24) Drepanodiform element, X87.5; (25) Acontiodiform element, X160; (30) Scandodiform element, type I, X154.

Figures 22, 26, 27 ?*Protopanderodus* sp. All specimens from NAP6. All lateral views. (22) Nearly symmetric element, X116; (26) Costate drepanodiform element, X130; (27) Costate drepanodiform element, X125.

Figure 28 *Prooneotodus gallatini* Müller and Nogami, 1971, X72; NH28; slightly oral view.

Figure 29 *Proconodontus muelleri* Miller, X100; NH39; lateral view.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Pl. 4

PLATE 5

Figure 1 *Proconodontus tenuiserratus* Miller, X165; NH24; lateral view.

Figures 2-11, 13 *Rossodus* n. sp. A. All specimens from NAP6 (2) Drepanodiform element, morphotype III, X72; lateral view; (3) Scandodiform element, X108; lateral view; (4) Oistodiform element, X175; lateral view; (5) Acodiniform element, X170; posterior view; (6) Scandodiform element, X83; lateral view; (7) Oistodiform element, X155; lateral view; (8) Oistodiform element, X164; lateral view; (9) Scandodiform element, with basal cone, X110; oral view; (10) Drepanodiform element, morphotype II, X112; lateral view; (11) Drepanodiform element, morphoype I, X111; lateral view; (13) Scandodiform element, X76; posterolateral view.

Figures 12, 14-16 *Rossodus* n. sp. B. All specimens from NH54. All lateral views. (12) Drepanodiform element, X157; (14) Scandodiform element, morphotype I, X216; (15) Oistodiform element, X200; (16) Compressed drepanodiform element, X210.

Figures 17-19 *Rossodus* n. sp. C. All specimens from NH53. All lateral views (17) Bicostate scandodiform element, X127; (18) Tricostate scandodiform element, X128; (19)

Drepanodiform element, X240.

Figures 20-22 Rossodus? highgatensis Landing et al. 1986. All specimens from WC32 (20) Suberectiform element, X72; lateral view; (21) Drepanodiform element, X112; lateral view; (22) Scandodiform element, X120; posterior view.

Figure 23 Scandodus sp. 2, X93; NAP16; lateral view.

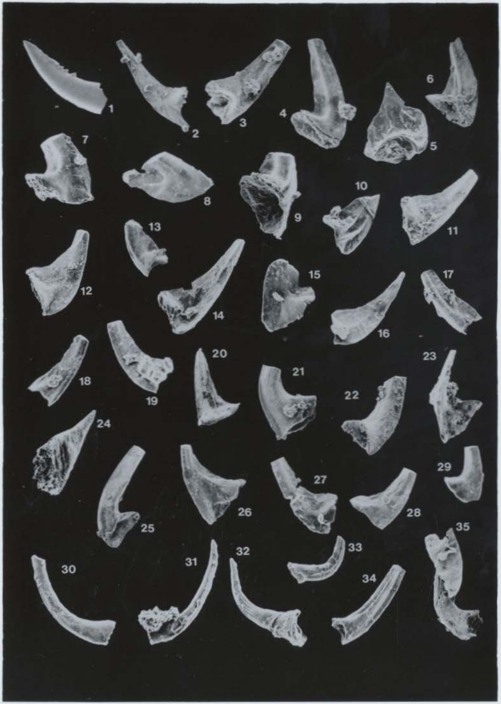
Figure 24 ?Sagittodontus eureka Müller, 1959, s.f., X104; NH37; oral view.

Figure 25 Scandodus sp. 1, X90; NAP14; lateral view.

Figures 26-29 ?Rossodus sp. All specimens from NH54 (26) Drepanodiform element, morphotype II, X192; lateral view; (27) Drepanodiform element, morphotype I, X180; lateral view; (28) Scandodiform element, X198; lateral view; (29) ?Oistodiform element, X157; lateral view.

Figures 30-33 Scolopodus sp. aff. S. cornuformis Sergeeva. All specimens from NAP16. All lateral views. (30) Non costate element, X260; (31) Sharply costate cornuform element, X178; (32) Costate cornuform element, X245; (33) Cornuform element, X192.5.

Figures 34, 35 Scolopodus gracilis Ethington and Clark. All specimens from EI13. Lateral views. (34) Symmetric triangulariform element, X192.5; (35) Filosiform element, X168.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Pl. 5

PLATE 6

Figures 1,2 Scolopodus gracilis Ethington and Clark. All specimens from EI13 (1) Graciliform element, X186; lateral view; (2) Asymmetric triangulariform element, X190; posterolateral view.

Figure 3 Scolopodus quadraplicatus Branson and Mehl, s.f., X170; NAP23; lateral view.

Figure 4-8 Semiacontiodus iowensis (Furnish, 1938). All specimens from NAP6 (4) Acontiodiform element, X125; posterior view; (5) Drepanodiform element, X133; lateral view; (6) Asymmetric acontiodiform element, X128; posterolateral view; (7) Acontiodiform element, X124; posterior view; (8) Scandodiform element, X111; posterolateral view.

Figures 9-13 ?Semiacontiodus propinquus (Furnish). All specimens from NAP6 (9) Costate scolopodiform element, 116; posterior view; (10) Symmetric acontiodiform element, X76; posterior view; (11) Drepanodiform element, X84; lateral view; (12) Asymmetric acontiodiform element, X80; lateral view; (13) Scandodiform element, X102; lateral view.

Figures 14, 15 Semiacontiodus sp. Specimens from WC24. Both lateral views. (14) Acontiodiform element, X150; (15) Drepanodiform element, X198.

Figures 16, 17 Teridontus nakamurai (Nogami). Specimens from NH44 (16) X190; lateral view; (17)180; posterolateral view.

Figure 18 Teridontus sp. aff. T. nakamurai (Nogami) Nowlan, 1985, X211; NH44; lateral view.

Figures 19-21 Microzarkodina flabellum (Lindström). All specimens from EIN1. All lateral views. (19) Irregular trichonodelliform element, X150; (20) Ozarkodiniform element, X121; (21) Ozarkodiniform element, X140.

Pl. 6

PLATE 7

Figure 1 Teridontus sp., X303; NH44; lateral views.

Figures 2-6 Variabiloconus sp. aff. V. bassleri (Furnish, 1938). All specimens from NAP6. All lateral views. (2) Bicostate element, X133; (3) Acontiodiform element. X131; (4) Asymmetric unicostate element, X105; (5) Acontiodiform element, X140; (6) Scandodiform element, X140.

Figures 7-14 Variabiloconus bassleri (Furnish, 1938). All specimens from WC32 (7) Bicostate element, X130; lateral view; (8) Strongly asymmetric element, X130; lateral view; (9) Acontiodiform element, X131; posterior view; (10) Scandodiform element, X121; lateral view; (11) Asymmetric bicostate element, X120; lateral view; (12) Acontiodiform element, X101; posterior view; (13) Asymmetric costate element, X102; lateral view; (14) Asymmetric costate element, X96; lateral view.

Figures 15-17 Gen. et sp. indet. 1. All specimens from NAP9 (15) Acontiodiform element, morphotype I, X125; posterior view; (16) Acontiodiform element, morphotype II, X107; posterior view; (17) Scandodiform element, X77; lateral view.

Figures 18-20 Gen. et sp. indet. 2. All specimens from WC23. All lateral views. (18) Costate element, X100; (19) Non costate element, X162; (20) Non costate element, X116.

Figures 21-23 Gen. et sp. indet. 3. All specimens from EIN1. All lateral views. (21) X122; (22) X122; (23) X145.

Figure 24 *Westergaardodina* sp. indet., X120; NH24; lateral view.

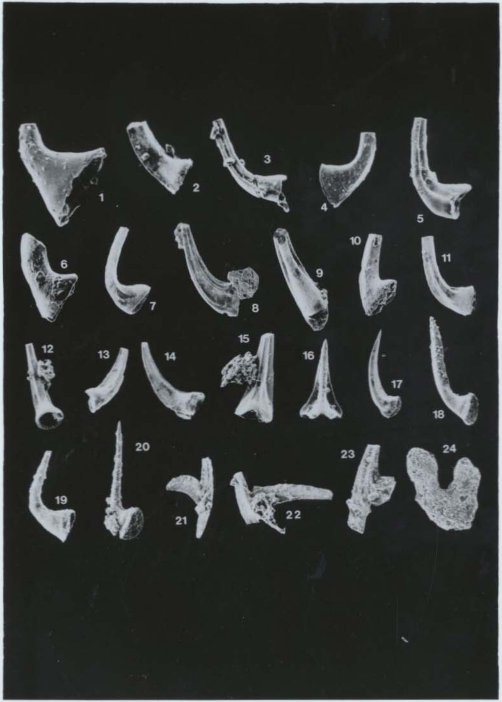

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PLATE 8

Figures 1-9 Anatolepis sp. A. All specimens from NH24 (1) General view of tubular specimen, note imbricated tubercles, X150; (2) Top view of plate fragment with typical arrangement of tubercles; note partially etched cover of some tubercles (arrow) revealing characteristic internal structure, X110; (3) Close up of imbricated tubercles of fig. 1, note the rods inside, X500; (4) General view of tubular specimen, X80; (5) Close up of plate fragment with elongate trapezoid shaped tubercles with characteristic internal structure, X200; (6,7) Close up of internal structure of the tubercles. Note that some of the rods are hollow; (6) X1000, (7) X500/5000; (8) Side view of a tubular specimen showing the cross-section, X800; (9) General view of a fragment of a tubular specimen, X80.


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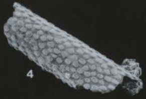
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Pl. 8

PLATE 9

Figures 1-9 Anatolepis sp. A. (1) Tubular specimen with Type II tubercles on the surface, X110; NH28; (2) Specimen with both Type I and Type II tubercles on the surface, X170; NH24; (3) Close up of surface of fig. 1; (4) Close up of tubercles of fig. 6, X400; (5) Plate fragment with Type II tubercles, X130; NH24; (6) Poorly preserved plate fragment with Type II tubercles, top view, X 130; NH24; (7) Close up of surface of fig. 2 showing both Type I and Type II tubercles, X400; (8) Tubular specimen, general view, X130; NH22; (9) Close up of Type II tubercle of fig. 5.

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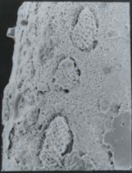

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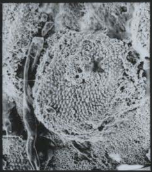

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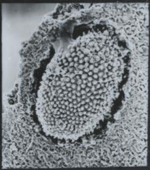

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Pl. 9

PLATE 10

Figures 1-9 Anatolepis sp. A. (1) Tubular specimen with Type I tubercles, X 170; NH27a; (2) Close up of the surface of fig. 1, note folds (arrows) in between the tubercles, X300; (3) Plate with Type I tubercles, note folds (arrow) at the base of the tubercles, X 110; NH24; (4) Close up of folds (arrow) at the base of tubercle, X1100; (5) Close up of folds (arrows) around tubercles, X350; (6) Lower surface of fig. 5 showing pits corresponding to the tubercles on the upper surface, X150; (7) Cross-section of a plate showing the wall structure with upper and lower lamellar layers. Middle spongy layer has been eroded away leaving the void, X3000; NH24; (8) Close up of one of the pits (arrow) of fig. 6, X800; (9) Plate with linearly arranged Type I tubercles. One tubercle has been removed leaving a void, X130.

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PLATE 11

Figures 1-9 Anatolepis sp. A. (1) Plate fragment with large Type I tubercles. Note borings(?) in the nodes, X170; NH28; (2) Lower surface of fig. 1. Note hollow tubercles corresponding to the ones on other surface, X130; (3) Cross-section through tuberculate part of a plate, X500; NH27a; (4) Close up of boring(?) of fig. 1, X2500; (5) Close up of hollow tubercle of fig. 2, X500; (6) Oblique side view of fig. 1, showing the tubercles on both surfaces, X220; (7) Fragment of a tubular specimen with partially preserved tubercles, X100; NH27a; (8) Close up of tubercle of fig. 7 X700; (9) Close up of Type I tubercle showing outer covering, internal rods and folds near the base, X800; NH24.


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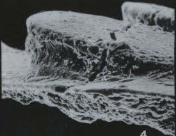
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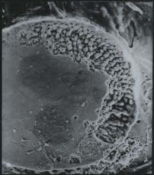
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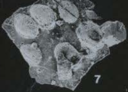
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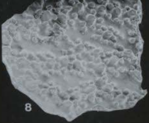
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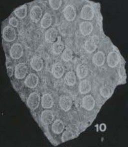
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Pl. 12

PLATE 12

Figures 1-10 Anatolepis sp. B. (1, 3) Plate fragment showing both Type I and the smaller tubercles, (1) X220; NH28; (3) X120; NH28; (2) Plate fragment with Type I tubercles, X100; NH28; (4) Side view of a plate fragment showing imbricated Type I tubercle, top lamellar layer of the wall structure and the middle spongy layer, X1100; NH22; (5) Close up of a tubercle of fig. 2 showing the outer covering and the inner rods, X700; (6) Wall structure of a plate fragment showing three layers, X600; NH28; (7) Plate fragment with partially preserved Type I tubercles, X150; NH22; (8) Lower surface of a plate fragment showing small, closely spaced tubercles, 130; NH28; (9) Close up of small tubercle of figs. 1 & 3, X1700; (10) Upper surface of fig. 8 showing Type I tubercles, X120.

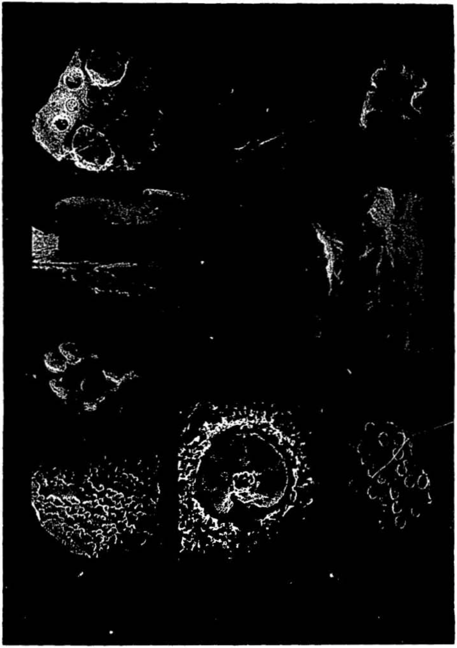

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PLATE 13

Figures 1, 2 Anatolepis sp. C. (1) General view, tubular specimen, X100; NH28; (2) Close up of tubercles of fig. 1, note openings and partially preserved rods inside the tubercles, X600.

Figures 3-10 Genus et sp. indet. 1. (3) Plate fragment with characteristic tubercles, X80; NH28; (4) Close up of the surface of a plate fragment showing two different sizes of tubercles, X300; NH24; (5,6) Plate fragments with characteristic pattern of tubercles, (5) X100; NH22; (6) X80; NH22; (7) Plate fragment with curled edges, X150; NH37; (8) Plate fragment showing three different sizes of tubercles, X150; NH28; (9) Close up of tuberculate surface of a plate fragment. Note outer covering and internal granular structure of the tubercle and folds on the plate surface, X1500; NH22; (10) Cross-section showing three layered wall structure with partially eroded middle spongy layer, X120; NH24.


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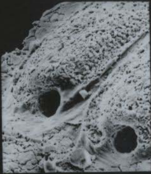
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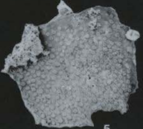
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PLATE 14

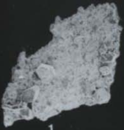
Figures 1-3, 10 Genus et sp. indet. 4. (1) General view of plate fragment (morphotype I), X100; NH39; (2) Close up of surface of fig. 1, note small rods (arrow) inside the depressions, X350; (3) Plate fragment with small nodes as well as depressions, X130; NH24; (10) Close up of the surface of fig. 3, X2200.

Figures 4-5 Genus et sp. indet. 2. (4) Plate fragment, general view, X130; NH41; (5) Close up of surface of fig. 4 showing characteristic surface ornamentation, X1100.

Figures 6, 8 Genus et sp. indet. 3. (6) General view of surface showing numerous rounded tubercles, X150; NH39; (8) Cross-section of fig. 6 showing characteristic fibrous wall-structure, X500.

Figure 7 Genus et sp. indet 5, general view, X120; NH24.

Figure 9 Genus et sp. indet. 6, general view. Note small pores (arrow) along the edges and bases of tubercles, X200; NAP6.



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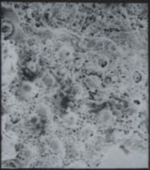

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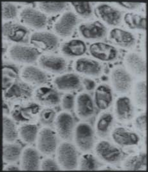

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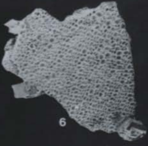

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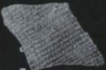

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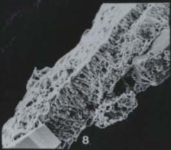

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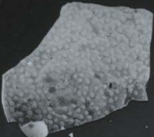
PLATE 15

Figures 1-6 Genus et sp. indet. 7. All specimens from NH23 (1) Upper surface of tuberculate plate fragment, X120; (2) Lower surface of fig. 1 showing numerous closely spaced tubercles, X100; (3) Cross-section of plate fragment og fig. 4. Note void (arrow) in the middle layer, X1300; (4) General view of tuberculate plate fragment, X100; (5) X60; (6) Cross-section showing layered wall structure, X400.

Figures 7-11 Genus et sp. indet. 8. All specimens from NAP6 (7) Plate fragment with numerous rounded tubercles on upper surface, X60; (8) Tuberculate plate fragment showing small spines along margin, X50; (9) Tuberculate plate fragment with well developed, discreet marginal spines, X200; (10) Close up of surface of fig. 7, X300; (11) close up of a tubercle of fig. 7. note opening at the top of the tubercle, X5000.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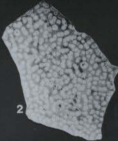
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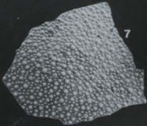
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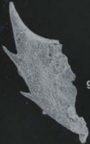
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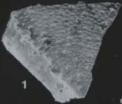
Pl. 15

PLATE 16

Figures 1-4 Genus et sp. indet. 8. (1) Plate fragment showing two surfaces one of which exhibits numerous tubercles, X80; NAP6; (2) Plate fragment with tubercles concentrated along the junction of two surfaces, X130; NH54; (3) Close up of surface of fig. 4 showing tubercles and small marginal spines, X250; (4) Plate fragment with small marginal spines, X80; NAP6.

Figures 5-7 Genus et sp. indet. 9. (5) Wall structure of fig. 6, X500; (6) Plate fragment with partially preserved ridge-like ornamentation, X70; NH45; (7) Close up of surface of fig. 6 showing the flattened tubercles forming the ridge-like pattern, X350.

Figures 8-10 Genus et sp. indet. 10. All specimens from NH24 (8) Plate fragment with characteristic surface ornamentation, X70; (9) Plate fragment with rounded edges, X80; (10) Close up of surface of fig. 8, X300.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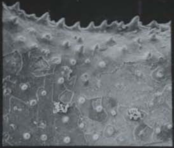
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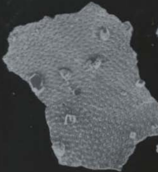
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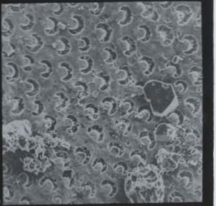
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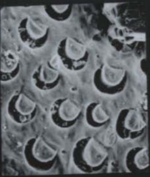
Pl. 16

PLATE 17

Figures 1-6 Genus et sp. indet 10. (1) Close up of surface of plate fragment showing characteristic crescentic openings. Note pores on the plate surface, X800; NH22; (2) Wall structure of a plate fragment showing upper lamellar layer and middle spongy layer, X2600; NH22; (3) Flattened tubular sclerite, X120; NH28; (4) X120; NH28; (5) Cross-section showing wall structure of fig. 3, X250; (6) Close up of one side of fig. 5 showing the lamellar layers and the intervening spongy material, X800.

Figures 7-10 Genus et sp. indet. 11. (7) Close up of surface of fig. 9, note folds (arrow) at the base of tubercles, X600; (8) Upper surface of tuberculate plate fragment, note folds on the surface, X170; NH28; (9) Lower surface of fig. 8 showing numerous tubercles, X130; (10) Slightly oblique view of layered wall structure of fig. 8, X800.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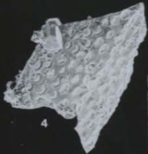
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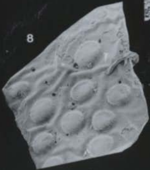
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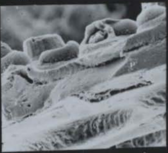
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Pl. 17

PLATE 18

Figures 1-3 Genus et sp. indet. 12. (1) General view, note opening (arrow) at the center of a depression, X220; NH22; (2) Broken specimen showing internal features, X220; NH22; (3) Wall structure, X3500.

Figures 4, 5 Genus et sp. indet. 14. (4) General view, note opening, X200; NH22; (5) X480; NH54.

Figure 6 Genus et sp. indet. 13, X130; NH24.

Figure 7 Genus et sp. indet. 15, note opening (arrow), X380; NH45.

Figure 8 Genus et sp. indet. 17, X 120; NH24.

Figures 9-12 Genus et sp. indet. 16. (9) Partially preserved specimen, X150; NH28; (10) X210; NH28; (11) X480; NH22; (12) Partially preserved specimen showing internal structure, X200; NH22.


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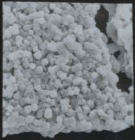
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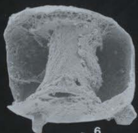
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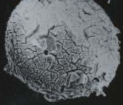
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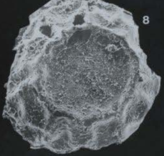
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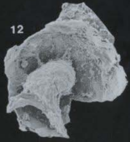
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Pl. 18

PLATE 19

Figures 1-4 Genus et sp. indet. 16. (1) General view, note internal partitions, X230; NH22; (2) Partially preserved specimens showing remains of internal partitions(?), X230; NH22; (3) Specimen showing double layered wall and internal chambers, X330; NH28; (4) X380; NH45.

Figures 5-7 Genus et sp. indet 18. (5) General view, note depression, X280; NH22; (6) Partially preserved specimen with central mass, X390; NH54; (7) X390; NH45.

Figures 8-12 Genus et sp. indet. 19. (8) Tubular specimen, general view, X90; NAP6; (9) Broken edge of a fragment showing characteristic wall structure, X990; NAP6; (10) Close up of part of fig. 8 showing arrangement of the different layers, X690; (11) Close up of folded layer of fig. 8 showing characteristic wall structure, X1500. (12) Wall structure showing lath-shaped crystals, X4000.


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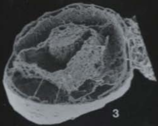
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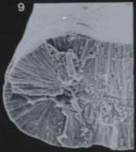
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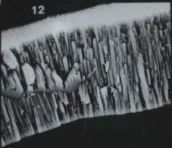
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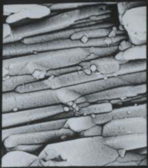
Pl. 19

PLATE 20

Figures 1-3 Genus et sp. indet. 19. All specimens from NAP6 (1) Wall structure, X20,000; (2) Close up of crystal arrangement at the core of fold of fig. 3, X35,000; (3) Wall structure of a folded layer, X11,000.

Figures 4-11 Genus et sp. indet. 20. All specimens from NAP6 (4) General view of tubular specimen, X60; (5) Partially preserved specimen, X60; (6) Close up of the surface of fig. 1, note three layers, with the middle layer exhibiting reticulate pattern, X290; (7) Partially preserved rectangular specimen, X60; (8) Specimen with an irregular outer covering; note the circular opening, X70; (9) Close up of surface and edge of a specimen. Note tubercles along edge and reticulate pattern on surface, X580; (10) Close up of circular opening of fig. 8. Also note the reticulate pattern on the surface, X690; (11) Wall structure, X8000.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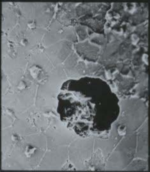

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Pl. 20

PLATE 21

Figures 1-7 Genus et sp. indet. 20. All specimens from NAP6 (1) Close up of surface pattern, X340; (2) X40; (3) Close up of surface pattern. Note rounded nodes at the junction of two or more ridges, X1190; (4) X120; (5) Wall structure, X7900; (6) Note circular nodes along the edge, X390; (7) Close up of one of the circular nodes of fig. 3, note opening in the node, X6900.

Figures 8, 11-13 Genus et sp. indet. 22. All specimens from NAP6 (8) X160; (11) X120; (12) X70; (13) X 40.

Figures 9, 10 Genus et sp. indet. 21. (9) General view, tubular specimen, X70; NH53; (10) Close up of the surface of fig. 9 showing characteristic reticulate pattern, X580.


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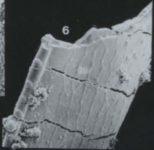
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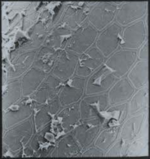
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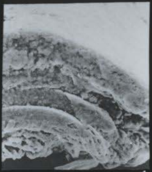
Pl. 21

PLATE 22

Figures 1-5 Genus et sp. indet. 22 All specimens from NH28 (1) Wall structure of fig. 4, X1480; (2) X60; (3) Close up of wall structure of fig. 2, X580; (4) X70; (5) Wall structure of fig. 2, X190.

Figures 6-13 Phosphannulus universalis Müller, Nogami and Lenz, 1974. (6) X160; NAP6; (7) X330; NH28; (8) X240; WC32; (9) X200; NAP6; (10) X190; NH28; (11) X290; NAP6; (12) X160; EI18; (13) X240; NAP6.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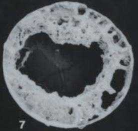
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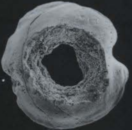
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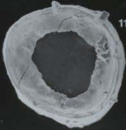
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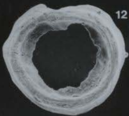
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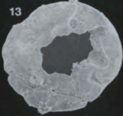
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Pl. 22

PLATE 23

Figures 1-3 Species A. (1) X190; NH44; (2) X140; NAP6; (3) X240; NAP6.

Figures 4, 5 Species B. (4) X140; NAP14; (5) X140; NAP14.

Figure 6 Species C, X240; NAP14.

Figures 7, 8, 10 Species I. All specimens from NAP6 (7) X120; (8) X240; (10) Note pore (arrow), X590.

Figures 9, 11 Species II. All specimens from NAP6 (9) X40; (11) X290.

Figure 12 ?Lapworthella sp., X160; NH54.

Figures 13-15 Genus et sp. indet. 27. (13) X140; EI13; (14) X190; EI13; (15) X290; NAP6.

Pl. 23

PLATE 24

Figures 1, 2 Species 1. (1) X190; NH28; (2) Close up of a portion of fig. 1, X390.

Figures 3-7 Species II. (3) X160; NH41; (4) X190; EI13; (5) X140; EI13; (6) X140; NAP23; (7) X210; EI18.

Figures 8-10 Genus et species indet. 26. (8) X60; NAP6; (9) Close up of surface of fig. 8, X1190; 10X140.


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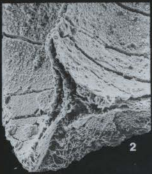
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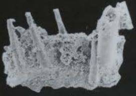
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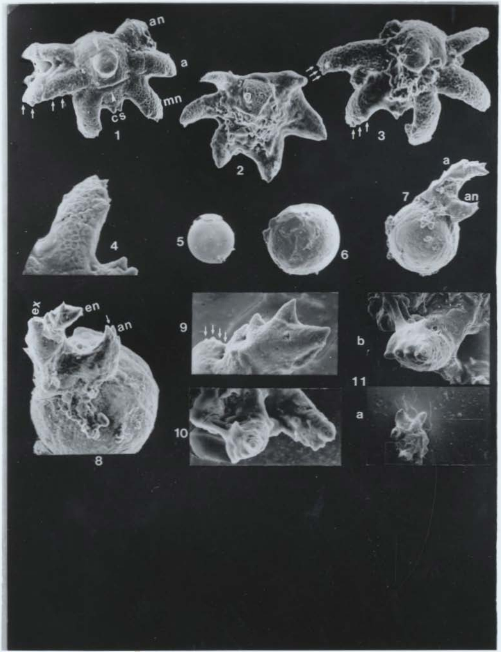
Pl. 24

PLATE 25

Figs. 1-4, 10, 11a,b, Larva Type 1. All specimens from NAP16 (1) Antero- ventral view, note antennule (an), antenna (a), mandible (mn), and caudal spines (cs); small arrows denote spinules, large arrow-head indicates the labrum and small arrow-head the incipient mouth, X560; (2) Antero-dorsal view, X500; (3) Antero-ventral view, X650; (4) Close-up of mandible of Fig. 1, note the terminal spinules, X1100; (10) Close-up of spinules, X940; (11a) Posterior view, X250, and (11b) close-up of appendage, X2500.

Figs. 5,6, Phosphatic spherules. All specimens from NAP16 (5) X250 (6) X500.

Figs. 7-9, Larva Type 2. All specimens from NAP16 (7) Lateral view, note antennule (an) and antenna (a), X500; (8) Near oblique view, note endopod (en), exopod (ex) and antennule (an), X1100. (9) Close-up of endopod, small arrows show positions of spinules, X2500.



Pl. 25

APPENDIX C

Abundance Table

The abundances of conodont elements in individual samples have been documented in the following table. Note that only fossiliferous samples have been listed and that the order of the samples is not stratigraphic.

	"Sagittodontus" eureka	? P. sp. drepanodiform	? R. sp. oistodiform	? R. sp. scandodiform	?Ansella sp.	?Clavohamulus sp.	?Oistodus triangularis	?Paltodus sp. 1	?Paltodus sp. 2	?Procerodontus posterocostatus	?Protopanderodus sp.	A. lineatus costate	A. lineatus non-costate	Hephigeisina danica	C. angulatus compressed	C. angulatus rounded	C. intermedius compressed	C. intermedius rounded	C. proavus compressed	C. proavus rounded	Chosonodina herfurthi	Cordylodus andresi
NH22	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..
NH24	..	..	..	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	..
NH27a	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH32	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH37	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH39	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0	..	..
NH41	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH42	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH44	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	6	4	..	..
NH45	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	5	..	3
NH46	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH48	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH49	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	3	..	2
NH53	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH54	..	14	4	8	..	..	..	..	..	..	..	2	..	..	4	3	1	..	..	..	1	..
NAP2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP6	..	..	..	..	..	..	..	3	3	..	22	4	2	..	3	6	..	1	..	..	..	..
NAP9	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..
NAP14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP16	..	..	..	..	3	..	..	1	..	..	..	8	2	..	..	..	..	..	..	..	2	1
NAP17	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP21	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
WC15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
WC23	..	..	..	..	1	..	..	..	..	..	..	..	..	..	3	3	1	2	3	5	..	3
WC24	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	3	4	1	..	..	..
WC28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..
WC32	..	..	..	..	..	1	..	..	..	..	..	11	..	..	..	..	..	..	..	..	3	..
EI10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI13	..	..	..	..	..	..	..	..	..	..	11	..	..	..	..	..	..	..	..	..	..	..
EI15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EIN1	..	..	..	..	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

	Cordylodus hastatus	Cordylodus lindstromi	Cordylodus oklahomensis	Cordylodus prion	Cordylodus sp.	D. forceps nomacurvatiform	D. forceps oistodiform	D. forceps scandodiform	D. forceps suberectiform	Drepanodus sp.	Drepanodus sp. aff. D. acutus	Drepanoistodus sp. drepanodiform	Drepanoistodus sp. oistodiform	Drepanoistodus sp. 1 drepanodiform	Drepanoistodus sp. 1 oistodiform	Drepanoistodus sp. 2 drepanodiform	Drepanoistodus sp. 2 oistodiform	E. alisonae drepanodiform	E. alisonae scandodiform	E. alisonae scolopodiform	Eoconodontus notchpeakensis	Genus et sp. indet. 1
NH22	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH27a	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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EI12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI13	..	..	..	..	..	17	7	6	4	3	..	..	..	..	..	..	..	..	..	..	..	..
EI15	..	..	..	..	..	14	3	..	4	..	..	..	..	..	..	..	..	..	..	..	..	..
EI18	..	..	..	..	..	2	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI19	..	..	..	..	..	7	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI24	..	..	..	..	..	6	9	4	8	..	..	..	..	..	..	..	..	..	..	..	..	..
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	Genus et sp. indet. 2	Genus et sp. indet. 3	I. aff. I. preaengensis cordylodiform	I. aff. I. preaengensis iapetognathiform	Loxodus bransoni	M. flabellum cordylodiform	M. flabellum ozarkodiniform	M. flabellum trichonodelliform	Macerodus sp. aff. M. dianae	Oepikodus evae belodiform	Oepikodus evae prioniodiform	Oistodus aff. O. scalenocarinatus	P. arcuatus	P. arcuatus acontiodiform	P. arcuatus drepanodiform	P. arcuatus scandodiform	P. cf P. aculeatus	P. cf P. elegans prioniodiform	P. flabellum multiramiform	P. flabellum oistodiform	P. flabellum prioniodiniform	P. parallelus drepanodiform
NH22	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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EI12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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EI24	..	..	..	..	..	..	..	..	..	..	..	..	..	5	7	3	..	92	..	..	..	..
EIN1	..	10	..	..	..	5	22	8	..	3	26	5	..	..	..	..	2	..	75	38	6	7

	P. proteus drepanodiform	P. proteus distodiform	P.cf P. aculeatus multiramiform	P.cf P. aculeatus distodiform	P.cf P. elegans belodiform	P.cf P. elegans falodiform	P.cf P. elegans tetraprioniodiform	P.cf P. elegans trichonodelliform	Phakelodus tenuis	Phakelodus tenuis cluster	Proconodontus muelleri	Proconodontus sp.	Proconodontus tenuiserratus	Prooneotodus gallatini	Prooneotodus sp. A	R. n. sp. A acodiniform	R. n. sp. A distodiform	R. n. sp. H. drepanodiform	R. n. sp. H. scandodiform	R. n. sp. B drepanodiform	R. n. sp. B distodiform	R. n. sp. B scandodiform
NH22	..	..	..	..	..	..	..	..	12	..	..	2	..	..	5	..	..	..	..	..	..	..
NH24	..	..	..	..	..	..	..	..	..	..	..	3	7	..	4	..	..	..	..	..	..	..
NH27a	..	..	..	..	..	..	..	..	12	..	..	..	..	..	..	..	..	..	..	..	..	..
NH28	..	..	..	..	..	..	..	..	..	10	..	6	7	4	..	..	..	..	..	..	..	..
NH32	..	..	..	..	..	..	..	..	..	2	..	1	1	..	..	..	..	..	..	..	..	..
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NH53	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH54	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	9	4	11
NAP2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	5	10	3	..	..	..
NAP9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NAP14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	4	..	..
NAP16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	10	7	3	4
NAP17	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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WC24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
WC28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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EI10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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EI18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI24	27	10	..	..	35	27	50	18	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EIN1	17	18	12	04	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

	R. n. sp. C drepanodiform	R. n. sp. C scandodiform	R.? highgatensis drepanodiform	R.? highgatensis scandodiform	R.? highgatensis suberectiform	S. aff S. cornuformis costate	S. aff. S. cornuformis cornuform	S. aff. S. cornuformis non-costate	S. gracilis filodiform	S. gracilis graciliform	S. gracilis triangulariform	S. iowensis asymmetric acontiodiform	S. iowensis drepanodiform	S. iowensis symmetric acontiodiform	S. propinquus acontiodiform	S. propinquus drepanodiform	S. propinquus scolopodiform	Scandodus sp. 1	Scandodus sp. 2	Scolopodus quadraplicatus s. f.	Semiacontiodus sp. acontiodiform	Semiacontiodus sp. drepanodiform
NH22	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
NH24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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NAP2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
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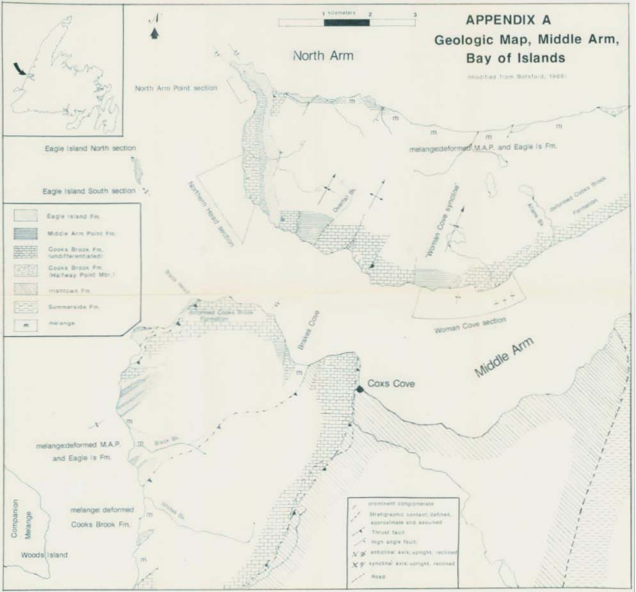
WC28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
WC32	..	..	6	1	1	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	..
EI10	..	..	..	..	..	..	..	..	15	4	3	..	..	..	..	..	..	..	..	..	..	..
EI12	..	..	..	..	..	..	..	..	..	3	2	5	..	..	..	..	..	..	..	..	..	..
EI13	..	..	..	..	..	..	..	..	4	3	6	..	..	..	..	..	..	..	..	2	..	..
EI15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EI24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
EIN1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

	Teridontus nakamurai	Teridontus sp.	Teridontus sp. aff. T. nakamurai	U. aff. U. bassleri acontiodiform	U. aff. U. bassleri costate	U. aff. U. bassleri scandodiform	U. bassleri costate	U. bassleri scandodiform	Westergaardodina sp. indet.		
NH22	..	..	..	..	..	..	..	..	..	..	NH22
NH24	..	..	..	..	..	..	..	..	3	..	NH24
NH27a	..	..	..	..	..	..	..	..	..	..	NH27a
NH28	..	..	..	..	..	..	..	..	..	..	NH28
NH32	..	..	..	..	..	..	..	..	..	..	NH32
NH37	..	..	..	..	..	..	..	..	..	..	NH37
NH39	..	..	..	..	..	..	..	..	..	..	NH39
NH40	..	..	..	..	..	..	..	..	..	..	NH40
NH41	10	..	..	..	..	..	..	..	..	..	NH41
NH42	..	..	..	..	..	..	..	..	..	..	NH42
NH44	23	5	..	..	..	..	..	..	..	..	NH44
NH45	30	..	10	..	..	..	..	..	..	..	NH45
NH46	3	..	..	..	..	..	..	..	..	..	NH46
NH48	3	1	4	..	..	..	..	..	..	..	NH48
NH49	..	..	52	..	..	..	..	..	..	..	NH49
NH53	..	..	..	..	..	..	..	..	..	..	NH53
NH54	..	..	..	3	18	5	..	..	..	..	NH54
NAP2	..	..	..	..	..	..	..	..	..	..	NAP2
NAP6	..	..	..	6	33	5	..	..	..	..	NAP6
NAP9	..	..	..	..	..	..	..	..	..	..	NAP9
NAP14	..	..	..	..	..	..	..	..	..	..	NAP14
NAP16	..	..	..	2	9	1	..	..	..	..	NAP16
NAP17	..	..	..	..	..	..	..	..	..	..	NAP17
NAP19	..	..	..	..	..	..	..	..	..	..	NAP19
NAP20	..	..	..	..	..	..	..	..	..	..	NAP20
NAP21	..	..	..	..	..	..	..	..	..	..	NAP21
NAP23	..	..	..	..	..	..	..	..	..	..	NAP23
WC15	..	..	..	..	..	..	..	..	..	..	WC15
WC23	..	..	..	..	..	..	..	..	..	..	WC23
WC24	..	..	..	..	..	..	..	..	..	..	WC24
WC28	..	..	..	..	..	..	..	..	..	..	WC28
WC32	..	..	..	..	..	..	74	18	..	..	WC32
EI10	..	..	..	..	..	..	..	..	..	..	EI10
EI12	..	..	..	..	..	..	..	..	..	..	EI12
EI13	..	..	..	..	..	..	..	..	..	..	EI13
EI15	..	..	..	..	..	..	..	..	..	..	EI15
EI18	..	..	..	..	..	..	..	..	..	..	EI18
EI19	..	..	..	..	..	..	..	..	..	..	EI19
EI24	..	..	..	..	..	..	..	..	..	..	EI24
EIN1	..	..	..	..	..	..	..	..	..	..	EIN1

APPENDIX A

Geologic Map, Middle Arm, Bay of Islands

(modified from Botsford, 1988)



APPENDIX B

STRATIGRAPHIC SECTIONS, COOKS BROOK AND MIDDLE ARM POINT FORMATIONS

(modified from Botsford, 1988)