

Uppermost Ordovician through Lower Silurian Conodont Biostratigraphy of the Cape
Phillips Formation, Cornwallis Island, Canadian Arctic Islands

by

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We accept this thesis as conforming
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Abstract

Lower Silurian conodont biostratigraphy is poorly known and not well correlated with the parallel graptolite biozonation. The Cape Phillips Formation contains a continuous record of sedimentation, and exceptionally well preserved faunas in the unstable shelf region of the Franklinian miogeoclinal succession in the Canadian Arctic Islands and north-west Greenland and affords a rare opportunity to integrate the conodont and graptolite biozonation. Detailed biostratigraphic sampling was completed from the base of the Cape Phillips Formation (Upper Ordovician), over the Ordovician-Silurian boundary, and through the entire Lower Silurian (Llandovery and Wenlock) succession on Cornwallis Island in the Canadian Arctic Islands. A total of 180 4.5 kg, samples were collected, yielding 7,575 conodont elements, from which 59 species representing 29 genera were recognised. One new genus and species are established from the lower Wenlock. Eleven conodont zones were recognized, 1 of which is new, and 3 of which are modified. Due to the multidisciplinary approach of the fieldwork, the conodont zones are integrated with the detailed graptolite biozonation over the entire interval.

The conodont zones recognised are the *A. ordovicicus* Zone, *O.? nathani* Zone, *Dapsilodus obliquicostatus-Decoriconus fragilis* Interval Zone, *Aspelundia petila* Zone, *Aspelundia fluegeli* Zone, *Pterospathodus celloni* Zone, *Pterospathodus a. amorphognathoides* Zone, *Pterospathodus p. procerus* Superzone, *Kockelella ranuliformis* Superzone, New genus, new species Zone and the *Kockelella patula* Zone.

Most of the Llandovery is dominated by the *Aspelundia-Walliserodus-Dapsilodus* biofacies, but the typically diverse late Telychian fauna is present. Significant conodont bioevents are recognized in the *persculptus* graptolite Zone, the middle to late Rhuddanian, the early Telychian, and the interval spanning the Llandovery-Wenlock boundary. These are possibly linked to sequence boundaries, isotope excursions, glacial events in the Southern Hemisphere, and/or global changes in ocean and climate states.

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Introduction

Location and General Geology

This thesis is based on conodont collections and study from nine measured sections on Cornwallis Island that span latest Ordovician through Early Silurian time. A paleogeographic map of Llandovery time is illustrated in Figure 1. Cornwallis Island, which is about 107 km long and 90 km wide, is located centrally in the Canadian Arctic Archipelago at 75°N between Bathurst and Devon Islands. Ordovician and Silurian strata outcrop extensively on the island. The sections in this study are composed entirely of rocks of the Cape Phillips Formation, whose type section on Cornwallis Island spans 2.5 km of strata from Ashgill to Pridoli or earliest Devonian. The Cape Phillips Formation represents the graptolitic slope/basinal equivalent of the carbonate shelf facies represented by the Allen Bay and Read Bay formations. On Cornwallis Island, an east-west trending facies front separates these shelf and basinal facies so that the southern half of the island is composed of shelf strata, while the Cape Phillips outcrops in the north. The Cape Phillips Formation is also exposed on Little Cornwallis, northern Devon and Bathurst and central Ellesmere, Melville, Truro, and Middle islands. Structurally, Cornwallis Island lies within the Boothia Uplift-Cornwallis Fold Belt, a 1000 km long area of uplift of Early Devonian intraplate contraction linked to the Caledonian orogen on East Greenland (Miall 1986; de Freitas and Mayr 1993). Cornwallis Island lies north of the Barrow Line, a feature that separates the diachronous deformation of the southern and northern segments of the Boothia Uplift (de Freitas and Mayr 1993).

Middle Silurian 425 Ma

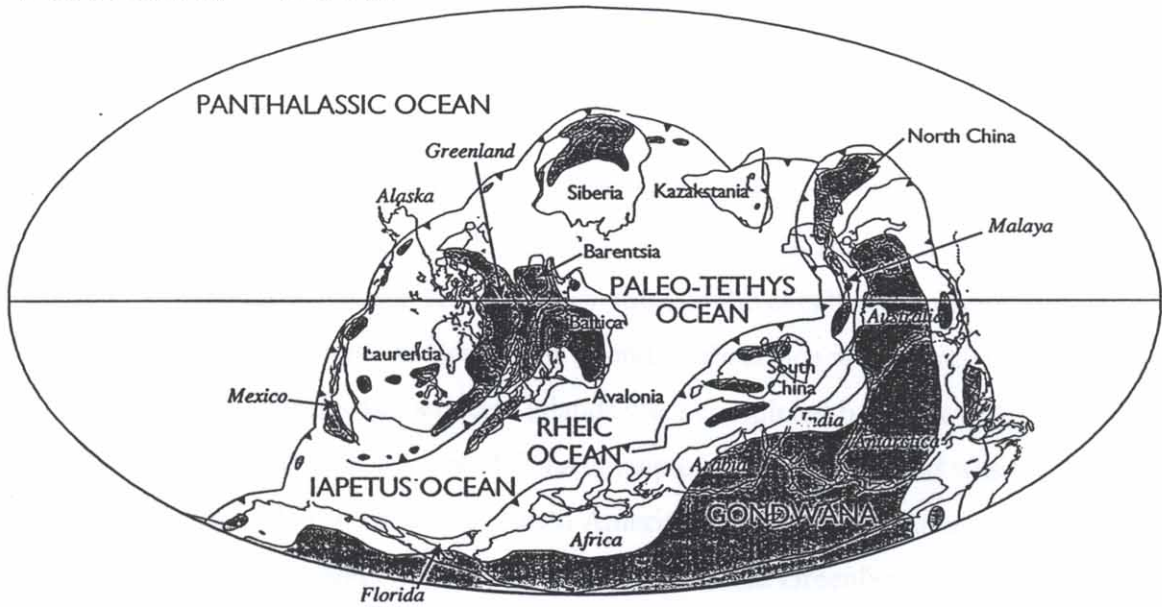


Figure 1. Llandovery paleogeography (Scotese 1997).

Previous Studies

The early geological subdivision of the Canadian Arctic, including the basic stratigraphy and formation names, was accomplished by Fortier et al. (1954), Thorsteinsson and Tozer (1960, 1970) and Fortier et al. (1963). The Cape Phillips Formation and its type section were originally described by Thorsteinsson (1958)

Kerr (1977) outlined the details of uplift in the Cornwallis Fold Belt, whereas de Freitas and Mayr (1993) showed that the Boothia Uplift, although linked to Caledonian orogenesis through intraplate contraction, is divisible into northern and southern sections that reacted differently to the orogenesis. Depositional facies of the Allen Bay, Read Bay, and Cape Phillips formations that outcrop on Cornwallis and Griffith Islands were detailed by Sodero and Hobson (1979). They stressed the excellent exposure of the Silurian shelf-to-basin strata on Cornwallis Island. Subsurface well correlation and stratigraphy of Cornwallis and adjacent islands were completed by Mayr (1978; 1980). The most recent Geological Survey of Canada map of Cornwallis Island was produced by Thorsteinsson (1986). The Decade of North American Geology volume on the Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland deals extensively with the Lower Paleozoic history of the region. de Freitas and Nowlan (1998) described a late Llandovery to Ludlow reef tract (including illustrated late Llandovery conodonts) in the Canadian Arctic and north Greenland. A complete overview and synthesis of the Silurian System of the Canadian Arctic, showing the structural provinces, litho- and sequence stratigraphy, is found in de Freitas et al. (1999). Patchett et al. (1999) showed that the geochemical signature of Caledonian tectonism first appeared in Late Ordovician time in the Canadian Arctic, and that sediments of the Cape Phillips Formation also retain this signature. An exhaustive reference list on the Arctic Silurian System is available in de Freitas et al. (1999); however, the major contributions to Lower Paleozoic conodont biostratigraphy are included in Previous Biostratigraphic Studies (below).

Recent descriptions of Cape Phillips Formation fossils include those of radiolarians (Goodbody 1982; MacDonald 1999), sponges (de Freitas 1987; Rigby and

Chatterton 1989), acanthodian scales, dentition cones, and jaw fragments (Burrow et al. 1999), and trilobites (Adrain and Edgecomb 1997).

Objectives

The objectives of this thesis are:

1. to document the detailed stratigraphy of the Cape Phillips Formation on Cornwallis Island
2. to taxonomically identify and describe the conodonts
3. to establish a refined conodont biostratigraphy of the Latest Ordovician through Early Silurian strata of the Cape Phillips Formation
4. to integrate the latter with the graptolite biostratigraphy and relate faunal changes to the Silurian Cycle models, the terminal Ordovician and Llandovery glaciations, and to oxygen and carbon isotope excursions.

Field and Laboratory Methods

Field work for this thesis was completed in July 1998 by the author along with others who sampled for other fossil groups. These included Dr. M. Melchin (field leader, graptolites), E. MacDonald (radiolarians), and A. Soufianne (chitinozoans). Additionally, sampling at the Abbott River West sections was co-ordinated with Dr. A. Lenz (graptolites) and Dr. P. Noble (radiolarians). Conodont samples were collected at 1 to 5 metre intervals depending on the nature and age of the strata. These were integrated in the field with the graptolite zonation by simultaneous collection of the two fossil groups. A total of 12 conodont samples were obtained from Ordovician strata of the Cape Phillips Formation. The remaining 168 conodont samples were from Silurian strata of the Cape Phillips Formation. Seventeen samples were obtained from the Cape Phillips South section, 6 from the Cape Manning Ordovician-Silurian boundary section, and 36 and 13 from the Cape Manning sections 2 and 3, respectively. Additionally, 63 samples

were obtained from the type section at Cape Phillips North, 8 from Abbott River East, and 14, 7 and 16 from Abbott River West sections 1, 2 and 3, respectively.

The samples were processed using the traditional technique of 10 percent glacial acetic acid dissolution. Normally, 3.0-3.5 kg of rock were processed from each sample of 4.0 – 4.5 kg, and each was exposed to a minimum of four acid baths lasting at least three days. Some samples contained a large amount of silt that slowed down or even prevented good dissolution. Most shale did not respond well to the acetic acid treatment, but many intervals contained concretions that did dissolve adequately. Samples that were least resistant to dissolution were from the lowermost Ordovician strata sampled (*fastigatus* and *pacificus* graptolite zones) and the late Telychian. After dissolution, the samples were wet-sieved through 2 mm and 90 μm sieves (mesh size 16 and 200, respectively). Dry 90 μm fractions were separated with the heavy liquid sodium polytungstate. The conodonts were then picked, sorted and identified under a binocular light microscope. The digital plate images were produced by the use of a scanning electron microscope. Some samples that yielded well, but were from samples that did not dissolve adequately, were reprocessed to obtain more conodonts. Formic acid dissolution was attempted on a small variety of samples that were resistant to the acetic acid, but this proved unsuccessful.

Regional Geologic Setting

Structural and Stratigraphic Framework

The Canadian Arctic Islands and Greenland are underlain by Early Cambrian to latest Devonian or Carboniferous strata that compose the Franklinian succession (Fig. 2). The summary of the Silurian System by de Freitas et al. (1999) is relied on heavily for this discussion of the regional geology of the Arctic. Some 12 km of sediments were deposited on this passive-to-convergent cratonic margin that experienced rapid subsidence following latest Precambrian continental break-up. The Franklinian mobile belt, exposed in the Arctic and Greenland, was formed through the convergence of an unknown landmass during Late Silurian, Devonian, and early Carboniferous time. Structurally, two provinces compose the Franklinian Mobile Belt. Pearya, which is exposed in northern Ellesmere, is thought to be an allochthonous terrane fragment related to the Caledonian orogeny of East Greenland, and was accreted to the Clements Markham Fold Belt on northern Ellesmere Island sometime in Ashgill to late Telychian time. The Caledonian orogeny began in the late Llandovery with the collision of Laurentia and Baltica as the Iapetus Ocean was subducted. The majority of the deformed strata of the Franklinian Mobile Belt form the second major structural province. These are represented by the various fold belts that lie along the northern and western margins of the Proterozoic and crystalline Archean basement of the stable cratonic shelf, roughly separating the shelf from the Hazen Deep Water Basin. Many of these fold belts were formed through Devonian and Tertiary convergent tectonics; however, the Cornwallis Fold Belt formed through intraplate contraction transmitted south-westwards from the Caledonian orogeny (Miall 1986). The shelf-to-basin transition advanced and retreated several times in the Cambrian, but was stationary for most of the Ordovician until the formation of the unstable shelf in Late Ordovician time when the transition retreated to the south and east forming the Cape Phillips Embayment. The Cape Phillips Basin received graptolitic mud and carbonate until the Boothia Uplift was formed in Late Silurian to Early Devonian time. A major source of clastic sediments throughout the

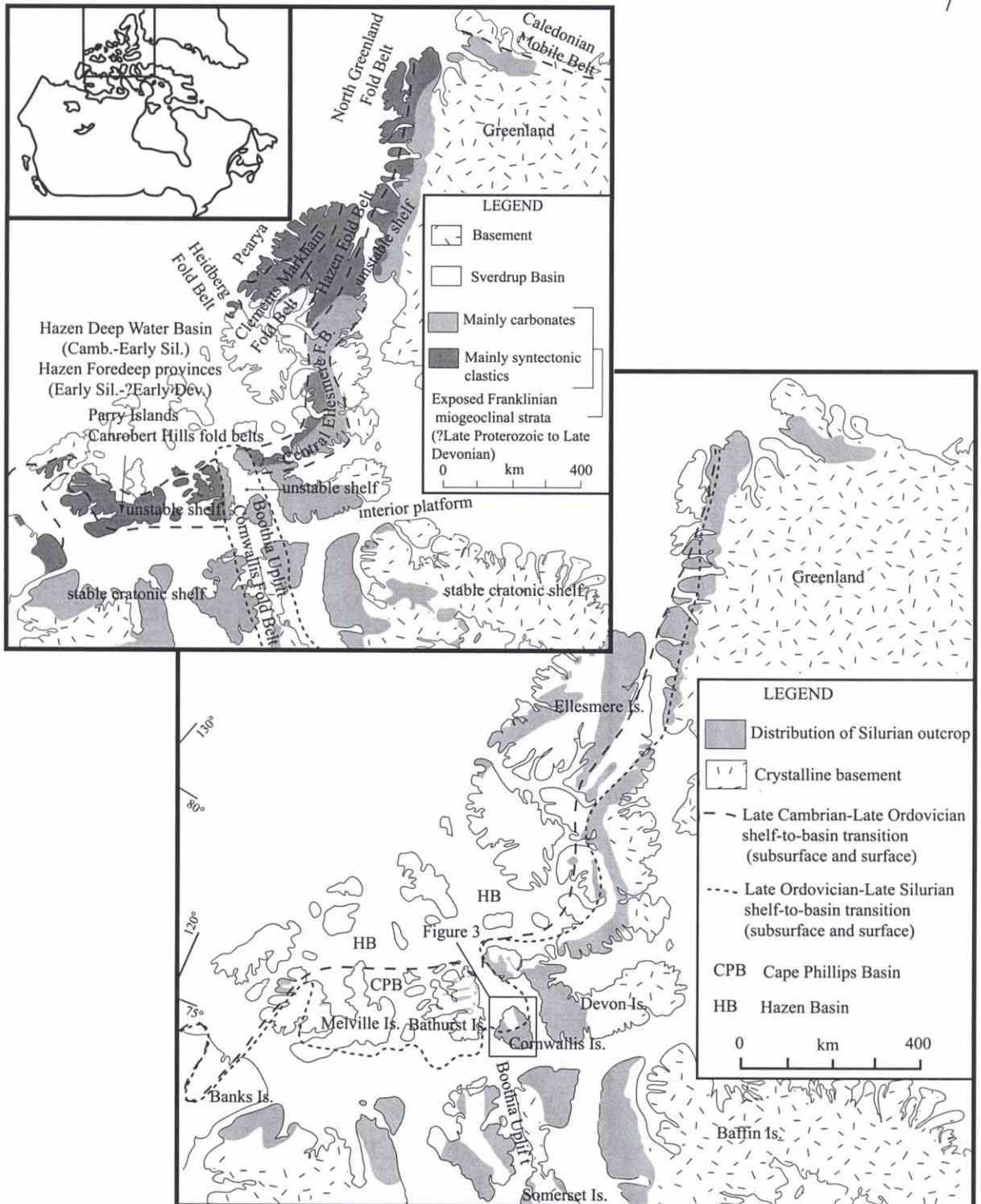


Figure 2. Map of the Canadian Arctic Islands and north-west Greenland showing the general structure and distribution of miogeoclinal Franklinian strata (upper), and the distribution of Silurian strata and the location of the shelf-to-basin transitions before and after the shelf step-back in the Late Ordovician (lower). Modified from de Freitas et al. 1999 (and references therein).

Franklinian succession has been interpreted to be the Caledonian mountains. Through the use of Nd isotope geochemistry, Patchett et al. (1999) demonstrated that sediments from the rising Caledonian mountains were first shed into the Franklinian trough near the time of the Ordovician-Silurian boundary and the Cape Phillips Formation itself retains this Caledonian isotopic signature. The latest phase of plate convergence, the Ellesmerian Orogeny (Thorsteinsson and Tozer 1970), ended the Late Devonian (Fammennian) infilling of the foredeep, that was created during the Caledonian orogeny, with shallow marine and non-marine syntectonic clastics.

Lithostratigraphic Framework and Sequence Stratigraphy

The shelf equivalent facies of the Cape Phillips Formation is the Allen Bay Formation (Thorsteinsson 1958), a thick, extensively exposed, mainly dolomitic shelf unit in the Canadian Arctic Islands (Fig. 3). Despite extensive microfossil sampling across the Ordovician-Silurian boundary strata of the Allen Bay Formation (Mirza 1976; Nowlan 1976; Ryley 1984), the *Oulodus? nathani* Zone has not been recognised, and the middle Member is disconformable on underlying Ordovician strata. This disconformity between the lower and middle members is thought to have developed during the Hirnantian glacioeustatic lowstand, and is supported by the presence of the *bohemicus* graptolite Zone in correlative Cape Phillips Formation strata (Melchin et al. 1991). The latest Ordovician-Rhuddanian transgression began with the flooding and step-back of the Allen Bay shelf and the deposition of *persculptus* Zone graptolitic strata over the shallow water facies. The base of the Silurian, marked by the appearance of *acuminatus*, occurs commonly less than 20 m above the base of the Cape Phillips Formation.

The unstable shelf margin was not entirely stable during deposition of the Cape Phillips Formation. de Freitas et al. (1999) proposed that three Lower Silurian sequences can be identified on the unstable shelf region. The first sequence, which corresponds to Latest Ordovician-Rhuddanian time, was the shelf step-back that formed the Cape Phillips Embayment. This occurred in *fastigatus* Zone time, and was followed by the

		Type Section Thorsteinsson 1958	Cape Phillips Fm. de Freitas and Mayr 1998	Cape Phillips Fm. Melchin 1989	Shelf Equivalent Facies Sodero and Hobson 1979			
Upper Ordovician	Cincinnatian	Lower Silurian						
						Richmondian	Member A	Member A
	Gamachian					Member B		
	Rhuddanian						Member B	Member A
	Aeronian					Member B		
	Llandovery						Member B	Member A
	Telychian					Member B		
	Sheinwoodian						Member C	Member C
	Wenlock					Member C		
	Homerian						Member C	Member C
			Irene Bay Fm.					

Figure 3. Upper Ordovician-Lower Silurian lithostratigraphy of the lower Cape Phillips Formation and shelf equivalent facies on Cornwallis and neighbouring islands.

~~~~~ disconformity



absent due to erosion/non deposition

end-Hirnantian eustatic lowstand. The newly developed shelf-to-basin transition was ramp-like, and was characterised by an absence of shelf reefs (de Freitas and Nowlan 1998).

The second transgressive-regressive sequence began with a major transgression in the latest Rhuddanian that deposited cherty mudrock directly on Allen Bay shelf strata (Mallamo 1989; de Freitas et al. 1999). Further transgressions in the Llandovery are dated at early and late Telychian, the early Telychian being the least prominent. The Aeronian-Telychian succession is characterised by an increase in shelf margin relief, and includes massive reef build-ups on north-west Greenland, sporadic reefs on Ellesmere Island, and a large proportion of grainstone on Devon and Cornwallis Islands (de Freitas et al. 1999). The former ramped shelf-to-basin transition developed into a ramp to rimmed shelf. The occurrence of resedimented carbonate between members B and C (Melchin 1989), a dolomitized shelf edge reef complex in the middle Allen Bay Formation (Sodero and Hobson 1979), and the occurrence of turbidites and debris flows in later Llandovery time demonstrates this shift to higher shelf margin relief. The Allen Bay Formation on Cornwallis Island preserves an inter-island bay complex where graptolitic strata interfinger with evaporitic deposits (Sodero and Hobson 1979; de Freitas et al. 1999); hence, Aeronian and Telychian strata were deposited during a period of climatic aridity.

The third succession corresponds to latest Telychian-early Ludfordian time. Similar to the preceding interval, the rimmed shelf component was further developed, although coral-stromatoporoid reefs, common to the Llandovery interval, tended to be replaced by coral-microbial boundstone build-ups (de Freitas and Nowlan 1998). The reefs of this sequence attained high relief, and coarse allochthonous debris flows are common. Wenlock deposits in the Cape Phillips Embayment tend to be highly condensed.

de Freitas et al. (1999) thus placed major transgressive events in latest Ordovician-Rhuddanian, end Rhuddanian, and end-Telychian time. They proposed that minor transgressions occurred in the Aeronian (mid-*convolutus* graptolite Zone) and early Telychian (*sedgwickii-guerichi* zones).

## *Lithostratigraphy*

The Cape Phillips Formation was originally described by Thorsteinsson (1958) from the type section on Cornwallis Island where he recognized three members. Melchin (1989) and de Freitas and Mayr (1998) also divided the Cape Phillips Formation into three members; however, these all differ significantly (Fig. 3). Melchin (1989) proposed that Member A is of Late Ordovician to middle Llandovery age, and is separated from Member C on Cornwallis, southern Bathurst, western Grinell Peninsula (Devon Island), and central Melville islands by an early to early-latest Telychian member of increased chert and reduced shale content (Member B). Melchin (1989) noted that where Member B does not occur, Member A is separated from Member C by a massive limestone unit. de Freitas and Mayr (1998) proposed that Member A consists of Ashgill, Llandovery, Wenlock and lowest Ludlow strata. In this report, the divisions of Melchin are utilised.

The principal lithologies of the Cape Phillips Formation are calcareous shale, argillaceous limestone, and calcareous siltstone. Detailed section descriptions, including sample descriptions, are given in Appendix B. Stratigraphic logs are illustrated in Appendix C. The location of the stratigraphic sections on Cornwallis Island are illustrated in Figure 4. The thickness of Cape Phillips strata studied and sampled in this study is approximately 750 m. The base of Member A of the Cape Phillips Formation is within the *fastigatus* graptolite Zone (Melchin 1987). Member A is marked at its base by a massive bioturbated dolomitic lime wackestone unit that contains a diverse shelly fauna that Melchin et al. (1991) interpreted as a shallow marine shelf environment within the photic zone. The abundance of benthic fossils indicates that the Late Ordovician basin had not attained fully anoxic conditions. Graptolites, the trilobite *Pseudogygites arcticus* Ludvigsen, and cephalopods within medium- to thin-bedded limestones and variably laminated calcareous shales mark a transition to deeper shelf conditions before a limestone or dolostone unit that characterises the top of the *fastigatus* Zone (from which the first conodont sample was collected in this study). Several cycles of limestone and dolostone, followed by a change to more argillaceous and laminated conditions in the *fastigatus* and *pacificus* graptolite zones are indicative of relative sea

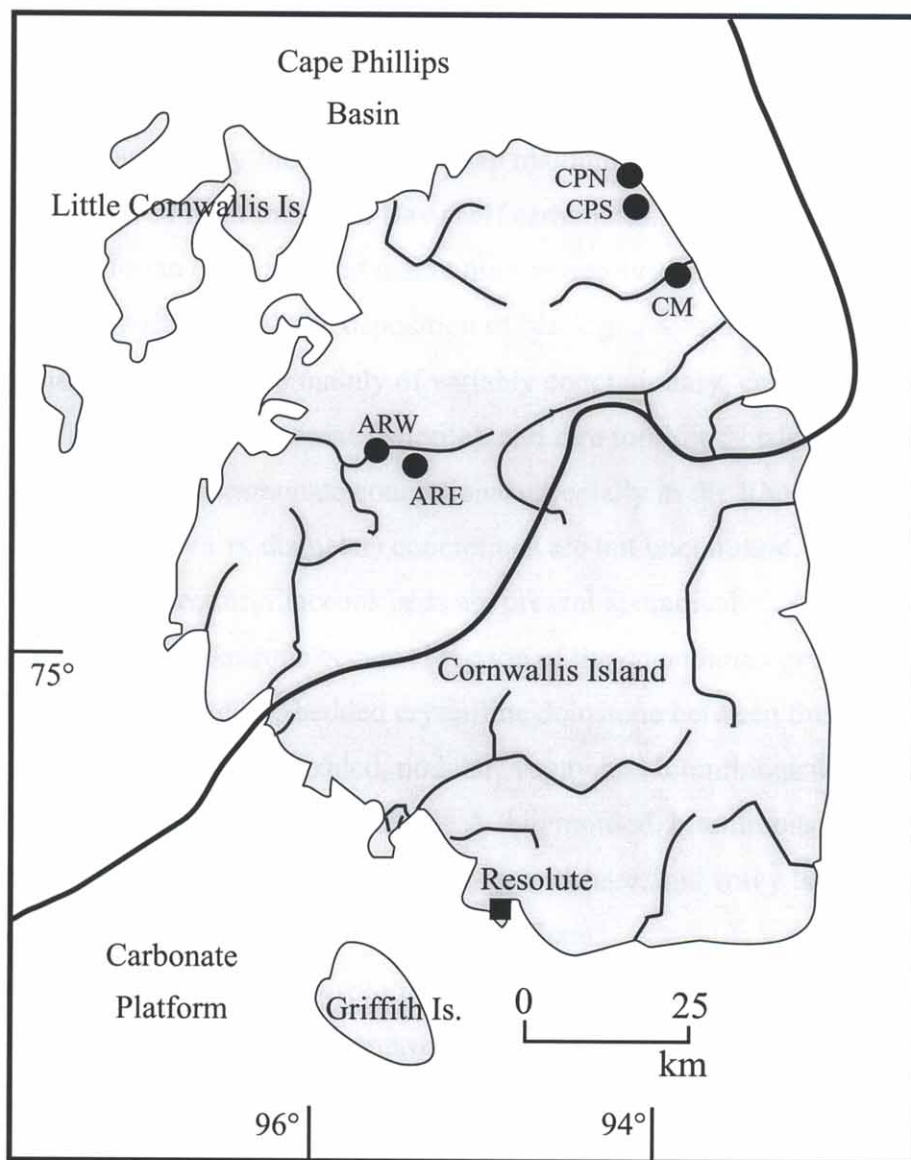


Figure 4. Location of stratigraphic sections on Cornwallis Island and the Silurian shelf-to-basin facies transition (black line). Cape Phillips North (CPN) (Type Section)  $75^{\circ}37'N$ ,  $94^{\circ}30'W$ ; Cape Phillips South (CPS)  $75^{\circ}32'N$ ,  $94^{\circ}31'W$ ; Cape Manning (CM)  $75^{\circ}26'N$ ,  $94^{\circ}20'W$ ; Abbott River West (ARW)  $75^{\circ}14'N$ ,  $95^{\circ}42'W$ ; Abbott River East (ARE)  $75^{\circ}13'N$ ,  $95^{\circ}32'W$ .

level change and switching from oxygenated to dysoxic or anoxic conditions (Melchin 1989). Overlying the massive dolomitic unit of the upper *pacificus* Zone is a greyish-green silty dolostone and dolomitic siltstone unit. Based on the presence of detrital carbonate and quartz, ripples, burrows, and other sedimentary features and the unit's correlation to the *bohemicus* graptolite Zone, Melchin et al. (1991) concluded that this unit correlates with glacially-induced Hirnantian maximum eustatic sea-level fall, and may have been derived from the Allen Bay shelf carbonates. The overlying unit crosses the Ordovician-Silurian boundary and marks the apparently abrupt transition to deeper slope or basinal conditions with the deposition of black graptolitic shale. The succeeding Llandovery strata are composed mainly of variably concretionary, calcareous shale, and argillaceous, thinly-bedded limestone (micrite), and rare turbiditic beds. Some intervals are extremely abundant in carbonate concretions, especially in the Rhuddanian and Aeronian. Very large (> 1 m diameter) concretions are not uncommon, even in Wenlock strata. More massive, less argillaceous beds are present sporadically. About a metre of finely crystalline dolowackestone occurs at the top of the *acuminatus* graptolite Zone, and at least one unit of medium-bedded crystalline dolostone between this and a relatively thick unit of medium-bedded, nodular, vuggy and bituminous dolostone spans the majority of the *acinaces* graptolite Zone. A thin mottled, bituminous, and crystalline vuggy dolostone with pelmatozoan-rich layers near its base, and wavy laminations near its top occurs near the top of the *cyphus* graptolite Zone.

An interval between the *convolutus* and *guerichi* zones, and thus at the Aeronian-Telychian boundary, is composed of approximately 5 metres of flaggy to thin-medium-bedded laminated silty-sandy dolostone that is overlain by black, calcareous shale of the *guerichi* Zone. Melchin (1989) noted that in intervals where Member B is not present, members A and C are separated by a massive limestone unit that does not contain graptolites. Due to its biostratigraphic position, Melchin suggested that this interval should be correlated with the *sedgwickii* Zone. Because of its lithology, no conodont samples were taken from this unit. The overlying shaly interval may represent the minor transgression suggested by de Freitas et al. (1999).

At Cape Phillips North section, the type section of the Cape Phillips Formation, the exposed base is early Telychian, possibly *crispus* graptolite Zone. Calcareous and dolomitic shale are interbedded with thick massive or laminated lime mudstone near the base, with some lime grainstone, mudchip conglomerate and cherty horizons within the *griestoniensis* graptolite Zone. The *crispus-griestoniensis* interval is also present at Cape Manning section 3, and is also variably cherty. Towards the top of the *sakmaricus* graptolite Zone, some grainstone horizons occur irregularly bedded with platy and thinly-bedded laminated lime mudstone. At Abbott River East, the exposed *sakmaricus* Zone interval is marked by undifferentiated laminated, calcareous shale to platy, argillaceous lime mudstone with irregular concretionary intervals. At both sections, however, the *sakmaricus-insectus* zonal boundary is characterised by a platy to thin-bedded concretionless interval that is much less limy than the underlying strata. This marks the base of Member C. At the type section, an interval of flaggy-platy laminated lime mudstone and lime siltstone rich in fish macrofossil debris spans the Llandovery-Wenlock boundary. The interval from the top of the *sakmaricus* and/or base of the *insectus* graptolite Zone on to the base of the *murchisoni* graptolite Zone marks a characteristic break from earlier facies in that it is dominated by shaly to platy, medium-dark grey, laminated, lime mudstone, with few or no concretions.

Member C, ranging from latest Llandovery through Early Devonian, is generally composed of argillaceous lime siltstone, mudstone, and shale and calcareous shale. At Cape Phillips North section, the calcite content is very low in the platy mudstone of the lowest beds; it increases significantly above the first 25 m of Wenlock strata. At the type section, most of the Sheinwoodian Stage is present and is characterised by a monotonous series of argillaceous lime mudstone and calcareous shale with concretionary horizons.

The Sheinwoodian-Homerian boundary interval was sampled at Abbott River West (ABW) Section 1, whereas the lower Homerian and Homerian-Gorstian interval strata were sampled at Abbott River West sections 2 and 3, respectively. Lithofacies at Abbott River West are characterised by an increased proportion of bioclastic beds. These tend to be pelmatozoan and brachiopod rich, commonly with fossils partially pyritized. Sheinwoodian and later Homerian strata have these bioclastic beds every 2-10 m, but

these are not as common in the lower Homeric. P. Noble (pers. commun. 2000) has divided Sheinwoodian-Homeric strata at Abbott River West into informal units. She divided ABW 1 into 2 units (A, B), ABW 2 into three units (A, B, C), and ABW 3 into 3 units also (A, B, C).

The base of the Sheinwoodian is not exposed at these Abbott River sections, and the majority of the Section 1 is within the *perneri* graptolite Zone, the topmost of the stage. Unit A consists of interbedded calcareous shale and medium-bedded calcareous limestone with rare, poorly sorted bioclastic limestone beds. The bioclastic flows tend to have an undulating lower surface and commonly pinch out laterally. Large concretions, up to 0.5 m in diameter, are common in various horizons in this unit. Unit B is characterised by a larger proportion of bioclastic limestone beds than the underlying unit, and the shale is platy. The Sheinwoodian-Homeric stage boundary occurs at approximately 50 m above the base of ABW Section 1, about 2 m below the top of the section.

Section 2 is confined to the lowermost Homeric *lundgreni* graptolite Zone. Unit A consists of poorly exposed calcareous shale and a few rare bioclastic limestone beds. The top of the uppermost bioclastic bed marks the base of Unit B. This unit is better exposed and marks the transition to a small cliff-forming interval on the outside of a meander of the tributary of the Abbott River. Large concretions are present in this interval, but otherwise the thin-bedded calcareous shale tends to be strongly laminated. Pyrite-rich strata are common. Unit C marks a transition to shaly carbonate as a dominant lithology. Large (1 m diameter) concretions and pyrite are common. The concretions are dolomitic and the carbonate is indurated (very hard, and difficult to process with acid dissolution).

The stratigraphically highest section at Abbott River West ranges from the *testis-lundgreni* through the *deubeli*, "highest Wenlock fauna" zones and into the lowermost Ludlow. Unit A is composed of indurated medium-thick-bedded shaly limestone with abundant 20-50 cm diameter concretions. Bioclastic limestone beds are common, and are intercalated as slumped medium to thick-beds every 1-2 m. Similar to earlier bioclastic beds, these are also poorly sorted, and rich in pelmatozoans and shelly fauna. The base

of Unit B is a graded bioclastic limestone bed that passes into a shaly interval, and then another bioclastic limestone bed, a further shaly interval, and another relatively thick bioclastic interval. Bioclastic beds in Unit B are rich in shell hash at their bases. The *lundgreni* Event, marking the extinction of *Cyrtograptus* and most monograptids, occurs in the shaly interval between the two lower bioclastic turbidites in Unit B. Unit C is a markedly yellow-weathering calcareous shale interbedded with medium-bedded bioclastic limestone beds approximately every 4 m. The *ludensis* Event occurs between 33.5 and 40 m above the base of ABW3, marking the Wenlock-Ludlow boundary.

## *Biostratigraphy*

### *Introduction*

Of the 180 samples taken from the Cape Phillips Formation, 118 yielded a total of 7,575 conodont elements. Of those that did not yield, most were not digestible using traditional techniques because they were too finely laminated, indurated, silty, dolomitic, or any combination of these factors. Most indigestible samples were from strata near the Ordovician-Silurian boundary, the Llandovery-Wenlock boundary and, to a lesser extent, from the early Telychian and middle Wenlock. Conodont yields per kilogram are commonly relatively low from Silurian rocks compared to Ordovician rocks, and typically contain more diverse faunas in the Telychian than the succeeding stages of the Llandovery. Conodont distribution data, including element totals and yields/kg are provided in Appendix A. Yields/kg varied from 50-180 elements/kg in the limited latest Ordovician samples, 20-30 elements/kg for the Rhuddanian and Aeronian, over 100 elements/kg for latest Llandovery, and 20-30 elements/kg for most of the Wenlock samples.

The conodont elements in this study were exquisitely preserved and delicate; thin specimens were translucent. The conodont colour alteration index (CAI) of the elements is 1 indicating burial temperatures of less than 90°C, although some elements, typically larger ones like the Pa elements of *Pterospathodus*, are much darker amber colour. A detailed zonation chart for the Cape Phillips Formation and relevant studies worldwide is illustrated in Figure 5. Conodont ranges are illustrated in Appendix C with stratigraphic sections and sample spacing.

### *Previous Biostratigraphic Studies*

This study was integrated during sampling with the detailed graptolite biostratigraphy that had been constructed over a number of field seasons to study the Cape Phillips Formation graptolite fauna. Upper Ordovician graptolites from the Cape

| U.S. SYSTEM    | LUD. SERIES | STAGES      | CP Fm. Graptolite Zones    | Cape Phillips Fm. Conodont Zones Herein | Std. Conodont Zonation Silurian Times n. 3 1995 | Carnic Alps Walliser 1964 | Greenland Armstrong 1990 Shelf Slope | Canadian Cordillera McCracken 1991b | Anticosti <sup>2</sup> | NWT Over and Chatterton 1987 | Australia Bischoff 1986; Simpson 1995 | Gotland Jeppsson 1997 | Oklahoma Barrick and Klapper 1976 | Std. Graptolite Zonation Silurian Times n. 3 1995 |                             |                                                  |
|----------------|-------------|-------------|----------------------------|-----------------------------------------|-------------------------------------------------|---------------------------|--------------------------------------|-------------------------------------|------------------------|------------------------------|---------------------------------------|-----------------------|-----------------------------------|---------------------------------------------------|-----------------------------|--------------------------------------------------|
| UPPER ORD.     | CINCINNATI  | GAMACHIAN   | progenitor                 |                                         | <i>K. stauros</i>                               | " <i>O. crassa</i> "      |                                      | <i>O. bohemia</i>                   |                        | <i>O. bohemia</i>            | UNZONED                               |                       | lower <i>K. variabilis</i>        | <i>nilsoni (colonus)</i>                          |                             |                                                  |
|                |             |             | <i>ludensis</i>            | UNZONED                                 | <i>O. bohemia</i>                               | " <i>S. sagitta</i> "     |                                      |                                     |                        |                              |                                       | <i>K. stauros</i>     |                                   | <i>ludensis</i>                                   | <i>praedenbelli-deubeli</i> |                                                  |
|                |             |             | <i>praeuebelli-deubeli</i> |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>parvus-massa</i>                              |
|                |             |             | <i>nassa</i>               |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>lundgreni</i>                                 |
|                |             |             | <i>testis-lundgreni</i>    |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>rigidus-perneri</i>                           |
|                |             |             | <i>opimus</i>              |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>riccartopensis-bellophorus</i>                |
|                |             |             | <i>astrenuus-kolobus</i>   |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>centrifugus-murchisoni</i>                    |
|                |             |             | <i>murchisoni</i>          |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>lapworthi-insectus spiralis interval Zone</i> |
|                |             |             | <i>centrifugus</i>         |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>griestoniensis-eremulata</i>                  |
|                |             |             | <i>insectus sokmaricus</i> |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             | <i>turricalatus-crispus</i>                      |
| MIDDLE ORD.    | TELYCHIAN   | RHUD-DANIAN | <i>sokmaricus</i>          |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>griestoniensis</i>      |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>crispus</i>             |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>turricalatus</i>        |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>guerichi</i>            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>sedgwickii</i>          |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>convolutus</i>          |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>curtus</i>              |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>cyphus</i>              |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>acinaces</i>            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
| LOWER SILURIAN | LUDOVICAN   | TELCHIAN    | <i>atavus</i>              |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>stutzini</i>            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>maderni-lubricus</i>    |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>persculptus</i>         |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>bohemicus</i>           |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>pacificus</i>           |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             | <i>fastigatus</i>          |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             |                            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             |                            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |
|                |             |             |                            |                                         |                                                 |                           |                                      |                                     |                        |                              |                                       |                       |                                   |                                                   |                             |                                                  |

Figure 5. <sup>1</sup>M. Melchin, A. Lenz (pers. comm. 2000); <sup>2</sup>McCracken and Barnes (1981); Uyeno and Barnes (1983).

Phillips Formation were described by Melchin (1987). Preliminary work on the Ordovician-Silurian boundary on Cornwallis and Truro islands, including the Cape Manning section studied here, is detailed in Melchin et al. (1991). Melchin (1989) also constructed the Llandovery graptolite biostratigraphy of the Cape Phillips Formation, whereas Lukasik and Melchin (1997) developed the taxonomy and biostratigraphy of Early Silurian graptolites from the Cape Manning section. Wenlock graptolite biostratigraphy of Cape Phillips strata on Cornwallis Island and adjacent areas was documented by Lenz and Melchin (1990,1991), Lenz (1993a, b), and Lenz (1995). Melchin and Mitchell (1991) detailed the Late Ordovician graptolite extinction worldwide, with reference to sections in northwestern and Arctic Canada. Melchin (1994) demonstrated a high rate of graptolite extinction over the Llandovery-Wenlock boundary in the British Isles, Arctic Canada, and Lithuania in apparent coincidence with sea-level fall.

Early conodont work in the Canadian Arctic was completed by Weyant (1968) on Hoved Island. Ordovician conodonts from the Canadian Arctic were described by Barnes (1974; 1977) In an unpublished M.Sc. thesis, Mirza (1976) described the strata and conodont faunas from the Allen Bay, Irene Bay and Cape Storm Formations on Devon and Ellesmere Islands. Nowlan (1976), in a largely unpublished PhD thesis, detailed the Late Cambrian to Late Ordovician (up to, and including, the Irene Bay and Allen Bay formations) conodont biostratigraphy from sections on Devon and Ellesmere Islands. Uyeno (1977) summarised the conodont biostratigraphy of the Read Bay Formation on Cornwallis Island. Landing and Barnes (1981) described Lower Ordovician conodonts from southern Devon Island. In a bachelor's thesis, Ryley (1984) completed biostratigraphic work on the lower Allen Bay Formation on Cornwallis Island, including strata from below and above the Ordovician-Silurian boundary. McCracken and Nowlan (1989) reported Late Ordovician conodonts from Southampton, Baffin, and Akpatok islands. Conodont biostratigraphic data for Upper Ordovician through Middle Devonian strata in the eastern Arctic, including samples from the Cape Phillips Formation are available in Uyeno (1990).

### *Conodont Biostratigraphy*

Unlike Ordovician conodonts that exhibited a high degree of provincialism, Silurian conodonts do not show a separation of Atlantic and Midcontinent faunal realms, although Silurian shelly faunas do exhibit some degree of provincialism (e.g. Boucout, 1990). The transition to a cosmopolitan conodont distribution occurred abruptly following the end-Ordovician extinction, and was maintained throughout Lower Silurian time (Barnes et al. 1973).

Walliser (1964, 1972) pioneered the first Silurian zonal scheme from the Cellon section, Carnic Alps, Austria. He proposed 11 conodont zones, the lowermost of which, Bereich I, contains upper Ordovician faunas at its base and *Icriodina irregularis*, the form species representing the Pa element of *Distomodus kentuckyensis* in the upper part, and was followed by the *celloni* and *amorphognathoides* zones of the Telychian. Since that time, numerous studies elsewhere supported and modified this zonal scheme, and it is now clear that the Cellon section contains some hiatuses. Aldridge (1972; 1975) established the *Icriodella discreta*-*I. deflecta*, (*D.*) *staurognathoides*, *Icriodella inconstans* and *Pterospathodus amorphognathoides* assemblage zones for Wales and the Welsh Borderland. It was recognised that the oldest Llandovery faunas were not present, the strata being sandstone together with a hiatus at the Ordovician-Silurian boundary.

In North America, workers were relatively successful correlating strata to the European zonation. This included the correlation of strata in the Niagara Gorge with Walliser's European Silurian zones (Rexroad and Rickard 1965), and the recognition of the upper part of Walliser's Bereich I interval in the Brassfield Formation in the Cincinnati Arch region of Kentucky and Ohio (Rexroad 1967). The *Icriodina irregularis* Assemblage Zone (= *D. kentuckyensis*) was proposed for the Brassfield, and in higher strata, the *celloni* Zone and *amorphognathoides-ranuliformis* Assemblage Zone were present in the Lee Creek Member and overlying Salamonie Dolomite. Conodonts of the *Icriodina irregularis* (= *D. kentuckyensis*) Zone and older faunas including *Spathognathodus* (= *Ozarkodina*) *hassi* and *Spathognathodus* (= *Ozarkodina*) *oldhamensis*, now known to be common in lowermost Silurian strata were recovered

from strata in northern Michigan and Ontario (Pollock et al. 1970). An interval between the top of the Ordovician and the base of the *I. irregularis* (= *D. kentuckyensis*) that contained only *Panderodus simplex* and *P. unicostatus* was defined as the *Panderodus simplex* Assemblage Zone, which Pollock et al. (1970) considered to correspond to the lower part of Walliser's Bereich I interval. The Brassfield was subsequently reassessed in multielement taxonomic terms by Cooper (1975), who also noted that the *Panderodus simplex* Zone is based on a long-ranging species and may be environmentally controlled. Indeed, the form species *Panderodus simplex* is synonymous with the compressiform element of the long-lived *Panderodus unicostatus* (Branson and Mehl) (Rexroad et al. 1978). All the above sequences were thus characterised by hiatuses, notably at the base of the Llandovery.

More recent work has refined the conodont zonation of the Ordovician-Silurian boundary and the Llandovery. Cooper (1980) attempted to improve Silurian conodont biostratigraphy by proposing a series of datums based on phylogenetic lineages and extinctions of well-documented species, including the appearance of *Distomodus stauognathoides*, *Pterospathodus amorphognathoides*, and the extinction of *Pterospathodus*. McCracken and Barnes (1981) showed that the base of the Silurian lies within the *Oulodus? nathani* Zone (Fig. 5), which has subsequently been found in the Mackenzie Mountains, Northwest Territories (Over and Chatterton 1987; Nowlan et al. 1988), and Nevada (Finney et al. 1999). Additionally, they recognised the underlying Gamachian Stage and *G. ensifer* Zone based on the abundance and range of the two new conodont species in the new genus *Gamachignathus*. The term Gamachian had been previously suggested by Twenhofel (1928) for the interval between the Richmondian and Anticostian series represented by the Ellis Bay Formation on Anticosti Island.

Armstrong (1990) proposed a zonation for North Greenland (Fig. 5), which generally lacked the typical zonal taxa such as *Distomodus* or *Icriodella*. In pre-*P. amorphognathoides* Zone and *P. celloni* Zone strata, Armstrong distinguished between shelf and slope and outer shelf biofacies, the former characterised by a 'Lower Silurian Fauna' or pre-*celloni* Zone fauna which consisted of *Ozarkodina hassi*, *Kockelella manitoulinensis*, *O. excavata* and *Panderodus unicostatus*. This followed an interval that

Armstrong correlated with the Ordovician Fauna 12 of Sweet et al. (1971) and Sweet and Bergström (1971), this barren interval he thought might be correlative with the Gamachian Stage of McCracken and Barnes (1981). In the pre-*celloni* Zone slope and outer shelf biofacies, Armstrong (1990) subdivided the Llandovery into the *Aspelundia expansa* (= *A. petila*) and *Aspelundia fluegeli* zones which appear after the barren interval and in the lower Aeronian stage, respectively. However, as McCracken (1991b) noted, the correlation of the base of the *A. fluegeli* Zone to the graptolite zonation in the Cape Schuchert Formation is tenuous and only indicates that it could be as low as the *convolutus* or underlying *argenteus* graptolite zones and could be as high as the *turriculatus* graptolite zone (see discussion in biozones section).

McCracken (1991b) proposed a zonation for the offshore basinal facies of the Road River Formation in the Canadian Cordillera that was similar to that of Armstrong (1990) (Fig. 5). He proposed the ?*D. obliquicostatus*, *A. petila* and *A. fluegeli* zones for pre-*P. celloni* Zone strata. The base of the *A. fluegeli* Zone was placed at the latter part of the *argenteus* graptolite Zone, in reference to the possible lowest occurrence in North Greenland; in the northern Yukon sections of the Cordillera, however, he found that the lower limit of *A. fluegeli* was likely in the lowest part of the *turriculatus* graptolite Zone. He concluded that *Aspelundia* might appear earlier in basinal environments, while in shelf strata it ranges from at least the *P. celloni* through the *P. amorphognathoides* zones. The *Aspelundia-Dapsilodus* fauna dominated the Llandovery until the appearance of the *Pterospathodus* zonal species in the Telychian *turriculatus* graptolite Zone, as elsewhere.

Rather different zonation schemes are those from Australasia, especially those of Bischoff (1986), Simpson (1995) and Simpson and Talent (1995) for Australia (Fig. 5); however, although there are some differences in the faunas, most key zonal taxa are present. Bischoff's zonation differs in that it includes zones defined on species of *Distomodus*, *Ozarkodina* and *Pterospathodus* only yet recognised in Australia. The rich diversity of species in these genera, along with those of *Aulacognathus* and *Oulodus* permitted Bischoff to trace the possible phylogeny of these conodont groups and aided in refinement of the zonation.

A refined conodont biostratigraphic zonation of the Wenlock has proven more difficult to achieve. Barrick and Klapper (1976) proposed a phylogeny for *Kockelella* (refined by Serpagli and Corradini 1998) on which they established four zones that followed the *P. amorphognathoides* Zone in the Clarita Formation of Oklahoma (Fig. 5). They postulated that their *K. ranuliformis* - *K. amsdeni* - *K. stauros* - *K. variabilis* zones could be correlated with Walliser's (1964) *patula* through *crassa* zones in the Carnic Alps. They were not able to confidently correlate the base of the Cellon section with the Clarita Formation, however, because of the uncertainties surrounding the chronostratigraphic range of *Kockelella patula*.

On Gotland, Jeppsson (1997b) proposed a high-resolution scheme to divide the Ireviken event datum planes over the Llandovery-Wenlock boundary and the succeeding typical Wenlock faunas. The biostratigraphic zonation is very detailed, although it was achieved by processing very large samples in some cases. Jeppsson (1997, figure 4) recognised many of the bioevents in Europe, Australia and North America. Corradini and Serpagli (1998) recently proposed a conodont biozonation for late Llandovery to end Pridoli in Italy which agrees well with others that have been proposed globally, and is based largely on the distribution of ozarkodinids in the Wenlock.

In terms of the standard global correlation charts as used in this report, Aldridge and Schönlaub (1989) considered all the available data and constructed a new global correlation chart that utilised the occurrences of ozarkodinids in the Wenlock and the typical Llandovery zonal species. An updated version of the global chart appeared in the *Silurian Times* no. 3, 1995 (see Figure 5).

## CAPE PHILLIPS FORMATION BIOZONES

In the following, 11 conodont zones are recognized, 1 of which is new, and 3 of which are modified (Fig. 5). The zones are integrated with the graptolite zonation (Fig. 5). In most cases the graptolite zone marking or nearest to the base of the conodont zone being defined is given. The conodont zone marking the base of the zone defines the upper limit of the preceding zone. Associated conodonts are listed alphabetically. A composite conodont stratigraphic range chart (Fig. 6) is illustrated at the end of this section.

*AMORPHOGNATHUS ORDOVICICUS* ZONE

*Definition.* The lower boundary of this zone is marked by the first appearance of *Amorphognathus ordovicicus*.

*Reference section.* Cape Phillips South, 19.7-22.5 m.

*Graptolite integration.* *fastigatus* through *persculptus* zones (but species persists through into the lowermost *acuminatus* Zone (Melchin et al. 1991)).

*Other conodonts.* *Belodina confluens*, *Besselodus borealis*, *Coelocerodontus trigonius*, *Decoriconus fragilis*, *Drepanoistodus suberectus*, *Eocarniodus carnulus*, *Panderodus unicostatus*, *Paroistodus* sp. A, *Protopanderodus insculptus*, *Pseudobelodina dispansa*, *Pseudooneotodus beckmanni*, *Pseudooneotodus mitratus*, *Walliserodus curvatus*.

*Remarks.* *Amorphognathus ordovicicus* is diagnostic of faunas 11-13 (Bergström 1971) (late Maysvillian to Gamachian) of the Midcontinent Province and the Ashgillian of the North Atlantic Province. It was recovered from the lowest strata sampled in this study, from the near the top of the *fastigatus* graptolite Zone. Melchin et al. (1991) recovered *A. ordovicicus* from the *persculptus* Zone with a typical Late Ordovician conodont fauna, as

well as with a transitional fauna containing early Silurian conodonts. Additionally, they recovered mixed faunas containing *A. ordovicicus* from within the lower *acuminatus* graptolite Zone.

*OULODUS? NATHANI ZONE*

*Definition.* The lower boundary of this zone is marked by the first appearance of *Oulodus? nathani*.

*Reference section.* Cape Phillips South, base of the *acuminatus* graptolite Zone 29.0 m above the base of the measured section.

*Graptolite integration.* *persculptus* Zone (in Melchin et al. 1991) through lowermost *acuminatus* Zone (*madernii-lubricus* Subzone).

*Other conodonts.* *Decoriconus fragilis*, *Dapsilodus obliquicostatus*, *Distomodus kentuckyensis*, *Oulodus? kentuckyensis*, *Ozarkodina hassi*, *Pseudooneotodus beckmanni*, ?*Walliserodus curvatus*.

*Discussion.* Melchin et al. (1991) provided preliminary data for various Ordovician-Silurian boundary sections of the Cape Phillips Formation. At Cape Manning, they found a mixed fauna, containing *Amorphognathus ordovicicus*, *Drepanoistodus suberectus*, and *Panderodus gracilis* (= *P. unicastatus* herein) together with *Oulodus? kentuckyensis* 1.1 m below the base of the *acuminatus* graptolite Zone. Further samples slightly higher in the section also yielded mixed faunas that included *A. ordovicicus* and *Ozarkodina* cf. *O. hassi* 30 cm above the base of the *acuminatus* Zone, and another transitional fauna sample about 1 m above the base of the *acuminatus* Zone. The first sample yielding *D. kentuckyensis* was recovered from about 1.5-1.7 m above the base of the *acuminatus* Zone. Some evidence of a transition fauna was also found by Melchin et al. (1991) at Eleanor Lake where a lower *acuminatus* Zone sample contained an *Oulodus?* element of *A. ordovicicus* Zone aspect.

In the samples studied here, those from the *persculptus* graptolite Zone yielded only *Decoriconus fragilis*, and only from the Cape Phillips South section. Concretions that dissolved reasonably from the upper part of the *persculptus* Zone at Cape Manning

were barren except for possibly one broken and abraded *Drepanoistodus* element in the middle part of the *persculptus* Zone.

Although Melchin et al. (1991) did not recognise the nominate species of the *Oulodus? nathani* Zone at Cape Manning, the species occurs in two samples here. The first, at Cape Phillips South section, was recorded precisely at the base of the *acuminatus* graptolite Zone in association with *Oulodus? kentuckyensis*, *Ozarkodina hassi*, *Distomodus kentuckyensis*, *Decoriconus fragilis*, *Dapsilodus obliquicostatus* and *Pseudooneotodus* sp. Further samples higher in the section at Cape Phillips South did not yield *Oulodus? nathani*, despite relatively good yields of *Oulodus? kentuckyensis*, *Ozarkodina hassi* and *Decoriconus fragilis*. A single Pa element of *O.? nathani* was also identified at Cape Manning Section 2 in association with *O. hassi*, *D. obliquicostatus*, and *Pseudooneotodus beckmanni* from the top of the *madernii-lubricus* Subzone of the *acuminatus* graptolite Zone. The absence of *O.? nathani* from high-yielding samples that produced *O.? kentuckyensis*, *Ozarkodina hassi* and *O. oldhamensis* (although the latter species is not present at Cape Phillips) in the *atavus* graptolite Zone at Cape Manning and Cape Phillips South as well suggests that the upper range of *O.? nathani* may lie within the middle part of the *acuminatus* Zone near the top of the *madernii-lubricus* Subzone.

Lower *acuminatus* Zone sections yielding conodonts are rare worldwide. The *O.? nathani* Zone was first defined on Anticosti Island as a pre-*Distomodus kentuckyensis* interval (McCracken and Barnes 1981) which, in addition to the nominate species, contained *O.? kentuckyensis*, *Ozarkodina hassi*, *O. oldhamensis*, and *Walliserodus curvatus*. The base of the *O. nathani?* Zone corresponds to the first appearance of the nominate species, and was defined to extend up to the base of the *D. kentuckyensis* Zone, with the majority of the taxa present in the *O.? nathani* Zone extending into the overlying Zone. McCracken and Barnes (1981) defined the base of the Silurian at the first appearance of *Ozarkodina*, some 2-3 m above the base of Member 6 of the Ellis Bay Formation, but noted that this was somewhat arbitrary because of the presence of transitional zones 1-1.5 m in thickness where Ordovician taxa co-occur with *Ozarkodina*. The appearance of *O.? nathani* with *O. hassi* and *O. oldhamensis* at the base of the *acuminatus* Zone is difficult to explain considering that Melchin et al. (1991) found

mixed faunas below and above the base of the *acuminatus* Zone at Cape Manning without the presence of the nominate species, although the samples from both these zones in this present study were barren except for *Decoriconus fragilis*.

Melchin et al. (1991) did not recover *Distomodus kentuckyensis*, but it was questionably recovered here from the base of the *acuminatus* Zone at Cape Phillips South and similarly at Cape Manning. The very low yields (lack of Pa elements) of *Distomodus kentuckyensis* precludes the ability to test whether *D. kentuckyensis* is present in boundary strata, although Pa elements of the species are present at least by the *atavus* graptolite Zone. An isolated Sa element of *Walliserodus curvatus* also occurs in a sample before one that yields *O.? nathani* at Cape Manning 2. Its early re-appearance after the Ordovician extinction and low frequency in the earliest Silurian is similar to that found on Anticosti Island.

*Dapsilodus obliquicostatus*, a taxon not found until the middle of the *D. staurognathoides* Zone on Anticosti Island (Uyeno and Barnes 1983), is found on Cornwallis Island in this interval, sharing its earliest appearance with *O.? nathani*.

***DAPSILODUS OBLIQUICOSTATUS-DECORICONUS FRAGILIS* INTERVAL ZONE**

*Definition.* Interval between last appearance of *O.?* *nathani* and first appearance of *Aspelundia petila*.

*Reference section.* Cape Manning Section 2, 4.0 m above the base of the measured section.

*Graptolite integration.* Uppermost *madernii-lubricus* Subzone of *acuminatus* Zone to the middle *atavus* Zone.

*Other conodonts.* *Decoriconus fragilis*, *Distomodus kentuckyensis*, *Oulodus?* *kentuckyensis*, *Ozarkodina hassi*, *Panderodus unicastatus*, *Pseudooneotodus beckmanni*, *Pseudooneotodus* sp., *Walliserodus curvatus*.

*Remarks.* McCracken (1991b) proposed the *D. obliquicostatus* Zone as a first appearance biozone based on the first appearance of the nominate species. *Dapsilodus obliquicostatus* was recovered from *gregarius* graptolite Zone beds in the northern Yukon sections associated with *Decoriconus fragilis*. Based on his unpublished data, McCracken (1991b) thought that *D. obliquicostatus* probably ranged into older strata. In fact, *D. obliquicostatus* does appear at the base of the *acuminatus* Zone with *O.?* *nathani* at Cape Phillips South section, and about 3.5 m above the Ordovician-Silurian boundary at Cape Manning section 2. Because the two appear together, the last occurrence of *O.?* *nathani* in the Arctic samples is taken to define the base of the *D. obliquicostatus*-*D. fragilis* Interval Zone. This interval zone is equivalent to most of the *Distomodus kentuckyensis* Zone (specimens of which are present in this interval), both of which, according to the standard zonation (Silurian Times n. 3, 1995), terminate near the Rhuddanian-Aeronian boundary. Confident identification of *Distomodus kentuckyensis* is difficult because of the sparse occurrence of elements of the species, and without the Pa element, distinguishing between *D. kentuckyensis* and *D. staurognathoides* is not possible. In slope sequences, where *Dapsilodus* and *Decoriconus* are much more

abundant, the *Dapsilodus obliquicostatus-Decoriconus fragilis* Interval Zone is preferred. Specimens of the *Decoriconus fragilis* were equally as common as those of *D. obliquicostatus*, hence both are included in the name.

*ASPELUNDIA PETILA ZONE*

*Definition.* The lower boundary of this zone is defined by the first appearance of the nominate species.

*Reference section.* Cape Manning Section 2, 16.1 m or 33.2 m above the base of the measured section.

*Graptolite integration.* *atavus* Zone? or *cyphus* Zone to the middle or upper *turriculatus* Zone.

*Other conodonts.* (Lowermost part of the zone: *Oulodus? kentuckyensis*, *Ozarkodina hassi*, *O. oldhamensis*), *Dapsilodus obliquicostatus*, *Decoriconus fragilis*, *Distomodus* (*D. staurognathoides* or *D. kentuckyensis*), *Panderodus unicostatus* (until *convolutus* graptolite Zone), *Pseudooneotodus beckmanni*, *Pseudooneotodus* sp., *Walliserodus curvatus*.

*Remarks.* The first sample to yield the full apparatus of *Aspelundia petila* was recovered from the mid-*cyphus* graptolite Zone strata at Cape Manning 2. Samples between the *atavus* Zone sample mentioned below and this *cyphus* Zone sample did not yield *A. petila*, but did contain a relatively rich typical *D. kentuckyensis* Zone fauna (*Dapsilodus obliquicostatus* zone of McCracken 1991a) fauna of *Distomodus* (*kentuckyensis?*), *W. curvatus*, *D. obliquicostatus*, *D. fragilis* and *P. unicostatus*. Samples from the *atavus* Zone at Cape Phillips South and Cape Manning 2 (pl. 3, fig. 1) however, yielded elements of the form species "*Neoprioniodus*" *planus*, an element that in multielement taxonomy has been assigned to the apparatus of *Aspelundia* and the species *Ozarkodina pirata* (Uyeno) the latter of which is limited to Gun River and lower half of the Jupiter formations at Anticosti, and hence is too young to be considered here. The occurrence of these planiform elements with *Oulodus? kentuckyensis* may suggest that the genus *Aspelundia* is related to this lower Llandovery species, although the M

(euprioniodiniform) elements of *O. kentuckyensis* are more similar to the M<sub>3</sub> element of *Aspelundia fluegeli* than they are to the M element of *A. petila*.

The disappearance of this M element, or any other element in the apparatus of *Aspelundia*, after the *atavus* Zone and until the *cyphus* Zone is interesting. It is possible that a shallowing upward trend characterised the *atavus* and *acinaces* zones, demonstrated by the vuggy and bituminous dolomitic unit that composes most of the *acinaces* Zone. A return to calcareous shale deposition in the *cyphus* Zone marks the reappearance of *A. petila*. Hence, the early M elements may be a biofacies response, and this early occurrence of the taxon may represent a brief migration of the genus from the deeper offshore realm.

In other studies, the earliest appearance of *A. petila* is from the *gregarius* or possibly the *cyphus* Zone in Australia (Bischoff 1986), uppermost *D. staurognathoides* Zone (Uyeno and Barnes 1983), the lowermost Aeronian at the base of the Gun River Formation (Zhang and Barnes in press) on Anticosti Island, the upper *P. amorphognathoides* Zone in the Mackenzie Mountains (Over and Chatterton 1987), and from the *P. amorphognathoides* Zone in Norway (Aldridge 1974; Aldridge and Mohamed 1982). The range of *A. petila* in North Greenland is probably early Aeronian, and perhaps as old as latest Rhuddanian (Armstrong 1990).

*ASPELUNDIA FLUEGELI ZONE*

*Definition.* The lower boundary of this zone is defined by the first appearance of the nominate species.

*Reference section.* Cape Phillips North section, base of measured section (0 m).

*Graptolite integration.* *crispus* Zone?, possibly *turriculatus* Zone to the middle *crispus* Zone.

*Other conodonts.* *Aspelundia* cf. *A. borenorensis*, *Panderodus unicostatus*, *Pterospathodus celloni*, *Walliserodus* cf. *W. sancticlairi*.

*Remarks.* At Cape Manning section 2, *Aspelundia petila* ranges at least up into the *turriculatus* Zone. The last sample that yielded *A. petila* is some 7 m above the base of the *turriculatus* Zone, however, the final 14 m of strata yielded no conodonts.

Between Cape Manning 2 and 3 there is a covered interval of at most a few tens of metres. These represent the remainder of the *turriculatus* Zone and possibly the lowermost portion of the *crispus* Zone, the latter of which is present at least by 2 m above the base of Cape Manning 3. The highest sample yielding unquestionable elements of *A. petila* occurs at 10 m, close to the top of the *crispus* Zone? at Cape Manning 3. A few isolated elements assigned to *A. petila* from 40 m (*griestoniensis* graptolite Zone) at the section may include elements of *A. fluegeli*. By 49 m, *Aspelundia* cf. *A. borenorensis* and *Walliserodus* cf. *W. sancticlairi* appear, and by 79 m *Aspelundia fluegeli* is definitely present. Samples at Cape Manning 3 were low yielding and did not dissolve well, and because a short covered interval occurs between Cape Manning 2 and 3 representing the uppermost and perhaps lower parts of the *crispus* Zone?, the lower limit of *A. fluegeli* may be near the *turriculatus*-*crispus* zonal boundary, which is in agreement with a probable *turriculatus* zone assignment in the northern Yukon sections of McCracken (1991b).

*Aspelundia fluegeli* is present at the base of the Cape Phillips North section, along with *A. cf. A. borenorensis* and *Walliserodus cf. W. sancticlairi*, in strata assigned to the lowermost *griestoniensis* or possibly *crispus* Zone. Although all elements were assigned to *A. fluegeli* at this section, a few isolated elements may be attributed to *A. petila* in the lowermost 10 m.

In northern Yukon (McCracken 1991b), *A. fluegeli* appears at least by the *turriculatus* graptolite Zone, or even as low as a zone in between the *turriculatus* and *convolutus* graptolite zones. McCracken (1991b, p. 75) also provided significant evidence that *A. fluegeli* appears before the *P. celloni*, and hence found that the *celloni* Zone overlies the *fluegeli* Zone. Armstrong (1990) argued that the appearance of *A. fluegeli* in North Greenland is within the *argenteus* graptolite Zone (equivalent to the upper part of the *curtus* graptolite Zone in the Arctic). As McCracken (1991b) noted, however, Armstrong's data and correlations indicate that it can only be placed within or below the *turriculatus* Zone, although possibly as low as the *convolutus* or *argenteus* zones. In Australia (Bischoff 1986), the *A. petila* and *A. fluegeli* appear together in the *M. triangulatis* Zone or possibly even the *cyphus* Zone, making this the earliest appearance of *A. fluegeli* known. In most regions (e.g. Norway (Aldridge and Mohamed 1982), California (Miller 1978), Alaska (Savage 1985)), *A. fluegeli* ranges from the *P. celloni* to *P. amorphognathoides* zones; hence McCracken (1991b) suggested that it may occur earlier in basinal environments, as confirmed by the present study.

*PTEROSPETHODUS CELLONI ZONE*

*Definition.* The lower boundary of the *Pterospethodus celloni* Zone is defined by the first appearance of the nominate species.

*Reference section.* Cape Phillips North Section, 8.0 m above the base of the section.

*Graptolite integration.* *crispus* Zone? or *griestoniensis* Zone to the uppermost *griestoniensis* Zone.

*Other conodonts.* *A. fluegeli*, *A. cf. A. borenorensis*, *Apsidognathus?* sp., *Belodella* sp. *A. Miller*, *Distomodus (staurognathoides?)*, *Pseudooneotodus beckmanni*, *Pseudooneotodus bicornis*, *Pterospethodus amorphognathoides angulatus?* (only in the uppermost part of the zone), *Walliserodus cf. W. sancticlairi*.

*Remarks.* The earliest diagnostic element (Pa) recovered was from 8.0 m above the base of the Cape Phillips North section; however, S elements of *Pterospethodus* that probably belong to *P. celloni*, were found below this, at 0 and 5.0 m above the base of the type section, from strata that are possibly assigned to the *crispus* Zone? or at least as old as the *griestoniensis* Zone. McCracken (1991b) noted that in the northern Yukon *A. fluegeli* appears in high yielding samples before *P. celloni*. Because of the low yields and few samples in this present study from the uppermost *turriculatus* Zone through *crispus* Zone interval, it is proposed that, like in the Road River Formation (McCracken 1991b), *A. fluegeli* probably also appears before *P. celloni* in the Cape Phillips Formation, making the *A. fluegeli* Zone very short in duration.

*PTEROSPATHODUS A. AMORPHOGNATHOIDES ZONE*

*Definition.* The lower boundary is defined by the first appearance of *Pterospathodus a. amorphognathoides*.

*Reference section.* Cape Phillips North Section, 59.7 m above the base of the section.

*Graptolite integration.* Middle to upper *griestoniensis* Zone to uppermost *sakmaricus* Zone.

*Other conodonts.* *Apsidognathus tuberculatus*, *Apsidognathus?* sp., *Aspelundia fluegeli*, *A.* cf. *A. borenorensis*, *Aulacognathus chapini*, *Distomodus staurognathoides*, *Ozarkodina hadra*, *Panderodus unicostatus*, *Panderodus recurvatus*, *Pseudooneotodus tricornis*, *Pterospathodus pennatus procerus*, *Walliserodus* cf. *W. sancticlairi*.

*Remarks.* The appearance of *P. amorphognathoides* is synchronous world-wide, and is constrained within the mid-upper *griestoniensis* Zone (Silurian Times, n. 3 1995).

*PTEROSPETHODUS PENNATUS PROCERUS SUPERZONE*

*Definition.* The base of the *P. p. procerus* Zone is defined by the last occurrence of *P. a. amorphognathoides*.

*Reference section.* Abbott River East Section, 16.0 m above the base of the measured section.

*Graptolite integration.* *insectus* Zone to lowermost *instrenuus-kolobus* Zone.

*Other conodonts.* *Belodella* sp. A Miller, *Distomodus staurognathoides*, *Decoriconus fragilis*, *O. e. excavata*, *Panderodus recurvatus*, *P. unicostatus*, *Pseudooneotodus beckmanni*, *Walliserodus* cf. *W. sancticlairi*.

*Remarks.* *Pterospethodus pennatus procerus* appears early in the Cape Phillips Formation, in the lowermost *sakmaricus* Zone. The base of the *K. ranuliformis* Interval Zone, which is recognised in the official Silurian biostratigraphic column (Silurian Times n. 3, 1995), is defined by the last occurrence of *Pterospethodus a. amorphognathoides*. This zone has been recognised in Oklahoma (Barrick and Klapper 1976), Australia (Bischoff 1986), and Italy (Corradini and Serpagli 1998). Jeppsson (1997b) subdivided the Llandovery-Wenlock boundary into much greater detail. He defined the lower boundary of his Lower *Pterospethodus procerus* Zone to coincide with the extinction of *P. amorphognathoides*. His Lower and Upper *P. procerus* zones can only be separated by the extinction datum of *Panderodus langkawiensis*, a rare taxon, and hence his alternate suggestion is followed to recognise the *P. pennatus procerus* Superzone only. Cooper (1980) named this the *Pterospethodus* extinction datum, and thought it was best represented in the Clarita Formation studies of Barrick and Klapper (1976). However, as Jeppsson (1997b) noted, Cooper did not recognise that *P. pennatus procerus* continues into overlying strata; however, as Jeppsson (1997b) correlated the lower boundary of this zone with the upper part of the *insectus* Zone or lower part of the *centrifugus* Zone. At Cape Phillips North, the last occurrence of *P. a. amorphognathoides* is well before the

end of the *sakmaricus* graptolite Zone, although distinguishing between the *P. a. amorphognathoides* and *P. p. procerus* can be somewhat arbitrary, especially if only juvenile Pa elements are present or if Pa elements are absent. The *insectus* Zone rocks in the Cape Phillips Formation are generally resistant to acid digestion. However, an *insectus* Zone sample at Abbott River East (sample ARE6) contains *P. p. procerus* but no *P. a. amorphognathoides*, although the latter species is present in the preceding sample. Hence, the extinction datum of *P. a. amorphognathoides* may lie low in the *insectus* Zone in the Cape Phillips Formation. The upper range of *P. p. procerus* in the Cape Phillips Formation is within the lower part of the *instrenuus-kolobus* graptolite Zone. Jeppsson (1997) correlated the last appearance of the species with the top of the *centrifugus* graptolite Zone. This occurrence in the Cape Phillips extends its range significantly.

**KOCKELELLA RANULIFORMIS SUPERZONE**

*Definition.* The extinction of the *Pterospathodus p. procerus* and hence the genus *Pterospathodus* marks the base of the *Kockelella ranuliformis* Zone.

*Reference section.* Cape Phillips North Section, between 182.0 and 196.0 m above the base of the measured section.

*Graptolite integration.* Lower *instrenuus-kolobus* Zone to middle *instrenuus-kolobus* Zone.

*Other conodonts.* *Kockelella ranuliformis*, *Dapsilodus obliquicostatus*, *Ozarkodina excavata excavata*, *Pseudooneotodus bicornis*.

*Remarks.* Jeppsson's (1997b) concept of the *K. ranuliformis* Superzone differs from that of the official Silurian biostratigraphic chart (Silurian Times, n. 3, 1995), and narrows the concept of the *K. ranuliformis* Zone proposed by Barrick and Klapper (1976). *Kockelella ranuliformis* ranges into the Llandovery and higher in the Wenlock than the middle Sheinwoodian, and hence this zone has traditionally been an assemblage zone whose base was defined by the extinction of *P. a. amorphognathoides*, and was considered to represent strata before the first appearance of *Kockelella patula*, *Ozarkodina sagitta rhenana* or *Kockelella amsdeni* (i.e., Barrick and Klapper, 1976; Silurian Times n. 3, 1995). As noted above, the top of the preceding zone for Jeppsson (1997b) is the extinction of the genus *Pterospathodus*. The Lower and Upper *K. ranuliformis* zones are divided by extinctions in the genus *Panderodus*, and an ozarkodinid, neither of which have been observed in this study, and hence the Superzone concept is used here. Jeppsson (1997b) considered that the base of this zone is likely correlative with part or all of the *murchisoni* Zone. Here the last appearance of *Pterospathodus pennatus procerus* is about 10 m above the base of the *instrenuus-kolobus* graptolite Zone. *Kockelella ranuliformis* may be present in *sakmaricus* graptolite Zone samples from the Cape Phillips Formation (see Systematic Paleontology), but does not appear again until near

the top of the *murchisoni* Zone. The samples from this interval, especially the *centrifugus* and lower *murchisoni* graptolite zones were extremely resistant to processing, and hence some data are unavailable, and it is assumed that *K. ranuliformis* ranges lower in the Wenlock than is reported in the range charts.

## NEW GENUS NEW SPECIES ZONE

*Definition.* The base of this zone is defined by the first appearance of New genus new species.

*Reference section.* Cape Phillips North Section, 206.6 m above the base of the measured section.

*Graptolite integration.* Middle *instrenuus-kolobus* Zone to lowermost *perneri-opimus* Zone.

*Other conodonts.* *Belodella* sp. A. Miller (only near end of range and not in same samples as nominate species), *Dapsilodus obliquicostatus*, *Kockelella ranuliformis*, *Ozarkodina excavata*, *Panderodus unicostatus*, *Walliserodus* cf. *W. sancticlairi*.

*Remarks.* The range of New genus new species is extremely short, between two successive Sheinwoodian graptolite zones. It occurs with a low diversity, delicate fauna of mostly *Dapsilodus obliquicostatus* and, to a lesser extent, *K. ranuliformis*. The samples also have abundant radiolarians. *Ozarkodina excavata excavata* ranges throughout this interval but did not occur in the same sample as New genus new species. In reference to the refined zonation of Jeppsson (1997b), the base of this new zone can probably be correlated with the base of his Upper *K. ranuliformis* Zone, which marks the end of the Ireviken Event.

*KOCKELELLA PATULA ZONE*

*Definition.* The base of this zone is defined by the first appearance of *Ozarkodina sagitta rhenana* or *Kockelella patula*. The former species was not recovered from the Phillips Formation, and because of the late appearance of *K. patula*, a questionable *K. patula* Zone is proposed here that extends probably from at least the *perneri-opimus* graptolite Zone across the Sheinwoodian-Homeric boundary into the lowermost *lundgreni* graptolite Zone. Only one element was found, from the *lundgreni* graptolite Zone.

*Reference section.* Abbott River West, Section 2, at the base of the measured section (0 m).

*Graptolite integration.* The upper limit of the zone is extended here to the base of the *lundgreni* Zone. Its lower limit is probably at least as low as the *perneri-opimus* Zone.

*Other conodonts.* *Kockelella absidata*, *Ozarkodina e. excavata*, *Ozarkodina confluens*, *Panderodus unicostatus*, *Pseudooneotodus bicornis*.

*Remarks.* At Cape Phillips North, most samples from the upper 30 m of strata that lie within the *perneri-opimus* graptolite Zone dissolved poorly and yielded no conodonts. Some 52 m of *perneri* Zone strata are present at Abbott River West Section 1. Based on the absence of New genus new species from that section, it is probably correlative with the upper part of the *perneri-opimus* Zone. A single Pa element of *Kockelella patula* was identified from strata near the base of the *lundgreni* Zone at Abbott River West, Section 2. In the standard zonation (Silurian Times, n. 3, 1995), the base of the *O. s. rhenana* – *K. patula* Zone is correlated with the middle of the *instrenuus-kolobus* Zone. These zonal conodont species are not present in samples from either of the *instrenuus-kolobus* and *perneri-opimus* graptolite zones. *Kockelella patula* is rare worldwide. Walliser (1964) found *K. patula*, and thus the base of his *K. patula* Zone, after the last appearance of *Pterospathodus amorphognathoides*, and the top of the zone was defined by the first appearance of *Ozarkodina s. sagitta* in the Carnic Alps. Barrick and Klapper (1976)

identified *K. patula* from the middle of their *K. amsdeni* Zone of the Clarita Formation in Oklahoma, and considered it only to be a partial range of the species. Over and Chatterton (1987) defined their *patula/ranuliformis* Zone by the first occurrence of *K. ranuliformis* or *Kockelella patula*, although the latter did not occur in their section until near the top of the zone. Hence, McCracken (1991b) considered the lower part of their *patula/ranuliformis* Zone as correlative with the *P. amorphognathoides* Zone, and the upper part only referable to the *K. patula* Zone. McCracken (1991b) and Over and Chatterton (1987) found *K. patula* in member 1D of the Delorme Group, Road River Formation along with *K. absidata*, *O. e. excavata*, *P. unicastatus* and *Pseudooneotodus bicornis*. Overlying this zone were conodonts assigned to the *Ozarkodina bohemica* Zone of the Homeric. Interestingly, Barrick and Klapper (1976) found that *K. patula* and *K. absidata* appeared together approximately in the middle of their *K. amsdeni* Zone. *Kockelella patula* also appears in the Road River Formation with *K. absidata*; here in the Cape Phillips Formation, *K. absidata* in the sample that yielded *K. patula*. Workers have often correlated the *K. patula* Zone with the *K. ranuliformis* Zone because Walliser (1964) found *K. patula* in strata directly overlying the *P. amorphognathoides* Zone at Cellon. As Jeppsson (1997b) pointed out, the gap at Cellon must be considerable, and the *K. patula* Zone is probably no older than the base of the *rigidus* graptolite Zone (equivalent to late *instrenuus-kolobus* graptolite Zone or early *perneri-opimus* graptolite Zone in the Arctic). No diagnostic conodonts have been recovered from the Cape Phillips Formation above the sample that contains *K. patula*. From the evidence presented here, it is clear the *K. patula* Zone crosses the Sheinwoodian-Homeric boundary, and that the age of its lower boundary may have been placed too low in the past. The Sheinwoodian-Homeric boundary was considered "Not Zoned" in the Silurian standard zonation (Silurian Times, n. 3, 1995). Additionally, Barrick and Klapper's (1976) *K. amsdeni* Zone may thus straddle the Sheinwoodian-Homeric boundary.

|               |            |           |                     |                           |
|---------------|------------|-----------|---------------------|---------------------------|
| UPPER ORD.    | CINCINNATI | WENLOCK   | progenitor          | CP Fm. Graptolite Zones 1 |
| RICHMOND, GAM | RHUDANIAN  | LANDOVERY | ludensis            | GOR STAGES                |
|               |            |           | praeduebeli-deubeli |                           |
|               |            |           | nassa               |                           |
|               |            |           | testis-lundgreni    |                           |
|               |            |           | perneri-opimus      |                           |
|               |            |           | instrenuus-kolobus  |                           |
|               |            |           | murchisoni          |                           |
|               |            |           | centrifugus         |                           |
|               |            |           | insectus            |                           |
|               |            |           | sakmaricus          |                           |
|               |            |           | griestoniensis      |                           |
|               |            |           | crispus             |                           |
|               |            |           | turriculatus        |                           |
|               |            |           | guerichi            |                           |
|               |            |           | sedgewickii         |                           |
|               |            |           | convolutus          |                           |
|               |            |           | curtus              |                           |
|               |            |           | cyphus              |                           |
|               |            |           | acimaces            |                           |
|               |            |           | atavus              |                           |
|               |            |           | sinitzini           |                           |
|               |            |           | acumini             |                           |
|               |            |           | modernii-lubricus   |                           |
|               |            |           | persculpius         |                           |
|               |            |           | bohemicus           |                           |
|               |            |           | pacificus           |                           |
|               |            |           | fastigatus          |                           |

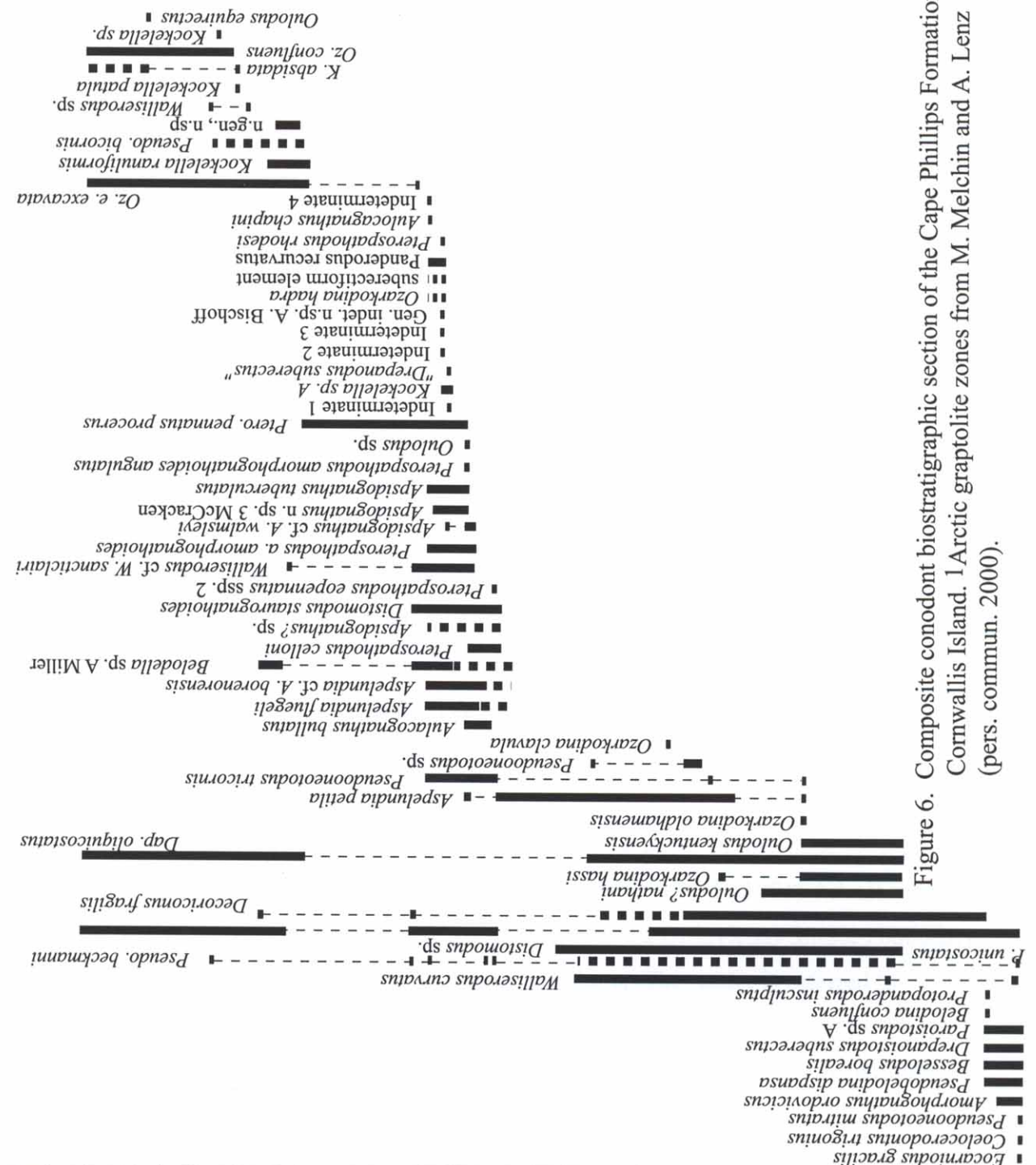


Figure 6. Composite conodont biostratigraphic section of the Cape Phillips Formation, Cornwallis Island. 1 Arctic graptolite zones from M. Melchin and A. Lenz (pers. commun. 2000).

### ***Biofacies Implications***

The biofacies and paleoecology of conodonts from Ordovician-Silurian boundary strata have been detailed for Anticosti Island (McCracken and Barnes 1981) and the Mackenzie Mountains (Nowlan et al. 1988). Strata in the Metapedia Basin of Gaspé Peninsula also yield uppermost Ordovician conodonts, although none were recovered from the lowermost Silurian strata (Nowlan 1981). In addition to their description of *O. nathani* and its assignment as the earliest Silurian conodont zone, McCracken and Barnes (1981) proposed a new latest Ordovician zone characterised by *Gamichignathus ensifer*. *Gamichignathus ensifer* and *G. hastatus* were assigned to Fauna 13 on Anticosti Island as the youngest addition to the faunas proposed by Sweet et al. (1981). *Gamachignathus* becomes abundant in the Ellis Bay Formation and persists into the transitional zone on Anticosti Island. *Gamachignathus* and *Panderodus gracilis* (= *P. unicostatus*) form offshore Community A of McCracken and Barnes (1981) and Barnes (1988). In the Mackenzie Mountains, neither *Amorphognathus ordovicicus* nor *Gamichignathus* were recovered. This was attributed to oceanic restriction in the Selwyn Basin, possibly due to the effects of eustatic sea level fluctuations (Nowlan et al. 1988). *Gamachignathus* was not recovered from the Cape Phillips strata; however, it has been recovered from the Allen Bay Formation on Cornwallis Island (Ryley 1984), and from the Cape Phillips Formation on Dundas Island (Melchin et al. 1991). Melchin et al. (1991) did not recover *Gamachignathus* from the more detailed sampling over the Ordovician-Silurian boundary of the Cape Phillips Formation than was conducted here. The reader is referred to Melchin et al. (1991) for a discussion of the details and implication of the mixed fauna that was recovered from their sections, but was not recognised here probably because of poor dissolution of the samples.

The distribution of Silurian conodonts was controlled environmentally. Seddon and Sweet (1971) suggested that conodonts were pelagic and depth stratified, while Barnes and Fåhræus (1975) considered that some were pelagic, especially the simple cone taxa, while others were nektobenthic. Because the function of the conodont element remains uncertain, and the mode of life is still under debate, attributing their distribution

to a particular environmental factor or factors is somewhat tenuous. Certain taxa do appear to have preferred particular environments that were related to water depth but some have argued that overall conodont diversity is not related simply to depth (Barnes 1975; Aldridge 1976). The major factor controlling the distribution of conodont taxa according to Sweet (1998) was temperature. Mabillard and Aldridge (1981) found little correspondence between the distribution of conodont species and lithofacies in the Llandovery-Wenlock interval.

In the early Llandovery, species of *Icriodella* in particular, usually associated with *Distomodus*, *Oulodus* and *Panderodus*, dominate high energy, near-shore environments, whereas later in the Llandovery *Distomodus* becomes more dominant, except in the near-shore facies of the Welsh Borderland (Aldridge 1972; Aldridge and Jeppsson 1984) where *Icriodella* remained common. The Telychian is characterised by a rapid increase in conodont abundance and diversity, beginning in the *P. celloni* Zone. Le Fèvre et al. (1976) postulated that the *P. celloni* fauna in the Hudson Bay Basin was derived from European migrations, while Armstrong (1990) considered that a global migration could have been possible only if the entire *P. celloni* Zone fauna was pelagic. Alternatively, he suggested that the mid- and Late Telychian fauna may have originally been restricted to the basinal environment, and migrated onto the shelf as a result of transgression.

Aldridge and Mabillard (1981, fig. 1.3) plotted the distribution of various conodont taxa relative to the postulated Welsh shoreline and found that there were clear trends in the distribution and abundance of species along the transect. Among these, *Dapsilodus obliquicostatus* showed a dramatic increase towards offshore environments in the Llandovery and early Wenlock. Similarly, Barrick (1983) found that *D. obliquicostatus* inhabited the farthest offshore environments. This association was also recognised by Armstrong (1990), McCracken (1991b), Sarmiento et al. (1993) and Barrick (1997).

Armstrong's (1990) Llandovery slope biofacies is dominated by *Aspelundia*, *D. obliquicostatus* and *Decoriconus fragilis*, and more minor *Walliserodus curvatus* and *W. cf. W. sancticlairi*. Similarly, McCracken (1991b) recognised a recurrent association of *D. obliquicostatus* and *Aspelundia* without *Decoriconus* but with the addition of

*Walliserodus blackstonensis*. The delicate, thin-walled and low diversity association of *Aspelundia*, *Dapsilodus*, *Decoriconus*, and *Walliserodus* fauna prompted McCracken (1991b) to suggest that the fauna may have been one of high productivity that favoured oceanic environments and termed this association the *Aspelundia-Dapsilodus* fauna. Barrick (1981) suggested that the habit of *Dapsilodus obliquicostatus* may have been analogous to planktic foraminifers in that they were a species of high productivity that appear to have favoured offshore environments.

In the Gun River Formation, *Aspelundia petila* (= *Oulodus? fluegeli*) is present, but in low abundance (Zhang and Barnes in press). It does not appear in the overlying Jupiter Formation until near the top (? *Oulodus fluegeli* subsp. A Uyeno) in beds that have been interpreted as representing a shallowing interval rather than the open marine shelf environment that persisted for the much of the time the sediments of the Jupiter Formation were being deposited (Uyeno and Barnes 1983) (this may be misleading because a significant barren interval separates the lower and upper faunas of the Jupiter Formation). *Aspelundia* was also recovered from two samples in the lower Chicotte Formation in association with *D. fragilis*, *W. sancticlairi*, *P. celloni*, *P. p. procerus*, and *P. unicostatus*, among others. Overall, however, as McCracken (1991b) noted for his faunas, *Aspelundia* never reaches more than 3 percent of the fauna present. In the Gun River Formation at on Anticosti Island, *Aspelundia* represents less than 1 percent of the fauna.

*Dapsilodus obliquicostatus* is present in the Member 4 of the Jupiter Formation for a relatively short interval in the *staurognathoides* Zone; an interval also characterised by specimens of *W. sancticlairi* and *D. fragilis*. Uyeno and Barnes (1983) concluded these intervals containing *D. obliquicostatus* could be comparable to Barrick's (1983) Mixed Biofacies.

In post-*atavus* graptolite Zone through pre-*P. celloni* conodont Zone strata of the Cape Phillips Formation the percentage of the fauna of *Aspelundia petila*, *Walliserodus curvatus* and *Dapsilodus obliquicostatus* is 56 percent, 20 percent, and 9 percent, respectively compared to McCracken's (1991b) 22 percent, 60 percent (*W. blackstonensis*) and 15 percent from his Blackstone River sections. The increased *A.*

*petila* component in the Cape Phillips Formation may suggest a shallower depositional environment than the Road River Group. In the Cape Phillips Formation, *Decoriconus fragilis* is present comprising less than 6 percent of the entire *pre-celloni* Zone fauna, but is more dominant in the *atavus* Zone and below where it comprises 13 percent of the fauna. It is possible that the *Decoriconus fragilis* fauna of the earliest Silurian represents an offshore biofacies.

*Dapsilodus obliquicostatus* and *Decoriconus fragilis* do not persist in the Llandovery Cape Phillips Formation beyond the mid-*guerichi* graptolite Zone. They are present in *P. celloni* strata in Greenland (Armstrong 1990), and McCracken (1991b) reported *D. obliquicostatus* from *gregarius* graptolite Zone through the Wenlock strata in the Yukon. Nicoll and Rexroad (1969) reported *D. obliquicostatus* from *Neospathognathodus* (= *Pterospathodus*) *celloni* and *P. amorphognathoides* zones in the Brassfield Limestone of Indiana and Kentucky, and it is also present in the *P. amorphognathoides* Zone of Tennessee (Barrick 1983) but it does not appear until the base of the *K. ranuliformis* Zone in Oklahoma (Barrick 1977).

The *P. celloni* and *P. amorphognathoides* zones are generally characterised by an increase in abundance of coniform elements in addition to a dramatic increase in overall conodont diversity. This has also been observed in Greenland (Armstrong 1990) and the Welsh Basin (Mabillard and Aldridge 1985). Aldridge (1976) considered that the association of *Walliserodus* and *Llandoverygnathus* (= *Pterospathodus*) *celloni* is almost exclusively limited to deep-water sediments in Britain. Shallower water, higher energy sediments of this interval contain icriodellids, *Hadrognathus* (= *Distomodus*) *staurognathoides*, *Ozarkodina excavata*, and others, and thus comprise a similar association of species as found in early Llandovery shallow water sediments. In the Cape Phillips Formation, the *P. celloni* and *P. amorphognathoides* zones are characterised by *Walliserodus* cf. *W. sancticlairi*, *Aspelundia fluegeli*, *Aspelundia* cf. *A. borenorensis*, *Panderodus unicostatus*, *Pterospathodus* species, and *Panderodus* sp. The association of *P. celloni* with *Walliserodus* is difficult to explain as representing a deeper water biofacies, considering the absence of *D. obliquicostatus* and *Decoriconus fragilis* from this interval in the Cape Phillips Formation, although the most recent isotope curves show

a decline in  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values through much of the Telychian which may be interpreted as representing sea-level highstand conditions (Azmy et al. 1998). *Aspelundia fluegeli* comprises 40 percent of elements in the *P. celloni* and *P. amorphognathoides* zone strata, whereas *Walliserodus* cf. *W. sancticlairi* reaches about 21 percent of the fauna, which is comparable to the distribution of these genera in pre-*P. celloni* Zone strata. *Panderodus* itself is inconspicuous with very low abundance through much of the Llandovery until the Telychian, where it becomes abundant, especially in the *P. amorphognathoides* Zone where it comprises as much as 40 percent of the fauna in a single sample.

*Panderodus unicastatus* is abundant throughout the Llandovery on Anticosti Island along with *Panderodus recurvatus*, which appears in the *D. staurognathoides* Zone. *Panderodus* usually comprises more than 50 percent of the fauna, sometimes exceeding 90 percent in samples from the Becscie and Gun River formations on Anticosti Island (Zhang and Barnes, in press). Aldridge and Mabillard (1981) showed that *P. unicastatus* dominates in near-shore environments. Its abundance in the uppermost Llandovery in the Cape Phillips Formation may suggest that the beginning of the regression that exposed much of the North American shelf began by early *amorphognathoides* Zone time.

A dramatic biofacies shift occurs in the early Wenlock in the Cape Phillips Formation. The fauna of the *K. ranuliformis* Superzone and the New genus new species Zone are almost entirely composed of *Dapsilodus obliquicostatus*, which reappears after its absence from the *P. celloni* and the *P. amorphognathoides* zones. It occurs with minor *K. ranuliformis* and *Ozarkodina e. excavata* and a higher proportion of New genus new species in the Sheinwoodian.

In their study of the Llandovery-Wenlock interval in the Welsh Basin, Aldridge and Mabillard (1981) found that *D. obliquicostatus* continued to dominate offshore environments in the post-*P. amorphognathoides* interval along with *Decoriconus fragilis* and *O. excavata*. *Ozarkodina excavata excavata*, which first appears in the Cape Phillips Formation in the *insectus* graptolite Zone, is present through at least the Telychian in the Welsh Basin. In the Welsh Basin it dominates the nearshore environment in the *P.*

*amorphognathoides* interval, but shifts to the offshore regions in the post-*amorphognathoides* interval. The re-appearance of *D. obliquicostatus* in the Wenlock is interesting, considering Barrick's (1997) study of the Wenlock depositional sequences on the southern North American shelf. He found that the major late Telychian regression that produced a regional unconformity on the southern shelf was followed by an early Wenlock transgression. The transgression brought a shift in biofacies concurrent with the transition from the *amorphognathoides* to *ranuliformis* zones where the *obliquicostatus* and Mixed biofacies of Barrick (1983) occur. This transition occurs at the shift from the basal shale (interpreted to contain a lag of pre-unconformity conodonts) to carbonates on the southern shelf. This may be equivalent to the shift from the platy shale of the *insectus*, *centrifugus* and lowermost *murchisoni* graptolites zones to the more carbonate rich mudstones of the remainder of the overlying *murchisoni* Zone and *instrenuus-kolobus* graptolite Zone strata in the Cape Phillips Formation. The offshore *obliquicostatus* Biofacies appears to have dominated much of the Sheinwoodian in the Cape Phillips Formation.

Additionally, Barrick (1997) identified a biofacies dominated by *Dapsilodus praecipuus*, which he considered to occupy a more offshore ecological position than *D. obliquicostatus* during the interval of 255 to 300 on his Southern Midcontinent Composite Standard. Barrick estimated that the Sheinwoodian-Homerian boundary lies at about 313 on his SMCS based on the Silurian Composite Standard of Kleffner (1989). The range of *D. praecipuus* is thus similar to that of New genus new species in the Cape Phillips Formation, and hence the latter may also record a shift to a more offshore biofacies in the mid-upper Sheinwoodian. The assertion that New genus new species may have inhabited an offshore environment is supported by its co-occurrence with abundant radiolarians in the samples that were productive.

The remainder of the Wenlock part of the Cape Phillips Formation is dominated by *Dapsilodus obliquicostatus*, *O. e. excavata*, *Panderodus unicastatus*, and in the Homerian, the addition of *Ozarkodina confluens*. Aldridge (1976) noted how Wenlock and Ludlow faunas world-wide are dominated by *O. excavata*, *O. confluens* and *P. unicastatus*, and suggested that these were generalised species that persisted during what

may have been an early Wenlock global conodont crisis. The relatively constant proportion of *D. obliquicostatus* through the Wenlock may reflect the continuation of the *obliquicostatus* offshore biofacies throughout the Wenlock. It is possible that kockelellids and ozarkodinids, which comprise much of the zonal taxa for the Wenlock, persisted in nearshore environments. Upper Sheinwoodian and Homeric strata at Abbott River West contain numerous debris flows with fining upward cycles that have rip up clasts and a shell hash at their base. Strata between these tended to be very resistant indurated shale. It is possible that the introduction of *K. absidata* and *K. patula* in the Homeric in the Cape Phillips strata may have been from debris flows sourced from the shelf margin.

## *Conodont Bioevents*

### *Ordovician-Silurian Boundary*

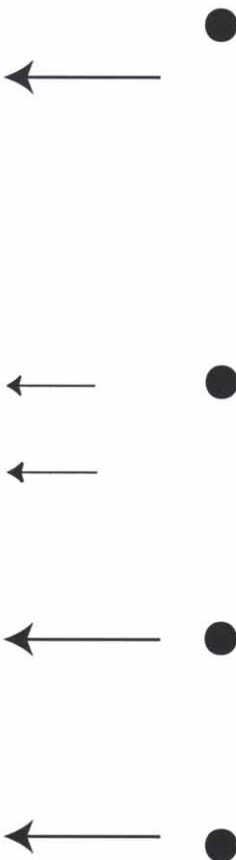
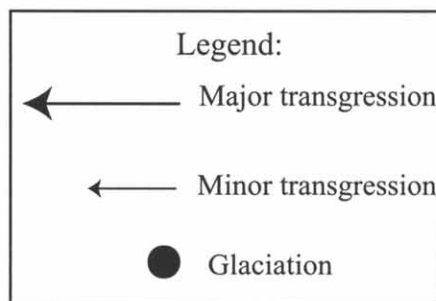
The Hirnantian glaciation, resultant sea-level draw-down and its effects on marine faunas have been the focus of many recent studies. Globally, bathymetric curves display a long-term rise in sea-level in the Caradoc, and a high-frequency fall in the Ashgill. The Caradoc transgression corresponds to the start of the second-order cycle of Ross and Ross (1992) that persisted until the end of the Ordovician. The late Ashgill eustatic cycle is correlated with early and mid Hirnantian for the fall and rise, respectively, with a magnitude of some 60 m (Crowley and Baum 1992) and a duration of 0.5 to 1 M.y. (Harland et al. 1990). The regression is also associated with major carbon and oxygen isotope events (e.g., Marshall et al. 1997; Azmy et al. 1998), and is linked to the development of a large continental glacier (Brenchley et al. 1994).

In terms of the effects on the conodont and graptolite faunas, the "first strike" of the Late Ordovician mass extinction event affected the graptolites, with the main episode of extinction for this group occurring at the end of the *pacificus* graptolite Zone (e.g., Melchin and Mitchell 1991), when almost complete extinction ensued (see Figure 5, herein for reference to zones). For reference, the various events presented in this section are illustrated in Figure 7. The graptolite extinction has been linked temporally to basinal oxygenation and cooling and to a major regression (Melchin et al. 1991).

The second phase of extinction, which drastically affected conodonts, occurs in the mid-*persculptus* graptolite Zone and extends across the Ordovician-Silurian boundary (Barnes 1988; Melchin et al. 1991), and is linked with the transgression following the Ordovician-Silurian glaciation (Brenchley et al. 1994). On Anticosti Island (McCracken and Barnes 1981), simple cone groups, including ?*Walliserodus curvatus*, *Pseudooneotodus beckmanni*, *Decoriconus costulatus* (= *D. fragilis*) and *Panderodus*

| System         | Series                | Stage                          | Graptolite Zone                  | Episode/Event                |
|----------------|-----------------------|--------------------------------|----------------------------------|------------------------------|
| Lower Silurian | Wenlock               | Homerian                       | <i>ludensis</i>                  | Klinte Secundo Episode       |
|                |                       |                                | <i>praedeubeli-deubeli</i>       |                              |
|                |                       |                                | <i>parvunassa</i>                | Mulde Secundo-Secundo Event  |
|                |                       |                                | <i>lundgreni</i>                 | Helvi Secundo Episode        |
|                |                       | Sheinwoodian                   | <i>rigidus-perneri</i>           | Valleviken Event             |
|                |                       |                                |                                  | Allekvia Primo Episode       |
|                |                       |                                |                                  | Lansa Secundo Episode        |
|                |                       |                                |                                  | Boge Event                   |
|                |                       |                                |                                  | Sanda Primo Episode          |
|                |                       |                                |                                  | Vattenfallet Secundo Episode |
|                |                       |                                | <i>riccartonensis-belophorus</i> |                              |
|                |                       |                                | <i>murchisoni</i>                |                              |
|                |                       |                                | <i>centrifugus</i>               | Ireviken Event               |
|                |                       |                                | Llandovery                       | Telychian                    |
|                | <i>lapworthi</i>      |                                |                                  |                              |
|                | <i>sprialis</i>       | Snipklint Primo Episode        |                                  |                              |
|                | <i>griestoniensis</i> |                                |                                  |                              |
|                | <i>crispus</i>        |                                |                                  |                              |
|                | <i>turriculatus</i>   | Sec.-Pri. Event                |                                  |                              |
|                | <i>guerichi</i>       | Malmoykalven Secundo Episode   |                                  |                              |
|                | Aeronian              | <i>sedgwickii</i>              |                                  | Sandvika Event               |
|                |                       | <i>convolutus</i>              |                                  | Jong Primo Episode           |
|                |                       | <i>argenteus</i>               |                                  |                              |
|                |                       | <i>triangulatus-pectinatus</i> |                                  |                              |
|                | Rhuddanian            | <i>cyphus</i>                  |                                  | Spirodden Secundo Episode    |
|                |                       | <i>vesiculosus</i>             |                                  |                              |
|                |                       | <i>acuminatus</i>              |                                  |                              |
|                |                       |                                |                                  |                              |

Figure 7. Oceanic episodes and events, T-R sequences, and glacial events of the Lower Silurian. Standard graptolite zonation after Silurin Times no. 3 (1995) and Koren et al. (1996); Silurian faunal cycles after Jeppsson (1990, 1996, 1997a,b), Aldridge et al. (1993), Jeppsson et al. (1995); regional Canadian Arctic T-R sequence boundaries (arrows) from de Freitas et al. (1999); glacial events (dots) from Grahn and Caputo (1992). Duration of graptolite zones not to scale.



(=*P. unicastatus*), are the only species surviving across the boundary. Similarly, in the Cape Phillips Formation, only the simple cone taxa *Walliserodus curvatus*, *Panderodus unicastatus*, and *Decoriconus fragilis* persist into the lowermost Llandovery. The immediate cause of the conodont extinction has been attributed to a rapid oceanic overturn that brought anoxic waters to the surface (Goodfellow et al. 1992), and a switch from eutrophic to oligotrophic conditions (Brenchley et al. 1995).

Central Nevada sections demonstrate that the graptolite and radiolarian extinctions were significantly earlier than the conodont and chitinozoan faunal turnovers (Finney et al. 1999). The graptolite extinctions were diachronous; shallower water biofacies were the first to show the effects of the extinction, while populations in continental slope and basinal environments disappeared last in the global turnover boundary. Conodonts and chitinozoans experienced diachronous extinction as well, with basinal species replaced by shelf and slope species as sea-level dropped. Finney et al. (1999) suggested that conodonts and chitinozoans persisted longer because platform conditions were maintained longer than the upwelling shelf-margin habitat of the graptolites. They thus place the emphasis on sea-level change in driving the Late Ordovician faunal turnover.

### ***Lower Silurian Events***

Cyclicality has been observed in the lithology, fossil content, and isotopic composition of Silurian strata. These Silurian cycles have been variously attributed to eustatic sea-level fluctuations and/or global climate and ocean state changes. Based on stratigraphic evidence, Grahn and Caputo (1992) placed multiple glaciations in Brazil at latest Ashgill and/or earliest Llandovery time, the latest Rhuddanian *gregarius* (= *cyphus* in the Cape Phillips Formation) graptolite Zone, earliest Telychian or possibly latest Aeronian, and latest Llandovery to earliest Wenlock time (the most widespread tillite). Azmy et al. (1998) showed that  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  isotopic shifts are negatively correlated with sea-level changes and glacial deposits in the early Aeronian, latest Aeronian, and early Wenlock. They suggested that the  $\delta^{13}\text{C}$  peaks may have been due to the increased

productivity of the oceans that experienced more vigorous circulation during glacial periods. Azmy et al. (1998) thought that the Lower Silurian glacial record did not appear to coincide with extinction events, with the possible exception of the earliest Wenlock episode that may be coincident with the Ireviken Event of Jeppsson et al. (1995).

Many studies of Silurian sea-level change have been recently published (e.g., Johnson et al. 1985; Johnson 1987; Johnson et al. 1991; Johnson and McKerrow 1991; Johnson 1996; Ross and Ross 1996; Barrick 1997; Johnson et al. 1998). Loydell (1998) attempted to refine the sea-level curves of previous authors and used the appearance of graptolitic laminated shales and mudstones, and the appearance of bioturbation and/or turbidites as evidence for transgression and regression, respectively. With this method, he considered that the highest Silurian sea-levels occurred in the Telychian *crispus*-lower *griestoniensis* and *spiralis*-lower *lapworthi* graptolite zone intervals, with others in the *convolutus* Zone (mid Aeronian), *guerichi*, and late *turriculatus* graptolite zones (early Telychian), as well as the early Sheinwoodian. He concluded that low sea-levels characterised the *sedgwickii* graptolite Zone (Aeronian) and intervening parts of the Telychian, among others. Loydell (1994) suggested that an early Telychian graptolite diversity reduction could be correlated with the late *guerichi* graptolite Zone (*utilis* Subzone) eustatic sea-level fall and Gondwanan glaciation. As noted earlier, detailed stratigraphic study in the Arctic has shown that major transgressive events occurred in the latest Ordovician, end-Rhuddanian, and end-Telychian, with more minor events in the middle Aeronian and earliest Telychian (de Freitas et al. 1999). The lithology of the Cape Phillips strata indicates that transgressions occurred also in the late Ordovician, late Rhuddanian, the earliest Telychian, and across the Llandovery-Wenlock boundary.

The competing hypothesis for understanding Silurian cyclicity is that of the Primo-Secundo episode model proposed and elaborated in a series of papers by Jeppsson, Aldridge, and Dorning (Jeppsson 1987, 1990, 1997a, 1997b, 1997c, 1998; Jeppsson et al. 1995; Aldridge et al. 1993). The model attempts to explain lithological and faunal changes observed in the Silurian succession on the island of Gotland, based on variations in the carbon cycle without necessarily being driven simply by eustatic sea-level change. Primo episodes, characterised by humid low latitudes and cooler high latitudes have cold

bottom waters and high nutrient supply and increased diversity and abundance of marine microplankton and communities dependent on microplankton. Secundo episodes have dryer low latitudes and warmer high latitude climates, rich benthos in expansive carbonate environments, salinity-dense bottom waters, and hence lower nutrient supply. Extinction occurs mainly in the transition between primo and secundo episodes, or "P-S events".

Aldridge et al. (1993) proposed that the conodont turnover in the Aeronian, which marks the last occurrences of *Ozarkodina hassi*, *O. oldhamensis*, *O. kentuckyensis*, and *Icriodella discreta* in the Oslo-Asker district of Norway (representative of the post-extinction fauna of the early Silurian), occurred in the transitional episode and event between the Spirodden Secundo Episode and the Malmoykalven Secundo Episode. This is correlated with the *sedgwickii* graptolite Zone (latest Aeronian). The Snipklint Primo Episode, which they correlated with the base of the *Pterospathodus celloni* Zone and much of the *P. amorphognathoides* Zone, marks the introduction of the diverse fauna of the Telychian.

### ***Cape Phillips Formation Bioevents***

#### **END-ORDOVICIAN BIOEVENT**

From the data presented here and by Melchin et al. (1991), the *ordovicicus* Zone persists into the lower *persculptus* graptolite Zone, with the major conodont extinction occurring in the mid-*persculptus* Zone in the Cape Phillips Formation. The maximum glacio-eustatic sea-level drawdown is placed within the *bohemicus* graptolite Zone, and the overlying *persculptus* graptolite Zone strata represent the transgressive deposits in the ensuing climatic amelioration. Although no transitional fauna was found in the samples for this study, Melchin et al. (1991) found that the transitional interval of the *nathani* Zone (spanning the mid-*persculptus* and lowermost *acuminatus* graptolite zones) on Cornwallis Island occurs over only about 2 m of strata. A transitional fauna has also been found in a number of areas, including Anticosti Island (McCracken and Barnes 1981; Barnes 1988), the northern Yukon (McCracken in Melchin et al. 1991), and Dob's Linn, Scotland (Barnes and Williams 1988).

### LATE RHUDDANIAN BIOEVENT

In the Cape Phillips Formation, species such as *Ozarkodina hassi*, *O. oldhamensis*, *O. kentuckyensis*, which are common in the Rhuddanian and lower Aeronian elsewhere, disappear relatively early in the *atavus* or *cyphus* graptolite zones, and are replaced by the fauna that is dominated by *Aspelundia petila*, *Walliserodus curvatus* and *Dapsilodus obliquicostatus* fauna. This is the main fauna throughout the remainder of the Rhuddanian, the Aeronian and the lower Telychian. The significance of this mid- to late Rhuddanian replacement is uncertain. The interval falls within the “stable” Spirodden Secundo Episode, and occurs before the postulated early Aeronian glacial phase, but does correlate with the end-Rhuddanian minor sequence boundary proposed by de Freitas et al. (1999). Because the former species are common in the Aeronian on Anticosti Island (Zhang and Barnes, in press), their early disappearance in the Cape Phillips Formation may be attributed solely to this (local?) transgressive event in the Rhuddanian. Hence, by the end of the Rhuddanian, the slope biofacies appears to have stabilised, and remained constant until the Telychian.

### EARLY TELYCHIAN BIOEVENT

The next major conodont turnover occurs in the early to middle Telychian interval, where *Aspelundia petila* and *Walliserodus curvatus* are replaced with *A. fluegeli* and *W. cf. W. sancticlairi*, respectively. Although the *sedgwickii* strata were not sampled from the Cape Phillips Formation, it is interesting to note that no faunal change was observed over the Aeronian-Telychian boundary. This is not expected, however, because the fauna that disappeared during the oceanic episodes or events in the Jeppsson models (e.g. *O. hassi*) had disappeared from the Cape Phillips Formation much earlier. In the *guerichi* Zone, *Walliserodus curvatus* and *Dapsilodus obliquicostatus* disappeared, the latter re-appearing again in the early Wenlock. Although *Aspelundia petila* has been recorded elsewhere from late Telychian strata (e.g. McCracken 1991b), it also disappeared in the early Telychian in the Cape Phillips Formation, approximately in the lower *turriculatus* graptolite Zone. Possibly as early as the late *crispus* Zone,

*Walliserodus* cf. *W. sancticlairi* appeared. In the late *turriculatus-crispus* interval, *Aspelundia fluegeli* and *Aspelundia* cf. *A. borenorensis* also appeared. Hence, the interval spanning the *guerichi*, *turriculatus* and lowermost *crispus* graptolite zones marks a peculiar faunal turnover in which species disappear but are replaced with closely related taxa. The coincidence of this replacement with the eustatically-induced graptolite turnover in the *guerichi-turriculatus* interval (Loydell 1994) is compelling. Hence, the appearance of these new lineages may have been eustatically driven. Alternatively, this interval corresponds approximately with the base of the Snipklint Primo Episode (Aldridge et al. 1993) in which the diverse late Telychian fauna appears.

#### TELYCHIAN-SHEINWOODIAN (IREVIKEN) BIOEVENT

The Ireviken Event (Aldridge et al. 1993; Jeppsson 1997a), which follows the Snipklint Primo Episode and straddles the Llandovery-Wenlock boundary, was the most dramatic faunal turnover of the Silurian, and strongly affected the composition of Wenlock faunas. The Ireviken Event is a stepped-extinction event, divided into 8 datums that have been integrated into a standard conodont zonation (Jeppsson 1997b). In the Cape Phillips Formation, as elsewhere, the beginning of the Ireviken Event lies near the base of the *insectus* graptolite Zone, immediately prior to the Llandovery-Wenlock boundary. In Jeppsson's (1997b) standard zonation, *P. amorphognathoides* continues into the *insectus* Zone until its extinction at datum 3 of the Ireviken Event; however, in the Cape Phillips Formation, *P. amorphognathoides* was not recovered above the *sakmaricus* graptolite Zone. This may indicate that some of the effects of the Ireviken Event occurred earlier in the Cape Phillips Formation than elsewhere. Datum plane 6 of the Ireviken Event, which marks the extinction of *Pterospathodus pennatus procerus*, and thus the genus, is also recognised in the Cape Phillips Formation, although it is placed within the base of the *instrenuus-kolobus* graptolite Zone, rather than at the base of the *murchisoni* graptolite Zone according to Jeppsson (1997b). The persistence of the species into the overlying graptolite zone marks its youngest known occurrence. These lowest samples did not dissolve well, and yielded only sparse elements of *P. p. procerus*. Barrick (1997) noted the presence of a transgressive lag containing

*Pterospathodus* at the transgressive base of the Wenlock; however it does not appear that the Cape Phillips specimens could have been reworked from underlying strata because they occur some 15 m above the base of the Wenlock. The other datum planes are not resolvable in this study because they are defined based on rare and/or short-ranged taxa that were not recovered.

#### MID-SHEINWOODIAN BIOEVENT

After the extinction of *Pterospathodus*, the dominant fauna is the low diversity association of *Ozarkodina e. excavata*, *Dapsilodus obliquicostatus*, and New genus new species. The Mid-Sheinwoodian bioevent is defined here at the appearance of New genus new species. Although the graptolite correlation between the standard zonation and the Cape Phillips Formation is difficult in this interval, the base of the New genus new species Zone correlates with the top of the *riccartonensis-belophorus* graptolite Zone or the base of the *rigidus-perneri* graptolite Zone and continues into the base of the *perneri-opimus* graptolite Zone in the Cape Phillips Formation. This interval is approximately equivalent to that in which the Sanda Primo Episode of Jeppsson et al. (1995) occurs. The acme of *Dapsilodus* (also abundant in the New genus. new species Zone of the Cape Phillips Formation) in the southern North American shelf (Barrick 1983), notably *D. praecipuus* in the Sheinwoodian, was considered by Barrick (1997) to represent a change in ocean state, possibly to a Primo Episode.

The causes of the Wenlock cycles are difficult to determine. Barrick (1997) thought that the major Wenlock depositional sequences in southern North America, which appeared to represent transgressive deposits, corresponded to Event-Secundo pairs; hence, he concluded that eustasy may have driven shifts in ocean and climate state. The primo events, however, he thought may represent a more complex change in ocean circulation not necessarily linked to eustasy. The Wenlock strata of the Cape Phillips Formation are difficult to analyse for evidence of sea-level change because they are condensed slope-basinal deposits, and the sampling interval was insufficient for a detailed comparison to the latest Sheinwoodian and Homerian cycles of the Jeppsson model.

## *Systematic Paleontology*

GENUS *Amorphognathus* BRANSON AND MEHL, 1933

*Type species*.—*Amorphognathus ordovicica* Branson and Mehl, 1933.

AMORPHOGNATHUS ORDOVICICUS Branson and Mehl, 1933

Plate 1, figs. 1-8, 31-32

*Amorphognathus ordovicica* BRANSON AND MEHL, 1933, p. 127, pl. 10, fig. 38.

‘carniodiform’ fragments

*Carniodus* sp. Walliser. PARIS, PELHATE AND WEYANT, 1982, p. 20, pl. 2, fig. 14.

*Eocarniodus? gracilis* (Rhodes). MCCRACKEN, 1987, p. 1457-1458, pl. 1, figs. 23, 28, 30.

‘carniodiform’ element, FERRETTI AND BARNES, 1997, p. 38, pl. 3, figs. 20, 22 (only);  
FERRETTI AND SERPAGLI, 1998, pl. 4, figs. 18-19.

*Amorphognathus* sp., NOWLAN, MCCRACKEN AND MCLEOD, 1997, pl. 3, fig. 13 only (= ‘denticulate blade fragment’).

Multielement

*Amorphognathus ordovicicus* Branson and Mehl, 1933. FERRETTI AND BARNES, 1997, p. 26, 28, pl. 1, figs. 1-15 (includes synonymy through 1994); FERRETTI AND SERPAGLI, 1998, pl. 1, figs. 12-14; DZIK, 1998, p. 248, pl. 2, figs. 13-37, 38-47.

*Types*.—Hypotypes GSC120403-120410.

*Material examined*.—Pa element- 14, Pb element- 10, M element- 4, Sa element- 1, Sb element- 2, Sc element- 6, Sd element- 4, ‘carniodiform’ fragment- 72.

*Occurrence.*—*ordovicicus* Zone.

*Discussion.*—The 'carniodiform' element is here placed in synonymy with *A. ordovicicus* (see also *Eocarniodus gracilis* Rhodes). These appear to be broken bars of the ramiform elements of the apparatus of *A. ordovicicus*. This is done cautiously, however, because only 13 S elements were present in the sample from which 72 'carniodiform' elements were found. The 'carniodiform' elements, although always broken on one end, appear to be slightly larger than the S elements in the same sample.

GENUS *Apsidognathus* WALLISER, 1964

*Type species.*—*Apsidognathus tuberculatus* Walliser, 1964.

## APSIDOGNATHUS TUBERCULATUS Walliser, 1964

## Pl. 2, Figures 1-4

*Apsidognathus tuberculatus*, WALLISER, 1964, p. 29, pl. 5, fig. 1; pl. 12, fig. 16-22, pl. 13, fig. 1-5.

## Multielement

*Apsidognathus tuberculatus tuberculatus* WALLISER, 1964. ARMSTRONG, 1990, p. 41, 42, 44, 46, pl. 1, figs. 12-16, pl. 2, figs. 1-4 (includes synonymy through 1987); MCCracken, 1991a, p. 106, pl. 1, figs. 2-4.

*Apsidognathus* n. sp. ARMSTRONG, 1990, p. 7, pl. 2, fig. 7 (only).

*Types.*—Hypotypes GSC1204333-120436.

*Material examined.*—Pa element- 5; Pb element- 9; lenticular element- 1; lyriform element- 4.

*Occurrence.*—*griestoniensis* through *sakmaricus* graptolite zones.

*Discussion.*—The apparatus and range of variation within *Apsidognathus* is not well known. The low transverse rugae of the lyriform element of Armstrong's (1990) *Apsidognathus* n. sp. were one of the major features that distinguished this species from *A. tuberculatus tuberculatus* which he figured and described as having a lyriform element with reticulate rugae (Armstrong, 1990, pl. 1, fig. 6-8). Armstrong (1990) did not refer to Bischoff's (1986) figures that include transverse rugae on the lyriform elements of both

his *Apsidognathus tuberculatus* subspecies (Bischoff, 1986, pl. 1, figs. 17-24).

Bischoff's (1986, pl. 1, figs. 8-16) illustrations of *A. t. tuberculatus* include elements with a relatively smooth platform and an ornamented basal margin, which seems to be within the range of variation between Armstrong's (1990) *A. t. tuberculatus* and *Apsidognathus* n. sp. The lyriform elements from the Cape Phillips Formation have transverse rugae. The low abundance of *Apsidognathus* in the Cape Phillips does not permit subspecies resolution.

APSIDOGNATHUS n. sp. 3 McCracken, 1991a

Pl. 2, Figure 7

*Apsidognathus* n. sp. 3 MCCRACKEN, 1991a, pl. 1, figs. 5-12, Figs. 3, 4.

*Types*.—Figured specimen GSC120437.

*Material examined*.—8 Pa elements.

*Occurrence*.—Upper *griestoniensis* and *sakmaricus* graptolite zones.

*Discussion*.—McCracken (1991a) noted that the upper surface of most of the elements of this apparatus is covered with microreticulation polygons. In the Cape Phillips Formation samples, some *Apsidognathus* Pa elements had this distinct feature.

## APSIDOGNATHUS CF. A. WALMSLEYI Aldridge, 1974

## Pl. 2, Fig. 8

*Apsidognathus walmsleyi* ALDRIDGE, 1974, p. 300-302, fig. 1A-D (Pa and arched scaphate element only).

?*Apsidognathus tuberculatus* Walliser. ALDRIDGE, 1975, pl. 1, fig. 2 (? arched scaphate only).

*Apsidognathus cf. walmsleyi* Aldridge. BISCHOFF, 1986, p. 157, pl. 2, fig. 26.

*Types.*—Hypotype GSC120440.

*Material examined.*—5 Pa elements.

*Occurrence.*—*griestoniensis* graptolite Zone.

*Discussion.*—As with Bischoff (1986), only specimens of the arched scaphate element have been found in this collection. The scaphate element is distinguished by having a tongue-like posterior structure, although the specimen illustrated here is not like Bischoff's in that this structure narrows, instead of widening, posteriorly. The entire upper surface is covered with distinct transverse ridges.

## APSIDOGNATHUS? SP.

## Pl. 2, Figures 5-6

*Description.*—The unusual elements consist of an oval cone with an upper surface covered with irregular nodes in a pattern vaguely similar to that common to *Apsidognathus*. A stubby cusp with similar ornament to the base may be present and reclined, otherwise, some of the nodes and ridges may be larger than the others forming a cusp-like protrusion from the base.

*Types.*—Figured specimens GSC120438-120439.

*Material examined.*—5 elements.

*Occurrence.*—*griestoniensis* and *sakmaricus* graptolite zones.

*Discussion.*—Both Armstrong (1990, pl. 1, fig. 15, pl. 2, fig. 9) and Bischoff (1986, pl. 2, figs. 22-25) illustrated ornamented coniform elements of the *Apsidognathus* apparatus. Armstrong's emended diagnosis of *Apsidognathus* includes a coniform element "which develops short rudimentary lateral processes and a costa on the posterior edge" (1986, p. 41). Bischoff (1986) thought that his coniform elements might be Pb elements. None of these other published coniform elements, however, appear to be similar enough to *Apsidognathus?* sp. to warrant synonymy here, and the sparse distribution of this element means that it can only be provisionally placed within *Apsidognathus*.

GENUS *Aspelundia* SAVAGE, 1985

*Type species.*—*Aspelundia capensis*, Savage, 1985

Savage (1985) proposed the multielement genus *Aspelundia*, which was revised by Armstrong (1990) and McCracken (1991b). However, as noted by Simpson and Talent (1995), Zhou et al. (1981) described new genera from the Early Silurian of the Guizhou Province. Their form genus "*Pseudolonchodina*" apparently included modified digyrate Pb elements similar to those here described as the denticulated Pa element of *Aspelundia* cf. *A. borenorensis*, while their genus "*Neoplectospathodus*" includes Sb elements with a third denticulate process apparently similar to those described here as the denticulated Sb element. Although these were based on form elements, Simpson and Talent proposed that they have priority over the more recent treatment of Savage (1985). *Pseudolonchodina* (Zhou, Zhai and Xian) was selected by Simpson and Talent (1995) as a "generally diagnostic" Pb element, bearing a third denticulate process. Because this author did not have access to the obscure publication by Zhou, Zhai and Xian (1981) to check their plates, it is preferred that the genus *Aspelundia* Savage be retained for this time.

In this study, *Aspelundia* is composed of two species, *A. petila* and *A. fluegeli*, as well as an a number of elements referred to *Aspelundia* cf. *A. borenorensis*, after the multielement species *Oulodus planus borenorensis* Bischoff, which contains a number of the aberrant elements. It is likely that this those elements referred to *A. cf. A. borenorensis* are derived from more than one species, including *A. fluegeli*.

## ASPELUNDIA CF. A. BORENORENSIS (Bischoff, 1986)

Pl. 3, figs. 11-23

**Symmetrical denticulated element***Pandorinellina plana*, SAVAGE, 1985 Fig. 18V-Y.*Oulodus planus borenorensis* n. subsp., BISCHOFF, 1986, pl. 20, fig. 37.*Aspelundia capensis?* Savage, 1985. MCCRACKEN, 1991a, p. 106, pl. 1, fig. 20 (only).**Asymmetrical denticulated element***Oulodus fluegeli* (Walliser, 1964). SAVAGE, 1985, p. 718-719, fig. 100-Q.*Oulodus? fluegeli* (Walliser). ALDRIDGE and MOHAMED, 1982, pl. 2, fig. 26.*Oulodus?* n. sp. 2, OVER AND CHATTERTON, 1987, p. 24, pl. 5, fig. 26.

Gen. and sp. indet. A HELFRICH, 1980, p. 568, pl. 1, figs. 10-11.

*Roundya* sp. B IGO AND KOIKE, 1968, p. 17, pl. 1, figs. 1-2.*Hibbardella? trichonodelloides* (Walliser). ALDRIDGE, 1972, p. 182, pl. 6, fig. 18 (only).**Asymmetrical adenticulate element***Diadelognathus nicolli* ALDRIDGE, 1972, p. 170-171, pl. 8, figs. 2, 3; MILLER, 1978, pl. 3, figs. 16-17.*Pandorinellina plana* SAVAGE, 1985 Fig. 18R-S.

Gen. and sp. indet. A HELFRICH, 1980, p. 568, pl. 1, figs. 7, 12.

**Denticulated Sb element***Aspelundia capensis* SAVAGE, 1985, p. 725-726, Fig. 19M-T.*Aspelundia fluegeli* (Walliser). ARMSTRONG, 1990, 53-55, pl. 3, figs. 6-7.*Aspelundia capensis?* Savage, 1985. MCCRACKEN, 1991a, p. 106, pl. 1, figs. 18.**Denticulated Pa element**

*Oulodus?* n. sp. 2, OVER AND CHATTERTON, 1987, p. 24, pl. 5, figs. 19 (Pa), 22.

*Oulodus planus borenorensis* n. subsp., BISCHOFF, 1986, pl. 21, figs. 16-19.

*Aspelundia capensis* SAVAGE, 1985, p. 725-726, Fig. 19A-D, E-F ('Pb'), J-L ('Sc').

### **Denticulated M-2 element**

*Aspelundia capensis* SAVAGE, 1985, p. 725-726, Fig. 19G-I ('M element').

*Types.*—Hypotypes GSC120469-GSC120481.

*Material examined.*—Denticulated Pa element- 45; symmetrical denticulated element- 27; asymmetrical adenticulate element- 59; asymmetrical denticulate element- 124; denticulate M-2 element- 41; denticulate S element- 21.

*Occurrence.*—*crispus* Zone?, *griestoniensis* and *sakmaricus* graptolite zones.

*Discussion.*—*Aspelundia* cf. *A. borenorensis* consists of various Late Llandovery elements of the genus *Aspelundia* with extra process which may or may not be denticulated. Bischoff (1986) proposed the new subspecies, *Oulodus planus borenorensis*, as a closely related form of *A. planus planus* (which includes elements of *Aspelundia petila* and *A. fluegeli* recognised here), which he found in his *P. amorphognathoides-P. latus* Assemblage Zone, and also in an allochthonous limestone dated as *celloni* Zone (*griestoniensis* Zone). As he described it, this subspecies differed from *A. petila* and *A. fluegeli* in the morphology of the Sb and Sc elements, and in that the Pa and Sa elements possess an additional denticulate process. Bischoff's figured Pa elements (1986, pl. 21, figs. 16-19), are synonymous with those described as the equivalent elements in Savage's *Aspelundia capensis* (1985, fig. 19A-D see below). These are referred to here as the denticulated Pa element. Although the proportion of Pa elements that have this process is unclear, one third of his (Bischoff 1986, p. 85) Sa (here termed the asymmetrical and symmetrical denticulate elements) elements have this

characteristic additional process (pl. 20, fig. 16, pl. 21, fig. 37, respectively). Bischoff (1986) did not distinguish between the symmetrical and asymmetrical denticulated elements that Savage (1985) attributed to *Pandorinellina plana* Sa and *Oulodus fluegeli* Sb, respectively.

Savage (1985) figured all the denticulated elements recognised here and assigned them to *Oulodus? fluegeli*, *Pandorinellina plana* (Walliser), and a new genus and species, *Aspelundia capensis*. Within *A. capensis* he grouped the Pa with a lateral process, and S elements with a denticulated posterior process recognised here. In Savage's figures and descriptions, his Pa, Pb and Sc elements may be synonymous, as each is characterised by a laterally compressed blade with upright denticles, anterior blade directed downwards, and a main cusp with a lateral process arising near it. The M element (Savage 1985, fig. 19G-I) has a distinct morphology, with a laterally flattened main cusp at its anterior end, and a lateral process arising near the anterior end. In the Cape Phillips samples, however, it was observed that many denticulated M elements could be considered a denticulated Pa element when oriented so that the anterior process with the large flattened cusp was directed posteriorly. The 'denticulated M elements' are very large and may be mature forms of the denticulate Pa element, although the presence of a large cusp is not recognised in other denticulated Pa elements. The Sa and Sb elements of Savage's (1985) *A. capensis* are characterised by lateral blades with a posterior blade arising from the cusp.

Savage (1985, fig. 18A-Y) constructed the apparatus of *Pandorinellina plana* with *Neoprioniodus planus* as the nominate form species (M element). Although the Pa, Pb and M elements are here placed in synonymy with *Aspelundia fluegeli*, the Sa, Sb and possibly Sc elements depart considerably from the morphology of *Aspelundia fluegeli*. His Sa element (Fig. 18V-Y), the morphology that is here called the symmetrical denticulate element, has a long denticulated posterior blade that arises from the junction of the lateral processes and the laterally compressed, posteriorly inclined cusp. Savage's (1985) figures (Fig 18V) show the alate Sa element with lateral processes in the W-shape, rather than the V-shape that is characteristic of *A. fluegeli*.

Savage's (1985) *Pandorinellina plana* Sb element and those figured here as the adenticulate, asymmetrical element, are characterised by a somewhat straight posterior bar, a long cusp strongly posteriorly recurved, and a laterally process which is posteriorly curved. Also, a basal groove is present on the aboral side of the cusp.

Savage (1985) also assigned to *Oulodus fluegeli* an element here termed the asymmetrical denticulated element, to the Sb position of that species (fig. 100-Q). The asymmetrical denticulated element has lateral processes and a cusp similar to the alate Sa element, however, because of its asymmetry was considered not to be alate. Its morphology was considered to possess a straight denticulated anterior bar that bears a main cusp that is followed by a prominently flexed posterior bar and a lateral process that projects antero-laterally in the same plane.

Armstrong (1990: Pl. 3, fig. 6-7, 19-20) figured a denticulated Sb element, and assigned it to the Sb<sub>1</sub> position within the apparatus of *Aspelundia fluegeli* and *Aspelundia petila*. Although the Sb<sub>1</sub> element assigned to *A. fluegeli* has a clear posterior process (his Pl. 3, fig. 6), the Sb<sub>1</sub> element attributed to *A. petila* (his Pl. 3, figs. 19-20) does not, and other studies (e.g. McCracken 1991a and this one) have not made the distinction between Sb elements of *Aspelundia petila*.

Published figures of these aberrant elements are rare. Aldridge (1979) noted that some of his Sa elements which he assigned to *Oulodus? fluegeli* possessed a denticulated posterior bar. McCracken (1991b) figured the denticulated Sb (Pl. 1, fig. 18) and symmetrical denticulated (Pl. 1, fig. 20) elements from the South Nahanni River, Mackenzie Mountains from *Pterospathodus amorphognathoides* Zone strata that also contained *Pterospathodus procerus*. Helfrich (1980) figured the asymmetrical denticulated element (Pl. 1, figs. 10-11, 'Sa'), and adenticulate asymmetrical process (Pl. 1, figs. 7, 12, 'Sb') as part of the apparatus of his Gen. and sp. indet. A from *amorphognathoides* Zone strata of the upper part of the Rose Hill Formation in the north-eastern United States. Over and Chatterton (1987) figured the asymmetrical denticulated element (Pl. 5, fig. 26 'Pa-Sa?'), and denticulated M (Pl. 5, fig. 22 'Sb-Sa?') which they assigned to *Oulodus? n. sp. 2* from upper *amorphognathoides* Zone strata at Avalanche Lake in the southern Mackenzie Mountains. They considered *Oulodus? n. sp. 2* to be

very similar to *O. ? fluegeli* except for the Pa and Sc elements. The Pa elements they figured appear to include a denticulated Pa element (Pl. 5, fig. 19), however they considered the Pa to be diagnostic because of the closely spaced and greater number of denticles on the processes. The Sc element they considered to be synonymous with the form species *Ligonodina* sp. Igo and Koike, 1968. In this study, the spacing of denticles and the morphology of Sc elements were not determined to vary considerably enough to warrant their inclusion in separate species, especially considering the apparent range of variation within *Aspelundia*. Igo and Koike (1968) figured the asymmetrical denticulated element as *Roundya*? sp. from the *amorphognathoides* Zone of Malaya, whereas Aldridge (1972) referred the same element to *Hibbardella*? *trichonodelloides* (Walliser) (Pl. 6, figs. 18). Aldridge (ibid.) considered the alate Sa element to be synonymous with the asymmetrical denticulated element. The original description of ?*Roundya trichonodelloides* from the *celloni* and *amorphognathoides* zones of Cellon by Walliser (1964) includes elements in which the posterior bar is adenticulate or denticulate, however it appears that Walliser was only considering the symmetrical elements. The asymmetrical adenticulate element was figured as the form species *Diadelognathus nicolli* by Aldridge (1972, Pl. 8, figs. 2, 3) from the *celloni* and *amorphognathoides* zones of Welsh Borderland, by Miller (1978) as the same form species from the *celloni* Zone of the Hidden Valley Dolomite of southeastern California, and by Aldridge and Mohamed (1982) as the Sb element of *Oulodus*? *fluegeli*. Zhou et al. (1981) proposed several form genera from the Early Silurian of the Guizhou Province, some of which can be assigned to *A.* cf. *A. borenorensis*. Without reference to their publication, however, it is not possible to determine whether their form genera should be listed within the synonymy.

Mirza (1976), in an unpublished M.Sc. thesis of conodonts from the Eastern Canadian Arctic Islands, proposed *Ozarkodina* n. sp. A that contained the what are referred to here as the denticulated M-2 element, denticulated Pa element, an undenticulated S element with similarly closely spaced denticles to the denticulated S elements recognised here and elsewhere, and the symmetrical denticulated element. These elements were recovered from the *amorphognathoides* Zone of the Cape Phillips Formation.

Clearly, the same elements have been assigned to different species and even different apparatus positions. From the study of the Cape Phillips material, it is preferred that until the relationships of the Late Llandovery forms be understood that all the morphotypes be considered as separate elements. In this case, this means that the normal vs. denticulated Pa's, asymmetrical denticulated vs. symmetrical denticulated for example, not be considered as equivalent elements within the range of variation of a single species. In addition, the apparatus location of some of the elements listed here is questionable, notably the adenticulate asymmetrical element (Sb/Pa?), and the asymmetrical denticulated element (Sa/Sb?).

Bischoff (1986) anticipated that his inclusion of these aberrant morphotypes within his construction of the *Oulodus planus borenorensis* apparatus may be incorrect and that they actually form part of a new species that marks an "evolutionary change towards an increase in the number of denticles and the processes that bear these" (p. 86). In general agreement with the Cape Phillips data, Bischoff (1986) also considered *Oulodus planus planus* (here considered to include elements of *Aspelundia petila* and *A. fluegeli*) to have given rise to *Oulodus planus planus* in the Late Llandovery, probably in the *celloni* Zone. Similarly, Over and Chatterton (1987) considered their *Oulodus* n. sp. 2 to be a "late form of the *O. fluegeli?* group" (p. 24) appearing in the upper *amorphognathoides* Zone at Avalanche Lake. Because it is unclear whether these elements form separate taxa, or may be shared with *A. fluegeli*, it is preferred to consider all these aberrant morphotypes as the "*borenorensis*" complex of elements, and are assigned to *Aspelundia* cf. *A. borenorensis*.

## ASPELUNDIA FLUEGELI (Walliser, 1964)

Pl. 2, figs. 9-26

*Lonchodina fluegeli* WALLISER, 1964, p. 44, pl. 6, fig. 4, pl. 32, figs. 22-24.

## Multielement

*Aspelundia fluegeli* (Walliser). ARMSTRONG, 1990, p. 53-55, pl. 3, figs. 2-5, 8-9, 11-12 (not figs. 1, 6-7); MCCrackEN, 1991b, p. 73-75, pl. 1, figs. 5-6, 10, 13-14, 17, 19-24, 26-27, 31-32, pl. 2, figs. 3-4, 7-8, 10, 11, 13-15, 17-25, 29, 32; McCrackEN, 1991a, p. 107, pl. 1, figs. 13-17; SARMIENTO, MENDÉZ-BEDIA, ARAMBURU, ARBIZU AND TRUYOLS., 1994, pl. 2, figs. 8-9, 11, 14; MÄNNIK AND MALKOWSKI, 1998, pl. 1, figs. 28-29, 32, 33. "*Neoprioniodus*" *planus* Walliser. KLAPPER AND MURPHY, 1975, p. 55, pl. 10, figs. 23-25.

*Oulodus fluegeli* (Walliser). SAVAGE, 1985, p. 718-719, fig. 10A-N, R-S (not O-Q).

*Oulodus?* *fluegeli* (Walliser). ALDRIDGE, 1979, p. 14-15, pl. 2, figs. 6-8, ?9, 10?;

ALDRIDGE AND MOHAMED, 1982, pl. 2, fig. 27 (only); ALDRIDGE AND JEPSSON, 1984, figs. g-h; ORCHARD in NORFORD AND ORCHARD, 1985, pl. 1, figs. 2, 9-10, 12-14, 16-18, 20-21; OVER AND CHATTERTON, 1987, p. 23, pl. 1, figs. 30-38.

*Oulodus?* cf. *O.?* *fluegeli* (Walliser). UYENO AND BARNES, 1983, p. 19, pl. 1, figs. 1-5.

*Ozarkodina plana* (Walliser). SWEET AND SCHÖNLAUB, 1985, p. 52, pl. 1, figs. 1, 4.

*Oulodus planus planus* (Walliser). BISCHOFF, 1986, p. 78-84, pl. 19, figs. 39-41, pl. 20, figs. 2, 7, 17-18, 20, 28-29, 35, 38, 42 (only), pl. 21, figs. 1-2, 5, 7-11 (only).

*Pseudolonchodina fluegeli* (Walliser). SIMPSON AND TALENT, 1995, p. 112-113, pl. 1, fig. 4.

*Types*.—Hypotypes GSC120441-120458.

*Material examined*.—Pa element- 54; Pb element- 99; M<sub>1</sub> element- 154; M<sub>2</sub> element- 2; M<sub>3</sub> element- 110; Sa element- 75; Sb element- 61; Sc element- 195.

*Occurrence.*—Probably at least the ?*crispus* graptolite Zone to the *sakmaricus* graptolite Zone.

*Discussion.*—*Aspelundia fluegeli* is characterised by narrowly expanded basal cavities and compressed denticles that tend to be more closely packed, wider, and more numerous than those of *A. petila*. The Sa element of *A. fluegeli* is diagnostic; the lateral processes are straight forming an Y-shape when the element is viewed from above. The apparatus differs from that of *A. petila* in that it possesses an additional M element ( $M_2$ ). (For detailed descriptions see McCracken 1991b). Armstrong's (1990) *Aspelundia fluegeli* differs from *A. petila* in that the former was constructed with a modified tertiopedate element (his Sd), and a second Sb morphotype,  $Sb_1$ , that possessed a posterior process. He argued that later Paleozoic apparatus bauplans commonly contain two Sb morphotypes. He also noted that Over and Chatterton (1987) figured a species with two such Sb morphotypes, and that their *Oulodus?* n. sp. 2 is probably synonymous with *Aspelundia capensis*; however, Armstrong (1990) did not consider any of his North Greenland elements to be part of the *A. capensis* apparatus. In this study the denticulated Sb element is assigned to the late Llandovery taxon, *Aspelundia*. cf. *A. borenorensis*.

As in *A. fluegeli* of Armstrong (1990), McCracken (1991, pl. 1, fig. 14) figured an *e*-3 (here= $M_3$ ) element that Armstrong (1990, pl. 3, figs. 8-9) assigned to the Sd position. The modified tertiopedate element (previously described by Armstrong, 1990), was, however, not recognised by Bischoff (1986) or Over and Chatterton (1987), from similar aged-strata yielding *Aspelundia fluegeli*, but is recognised here from the Cape Phillips Formation (pl. 2, figs. 17, 22).

A rare  $M_2$  element (pl. 2, fig. 18) comparable to the *e*-2 element of McCracken (1991a, pl. 1, fig. 10) was also recovered from a sample rich in *A. fluegeli* and *A.* cf. *A. borenorensis* complex elements. This  $M_2$  element has a short anterior process with one or two denticles. The cusp is laterally compressed.

A rare (not figured) Sc element occurs associated with *Aspelundia fluegeli* and *A.* cf. *A. borenorensis* elements. The element has similar compressed denticles and anterior and posterior processes as the typical *A. fluegeli* Sc elements, except that a small

adenticulate projection directed in the anterolateral direction is present on the outer face of the element at the point where the main cusp projects posteriorly. In specimens where this projection is present, the lower inner lateral surface between the anterolateral process, cusp, and posterior process is more angular than smooth and rounded, as is typical of the Sc elements of the species.

## ASPELUNDIA PETILA (Nicoll and Rexroad, 1969)

## Plate 3, figures 1-10

*Ligonodina petila* NICOLL AND REXROAD, 1969, p. 38-39, pl. 5, figs. 20-22.

## Multielement

*Aspelundia expansa*, ARMSTRONG, 1990, p. 50, 52, pl. 3, figs. 13-20; MÄNNIK AND MALKOWSKI, 1998, pl. 1, figs. 34-35.

?*Aspelundia* n. sp. 1 (Over and Chatterton). ARMSTRONG, 1990, p. 55, pl. 3, fig. 10.

*Aspelundia?* n. sp. B, ARMSTRONG, 1990, p. 56, 58, pl. 4, figs. 6-8, 10.

*Aspelundia petila* (Nicoll and Rexroad). McCracken, 1991b, p. 75-78, pl. 1, figs. 1-4, 7-9, 11-12, 15-16, 18, 25, 28-30, pl. 2, figs. 1, 2, 5, 6, 9, 12, 16, 26-28, 30-31 (includes further synonymy through 1990); Sarmiento, Mendéz-Bedia, Aramburu, Arbizu and Truyols., 1994, pl. 2, figs. 6-7.

*Oulodus? expansus* (Armstrong, 1990). Zhang and Barnes (in press).

*Oulodus? fluegeli* (Walliser). Mabillard and Aldridge, 1983, pl. 2, figs. 15, 16.

*Oulodus? fluegeli* subsp. A Uyeno and Barnes, 1983, p. 18, 19, pl. 7, figs. 11-22 (except fig. 19 may be a broken posteriorly-denticulated Sb sensu Savage).

*Oulodus?* sp. cf. *O.? fluegeli* (Walliser). Orchard in Norford and Orchard, 1985, p. 11, pl. 2, figs. 8, 9, 12, 15, 16, 23, 24.

*Oulodus?* n. sp. 1, Over and Chatterton, 1987, p. 23-24, pl. 5, figs. 11-17.

*Oulodus planus planus* (Walliser). Bischoff, 1986, p. 78-84, pl. 20, figs. 1, 3-6, 19, 21-27, 30-34, 36-37, 39-41, 43-44 (only), pl. 21, figs. 3-4, 6, 12 (only).

*Pseudolonchodina expansa* (Armstrong). Simpson and Talent, 1995, p. 111-112, pl. 1, fig. 3.

*Types.*—Hypotypes GSC120459-120468.

*Material examined.*—Pa element- 41; Pb element- 52; M element-95; Sa element- 37; Sb element- 82; Sc element- 118.

*Occurrence.*—In the Cape Phillips Formation, unquestionable *Aspelundia petila* appears in the middle of the *cyphus* graptolite Zone at Cape Manning (CM2C-5). In the *atavus* graptolite Zone at both Cape Phillips South and Cape Manning, however, M elements that are small, but identical to those assigned to *Aspelundia* are present in small numbers (Pl. 3, fig. 1). These are tentatively assigned to *A. petila*. This is the lowest known occurrence of the species worldwide, as it has not been previously identified within the Rhuddanian Stage; its upper limit is the *sakmaricus* graptolite Zone. On Anticosti Island, the species ranges throughout the Gun River Formation, and also appears in member 4 of the Jupiter Formation, and the lower Chicotte Formation (Uyeno and Barnes 1983; Zhang and Barnes in press).

*Discussion.*—*Aspelundia petila* has elements characterised by broad, shallowly excavated basal cavities and compressed relatively discrete and robust denticles. The Sa element is most diagnostic, having lateral processes that are bowed posteriorly forming a W-shape when viewed from above. McCracken (1991b, p. 76-77) described in detail the differences between the two most common species of *Aspelundia*, *A. petila*, and *A. fluegeli*. Armstrong's (1990) description of this species included Sb<sub>1</sub> and Sb<sub>2</sub> elements, but the interpretation of McCracken (1991b) is preferred identifying a single Sb (his *b*) element. McCracken (1991b) distinguished two kinds of Sc morphotypes, *a-1* and *a-2*, but these differences were not observed in the Cape Phillips material. McCracken (1991b) found a rare additional M element in his *Aspelundia petila* and *A. fluegeli*, which he termed *e-2*, that possesses a denticulate anterior corner. Despite a significant yield of 95 M elements, this element is not recognised in either species from the Arctic.

Although there has been a tendency to assign elements with additional denticulated or adenticulate processes to *A. fluegeli* (see synonymy of *A. cf. A. borenoensis*), these have never been ascribed to the earlier species, *A. petila*. Although there are large number of these aberrant elements, they do not occur in pre-*crispus* graptolite Zone? strata, and hence cannot be components of the *A. petila* apparatus.

GENUS *Astropentagnathus* MOSTLER, 1967

Type species.—*Astropentagnathus irregularis* Mostler, 1967.

ASTROPENTAGNATHUS? SP.

Plate 11, figs. 17-18

*Types*.—Figured specimens GSC120655-120656.

*Material examined*.—Sa? element- 1; Sc? element-1.

*t*

*Occurrence*.—Base of the *guerichi* graptolite Zone.

*Discussion*.—These elements are similar to the Sa and Sc elements of *Astropentagnathus irregularis* (Over and Chatterton, 1987, pl. 2, fig. 8) and *A. irregularis* (Armstrong, 1990, pl. 5, fig. 8). The S element of *A. irregularis* (figured in Over and Chatterton) and the Sa element of *A. irregularis* figured in Armstrong (pl. 5, fig. 8) are both alate with lenticular cusp similar to the Sa element figured here (pl. 11, fig. 18). Also, the processes have a similar number of compressed denticles. The beginnings of the posteriorly-directed short triangular projection beneath the cusp, like that in *A. irregularis*, is also evident in this specimen. The bipennate Sc element (pl. 11, fig. 17, herein) with an inwardly flexed anterior process is also similar to that figured by Armstrong (1990, pl. 5, fig. 10). Unlike the latter, however, the basal cavity of the Sc element of *Astropentagnathus?* sp. is not deeply excavated. The size and denticle morphology of the Sc element is similar to that of the Sa in the sample. The overall morphology of these elements is also comparable to the Sb and Sa elements of *Ozarkodina gulletensis* (Aldridge) (e.g. Uyeno and Barnes, 1983, pl. 4, figs. 16, 19). Their early occurrence and lack of co-occurrence with diagnostic Pa elements, means that they can only be placed questionably within *Astropentagnathus*.

GENUS *Aulacognathus* MOSTLER, 1967

*Type species.*—*Aulacognathus kuehni* Mostler, 1967.

AULACOGNATHUS BULLATUS (Nicoll and Rexroad, 1969)

Plate 4, figs. 2, 3, 6

*Neospathognathodus bullatus* NICOLL AND REXROAD, 1969, p. 44, pl. 1, figs. 5-7.

Multielement

*Aulacognathus bullatus bullatus* (Nicoll and Rexroad). OVER AND CHATTERTON, 1987, pl. 3, figs. 1-2, 6;

*Aulacognathus bullatus* (Nicoll and Rexroad). ARMSTRONG, 1990, p. 62, 64-65, pl. 6, figs. 1-2, 4-7 (contains synonymy through 1990); McCracken, 1991a, p. 108, pl. 3, figs. 1-2.

*Types.*—Hypotypes GSC120483, 120485, 120488.

*Material examined.*—Pa elements- 5; Sb/Sc elements- 3.

Pa elements- 4; Pb elements- 3; M elements- 2; Sa elements- 10; Sb elements- 6; Sc elements- 2.

*Occurrence.*—Lower *griestoniensis* graptolite Zone.

*Discussion.*—Armstrong noted that the Pa element is highly variable. In the Pa element (pl. 4, fig. 2, herein), the lateral processes are not long and are not both anteriorly-directed; however, they are broad as in Armstrong's description. One or two coalescing nodes ornament the tips of each lateral process. The Sb/Sc elements are similar to those

figured by Armstrong (1990, p. 64, fig. 31) with tall, laterally compressed and posteriorly-inclined cusps, and a downward-directed anterior process that is shorter than the posterior process.

## AULACOGNATHUS CHAPINI (Savage, 1985)

## Plate 4, figs. 9-10

*Neospathognathodus chapini*, SAVAGE, 1985, p. 717-718, fig. 8A-F.

*Aulacognathus chapini* (Savage). OVER AND CHATTERTON, 1987, p. 21, pl. 3, figs. 13, 14, 21; MCCrackEN, 1991a, pl. 3, fig. 3.

*Types*.—Hypotypes GSC120490-120491.

*Material examined*.—Pa element- 2; Pb element- 3.

*Occurrence*.—*Aulacognathus chapini* ranges through the *amorphognathoides* Zone into the *ranuliformis* Zone on Cap Island, southeastern Alaska (Savage 1985). At Avalanche Lake (southern Mackenzie Mountains) it occurs in the upper *amorphognathoides* Zone (Over and Chatterton 1987). In the Rocky Mountains at McLeod Lake, a single specimen was found in the *celloni* Zone (McCracken 1991a). In the Cape Phillips Formation, *A. chapini* is limited to a single sample (ARE5) at the top of the *sakmaricus* graptolite Zone.

*Discussion*.—Savage (1985) did not regard *Neospathognathodus* to be a synonym of *Aulacognathus*; however, Over and Chatterton (1987) did not consider the morphologies to be significantly different to warrant separate generic names to be established, especially since the complete apparatus and phylogenetic relationships are unknown. Over and Chatterton's (1987) interpretation is followed herein, and Savage's "*Neospathognathus*" *chapini* is assigned to *Aulacognathus* (Mostler 1967). Several Pa and Pb elements were found in a single Late Llandovery sample. The distinctive elements are identical to those described by Savage. Over and Chatterton (1987) concluded that *A. chapini* is related to *A. bullatus*, possibly through a couple of intermediate forms, his *A. bullatus* n. ssp. A and *A. aff. A. latus*. Although these intermediates were not recovered from the Cape Phillips Formation, an ancestor-

descendent relationship between the two species continues to be supported by the stratigraphic relationship of the *A. bullatus* and *A. chapini*.

GENUS *Belodella* ETHINGTON, 1959

*Type species.*—*Belodus devonicus* Stauffer, 1940.

BELODELLA SP. A Miller, 1978

Plate 4, figs. 8, 11-15

Sc element

*Belodella* sp. A MILLER, 1978, p. 341, pl. 1, figs. 19-23; OVER AND CHATTERTON, 1987, pl. 6, figs. 4, 8-12.

?*Belodella* sp. MÄNNIK AND MALKOWSKI, 1998, pl. 2, figs. 15, 18.

*Emended Diagnosis.*—Species of *Belodella* with Sa, Sb, Sc and M elements, all bearing posterior denticles. Sc and M elements ornamented with furrows on one lateral face.

*Description.*—Sa element: (rare, not illustrated) similar to the Sa element of *Walliserodus* in that it is symmetrical and has anterolaterally-directed keels. This element is a symmetrical version of the Sb element.

Sb element: Cusp proclined. Element curved inwardly. Outer face has antero-lateral keel/costa (asymmetrical version of Sa element). Inner face smooth except for slightly convex base. Anterior keel curves inwards slightly.

Sc element: Cusp proclined to erect. Highly curved inwards. Outer face has distinct furrow near posterior margin that begins at base and continues to tip of cusp. Inner face has sharp costa slightly anterior of medial beginning one-third of the way towards base of cusp and ending at point of maximum curvature of the cusp. Minute striae occur along base of element.

M element: Laterally compressed element. Cusp erect. Denticles wider, mainly anteriorly-directed. Inconspicuous furrow on one lateral face situated slightly posterior

of middle of lateral face begins at base and continues to tip of cusp. Minute striae occur along base.

*Types.*—Hypotypes GSC120492-120497.

*Material examined.*—Sa element- 13; Sb element- 24; Sc element- 31; M element- 8.

*Occurrence.*—This species first appears in the *crispus* graptolite Zone? and ranges into the *amorphognathoides* Zone, as well as into the Sheinwoodian, although it is not clear whether the sparse Sheinwoodian elements represent the same species. *Belodella cooperi* ranges from the *P. celloni* Zone into the upper Wenlock in North Greenland (Armstrong 1990).

*Discussion.*—Miller (1978) described the monoelemental *Belodella* sp. A from the *amorphognathoides* Zone of southeastern California. His elements possessed an inner anterolateral costa, and outer face with a “faint to distinct costa and groove” (p. 341). These are identical to the Sc element described here. Over and Chatterton (1987) figured, but did not describe, four forms of *Belodella* sp. A Miller. The forms differ in the presence or absence of a medial to slightly anterior costa and this may thus be a variable character.

Armstrong (1990) described a new species, *Belodella cooperi*, from *celloni* Zone to upper Wenlock? strata in North Greenland. This species is trimembrate with Sa, Sc and M (his sym. p, aq, and sq elements) elements. The Sa and Sc elements he found to be synonymous with *Belodus triangularis* Stauffer (1940) and *Belodus devonicus* Stauffer (1940). Cooper (1974, 1976) considered the Upper Silurian forms of *Belodella* to consist of Sa and Sc elements. Armstrong (1990) considered these to be synonymous with *B. triangularis* and *B. devonicus*. Ordovician species of *Belodella* have been described with denticulate Sa and Sc elements and adenticulate M and oistodiform elements (Löfgren, 1978), with a denticulate M element (Löfgren 1978), and with only denticulate Sa and Sc elements (Ethington and Clark 1982).

Armstrong's (1990) M element (pl. 7, figs. 5-6) is not comparable to that identified here because it does not have a furrow, is proclined, and is ornamented with a number of costae. Although the rare Sa element is comparable, the Sc element of Armstrong (1990, pl. 7, figs. 3-4) does not have an inner costa or outer posterior furrow.

Barrick (1977) described a new species, *Belodella silurica*, from the Wenlock of Oklahoma. His specimens (pl. 1, figs. 1-6, 9-10) compose a similar apparatus to that recognised here, with Sa, Sb, Sc and M elements, except the M elements are adenticulate. The elements of *B. silurica* have grossly different morphology than those recognised here.

Uyeno (1990) described several species of *Belodella* among which are *Belodella* sp. A. Uyeno (pl. 19, figs. 15, 18-22) and *B. cf. B. reisma* (Philip) (pl. 16, figs. 18-22, 25) from Devonian and Upper Silurian-Devonian strata of the Arctic, respectively. Both of these species have Sa, Sb, Sc and adenticulate M elements (*B. sp. A* also was assigned a Sd element). Hence, as Armstrong (1990, p. 66) noted, the apparatus of *Belodella*, at least in Silurian-Devonian time, has an apparatus and elements with close morphological similarities to *Walliserodus*. Assigning an Sb element to the apparatus is in keeping with this assertion. Other recent descriptions of Upper Silurian and Devonian belodellids (i.e. Barrick and Klapper 1992) have included adenticulate M elements, and even falciform elements, similar to the apparatus of *Panderodus* and *Belodina* after the work of Jeppsson (1989). The tortiform element was not identified in the Cape Phillips samples; however, elements of the genus were not found in great numbers.

GENUS *Belodina* ETHINGTON, 1959

*Type species.*—*Belodus compressus* Branson and Mehl (emended Bergström and Sweet, 1966).

## BELODINA CONFLUENS Sweet, 1979

Pl. 1, figs. 10-11

*Belodina confluens* SWEET, 1979, p. 59-60, Fig. 5.10, 17, Fig. 6.9; NOWLAN, 1983, p. 662, 664, pl. 3, figs. 3, 4 (contains pre-1981 synonymy); MCCRACKEN, 1987, pl. 1, figs. 1-4; NOWLAN, MCCRACKEN AND CHATTERTON, 1988, pl. 1, figs. 16-21; MCCRACKEN AND NOWLAN, 1989, pl. 1, figs. 19-21; pl. 2, figs. 1, 2; UYENO, 1990, p. 71-72, pl. 1, figs. 8, 9; NOWLAN, MCCRACKEN AND MCLEOD, 1997, pl. 1, figs. 1, 2; pl. 3, figs. 5, 6, 9, 10.

*Belodina compressa* (Branson and Mehl). NOWLAN AND BARNES, 1981, p. 12, pl. 8, figs. 1-4; MCCRACKEN AND BARNES, 1981, p. 75, pl. 3, figs. 10-12, 16-18; LENZ AND MCCRACKEN, 1982, pl. 2, figs. 3, 4, 7.

*Types.*—Hypotypes GSC120411-120412.

*Material examined.*—Grandiform element- 12; compressiform element- 7.

*Occurrence.*—*pacificus* graptolite Zone.

*Discussion.*—Nowlan et al. (1988) noted the micro-ornament of *Belodina confluens* is not restricted to the basal region, beneath the groove, and the cusp as in *Pseudobelodina*, but is present over most of the surface of the grandiform and compressiform elements (except the distal regions of the denticles and upper part of heel). The elements illustrated here have only faint striae in the basal region. Trotter and Webby (1994) noted that *Pseudobelodina dispansa* might be part of the apparatus of *Belodina confluens*.

Sweet (1979) proposed that *Pseudobelodina* is composed entirely of rastrate elements, whereas the *Belodina* apparatus includes an eobelodiniform element. No eobelodiniform elements were recovered here, although the total count was low. Grandiform and compressiform elements are recognised; these are distinguished from elements of *Pseudobelodina? dispansa* based on their having wider, less anteriorly-directed denticles.

GENUS *Besselodus* ALDRIDGE, 1982

*Type species.*—*Besselodus arcticus* Aldridge, 1982.

## BESSELODUS BOREALIS Nowlan and McCracken, 1988

Plate 1, figs. 9, 12-14

*Besselodus borealis* NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 13-14, pl. 2, figs. 13-17; pl. 5, fig. 7 (synonymy through 1983); MCCRACKEN and NOWLAN, 1989, p. 1888, pl. 2, figs. 13-17; NOWLAN MCCRACKEN AND MCLEOD, 1997, pl. 1, fig. 3.

*Types.*—Hypotypes GSC120413-120416.

*Material examined.*—M element- 19; Sa element- 1; Sb element- 10; Sd element- 8.

*Occurrence.*—*fastigatus-pacificus* graptolite zones.

*Discussion.*—All elements are bicostate and laterally compressed. Unlike those in *Besselodus borealis* figured and described in Nowlan et al. (1988), the *e* (=M) elements include not only bicostate forms, but also acostate and unicostate elements. The M elements figured in McCracken and Nowlan (1989) do not appear to have any costae. Hence the presence of costae may be a variable feature of *B. borealis*.

McCracken and Nowlan (1989) note that *Besselodus borealis* has fine anterior striations on all elements including and the *e* element, which, along with the shape, distinguishes it from *Besselodus arcticus* Aldridge. Striae are present on the Sb elements illustrated, but not on the M element; however the coarseness and obliqueness of the striae is unusual for this species, and suggest that they could belong to *Dapsilodus*.

GENUS *Coelocerodontus* ETHINGTON, 1959

*Type species.*—*Coelocerodontus trigonius* Ethington, 1959.

## COELOCERODONTUS TRIGONIUS Ethington, 1959

Plate 1, figs. 15-17

*Coelocerodontus tetragonius* ETHINGTON, 1959, p. 273, pl. 39, fig. 14.

## Multielement

*Coelocerodontus trigonius* Ethington. NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 14-15, pl. 3, figs. 1-5, 8-10; MCCRACKEN AND NOWLAN, 1989, pl. 2, fig. 18; NOWLAN, MCCRACKEN AND MCLEOD, 1997, pl. 1, fig. 4.

*Types.*—Hypotypes GSC120417-120419.

*Material examined.*—Trigoniform element- 2; tetragoniform element- 3; basal funnels- 3.

*Occurrence.*—*fastigatus* graptolite Zone.

*Discussion.*—Only a few specimens were recovered from Ordovician strata of the Cape Phillips Formation.

GENUS *Dapsilodus* COOPER, 1976

*Type species.*—*Distacodus obliquicostatus* Branson and Mehl, 1933

DAPSILODUS OBLIQUICOSTATUS (Branson and Mehl, 1933)

Plate 5, figs. 1-3

*Distacodus obliquicostatus* BRANSON and MEHL, 1933, p. 41, pl. 3, fig. 2.

Multielement

*Dapsilodus obliquicostatus* (Branson and Mehl). MCCracken, 1991a, pl. 4, figs. 11, 13, 14, 16-28, 30-32, 35, 40 (includes synonymy through 1991); SARMIENTO, MENDÉZ-BEDIA, ARAMBURU, ARBIZU AND TRUYOLS., 1994, pl. 1, figs. 1, 6; LEHNERT, BERGSTRÖM, BENDETTO, AND VACCAR, 1999, p. 125, Figure 7d, h, i.

*Types.*—Hypotypes GSC120498-120500.

*Material examined.*—M element- 126; Sa element- 37; Sb/Sc element- 351.

*Occurrence.*—Aldridge and Mabillard (1983) noted the dominance of *Dapsilodus obliquicostatus* in offshore environments in pre-*amorphognathoides* zone through Wenlock time. Similarly, Barrick (1983)(Barrick 1983) found that *Dapsilodus obliquicostatus* biofacies, representing the furthest offshore environment, dominated lower Sheinwoodian strata in Tennessee. Also, Armstrong (1990) and McCracken (1991b) reported Llandovery slope and basal biofacies from Greenland and the Yukon, respectively, that are dominated by *D. obliquicostatus*, *D. fragilis* and *Aspelundia petila/fluegeli*. *D. obliquicostatus* appears in the Cape Phillips Formation directly at the Ordovician-Silurian boundary (CPS 7); at Cape Manning in the *madernii-lubricus* (lower *acuminatus*) graptolite Zone with last appearance in the Llandovery in the *guerichi* graptolite Zone; *instrenuus-kolobus* to *perneri-opimus* zones (CPN); and approximately

throughout the remainder of the Wenlock and earliest Ludlow (ARW). On Anticosti Island, *Dapsilodus obliquicostatus* appears for a relatively short interval in the upper part of the Jupiter Formation (*staurognathoides* Zone) (Uyeno and Barnes 1983), whereas McCracken (1991b) found it as early as the *gregarius* graptolite Zone in the northern Yukon. It has also been found in Rhuddanian beds in Northwest Spain (Sarmiento et al. 1994). The oldest reported Silurian occurrence in North America is from the southwestern District of Mackenzie (Over and Chatterton 1987), possibly from the *Oulodus? nathani* Zone, comparable to its first appearance in the Cape Phillips Formation.

*Discussion.*—Barrick (1976) noted the intergradation between the Sb and Sc (asymmetrical distacodiform) elements that necessitated tabulating the two together. This was also done in the Cape Phillips specimens. Sa elements are very rare in the Cape Phillips sections, and none are figured here. All elements except the M element have oblique striae on the anterior margins. Barrick (1971) described three additional *Dapsilodus* species, *D. praecipuus*, *D. sparsus*, and *D.? sp.* Although a number of the elements have some curvature, the other characters attributed to these other species were not observed in this study and hence all specimens have been assigned to *D. obliquicostatus*.

GENUS *Decoriconus* COOPER, 1975

*Type species.*—*Paltodus costulatus* Rexroad, 1967

## DECORICONUS FRAGILIS (Branson and Mehl, 1933)

Plate 5, figs. 4-9, 13

*Paltodus fragilis* BRANSON and MEHL, 1933, p. 43, pl. 3, fig. 6.

## Multielement synonymy

*Decoriconus costulatus* (Rexroad). COOPER, 1975 p. 992-993, pl. 1, figs. 1, 12, 15, 22; NOWLAN, 1981, pl. 4, fig 7, pl. 5, fig. 25; McCracken and Barnes, 1981, p. 75-76, pl. 2, figs. 24-27; NOWLAN, McCracken and Chatterton, 1988, p. 16, pl. 3, figs. 14-18, 23.

*Decoriconus fragilis* (Branson and Mehl) COOPER, 1976, p. 212-213, pl. 2, figs. 5, 8, 14-17; BARRICK, 1977, p. 53-54, pl. 2, figs. 15, 21-23; UYENO and BARNES, 1983, p. 16-17, pl. 9, figs. 1-10, 13-16; ALDRIDGE and JEPSSON, 1984, Text-Figs. 3d-f; KLEFFNER, 1987, figs. 6.19, 20; ZHANG and BARNES (in press; includes complete synonymy).

*Description.*—Sc element with anticusp: the inner lateral side of the anticusp elements has a raised area midway between the anterior and posterior margins that has at least two or three fine costae that merge proximally. The outer lateral side has numerous fine costae that extend from near the base to the tip of the cusp.

*Types.*—Hypotypes GSC120501-120507.

*Material examined.*—Sa element- 38; Sb element- 49; Sc element- 47.

*Occurrence.*—On Anticosti Island, *Decoriconus fragilis* ranges from the top of the Ellis Bay Formation infrequently to the Chicotte Formation (lowest Becscie, uppermost Gun River, Jupiter, lower Chicotte formations). In the Cape Phillips Formation, *D. fragilis* appears in the *persculptus* graptolite Zone and ranges more infrequently to the end of the *cyphus* graptolite Zone, but reappears (1 element) just before the Llandovery-Wenlock boundary. Isolated specimens were recovered from late Sheinwoodian and Homeric strata.

*Discussion.*—*D. fragilis* is characterised by three small morphotypes: acontiodontiform (Sa), paltodontiform (Sb), and drepanodontiform (Sc).

*Decoriconus costulatus* and *D. fragilis* were originally thought to differ based on the lack of a drepanodontiform (Sc) element in the former (Cooper 1975), and later by the absence of marked asymmetry in the Sc element in *D. costulatus* (Cooper 1976; Barrick 1977). Zhang and Barnes (in press), through study of the Anticosti Island material, confirmed the hypothesis of McCracken and Barnes (1981) and Uyeno and Barnes (1983) that the two are in fact synonymous.

In the Cape Phillips Formation, some Sc elements (described above) possess an extended lower margin that is extended into an inwardly flexed process or anticusp like that of the form species *Drepanodus aduncus* from the Brassfield Limestone (Nicoll and Rexroad 1969), but unlike those recovered from Anticosti Island, which lack this character (Zhang and Barnes, in press). Zhang and Barnes (in press) considered this to be a variable character of the Sc element of *Decoriconus fragilis*.

GENUS *Distomodus* BRANSON AND MEHL, 1947

*Type species.*—*Distomodus kentuckyensis* Branson and Branson, 1947.

*Distomodus* specimens are very dispersed among the Cape Phillips Formation samples. The Pa element of the genus is most diagnostic, and when it is not present, differentiating between the two species, *D. kentuckyensis* and *D. staurognathoides*, is not possible.

DISTOMODUS KENTUCKYENSIS Branson and Branson, 1947

Plate 5, figs. 10-12, 14, 17

*Icriodina irregularis* BRANSON and BRANSON, 1947, p. 551, pl. 81, figs. 3-11, 18, 19.

Multielement synonymy

*Distomodus kentuckyensis* Branson and Branson. COOPER, 1975, p. 998-1000, pl. 2, figs. 6, 8, 10, 11, 13, 14 (includes synonymy to 1975); NOWLAN, 1981, pl. 4, figs. 22-26; NOWLAN, 1982, Fig. 4 M, N; ALDRIDGE AND MOHAMED, 1982, pl. 1, figs. 1-10; ALDRIDGE, 1985, pl. 3.1, fig. 1; OVER AND CHATTERTON, 1987, pl. 1, figs. 17-21; ZHANG AND BARNES (in press, see for complete synonymy including form species).

*Types.*—Hypotypes GSC120508-120512.

*Material examined.*—Pa element- 3; Pb element- 2; M element- 7; Sa element- 13; Sb element- 14; Sc element- 6.

*Occurrence.*—Rhuddanian and younger strata (*Distomodus* occurs throughout the Llandovery).

*Discussion.*—The Pa element of the *D. kentuckyensis*, the form species *Icriodina irregularis* is the most diagnostic element of the species, with four process at approximately right angles to each other (pl. 5, fig. 10).

## DISTOMODUS STAUROGNATHOIDES (Walliser, 1964)

Plate 5, figs. 15, 16, 18-20

*Hadrognathus staurognathoides* Walliser, 1964, p. 35, pl. 5, fig. 2; pl. 13, figs. 6-15.

## Multielement synonymy

*Distomodus staurognathoides* (Walliser). NAKREM, 1986, figs. 8a, b; KLEFFNER, 1987, Fig. 5 PMs 23-28; ARMSTRONG, 1990, p. 73-74, 76, pl. 8, figs. 6-10 (synonymy through 1987); pl. 9, figs. 2-3; UYENO, 1990, pl. 3, figs. 21, 26-29; pl. 12, fig. 8; KLEFFNER, 1991, Figs. 6.19, 19, 23; ZHANG AND BARNES (in press, see for complete synonymy including form elements).

*Types*.—Hypotypes GSC120513-120517.

*Material examined*.—Pa element- 1; Pb element- 3; M element- 8; Sa element- 11; Sb element- 11; Sc element- 10.

*Occurrence*.—Upper boundary is at least the *insectus* graptolite Zone, lower boundary unknown because of species level identification difficulties.

*Discussion*.—Barrick and Klapper (1976) noted that *Distomodus staurognathoides* can be distinguished from *Distomodus kentuckyensis* on the basis of the morphology of their Pa and Pb elements. The Pa element has five or more processes, while *D. kentuckyensis* has four or less. The Pb element has a variably morphology, as discussed in Zhang and Barnes (in press), and was not identified in the sparse Cape Phillips Formation occurrences of *Distomodus*. Distinguishing between Sb and Sc elements can also be difficult. The paucity of Pa elements has made it difficult to distinguish between the two species, *D. kentuckyensis* and *D. staurognathoides*, and hence the stratigraphic range chart for Cape Manning Section 2 shows the range for the genus alone. A *D.*

*staurognathoides* Pa element was found at Abbott River East, however, in *sakmaricus* graptolite Zone strata.

GENUS *Drepanoistodus* LINDSTRÖM, 1971

*Type species.*—*Oistodus forceps* Lindström, 1955.

DREPANOISTODUS SUBERECTUS (Branson and Mehl, 1933)

Plate 1, figs. 18-20

Oistodiform element

*Oistodus suberectus* BRANSON AND MEHL, 1933, p. 111, pl. 9, fig. 7.

Multielement

*Drepanoistodus suberectus* (Branson and Mehl). NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 16, pl. 3, figs. 19-22 (synonymy through 1983); UYENO, 1990, p. 76, pl. 1, figs. 13, 16-18; NOWLAN, MCCRACKEN AND MCLEOD, 1997, pl. 1, figs. 7-9.

*Types.*—Hypotypes GSC120420-120422.

*Material examined.*—oistodiform element- 4; homocurvatiform element- 21; suberectiform element- 1.

*Occurrence.*—*fastigatus* and *pacificus* graptolite zones

*Discussion.*—No suberectiform elements were identified in the sparse samples that contained this species.

GENUS *Eocarniodus* ORCHARD, 1980

*Type species.*—*Prioniodus gracilis* Rhodes, 1955.

EOCARNIODUS GRACILIS (Rhodes, 1955)

Plate 1, figs. 29-30

Multielement

*Eocarniodus gracilis* (Rhodes). ORCHARD, 1980, p. 20, pl. 2, figs. ?13, 14, ?15, 18-21, 24-26, ?27, 28, 30, ?31, 33-34, ?36, 38 (includes synonymy).

'carniodiform element' FERRETTI AND BARNES, 1997, p. 38, pl. 3, figs. 21 (only).

*Types.*—Hypotypes GSC120431-120432.

*Material examined.*—16 elements

*Occurrence.*—*fastigatus* graptolite Zone.

*Discussion.*—Orchard (1980) attempted to reconstruct the new multielement genus and species *E. gracilis* based on material from the Upper Ordovician of England and Wales. He described platform, M, and possibly elements of the transition series. The recognition of the species is hindered by its co-occurrence with *Amorphognathus*, the bars of which are often broken off the larger ramiform element. As Ferretti and Barnes (1997) indicate, however, it is the flexure of the processes that extend from the central cusp that differentiates this species from *Amorphognathus*. In bars that are not flexed in this manner, at least one process tends to be clearly broken, indicating that it was probably derived from a larger ramiform (*Amorphognathus*). The elements figured here (pl. 1, figs. 29-30) have two short denticulated process about a central cusp. Vertical striae, similar to those on *Amorphognathus ordovicicus* S elements, occur on the cusp and

portions of these processes. The published figures of this broken *Amorphognathus* element that were called *Eocarniodus* are included in the synonymy of *A. ordovicicus*.

GENUS *Kockelella* WALLISER, 1957

*Type species.*—*Kockelella variabilis* Walliser, 1957.

Biostratigraphic studies of late Llandovery-Ludlow sections have shown that the Genus *Kockelella* underwent a radiation during Wenlock and Ludlow time. Barrick and Klapper (1976) proposed a number of zones for the Clarita Formation based on the phylogeny of the genus that they correlated with the European Standard zones of the Carnic Alps (Walliser 1964; Walliser 1971). Their interpretation was that *K. ranuliformis*, the basal stock of all later forms, appeared in the *amorphognathoides* Zone, and radiated throughout the Wenlock and Ludlow allowing the construction of the *ranuliformis*, *amsdeni*, *stauros* and *variabilis* zones. Serpagli and Corradini (1998) recently reconstructed a phylogenetic tree for the genus based on abundant *Kockelella* specimens from Italy, and the work of Barrick and Klapper (1975), Fordham (1991), and Kleffner (1994). They noted that *K. ranuliformis*, the basal late Llandovery stock (possibly derived from *Ozarkodina abrupta* (Aldridge, 1972)), produced a number of main lineages in the Wenlock, *K. latidentata*, *K. absidata*, *K. variabilis*, and *K. walliseri* (Serpagli and Corradini, 1998, Text-fig. 1) before the genus disappeared in the *P. siluricus* Zone (Ludlow).

The *K. absidata* lineage was derived directly from *K. ranuliformis* sometime in the late Sheinwoodian *Ozarkodina sagitta rhenana* Zone, very near the last appearance of *K. ranuliformis*, which persists past the Sheinwoodian-Homerian boundary. The phylogeny of *K. patula* (as well as *K. crassa*) is more difficult to decipher, and Serpagli and Corradini (1998) placed these as separate groups not linked to the *K. ranuliformis* basal stock. *Kockelella patula* has a short range, appearing and disappearing in the upper *Ozarkodina s. rhenana* Zone before the Sheinwoodian-Homerian boundary. Fordham (1991) considered *Kockelella* sp. nov. A Klapper and Murphy and *Ancoradella ploeckensis*, which are Late Homerian and mid-Ludlow species, respectively, as possible descendants of the *K. patula* lineage.

## KOCKELELLA ABSIDATA ABSIDATA Barrick and Klapper, 1976

## Plate 6, figs. 1-2, 4

## Multielement

*Kockelella absidata* BARRICK AND KLAPPER, 1976, p. 76-77, pl. 2, figs. 15-16; BARRICK, 1983, fig. 18G; OVER AND CHATTERTON, 1987, pl. 7, figs. 3-6; JEPSSON, VIIRA AND MÄNNIK, 1994, fig. 5a-b.

*Kockelella absidata?* Barrick and Klapper. KLEFFNER, 1991, Fig 6.29.

*Kockelella absidata absidata* Barrick and Klapper. SERPAGLI AND CORRADINI, 1998, p. 277-278, pl. 1, figs. 8-13 (includes further synonymy).

*Types.*—Hypotypes GSC120518-120520.

*Material examined.*—Pa element- 9; Pb element- 2 ; M element- 3; Sa element- 4; Sb element- 2; Sc element- 7.

*Occurrence.*—*lundgreni*, *deubeli* and *progenitor* graptolite zones.

*Discussion.*—The Pa elements match the description of Serpagli and Corradini (1998), including the fused denticulation anterior of the cusp. They also noted that based on present knowledge, the Pb, M, Sa, Sb, and Sc elements are indistinguishable from the corresponding element of the *K. variabilis variabilis*, which appears in the lowermost Gorstian (earliest Ludlow). Sa and Sc elements were difficult to differentiate from the co-occurring elements of *Ozarodina confluens*.

KOCKELELLA PATULA Walliser, 1964  
Pl. 6, fig. 3

*Kockelella patula* WALLISER, 1964, p. 39, pl. 7, fig. 2; pl. 15, fig. 16.

Multielement

*Kockelella patulla* WALLISER, 1972, p. 77.

*Kockelella patula* Walliser. BARRICK AND KLAPPER, 1976, p. 75, pl. 3, figs. 18-26; OVER AND CHATTERTON, 1987, pl. 7, fig. 2.

?*Kockelella* aff. *K. patula* Walliser. ARMSTRONG, 1990, p. 82, pl. 10, fig. 1.

*Types*.—Hypotype GSC120521.

*Material examined*.—A single Pa element.

*Occurrence*.—Base of the *lundgreni* graptolite Zone. At Cellon, the appearance of *K. patula* marks the base of the *K. patula* Zone (Walliser, 1964). It has not been found in the Welsh Borderland, but was found in the southern Mackenzie Mountains, Northwest Territories, in the *patula/ranuliformis* and basal *bohemica* zones (Over and Chatterton, 1987) and until now, has not been integrated with the graptolite zonation. Barrick and Klapper (1976, fig. 5, p. 67) regarded *K. patula* as the probable descendent of *K. ranuliformis*, however, Serpagli and Corradini (1988) preferred not to place *K. patula* as a branch of the *K. ranuliformis* lineage. The range of *K. patula* in the Clarita is through only the middle portion of their *K. amsdeni* Zone.

*Discussion*.—*Kockelella patula*, as originally described by Walliser (1964), is characterised by a widely expanded basal pit that bears one row of denticles on the ?inner side, and up to three rows on the other side. Serpagli and Corradini (1998) place the lineage of *K. patula* as originating and ending within the upper part of the *Ozarkodina sagitta rhenana* Zone, before the end of the Sheinwoodian. *Kockelella patula* differs

from *K. sp. nov.* A Klapper and Murphy (1975) in that the basal cavity is of the Pa element is divided into sinuses between the secondary processes. *K. patula* differs from *K. variabilis* in that the Pa element platform of the former is more broadly expanded than the latter. Walliser (1964, p. 39-40) noted that in early forms of *K. variabilis* (those in the *crassa* Zone), the Pa element has a relatively widely extended base and approaches the morphology of *K. patula*.

## KOCKELELLA RANULIFORMIS (Walliser, 1964)

## Plate 6, figs. 5-10

## Pa element

*Spathognathodus ranuliformis* WALLISER, 1964, pl. 6, fig. 9, pl. 22, fig. 5-7.

## Multielement

*Kockelella ranuliformis* (Walliser). BARRICK AND KLAPPER, 1976, p. 76, pl. 2, figs. 1-11; BARRICK, 1983, fig. 18I; NOWLAN, 1982, fig. 3V, W; UYENO AND BARNES, 1983, p. 18, pl. 6, figs. 1-4; SAVAGE, 1985, p. 720, Fig. 12A-N; BISCHOFF, p. 218-220, pl. 14, figs. 1-26; KLEFFNER, 1994, p 148-149, fig. 101-8, 10.10; SIMPSON AND TALENT, 1995, p. 135-137, pl. 6, figs. 1-7 (includes further synonymy).

?*Kockelella* cf. *K. ranuliformis* (Walliser). ARMSTRONG, 1990, p. 80, 82, pl. 9, figs. 15-19.

*Description.*—Sb element. In contrast to those described by Barrick & Klapper (1976), the cusp is not compressed in the same plane as the process, and is thus more similar to those figured by Savage (1985). The anterior process bears two to three discrete compressed denticles. The posterior process bears three to six similar denticles.

M element: Conforms to that of Barrick and Klapper (1976), except the element is more strongly curved and basal cavity continues posteriorly for most of the length of the process.

*Types.*—Hypotypes GSC120522-120527.

*Material examined.*—Pa element- 3; Pb element- 3; M element- 1; Sa element- 5; Sb element- 2 Sc element- 2.

*Occurrence.*—The range of *K. ranuliformis* varies regionally. In Oklahoma, the base of the *ranuliformis* Zone is defined by the extinction of *Pterospathodus amorphognathoides* (Barrick 1983). *Kockelella ranuliformis* occurs in *celloni* Zone strata in Britain (Aldridge 1972), and the upper *amorphognathoides-ranuliformis* Zone of Nicoll and Rexroad (1969). In the Clarita Formation, *K. ranuliformis* appears at the level of extinction of *P. amorphognathoides* (Barrick and Klapper 1976), as it does at Avalanche Lake in the Mackenzie Mountains (Over and Chatterton 1987). Savage (1985) found that *K. ranuliformis* and *P. amorphognathoides* co-occur in Alaska. Over and Chatterton (1987) defined their *patula/ranuliformis* Zone by the first appearance of either species at Avalanche Lake, but a 80 m thick shale unit separates the earlier appearing *K. ranuliformis* from *K. patula*, so that the two species have no range overlap.

Unquestionable *K. ranuliformis* specimens were identified from the mid-*instrenuus-kolobus* to mid?-*perneri-opimus* graptolite zones at the Cape Phillips Formation type section. A few specimens attributed to *Kockelella* (*Kockelella?* sp.) were recovered from late Llandovery strata of the type section.

*Discussion.*—Barrick and Klapper (1976) noted that later forms of *K. ranuliformis* may develop an asymmetrical basal cavity in its apparent evolutionary transition to *K. walliseri* in the middle of the *K. ranuliformis* Zone. The Pa element of *K. walliseri* possesses an asymmetrical basal cavity and one lateral process. At least one of the Pa elements identified from the Cape Phillips as *K. ranuliformis* could be considered to have an incipient lateral process (denticle growth), making it intermediate between the two species.

## KOCKELELLA? SP.

Plate 6, figs. 11-14

*Description.*—Pa element. One specimen (pl. 6, fig. 11) has six distinct pointed denticles, the other (pl. 6, fig. 12) has numerous small, broken but apparently confluent denticles. The basal margin is expanded laterally at the posterior end of the element. Sa and Sb elements: these have distinct laterally compressed denticles. The cusp is also laterally compressed, sometimes having sharp lateral margins, and is slightly expanded posteriorly at its base.

*Types.*—Figured specimens GSC120528-120531.

*Material examined.*—Pa element- 7; Sa element-4; Sb element-5.

*Occurrence.*—*sakmaricus* graptolite Zone.

GENUS *Oulodus* BRANSON AND MEHL, 1933

*Type species*.—*Cordylodus serratus* Stauffer, 1930, senior subjective synonym of *Oulodus mediocris* Branson and Mehl, 1933.

## OULODUS EQUIRECTUS Kleffner, 1990

Plate 6, fig. 17

## Multielement

?*Deltotaxis* sp. KLAPPER AND MURPHY, 1975, p. 46, pl. 10, fig. 22.

*Deltotaxis* sp. A BARRICK AND KLAPPER, 1976, p. 70, pl. 4, figs. 24, 25 (only).

*Oulodus* sp. KLEFFNER, 1987, p. 85-86, fig. 6, PMs 10-14.

*Oulodus equirectus* KLEFFNER, 1990, p. 324, fig. 3.1-3.11; Kleffner, 1994, fig. 10.25; SIMPSON AND TALENT, 1995, p. 109, pl. 1, fig. 1.

*Types*.—Hypotype GSC120532.

*Material examined*.—A single Pa element.

*Occurrence*.—*deubeli* graptolite Zone.

*Discussion*.—Kleffner (1990) proposed the new species with a diagnostic Pa element from elements collected from lower to middle Wenlockian strata from Ohio, New York and Ontario. He put it in synonymy with *Deltotaxis* sp. A Barrick and Klapper that had been reported from the Clarita Formation in Oklahoma (mid Wenlock to lower Ludlow) (Barrick and Klapper, 1976). Kleffner (1990) noted that *O. equirectus* is never found in abundance, and is more common in skeletal packstones and grainstones, and hence may have preferred shallow water conditions. He concluded that the lack of overlap in the observed ranges between *O. equirectus* and *Deltotaxis* sp. A could be explained by the low abundance of the elements. In his diagnosis, Kleffner (1990) noted that the Pb

element grades morphologically with the M element and suggested the former was derived from the latter. Barrick and Klapper (1976) noted that their *Deltotaxis* sp. A Pb element fell within the range of variation of the form species *Lonchodina walliseri* Ziegler *sensu* Walliser (1964, pl. 30, figs. 26-33). The range of *L. walliseri*, according to Walliser (1964) is Homeric through Lower Devonian (beginning in his *sagitta* Zone). The Pb element illustrated here also falls into this range of variation and hence it is assigned, with Kleffner (1990), to *O. equirectus*.

## OULODUS? KENTUCKYENSIS (Branson and Branson, 1947)

Plate 6, figs. 15-16, 18-20, 23

## Sc element

*Ligonodina kentuckyensis* BRANSON AND BRANSON, 1947, p. 555, pl. 82, figs. 28, 35.

## Multielement synonymy

*Oulodus? kentuckyensis* (Branson and Branson). MCCracken AND BARNES, 1981, p. 80-81, pl. 6, figs. 1-20; ZHANG AND BARNES (in press).

*Types*.—Hypotypes GSC120533-120538.

*Material examined*.—Pa element- 12; Pb element- 18; M element- 9; Sa element- 12; Sb element- 16; Sc element- 22.

*Occurrence*.—*acuminatus-atavus* graptolite zones.

*Discussion*.—McCracken and Barnes (1981) and Zhang and Barnes (in press) reported *Oulodus? kentuckyensis* from Member 6 of the Ellis Bay Formation, and the Becscie and Gun River formations, respectively, from Anticosti Island. The apparatus, consisting of Pa (modified oulodiform), Pb (lonchodiniform), M (euprioniodiniform), Sa (trichonodelliform), Sb (zygognathiform) and Sc (ligonodiniform) is distinguished from *Oulodus? nathani* particularly on the presence of the modified oulodiform Pa element in *O. kentuckyensis* and the Pa (blade) in *O.? nathani*. Zhang and Barnes (in press) revised the synonymy of McCracken and Barnes (1981), suggesting that some of the questionable synonyms made by the latter authors could actually be more closely compared with other oulodids from Anticosti Island, like *O. jeannae* Schönlaub, *O. sigmoideus* Zhang and Barnes, and *O. panuarensis* Bischoff.

In the Cape Phillips Formation, *O.? kentuckyensis* was recovered from a single sample at Cape Manning (*atavus* graptolite Zone), and in Ordovician-Silurian boundary

through *atavus* graptolite Zone strata at Cape Phillips South. Those at Cape Manning have an M element and less expanded basal cavities (particularly the Sb element) like those figured in McCracken and Barnes (1981) and Zhang and Barnes (in press). No Pa element was recovered from CPS, but basal cavities of the elements attributed to this species are generally widely flaring, which, according to McCracken and Barnes (1981) is a diagnostic feature of *O.? kentuckyensis*.

## OULODUS? NATHANI McCracken and Barnes, 1981

Pl. 6, figs. 21-22, 24-26

## Multielement synonymy

*Oulodus? nathani* McCracken and Barnes, 1981, p. 81-82, pl. 6, figs. 21-32; Nowlan, 1981, pl. 4, figs. 14, 17; Zhang and Barnes (in press).

*Types.*—Hypotypes GSC120539-120543.

*Material examined.*—Pa element- 8; Pb element- 7; M element- 3; Sa element- 12; Sb element- 2; Sc element- 13.

*Occurrence.*—*acuminatus* and *acinaces* graptolite zones.

*Discussion.*—*Oulodus? nathani* is here recognised from a sample at the Ordovician-Silurian boundary, and another (CM2-3) within the *acinaces* Zone. Its absence from intervening strata may represent biofacies control; however, it is difficult to distinguish it from its contemporary, *O.? kentuckyensis* without the presence of the diagnostic Pa element.

GENUS *Ozarkodina* BRANSON AND MEHL, 1933

*Type species.*—*Ozarkodina typica* (Branson and Mehl, 1933) =junior synonym of *Ozarkodina confluens* (Branson and Mehl)].

OZARKODINA CLAVULA Uyeno, 1983 emended Zhang and Barnes (in press)

Plate 7, fig. 1

Multielement synonymy

*Ozarkodina oldhamensis* (Rexroad). MÄNNIK, 1982, fig. 5. A-D.

*Ozarkodina clavula* UYENO in Uyeno and Barnes, 1983, p. 20-21, pl. 7, figs. 4, 7-10;  
ZHANG AND BARNES (in press; includes synonymy through 2000).

*Types.*—Hypotype GSC120544.

*Material examined.*—A single Pa element.

*Occurrence.*—*convolutus* graptolite Zone.

*Discussion.*—The single element (Pa) conforms to the emended description of *Ozarkodina clavula* in Zhang and Barnes (in press). They noted that Pa elements from the Gun River Formation differ from those of the Jupiter Formation (Uyeno and Barnes, 1983) in the symmetry of the flare of the basal cavity and its length to width ratio. The specimen figured here has a symmetrical flare of the basal cavity, and its length to width ratio is almost 1:1.

## OZARKODINA CONFLUENS (Branson and Mehl, 1933)

Plate 7, figs. 2-5

Sc element

*Hindeodella confluens* BRANSON and MEHL, 1933, p. 45-46, Pl. 3, figs. 21-23.

Multielement

*Ozarkodina confluens* (Branson and Mehl). SIMPSON AND TALENT, 1995, p. 142-146, pl. 7, figs. 26-28, pl. 8, figs. 1-6 (contains synonymy through 1995); MÄNNIK AND MALKOWSKI, 1998, pl. 2, fig. 19.*Types*.—Hypotypes GSC120545-120548.*Material examined*.—Pa element- 24; Pb element- 4; M element- 3; Sa element- 2; Sb element- 1; Sc element- 3.*Occurrence*.—*deubeli* through *progenitor* graptolite zones.*Discussion*.—*Ozarkodina confluens* s.l. is characterised by having a Pa element of variable morphology. Klapper and Murphy (1975) proposed five informal Pa morphotypes for the species. Later, others (e.g. Helfrich, 1975, Rexroad et al. (1978) ) proposed further subspecies. The Pa elements recognised here are most like the alpha morphotype of Klapper and Murphy (1975) with two to four high anterior denticles and also may have a few higher denticles on the posterior process. *Ozarkodina confluens* was recovered from upper Wenlock and Ludlow strata in relatively low numbers and this made it difficult to confidently identify the M and Sc elements. The similarity of the transitional series elements with *O. excavata excavata* in the same samples made it impossible to separate some of the elements of these two species. The Sc elements of *O.*

*confluens* are supposed to have broader and denticles that are fused near their bases however, as noted by Simpson and Talent (1995).

## OZARKODINA EXCAVATA EXCAVATA (Branson and Mehl, 1933)

## Plate 7, figs. 6-10, 13

## M Element

*Prioniodus excavatus* BRANSON and MEHL, 1933, p. 45, Pl. 3, figs. 7, 8.

## Multielement

*Ozarkodina excavata excavata* (Branson and Mehl). KLAPPER AND MURPHY, 1975, p. 34-37, Pl. 6, figs 1-20; BARRICK AND KLAPPER, 1976, p. 78-79, Pl. 4., figs. 13-23, 26; BISCHOFF, 1986, p. 134-137, Pl. 25, figs. 35-40, Pl. 26, figs. 1-40; OVER AND CHATTERTON, 1987, pl. 7, figs. 18-19; KLEFFNER, 1990, fig. 3.23; UYENO, 1990, p. 89-90, Pl. 3, figs. 11, 12, Pl. 8, figs. 7, 10, 11, Pl. 14, figs. 11, 14-19, 23-25, 31, Pl. 15, figs. 15.18; SARMIENTO, 1994, pl. 2, figs. 10, 12-13, 15; SIMPSON AND TALENT, 1995, pl. 8, figs. 16-25, pl. 9, figs. 1-24 (contains further synonymy through 1995).

*Types*.—Hypotypes GSC120549-120554.

*Material examined*.—Pa element- 49; Pb element- 33; M element- 26; Sa element- 16; Sb element- 49; Sc element- 59.

*Occurrence*.—*instrenuus-kolobus* through *progenitor* graptolite zones. Armstrong (1990) identified a Llandovery ozarkodinid as *O. excavata*, and discriminated between the former and *O. excavata excavata* based on the morphology of his M and ?Sb elements. No Llandovery *O. excavata excavata* have yet been identified, although Bischoff (1986) considered *O. australensis* and *O. excavata eosilurica* as ancestors of the Wenlock-Ludlow *O. e. excavata*.

*Discussion.*—The intra-subspecific variation of the apparatus of *O. excavata* has been outlined by Klapper and Murphy (1975), Jeppsson (1974), Bischoff (1986) and Simpson and Talent (1995). Despite the range of morphologies, Bischoff (1986) concluded that there was no biostratigraphical order of appearance of the characters. Bischoff (1986) described a number of new species in his study from midwestern New South Wales. He concluded that there was an ancestor-descendent relationship between his *Ozarkodina australensis* n. sp. (Early Llandovery), *O. excavata eosilurica* n. subsp. (latest Llandovery), and *O. excavata excavata* (base of *ranuliformis* Zone).

The elements of the transition series were difficult to separate from elements of *Ozarkodina confluens* when in the same sample.

## OZARKODINA HADRA (Nicoll and Rexroad, 1969)

Plate 7, figs. 11-12, 14-17

## Pa element

*Spathognathodus hadros* NICOLL and REXROAD, 1969, p. 59, pl. 2, figs. 17, 18.

## Multielement

*Ozarkodina* aff. *O. hadra* (Nicoll and Rexroad). NOWLAN, 1982, Fig. 3.I, L-P.

*Ozarkodina* cf. *O. hadra* (Nicoll and Rexroad). ARMSTRONG, 1990, p. 90, 92, pl. 13, figs. 4-9.

*Ozarkodina hadra* (Nicoll and Rexroad). KLAPPER AND MURPHY, 1975, p. 37-38, pl. 8, figs. 5, 6; STOUGE AND STOUGE, 1984, figs. 6, 11 (only); KLEFFNER, 1987, Fig. 5 PM 12; OVER AND CHATTERTON, 1987, pl. 5, figs. 1-8; KLEFFNER, 1991, Fig. 6.30; KLEFFNER, 1994, Fig. 10.33.

?*Ozarkodina hadra* (Nicoll and Rexroad). SAVAGE, 1985, p. 722, 723, Fig. 15 D-F.

*Types*.—Hypotypes GSC120555-120560.

*Material examined*.—Pa element- 5; Pb element- 6; M element-3; Sa element- 7; Sb element- 9; Sc element- 3.

*Occurrence*.—Armstrong (1990) found *Ozarkodina* cf. *O. hadra* in *celloni* Zone strata in North Greenland, whereas Kleffner (1987, 1991) documented its occurrence in the *amorphognathoides* Zone in southern Ohio and New York as did Over and Chatterton (1987). In the Cape Phillips Formation, it was found in the *sakmaricus* graptolite Zone.

*Description*.—The Pa element conforms to the form species *Spathognathodus hadros* (Nicoll and Rexroad). The Pb element (Pl. 7, fig. 14) is similar to that figured and described by Over and Chatterton (1987). The cusp has sharp anterior and posterior

costae. The broken posterior process bears similar denticles to that on the posterior process. The anterior process is longer, and the slightly flared basal cavity beneath the cusp continues almost exclusively beneath the posterior process for a short distance, terminating by the second denticle. The M element differs from Armstrong's (1990) description in that the denticles are more similar to the Pa and Pb elements (confluent and laterally compressed). The anterior process bears three denticles, whereas the posterior process bears 19-20 denticles. The basal cavity extends beneath the posterior process to the first denticle. The Sa-Sc elements all bear peg-like denticles. The Sa and Sb elements are similar to Armstrong's (1990) except that the denticle interspaces are slightly U-shaped. The angle between the lower part of the anterior process and that of the posterior process of the Sc element is much less than that of Armstrong (1990), about  $110^\circ$  rather than  $160^\circ$ .

*Discussion.*—*Ozarkodina hadra* was named after its large size, a feature also noted by Armstrong (1990). Similar large size and colour aided the identification of the *O. hadra* apparatus in the single sample where it was found.

## OZARKODINA HASSI (Pollock, Rexroad and Nicoll, 1970)

Plate 7, figs. 18-22, 26

## Pa element

*Spathognathodus hassi* POLLOCK, REXROAD AND NICOLL, 1970, p. 760-761, Pl. 111, figs. 8-12.

## Multielement

*Ozarkodina hassi* (Pollock, Rexroad and Nicoll). McCracken and Barnes, 1981, p. 83, Pl. 7, figs. 1, 2, 4, 6-13 (includes synonymy to 1980); Nowlan, McCracken and Chatterton, 1988, p. 17, P. 4, figs. 16-20, Pl. 5, figures 16-21 (includes synonymy 1981-1988); Armstrong, 1990, p. 92-94, Pl. 13, figs. 10-16.

*Types.*—Hypotypes GSC120561-120566.

*Occurrence.*—*acuminatus-atavus* graptolite zones; also top of the *cyphus* graptolite Zone at Cape Manning.

*Material examined.*—Pa element- 22; Pb element- 33; M element- 25; Sa element- 19; Sb element- 26; Sc element- 29.

*Remarks.* McCracken and Barnes (1981) were unable to confidently separate the M, Sa, Sb, and Sc elements of *O. hassi*, and *O. oldhamensis*. Here Pa, Pb and M elements are distinguished, and the S elements are tabulated under *Ozarkodina hassi*.

## OZARKODINA OLDHAMENSIS (Rexroad, 1967)

Plate 7, figs. 23-25

## Pa element

*Spathognathodus oldhamensis* REXROAD, 1967, p. 49-50, Pl. 3, figs. 1,2

## Multielement

*Ozarkodina oldhamensis* (Rexroad). MCCracken AND BARNES, 1981, p. 84, Pl. 7, figs. 3, 5, 14-18 (includes synonymy to 1981); SMELROR, COCKS, MORK, NEUMAN, NAKREM, 1997, figs. 11c, g, I; LEHNERT, BERGSTRÖM, BENDETTO, VACCAR, 1999, p. 128, Figs. 7g, k-p, 8a-n; ZHANG AND BARNES (in press).

*Types*.—Hypotypes GSC120567-120569.

*Occurrence*.—*atavus* graptolite Zone. On Anticosti Island, *O. oldhamensis* ranges from the base of the Becscie to near the top of the Gun River Formation.

*Material examined*.—Pa element- 77; Pb element- 25; M element- 8; Sb element- 11; Sc element- 31.

*Remarks*.—McCracken and Barnes (1981) found the form species *S. manitoulinensis* Pollock, Rexroad in Nicoll in the Anticosti Island material, as well as rare Pa element of *O. oldhamensis* with a slightly bowed posterior process. They suggested that the rare *O. oldhamensis* Pa elements may be transitional between *O. oldhamensis* and *S. manitoulinensis*. A small number of the rare Pa elements of *O. oldhamensis* were recovered from the Cape Phillips Formation (CM2B-1). Armstrong (1990, p. 77-78, 80, pl. 9, figs. 4-14) recorded *Kockelella manitoulinensis* from North Greenland and suggested that the apparent phylogenetic link between *O. oldhamensis* and *K. manitoulinensis* was coincidental. Although he considered the apparatus of the two to be

quite different, except for the Pa elements, his illustrated elements do not differ significantly from those assigned to *O. hassi* and *O. oldhamensis* herein. Hence, the Cape Phillips material does not support Armstrong's suggestion.

Distinguishing the Sa-Sc elements between *O. hassi* and *O. oldhamensis* is difficult as noted by McCracken and Barnes (1981), and this was not possible here either. The differences between *O. hassi* and *O. oldhamensis* were outlined by McCracken and Barnes (mainly in the Pa and Pb elements) and are also recognised here.

## OULODUS SP.

Pl. 4, figs. 4, 5, 8

*Description.* The Sa elements have a wide, anterior-posteriorly compressed cusp with sharp lateral margins. Approximately three denticles, much shorter, but of similar overall morphology to the cusp, arise from the two lateral processes. The base flares posteriorly under the cusp. The Sc element has a posteriorly directed cusp and denticles that are compressed with sharp lateral margins as the Sa element.

*Types.*—Figured specimens GSC120486, 120487, 120489.

*Material examined.*—Sa element- 12; Sc element-6.

*Occurrence.*—Upper *griestoniensis* graptolite Zone.

GENUS *Panderodus* ETHINGTON, 1959

*Type species.*—*Paltodus unicastatus* Branson and Mehl, 1933, p. 42.

PANDERODUS RECURVATUS (Rhodes, emended Zhang and Barnes, in press)  
(not figured)

## Multielement

*Panderodus recurvatus* (Rhodes). BARRICK, 1977, p. 54-55, pl. 3, figs. 3, 4, 7-12; UYENO AND BARNES, 1983, p. 22, pl. 9, figs. 23-26; ARMSTRONG, 1900, p. 104-107, pl. 16, figs. 1-11; SIMPSON AND TALENT, 1995, p. 117-118, pl. 1, figs. 21-27; ZHANG AND BARNES (in press).

*Description.*—Based on the abundant Anticosti Island material, this species has recently been emended by Zhang and Barnes (in press) to include double-furrowed aequaliform, symmetric acostatiform, and asymmetric acostatiform elements. Single furrowed elements of the species are sub-symmetric graciliform, asymmetric graciliform, arcuatiform, compressiform, and truncatiform elements.

*Material examined.*—Aequaliform- 5; asymmetric graciliform- 8; arcuatiform- 7; compressiform- 30; truncatiform- 3.

*Occurrence.*—The lowest reported occurrence of *P. recurvatus* is from the *staurogathoides* Zone of the Gun River Formation, Anticosti Island. In the Cape Phillips Formation, *Panderodus recurvatus* was found in late Llandovery strata.

## PANDERODUS UNICOSTATUS (Branson and Mehl, 1933)

## Plate 12, figs. 1-10

## Multielement synonymy

*Panderodus unicostatus* (Branson and Mehl). ARMSTRONG, 1990, p. 108-110, pl. 17, figs. 1-7; KLEFFNER, 1987, figs. 6PM's 8, 9; UYENO, 1990, p. 70-71, pl. 1, figs. 27, 28; pl. 4, fig. 10; SIMPSON AND TALENT, 1995, p. 118-121, pl. 2, figs. 1-32; ZHANG AND BARNES (in press; includes further synonymy through 1998).

*Panderodus acostatus* (Branson and Branson). SANSOM, ARMSTRONG AND SMITH, 1994, text-figs. 2A-2R.

*Types*.—Hypotypes GSC120639-120648.

*Material examined*.—Aequaliform- 48; symmetrical/asymmetrical unicostatiform- 542; tortiform- 96; truncatiform- 56; arcuatiform- 381; compressiform- 586.

*Occurrence*.—*fastigatus-convolutus* graptolite zones, *crispus-progenitor* graptolite zones.

*Discussion*.—Zhang and Barnes (in press) described aequaliform and truncatiform elements, in addition to the tortiform, subsymmetrical graciliform, asymmetrical graciliform, arcuatiform and compressiform (falciform) elements that have already been described (Sansom et al. 1994). Sansom et al. (1994) noted how distinguishing between the graciliform elements is difficult. When possible, these were distinguished in the Cape Phillips Formation samples. Separating aequaliform elements from subsymmetrical unicostatiform elements was difficult also, because the overall small size and translucence of the elements made it difficult to see if furrows were present.

GENUS *Paroistodus* LINDSTRÖM, 1971

*Type species.*—*Oistodus parallelus* Pander, 1856. *PAROISTODUS?* NOWLANI Zhen, Webby and Barnes, 1998  
Plate 1, figs. 21-23

## Multielement

*Paroistodus?* sp. A. NOWLAN, MCCracken, AND CHATTERTON, 1988, p. 24-26, pl. 9, figs. 1-22 (includes synonymy through 1983); MCCracken AND NOWLAN, 1989, pl. 3, figs. 1-6; NOWLAN, MCCracken AND McLEOD, 1997, pl. 1, figs. 26, 27; pl. 3, figs. 14, 15, 17-19, 21.

*Paroistodus? nowlani* ZHEN, WEBBY AND BARNES, 1998, p. 89-90, figs. 8.1-16.

*Types.*—Hypotypes GSC120423-120425.

*Material examined.*—M element- 24; Sa element- 1; Sb-element- 4; Sc-element- 8.

*Occurrence.*—*fastigatus* through *pacificus* graptolite zones.

*Discussion.*—Nowlan et al. (1988) included in their *Paroistodus?* sp. A an oistodiform element although they noted that it was found in superabundance. In the Cape Phillips Formation, oistodiform elements are found in a 3:1 ratio relative to the elements of the transition series in CPS 1 (*fastigatus* graptolite Zone).

GENUS *Protopanderodus* LINDSTRÖM, 1971

*Type species.*—*Acontiodus rectus* Lindström, 1955.

PROTOPANDERODUS INSCULPTUS (Branson and Mehl, 1933)

(not figured)

Multielement

*Protopanderodus insculptus* (Branson and Mehl). MCCracken, 1989, p. 16, 18, pl. 3, figs. 9-14, 17, 19; Trotter and Webby, 1994, p. 485, pl. 4, figs. 1, 7-12; Zhen, Webby and Barnes, 1998, p. 90, 92, figs. 9.6-9.

*Material examined.*—Sc/Sb element- 6; Sa element 1; M element 1.

*Occurrence.*—*pacificus* graptolite Zone.

*Discussion.* talk about 2<sup>nd</sup> denticle etc.

GENUS *Pseudobelodina* SWEET, 1979

*Type species.*—*Belodina kirki* Stone and Furnish, 1959.

PSEUDOBELODINA? *DISPANSA* (Glenister, 1957)

Pl. 1, figs. 24-27

*Belodus dispansus* Glenister, 1957, p. 729, 730, pl. 88, figs. 14, 15.

## Multielement

*Pseudobelodina dispansa* (Glenister). UYENO, 1990, p. 73, pl. 1, figs. 24, 30; TROTTER AND WEBBY, 1994, p. 485, pl. 1, figs. 21-26, 31-33, (27-29, 34, 35).

*Pseudobelodina? dispansa* (Glenister). NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 30-31, pl. 12, figs. 8-26 (contains synonymy through 1983); MCCRACKEN AND NOWLAN, 1989, pl. 4, figs. 2-4. NOWLAN, MCCRACKEN AND MCLEOD, 1997, pl. 3, figs. 1-4, 7, 8, 11, 12.

*Description.*—Unbowed, acostate element (pl. 1, fig. 24): Element large and unfurrowed. Lateral faces slightly convex. Four to five posterior denticles are only slightly anteriorly directed. The long heel and acostate nature of this element are atypical of the species.

This morphotype was not recognized by Nowlan et al. (1989).

Slightly bowed unicostate element (pl. 1, fig. 25): Element is slightly bowed to unfurrowed side. Furrow pronounced at base, beginning medially and becoming more conspicuous and posterior towards tip of the cusp. Costa present on outer face near anterior margin. Inner side smooth.

Strongly bowed unicostate element (pl. 1, fig. 26): Element is strongly bowed to unfurrowed side. Furrow similar to the slightly bowed unicostate element, also similar costa running close to the anterior margin.

Bowed bicostate element (pl. 1, fig. 27): Element is strongly bowed to unfurrowed side. Outer face has slight costae near anterior margin. Inner face has pronounced costa near anterior margin.

*Types.*—Hypotypes GSC120426-120429.

*Material examined.*—Unbowed, acostate element- 3; bowed acostate element- 14; bowed, bicostate element- 2.

*Occurrence.*—*fastigatus* through *pacificus* graptolite zones.

*Discussion.*—Nowlan et al. (1988) found elements of *Pseudobelodina? dispansa* that were bowed to the unfurrowed side, bowed to the furrowed side, and unbowed. Their unbowed elements were bicostate, unlike the acostate, unbowed element figured here (pl.1, fig. 24). They found that element bowed to the unfurrowed side were bicostate, whereas unicostate elements are recognized here that are bowed to the unfurrowed side (pl. 1, figs. 25, 26). Trotter and Webby (1994) noted that *Pseudobelodina dispansa* might be part of the apparatus of *Belodina confluens*. Two few specimens are present to comment on this hypothesis. However, the unbowed, acostate element, could be referable to *Belodina* sp, but not *B. confluens*, because of its long heel. Except for the unbowed, acostate element, the elements assigned here to *Pseudobelodina dispansa* have closely spaced, laterally compressed and anteriorly directed denticles.

GENUS *Pseudooneotodus* DRYGANT, 1974

*Type species.*—*Oneotodus? beckmanni* Bischoff and Sannemann, 1958.

Barrick (1977) reconstructed a trimembrate apparatus of *Pseudooneotodus tricornis* and *P. bicornis* consisting of a slender conical element, unidenticate squat element, and tri- or bi-denticulate squat element, for *P. tricornis* and *P. bicornis*, respectively. Bischoff (1986) found that the distribution of his unidenticate squat elements was not consistent with Barrick's (1977) reconstruction, and considered the taxa to be unimembrate. Bischoff (1986) figured and described a slender conical element, *Pseudooneotodus borenoensis* n. sp., that somewhat resembles those of Barrick (1977), and co-occurs with both taxa.

Isolated and small collections have made the reconstruction of the apparatus of *P. tricornis* and *P. bicornis* difficult; however, Uyeno and Barnes (1983), Over and Chatterton (1987) and Armstrong (1990) all considered the apparatus to be multi-membrate. Armstrong (1990, p. 112, 114) also described *Pseudooneotodus* cf. *P. beckmanni*, which is indistinguishable from the undenticulated element of *P. bicornis* and *P. tricornis*. Zhang and Barnes (in press) recovered only the unidenticate elements which they assigned to *P. beckmanni* from the Becscie and Gun River formations on Anticosti Island. Herein are assigned all undenticulate elements to *P. beckmanni* for the sparse Cape Phillips occurrences, but the slender, conical elements are retained within the apparatus of *P. tricornis*.

Barrick (1977) suggested that *Pseudooneotodus bicornis* was derived from *P. tricornis* through the loss of a single apical denticle in the denticulated squat, conical element. He found that the former ranged from the *amorphognathoides* Zone possibly into the base of the *ranuliformis* Zone, whereas the latter ranges from the *K. ranuliformis* through *K. variabilis* zones; however, *P. bicornis* ranges throughout the Estill Shale (*amorphognathoides* Zone) and Bisher Formation (*ranuliformis* Zone) in southern Ohio, appearing before *P. tricornis* (Kleffner 1987).

## PSEUDOONEOTODUS BECKMANNI (Bischoff and Sannemann, 1958)

## Plate 8, fig. 6

*Oneotodus? beckmanni* BISCHOFF and SANNEMANN, 1958, p. 58, pl. 15, figs. 22-25.

*Pseudooneotodus beckmanni* (Bischoff and Sannemann). COOPER, 1977, p. 1068, pl. 2, figs. 14, 17 (includes comprehensive synonymy through 1976); NOWLAN AND BARNES, 1981, p. 23; MCCRACKEN AND BARNES, 1981, p. 89, pl. 2, figs. 30, 31; UYENO, 1990, p. 99-100, pl. 1, figs. 36, 37 (includes synonymy through 1986); MÄNNIK AND MALKOWSKI, 1998, pl. 1, fig. 26.

*Types*.—Hypotype GSC120575.

*Material examined*.—17 elements.

*Occurrence*.—*fastigatus*, *acinaces* through *sakmaricus* graptolite zones.

*Discussion*.—On Anticosti Island, *Pseudooneotodus beckmanni* is present in the Vauréal (Nowlan and Barnes 1981), Ellis Bay (McCracken and Barnes 1981), Becscie, Gun River (Zhang and Barnes, in press) and Jupiter formations (Uyeno and Barnes 1983) and has a variable basal outline with no discernible stratigraphic pattern. As noted above, all unidenticulate elements were thus assigned to this species in the Cape Phillips samples.

## PSEUDOONEOTODUS BICORNIS Drygant, 1974

## Plate 8, fig. 5

*Pseudooneotodus bicornis* DRYGANT, 1974, p. 76, pl. 2, figs. 40-48.

*Pseudooneotodus bicornis* Drygant. BARRICK AND KLAPPER, 1976, p. 81, pl. 1, fig. 15; COOPER, 1977, p. 1069, pl. 2, fig. 8-9, 11; BARRICK, 1977, p. 57-58, pl. 2, fig. 14, 17, 20; UYENO AND BARNES, 1983, p. 22, pl. 3, fig. 27; MABILLARD AND ALDRIDGE, 1985, fig. 7e; BISCHOFF, 1986, p. 234-235, pl. 27, figs. 18-19, 21-27; KLEFFNER, 1987, fig. 5.16;; OVER AND CHATTERTON, 1987, pl. 6, fig. 23, 24; ARMSTRONG, 1990, p. 114, pl. 18, figs. 10, 13-15; KLEFFNER, 1990, Fig. 3.24; MÄNNIK AND MALKOWSKI, 1998, pl. 2, fig. 2a-b.

*Types*.—Hypotype GSC120574.

*Material examined*.—3-squat, bidenticulate.

*Occurrence*.—*murchisoni* through *testis-lundgreni* zones. *Pseudooneotodus bicornis* occurs infrequently through the Wenlock in the Cape Phillips Formation.

*Discussion*.—The slender element was not recovered from the Cape Phillips Formation.

## PSEUDOONEOTODUS MITRATUS (Moskalenko, 1973)

## Plate 1, fig. 28

*Ambalodus mitratus mitratus* MOSKALENKO, 1973, p. 86, pl. 17, figs. 9-11.

*Pseudooneotodus mitratus* (Moskalenko). NOWLAN AND BARNES, 1981, p. 23, pl. 2, figs. 17-19 (includes synonymy to 1978); MCCrackEN AND BARNES, 1981, p. 89, pl. 2, fig. 32; ZHANG, 1998, p. 85, pl. 14, fig. 12 (includes synonymy to 1995).

*Types*.—Hypotype GSC120430.

*Material examined*.—4 elements.

*Occurrence*.—The latest occurrence of *Pseudooneotodus mitratus* on Anticosti Island is at the base of Member 2 of the Ellis Bay Formation, within the *Amorphognathus ordovicicus* Zone (McCracken and Barnes 1981). In the Cape Phillips, it is limited to a single end-*fastigatus* Zone sample.

## PSEUDOONEOTODUS TRICORNIS Drygant, 1974

## Plate 8, figs. 1-2

*Pseudooneotodus tricornis* Drygant. BARRICK, 1977, p. 58, pl. 2, fig. 18; COOPER, 1977, p. 1069, pl. 2, figs. 15, 16; UYENO and BARNES, 1983, p. 23, pl. 6, figs. 18-20; MABILLARD and ALDRIDGE, 1985, fig. 7f; BISCHOFF, 1986, p. 238-239, pl. 27, figs. 20, 28-37; KLEFFNER, 1987, fig. 5.15; OVER AND CHATTERTON, 1987, pl. 6, figs. 21-22; ARMSTRONG, 1990, p. 114, pl. 18, figs. 16, 18; MCCrackEN, 1991b, p. 109, pl. 4, fig. 3; MÄNNIK AND MALKOWSKI, 1998, pl. 2, fig. 5.

*Types*.—Hypotypes GSC120570-120571.

*Material examined*.—slender conical-8; squat, tridenticulate-7.

*Occurrence*.—*atavus* graptolite Zone, *curtus* graptolite Zone, ?*crispus* through *sakmaricus* graptolite zones.

*Discussion*.—Slender, conical elements (pl. 8, fig. 1) were found associated with the tridenticulate elements of *P. tricornis*. These have a semi-erect cusp that widens at the base and is ornamented by striae along the lower third before the base. The base is circular as is the cusp but is two to three times greater in circumference than the cusp.

## PSEUDOONEOTODUS SP.

Plate 8, figs. 3-4

*Description.*— Simple-cone like elements. Smooth, rounded anterior and posterior margins. No costae or furrows are present. Cusp recurved and gradually narrows to point. Base narrow and high. Very fine parallel striae ornament cusp from just above point of curvature to tip of cusp.

*Types.*—Figured specimens GSC120572-120573.

*Material examined.*—5 elements.

*Occurrence.*—*acuminatus* through *atavus* zones. *Pseudooneotodus* sp. first appears at the Ordovician-Silurian boundary, and is found infrequently in the lowermost Silurian and last appears before the end of the Rhuddanian in the *atavus* graptolite Zone.

*Discussion.* These specimens were much darker than co-occurring conodont elements.

GENUS *Pterospathodus* WALLISER, 1964

*Type species.*—*Pterospathodus amorphognathoides* Walliser, 1964.

*Discussion.*—The diverse Llandovery genus *Pterospathodus* has recently undergone revision by Männik (1998). Using collections from Estonia, Gotland and Sweden, he proposed that the genus *Carniodus* is not valid, and is composed of elements that belong to the *Pterospathodus* apparatus. The latter is thus here considered to be composed of Pa, Pb<sub>1</sub>, Pb<sub>2</sub>, Pc, M<sub>1</sub> (+M<sub>2</sub> in *P. pennatus procerus*), Sc<sub>1</sub>, Sc<sub>2</sub>, Sc<sub>3</sub>, Sb<sub>1</sub>, Sb<sub>2</sub>, Sa, cf (carnuliform), ccf (carniciform), and a curved element. The elements previously assigned to *Carniodus* are Pb<sub>2</sub> (previously Pb/carinthiaciform), M<sub>1</sub> (M/triangulariform), Sc<sub>1</sub> (Sb/carniform), Sc<sub>2</sub> (Sc/neopriodian), Sa (Sa/latialatiform), and cf (Pa/carnuliform). Although Männik and Aldridge (1989) previously placed in synonymy *P. angulatus* and *P. pennatus* with *P. celloni*, Männik (1998) proposed that two ecologically distinct lineages of *Pterospathodus* characterised the Telychian, in part because of the apparent morphological differences between dextral and sinistral Pa elements. One lineage, *angulatus*—*lennarti*—*lithuanicus*—*amorphognathoides*, he considered to have been dominant in the open shelf environment. The other, *pennatus*—*procerus*, was thought to have preferred the more basinal, graptolitic facies. *Pterospathodus celloni* was assigned as a short-lived branch of *P. p. pennatus*, although tentatively, because of its rare occurrence in his studied sections. Clearly, this illustrates the difficulty in distinguishing between the elements of *Pterospathodus*, whose diagnostic elements are limited to, at best, the Pa elements.

Bischoff (1986) proposed that the ancestry of *Pterospathodus* could be found in his new Rhuddanian-Aeronian species, *Pterospathodus cadiaensis*; however, this was later shown to belong to the genus *Gamachignathus* (Wang and Aldridge 1996). The earliest *Pterospathodus* taxon to appear in Männik's (1998) collections is the Telychian form, *P. eopennatus*, which they noted appears "without a direct antecedent", has a Pa element that is "morphologically highly variable, with a pennate inner lateral process" (1998, p. 1009). The Pb<sub>2</sub> element may be the most diagnostic, having an undenticulated

anterior process. In fact, this species contains Pa morphotypes that are difficult to distinguish from the either of the later *P. pennatus pennatus*, *P. amorphognathoides angulatus* or *P. celloni* species or subspecies. Further obscuring the identifications is the gradual increasing trend in size throughout the Telychian. Clear examples of the *P. a. amorphognathoides*, with well-developed platform margins, and bifurcated outer-lateral process are virtually always many times larger than co-occurring specimens of *P. pennatus procerus*. Hence, some species identified as juvenile *P. a. amorphognathoides* in the literature may actually be *P. pennatus procerus*, or vice versa. At least in the Cape Phillips Formation, the clearest species boundaries are between *P. celloni* and the *P. amorphognathoides*—*P. pennatus* complex of species because generally even the most 'juvenile' specimens show the incipient development of a lateral process of some kind. Another possible antecedent of the *Pterospathodus* lineage may be *Pterospathodus? originalis* n. sp. Zhang and Barnes (in press) from the lower part of the upper Becscie Formation on Anticosti Island.

It is possible that the earliest specimens of *Pterospathodus* identified here from the Cape Phillips Formation as *P. celloni* may be reclassified under Männik's *P. eopennatus* lineage; however, no Pb<sub>2</sub> elements were recovered from this early interval, and only a few fragile Pa elements were found.

## PTEROSPETHODUS AMORPHOGNATHOIDES AMORPHOGNATHOIDES Walliser, 1964

## Plate 8, figs. 7-20

*Pterospethodus amorphognathoides* WALLISER, 1964, p. 67, pl. 15, figs. 9-15.

*Pterospethodus amorphognathoides amorphognathoides* Walliser. MÄNNIK, 1998, p. 1021-1022, 1025-1026, 1029-1030, 1033, 1035, pl. 4, figs. 1-20, 22-27, pl. 5 (includes synonymy through 1998).

*Types*.—Hypotypes GSC120576-120589.

*Material examined*.—Pa- 12; Pb<sub>1</sub>- 6; Pb<sub>2</sub>- 5; PC- 3; M<sub>1</sub>- 11; Sc<sub>1</sub>- 6; Sc<sub>2</sub>- 8; Sc<sub>3</sub>- 2; Sb<sub>1</sub>- 0; Sb<sub>2</sub>- 2; Sa- 2; cf- 13; mcf- 2; ccf- 2; curved- 10.

*Occurrence*.—*griestoniensis* through *sakmaricus* graptolite zones.

*Discussion*.—A limited number of the specimens identified as *Pterospethodus* have been assigned to *P. a. amorphognathoides*. Pa elements with a branched lateral process were assigned to this subspecies, as well as some large Pa elements without a secondary process but with an upturned platform (Pl. 8, fig. 7). Most of the elements figured by Männik (1998) are recognised here, except and the fine distinctions between the cf elements (cf,a and cf,b) and the curved elements (curved a, curved b, etc).

Männik (1998) noted that the M<sub>2</sub> element is only developed in the *P. pennatus procerus* apparatus. This is supported by the specimens in this study, as none were found associated solely with *P. a. amorphognathoides*. There does appear to be a high degree of morphological variation in the M element of the species, however, as some of them do not possess a denticulated posterior process, while others have a costa that runs up the inner later face of the cusp.

## PTEROSPATHODUS AMORPHOGNATHOIDES ANGULATUS (Walliser, 1964)

(not figured)

*Pterospathodus amorphognathoides angulatus* (Walliser). MÄNNIK, 1998, p. 1015-1016, 1019, pl. 2, figs. 1-22, 24-31; Text-figures 7-8 (includes comprehensive synonymy).

*Discussion.*—Männik (1998) suggested that *P. amorphognathoides angulatus* is characterised by elements without a platform and a Pa element with a lateral process which is long, pennate (unbranched) and having lower denticles on the middle part of the blade (Männik 1998). He considered this species to be the oldest of the lineage that led to *P. a. lennarti* and then *P. a. amorphognathoides*. Elements of *P. a. angulatus* were found in a single sample in the Cape Phillips Formation, where it co-occurred with elements of *Pterospathodus celloni*, and *P. a. amorphognathoides* hence separation of the other generally undiagnostic elements of the apparatus was not possible. These elements are tabulated under *P. a. angulatus* but not figured. Except for some small Pb<sub>1</sub> elements, the Pb<sub>1</sub> and Pb<sub>2</sub> in the sample possess a small platform or lateral margins that bulge under the denticles, contrary to the description of Männik (1998).

*Material examined.*—Pa elements- 18; other questionable elements- see tables.

*Occurrence.*—upper *griestoniensis* graptolite Zone.

## PTEROSPATHODUS CELLONI (Walliser, 1964)

## Plate 8, figs. 21-31

*Pterospathodus celloni* (Walliser, 1964). ARMSTRONG, 1990, p. 118-119, pl. 19, figs. 6-14 (synonymy to 1986); MÄNNIK, 1998, p. 1041, pl. 6, figs. 26, 36-54, Text-fig. 17 (includes synonymy through 1997); ZHANG and BARNES (in press).

*Types*.—Hypotypes GSC120590-120600.

*Material examined*.—Pa element- 24; Pb<sub>1</sub> element- 9; Pb<sub>2</sub> element- 1; PC element- 6; M<sub>1</sub> element- 6; Sa element- 1; Sb<sub>1</sub> element- 1; Sb<sub>2</sub> element- 10; Sc<sub>1</sub> element- 2; Sc<sub>2</sub> element- 12; Sc<sub>3</sub> element- 5; ccf element- 2.

*Occurrence*.—*crispus* Zone? through upper *griestoniensis* graptolite zones. Männik (1998) noted that *P. celloni* may have had a greater abundance in basinal environments, and was very rare in open shelf environments.

*Discussion*.—Männik (1998) figured Pa, Pb<sub>1</sub>, Pb<sub>2</sub>, Pc, M<sub>1</sub>, Sb<sub>2</sub>, Sc<sub>1</sub>, Sc<sub>2</sub>, cf, ccf elements of *P. celloni*. He noted that Pa and Pb<sub>1</sub> elements, with the Pb<sub>2</sub> element somewhat common, mostly represent the Estonian collections. Although *P. celloni* samples were found in low numbers, a relatively large number of S, cf, and ccf elements were recovered in the Cape Phillips Formation. No Pb<sub>2</sub> elements were found.

Two unusual ?Pa elements of *P. celloni* were recovered from a sample rich in elements of the species. The element (Pl. 8, fig. 24) has anterior denticles and the lateral lobes that are characteristic of the Pa element of *P. celloni*, however, the posterior denticles are greatly reduced. The size of the element is similar to the others, hence assigning it as a juvenile form is problematic.

## PTEROSPETHODUS EOPENNATUS SSP. 2 Männik, 1998

Pl. 4, fig. 1

*Pterospethodus eopennatus* MÄNNIK, 1998, p. 1013, pl. 1, figs. 1-9, 11-15; pl. 2, figs. 23-25, 27.

*Types.*—Hypotypes GSC120482.

*Material examined.*—Pa element- 1.

*Occurrence.*—Base of the *griestoniensis* graptolite Zone.

*Discussion.*—Männik (1998) proposed this new *Pterospethodus* species and subspecies based on an exhaustive study of the genus. His morph 4 (p. 1009) was grouped within *P. eopennatus* ssp. 2, and was described as being characterised by short anterior denticles that are highest proximally and decrease in height anteriorly, with short posterior denticles. His description agrees well with the element figured here (pl. 4, fig. 1). The samples in this interval (CM3) were low-yielding because of their resistance to dissolution. The first elements of *Pterospethodus celloni* were recovered from strata approximately 25 m higher in the section.

## PTEROSPETHODUS PENNATUS PROCERUS (Walliser, 1964)

Plate 9, figs. 1-15

## Multielement

*Pterospethodus pennatus procerus* (Walliser, 1964). MÄNNIK, 1998, p. 1037, 1040, pl. 6, figs. 25, 27-35, Text-fig. 16 (synonymy through 1997); MÄNNIK AND MALKOWSKI, 1998, pl. 1, figs. 6-7, 11-13, 18.

*Types*.—Hypotypes GSC120601-120615.

*Material examined*.—Pa element- 53; Pb<sub>1</sub> element- 28; Pb<sub>2</sub> element- 12; PC element- 13; Sa element- 0; Sb<sub>1</sub> element- 4; Sb<sub>2</sub> element- 13; Sc<sub>1</sub> element- 17; Sc<sub>2</sub> element- 19; Sc<sub>3</sub> element- 7; carnuliform element- 9; carniciform element- 3; modified carnuliform element?- 2.

*Occurrence*.—Männik (1998) noted that *P. p. procerus* dominates over *P. a. amorphognathoides* towards offshore environments, but has been found in open shelf environments during the short interval above the last appearance of *P. a. amorphognathoides* (the Lower and Upper *P. p. procerus* zones within the Ireviken Event of Jeppsson 1997b). In the Cape Phillips Formation, *P. p. procerus* ranges from the *sakmaricus* (possibly *griestoniensis*) graptolite Zone to the lower *instrenuus-kolobus* graptolite Zone.

*Discussion*.—The diagnostic element of *P. pennatus procerus*, the Pa element, has a pennate, unbranched lateral process, and has generally been considered to have a platform, although often much less developed than in *P. a. amorphognathoides*. In the Cape Phillips Formation, the presence of a branched lateral process and upturned platform was used to distinguish between *P. a. amorphognathoides* and *P. p. procerus*. Neither characters are present in the latter species. A number of specimens may be considered to be juvenile *Pterospethodus*, some possessing an incipient lateral process,

some with the beginnings of a narrow platform, and others with neither. It is not clear whether all the characteristics present in the mature animal were necessarily present in the juvenile. Walliser (1964, table 15, figs. 9-15) figured an ontogenetic series of *P. a. amorphognathoides* showing that the platform and extra process are not present in the most juvenile forms. In Europe and Britain, most *Pterospathodus pennatus procerus* specimens are juveniles (Jeppsson 1997b). An ontogenetic series is figured in Plate 9, figs 2-4.

Männik's (1998, pl. 6, fig. 16) figured  $Sb_1$  specimen possesses a very tall cusp and little, if any aboral/lateral flare under the cusp. This also is a characteristic of the  $Sb_1$  elements in the Cape Phillips Formation, and hence seems a common feature of *P. p. procerus* (although not always e.g., Uyeno and Barnes 1983). The  $M_1$  elements in the Cape Phillips do not have denticulated anticusps or posterior processes, as Männik's (1998) figured  $M_1$  elements do (Pl. 6, figs. 2, 4). Männik (1998) introduced the  $M_2$  element as limited to the apparatus of *P. p. procerus*. In his original description, the  $M_2$  element is dolabrate, more slender, less curved, lacking an anticusps, and possessing shorter processes than the  $M_1$  element. A comparable element is identified here (Pl. 9, figure 13). It is characterised by an underdeveloped anticusps, a sharp, short inner-lateral process, and a relatively longer posterior process, none of which are denticulated.

## PTEROSPATHODUS RHODESI (Savage, 1985)

## Plate 9, figs. 17-18

*Pterospathodus amorphognathoides rhodesi* SAVAGE, 1985, p. 714, Fig. 3 A-T.

*Pterospathodus rhodesi* (Savage, 1985). MÄNNIK, 1998, p. 1041, 1042, 1045 (includes synonymy to 1998).

*Types*.—Hypotypes GSC120617-120618.

*Material examined*.—Pa elements- 3; M elements 1.

*Occurrence*.—*sakmaricus* graptolite Zone. *Pterospathodus rhodesi* has been found in Alaska (latest *amorphognathoides* Zone) (Savage 1985), Greenland (uppermost *celloni* through *amorphognathoides* Zone strata) (Armstrong 1990), the Northwest Territories (latest *amorphognathoides* Zone) (Over and Chatterton 1987), and New South Wales, Australia (*P. latus* Zone ~ *amorphognathoides* Zone) (Bischoff 1986).

*Discussion*.—*Pterospathodus rhodesi* is characterised by a Pa element that has extremely wide platform/platform ledges, upturned margins, and a lobe-like inner lateral process but may have either a pennate, unbranched or a bifurcate outer lateral process (Männik and Aldridge 1989). The Pa elements from the Cape Phillips Formation have a pennate lateral process. Due to difficulties separating the other elements of the apparatus from co-occurring *P. pennatus procerus* elements, only the M element is figured in addition to the Pa element.

GENUS *Walliserodus* SERPAGLI, 1967

*Type species.*—*Acodus curvatus* Branson and Branson, 1947.

## WALLISERODUS CURVATUS (Branson and Branson, 1947)

## Plate 10, figs. 1-12

## Sc element

*Acodus curvatus* BRANSON AND BRANSON, 1947, p. 554, pl. 81, fig. 20.

## Multielement

*Walliserodus curvatus* (Branson and Branson). COOPER, 1975, p. 995, 996, pl. 1, figs. 10, 11, 16-21; REXROAD, NOLAND AND POLLOCK, 1978, p. 12, pl. 1, figs. 1-5; HELFRICH, 1980, pl. 2, figs. 20, 25; MCCRACKEN AND BARNES, 1981, p. 90-91, pl. 1, figs. 26-30; NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 41, pl. 19, fig. 16; ARMSTRONG, 1990, p. 124-126, fig. 6-15; MCCRACKEN 1991, p. 81, pl. 4, fig. 12; SIMPSON AND TALENT, 1995, p. 127-128, pl. 4, figs. 21-25.

*Walliserodus* cf. *W. curvatus* (Branson and Branson). BOLTON AND NOWLAN, 1979, p. 21, pl. 8, figs. 19-32; NOWLAN AND BARNES, 1981, p. 24-25, pl. 8, figs. 17-24; MCCRACKEN AND BARNES, 1981, p. 91, pl. 1, figs. 22-25.

*Walliserodus amplissimus* (Serpagli). ORCHARD, 1980, p. 26-27, pl. 3, figs. 3-7, 9, 12, 17; NOWLAN, MCCRACKEN AND CHATTERTON, 1988, p. 40-41, pl. 19, figs. 9-13.

*Walliserodus sancticlairi* COOPER, 1976, p. 214-215, pl. 1, figs. 8-11, 16-21; BARRICK, 1977, p. 59, pl. 1, figs. 11, 13-20; UYENO AND BARNES, 1983, p. 26, pl. 7, figs. 1-3, 5, 6; KLEFFNER, 1987, figs. 6.15-18; MCCRACKEN, 1991b, p. 81-82, pl. 4, figs. 3-10, 15; SIMPSON and TALENT, 1995, p. 128-129, pl. 4, figs. 26, 27.

*Types.*—Hypotypes GSC120619-120630.

*Material examined.*—M element- 54; Sa element- 29; Sb element-23; Sc element- 53; multicostatiform element- 14.

*Occurrence.*—*fastigatus*? Zone, *acuminatus* through *guerichi* graptolite zones.

*Discussion.*—Zhang and Barnes (in press) placed in synonymy three species of *Walliserodus*, *W. amplissimus*, *W. curvatus* and *W. sancticlairi* because insufficient characters were present to readily differentiate the three species, and their ranges overlapped significantly. They noted that variability occurs in the M and Sc elements. The M element may be acostate or have one outer lateral costa, while the Sc element has either 0, 1, 2, or 3 lateral costae on the inner face.

In the Cape Phillips Formation specimens, very few M elements possess an outer lateral costae. Costae were found on the inner face of very few of the Sc elements, however, some Sc? elements (Pl. 10, fig. 7) had a medial outer lateral costae. McCracken's (1991b) *b-1* element (see below) possesses an outer lateral costae, and the element is "less inwardly bowed" (p. 80) than the Sc element. The Sc? elements in this study that possessed this feature were bowed to a relatively large degree and hence it is not clear whether two Sb (*b-1*, *b-2*) morphotypes exist, or whether some Sc elements can possess an outer costae.

McCracken (1991b) described a new species of *Walliserodus*, *W. blackstonensis*, from the Canadian Cordillera. In light of Zhang and Barnes' synonymy, it is possible that *W. blackstonensis* may also be placed in synonymy with *W. curvatus*, as few distinctive characters can separate the two species. Zhang and Barnes (in press) did not place the two in synonymy. McCracken's diagnosis was based on a large number of specimens that included some 2000 from a single sample, and thus his description of *W. blackstonensis* involves a rigorous study and may represent the apparatus of a closely related species of *W. curvatus*. McCracken's (1991b) *W. blackstonensis* included *b-1* and *b-2* elements, the latter of which may be synonymous with the Sb element of *W. curvatus*. The *b-1* element may be synonymous with the unicostate Sc element of *W. curvatus*. Similarly the *e* (=M) element of *W. blackstonensis* is acostate, a feature that Zhang and

Barnes (in press) note is common in *W. curvatus*. Large collections are needed to determine the limits of intraspecies variation within the species of *Walliserodus*.

WALLISERODUS CF. *W. SANCTICLAIRI* Cooper, 1976

## Plate 10, figs. 13-20

cf. *Walliserodus sancticlairi* COOPER, 1976, p. 215, pl. 1, figs. 8-11, 16-21.

*Walliserodus* cf. *W. sancticlairi* Cooper. ARMSTRONG, 1990, p. 126-127, pl. 21, figs. 16-24.

*Diagnosis.*—Species of *Walliserodus* characterised by absence of lateral costae and Sa element that lacks posterolateral costae. Each element bears faint zone of basal wrinkles.

*Description.*—Sa (dyscritiform) element—thin-walled, symmetrical element. Base has pronounced antero-lateral costae which merge at point of curvature of cusp and disappear or form small keel. No postero-lateral costae. Cusp proclined to erect.

Sb (deboltiform) element—asymmetrical version of Sa element. Element bowed to inner side. Inner face convex along base to point of curvature of cusp. Anterior margin developed into prominent keel curved slightly inwards. Outer face is smooth, becoming more convex towards base. Outer antero-lateral keel/costae is sharp and continues to point of curvature of cusp.

Sc (curvatiform) element. Element highly inwardly flexed. No costae present. Inner face slightly convex near base. Outer face also convex at base. Base may be relatively wide or slender. Cusp proclined to almost erect.

M (unicostatiform)—Not noticeably flexed to either side, laterally compressed. Base of inner side only slightly convex. Base of outer side noticeably convex. No costae present.

*Types.*—Hypotypes GSC120631-120638.

*Material examined.*—M element- 104; Sa element- 31; Sb element- 67; Sc element-

362. *Occurrence.*—?*crispus* through *insectus* graptolite zones; one possible occurrence in the upper *instrenuus-kolobus* Zone. In North Greenland, Armstrong (1990) found *Walliserodus* cf. *W. sancticlairi* in the *celloni* through *amorphognathoides* zones.

*Remarks.*—Armstrong (1990) constructed the species *Walliserodus* cf. *W. sancticlairi* based on elements from *celloni* Zone and *amorphognathoides* Zone strata of North Greenland. His apparatus consisted of sym. p, ap, aq, sq and r elements. The sym. p, ap, aq and sq elements are considered here to correspond the Sa, Sb, Sc, and M positions, respectively, while the r element is placed in synonymy with the Sc element, as notable differences in the Cape Phillips Formation were not observed that would allow separation of the two elements.

McCracken (1991b) placed in synonymy Armstrong's (1990) *Walliserodus* cf. *W. sancticlairi* with his *W. sancticlairi* because he found that their elements were comparable. McCracken (1991b) figured a Sa element (pl. 4, fig. 10) which he described as having a posterior margin and lateral costae that make the cusp have a square cross section.

Armstrong (1990) distinguished between *Walliserodus* cf. *W. sancticlairi* and *W. sancticlairi* (Cooper, 1976) on the basis of the absence of upper lateral costae and the absence of lateral costae on the Sa and Sc elements, respectively, of *Walliserodus* cf. *W. sancticlairi*. The specimens from the Cape Phillips Formation also lack these characters.

Unlike *Walliserodus curvatus*, then, the Sa elements of *W. cf. W. sancticlairi* do not have upper lateral costae, M elements with outer lateral costae, or Sc elements with costae on the inner lateral face. Although this range of variation (except Sa element morphology of *W. cf. W. sancticlairi*) does fall within the range of variation of *W. curvatus* proposed by Zhang and Barnes (in press), it is preferred to maintain *W. cf. W. sancticlairi* as a separate species because of the distinctive Sa element and the absence of costae on the Sc and M elements. The stratigraphic distribution of *W. curvatus* and *W. cf. W. sancticlairi* in the Cape Phillips Formation suggests a loss of the postero-lateral costae from the former to the latter.

In the Cape Phillips Formation collections, *Walliserodus* cf. *W. sancticlairi* lacks a Sd (multicostatiform) element. McCracken (1991b) figured a multicostatiform element for his *W. sancticlairi*. There may be a tendency for elements of *Walliserodus* to lose lateral and upper costae, and the Sd in the latest Llandovery. Although a range of

variation in Sc elements was observed, it is not probable that one of these morphologies could be considered to represent the Sd element because this element is typically not curved and generally noticeably laterally compressed along its base. It is possible that an Sd element could be identified in larger collections as it is generally rare in other species of the genus.

## NEW GENUS NEW SPECIES

## Plate 12, figs. 1-5

*Description.*—Small, entirely excavated cone or pyramidal elements. Three costae diverge aborally from a central upper apex, and, in some elements, continue free of the lateral wall for a distance representing one third to one half of the total height of the specimen. Costae may be prominent or present as rounded corners between the faces. Lateral surfaces adjoining corners are smooth, or may be slightly concave or convex. These lateral surfaces continue to near endpoints of apices, or end approximately midway between apex and tips and continue as spike-like protrusions.

*Types.*—Holotype GSC120658; Paratypes GSC120657, GSC120659-120661.

*Material examined.*—36 elements.

*Occurrence.*—early-middle *instrenuus-kolobus* through lowermost *perneri-opimus* graptolite zones. These samples are from concretions that also yielded prolific radiolarians.

*Discussion.* No transitional series could be identified from the collections of this species, although fine differences in symmetry exist. The species was found co-occurring with *Pseudooneotodus bicornis*, *Kockelella ranuliformis*, and *Dapsilodus obliquicostatus*. The morphology of the elements is reminiscent of *Coelocerodontus*, but their colour (which was identical to other species in the samples) is not typical of the Ordovician genus, which tends to be darker or white. Because of their unique morphology, their status as conodonts may be questionable, but their similarity in colour and texture to the other conodonts in the sample makes this unlikely.

## GENUS INDETERMINATE

## GENUS AND SPECIES INDETERMINATE 1

## Plate 11, fig. 11

*Description.*—Pyramidal, with 3 aboro-laterally directed anticusps (spike-like protrusions) that merge upwards to a cusp-like structure. Upper surface of some of the anticusps have a stubby denticle. Inner surface of anticusps excavated so that they appear spade-like when viewed from inside.

*Types.*—Figured specimen GSC120649.

*Material examined.*—4 elements.

*Occurrence.*—*sakmaricus* graptolite Zone.

*Discussion.*—These elements are somewhat similar in overall morphology to the new genus described above, however they are much larger and each anticusp is much more distinct. Many of the elements appear that they have been laterally crushed in the vertical plane.

## GENUS AND SPECIES INDETERMINATE 2

## Plate 11, fig. 13

*Description.*—Platform? element with four sub-circular denticles. Denticles located on each endpoint and other two opposite each other about midway between the two ends. Element bends almost 90° between one endpoint denticles and the paired denticles.

*Types.*—Figured specimen GSC120651.

*Material examined.*—1 element.

*Occurrence.*—*sakmaricus* graptolite Zone.

## GENUS AND SPECIES INDETERMINATE 3

Pate 11, fig. 14

*Description.*—Platform or flared base with single row of denticles along the anterior-posterior length. Platform not well developed, with jagged margins. Thin platform begins posteriorly, becomes widest at midpoint between anterior and posterior ends of element, and tapers anteriorly before reaching anterior end of element. Denticles are confluent and laterally compressed.

*Types.*—Figured specimen GSC120652.

*Material examined.*—4 elements.

*Occurrence.*—*sakmaricus* graptolite Zone. The elements were found in the largest producing sample processed from the Cape Phillips Formation.

*Discussion.*—The form of this platform is vaguely similar to those of Wenlock ozarkodinid like *Ozarkodina bohemica*.

## GENUS AND SPECIES INDETERMINATE 4

## Plate 11, fig. 15

*Description.*—Lanceolate (tapered to a point at either end) platform. Approximately symmetrical except anterior and posterior tapered points are directed in opposite lateral directions. Upper surface of platform covered in a undulating or pocked surface.

*Types.*—Figured specimen GSC120653.

*Material examined.*—1 element.

*Occurrence.*—upper *sakmaricus* graptolite Zone.

*Discussion.*—The surface ornamentation of this element is similar to that on the elements attributed to *Apsidognathus?* sp.

## GENUS AND SPECIES INDETERMINATE 5 (Branson and Branson)

## Plate 11, fig. 12

?Simple cone elements group "a" UYENO AND BARNES, 1983, p. 26, pl. 8, figs. 4, 8.

?Simple cone elements group "b", UYENO AND BARNES, 1983, p. 26, pl. 8, figs. 5, 13

?aggregations "*Drepanodus suberectus*" Zhang and Barnes (in press, includes synonymy).

*Types*.—Figured specimen GSC120650.

*Material examined*.—1 element.

*Occurrence*.—*sakmaricus* graptolite Zone.

*Discussion*.— This element has a simple cone that widens towards oval base and a suberect cusp. Uyeno and Barnes (1983) described some similar simple cone elements from the Chicotte Formation, Anticosti Island, and postulated a transition series. Zhang and Barnes (in press) describe several aggregations of the form species "*Drepanodus suberectus*" (Branson and Branson). They could not reconstruct an apparatus for these rare simple cone elements. It is probable that many suberectiform simple cone elements belong to the apparatus of *Pterospathodus*, and could possibly be variants of the M<sub>1</sub> element of the apparatus of that genus.

## 'SUBERECTIFORM' element

Pl. 9, fig. 16a-b

*Description.*—The cusp is suberect and increases in width towards the base. At the point of where the cusp and base meet, the element is restricted, and then expands or flares slightly towards the basal margin. The entire element is somewhat laterally compressed and slightly curved to the inner side.

*Types.*—Figured specimen GSC120616.

*Material examined.*—'suberectiform' element- 34.

*Occurrence.*—mid-*griestoniensis* through *sakmaricus* graptolite zones.

*Discussion.*—The "suberectiform" element (Plate 9, fig. 16a) was often associated with *Pterospathodus p. procerus* elements, and *Pterospathodus amorphognathoides amorphognathoides* as well. Unlike all other elements of *Pterospathodus*, the surface of the element is much smoother (Plate 9, fig. 16b). Fine longitudinal striae are barely visible at high magnifications.

## GENUS AND SPECIES INDETERMINATE 6

## Plate 11, fig. 16

N .sp. A BISCHOFF, 1986, p. 245-246, pl. 34, figs. 38-42.

*Types*.—Figured specimen GSC120654.

*Material examined*.—1 element.

*Occurrence*.—Bischoff (1986) found 48 specimens of this element in samples from the *P. amorphognathoides* – *P. latus* Assemblage Zone which can be approximately equated with the *P. amorphognathoides* Zone. A single specimen of this rare species is found in the Cape Phillips samples from the *sakmaricus* graptolite Zone.

*Discussion*.—Bischoff (1986) described this modified terriopedate to pastinate element from New South Wales. The triangular cusp, denticulated anterior and posterior (broken) process, adenticulate lateral process, length of processes, and the distinctive cell imprints that cover the lateral faces of the processes and the cusp all conform to his description.

Bischoff (1986) noted that n. sp. A is very similar to the Middle Ordovician genus *Pygodus* Lamont and Lindström, but it was not associated with any other elements that make up that apparatus.

## *Summary and Conclusions*

The Silurian Period is an intriguing Lower Paleozoic time because it contains a record of the recovery of marine populations from the second greatest Phanerozoic mass extinction event linked to the terminal Ordovician glaciation, several sequence boundaries associated with sharp isotopic excursions, glacial sequences in the Southern Hemisphere, and the presence of various biotic cycles that can be correlated with these global sea-level or climate/ocean state reversals. The Cape Phillips Formation on Cornwallis Island preserves a detailed record of the latest Ordovician through Silurian events on the unstable shelf region, or "Cape Phillips Basin", of the Franklinian miogeoclinal succession. The nine continuous sections covering the base of the Cape Phillips Formation in the Upper Ordovician and the entire Lower Silurian (Llandovery, Wenlock) are unique because of their exquisitely preserved graptolite and conodont faunas, enabling high resolution correlation between these two most important Lower Paleozoic biostratigraphic groups.

The composition, distribution and relationships of Lower Silurian deep water faunas are poorly known; however, because of the unique stratigraphic setting of the Cape Phillips Formation, an excellent record has been preserved. Detailed sampling of some 750 m of strata distributed among 9 continuous sections yielded 7,575 conodont elements from 180 samples. From the yields, 61 species representing 25 genera and 6 indeterminate genera are taxonomically described. One new taxon, New genus new species is recognised in the early Wenlock. Among the abundant Llandovery conodont faunas is the Telychian genus, *Pterospathodus*, and the two dominant lineages of the Llandovery, *Aspelundia* and *Walliserodus*, from which several species are described.

This diverse conodont assemblage and its integration with the graptolite biozonation enable the recognition of 11 conodont zones in the Cape Phillips strata. Three of these conodont zones are modified because of the higher temporal resolution of the graptolite biozonation, and the uniqueness of the slope environment relative to most other studied sequences that are based on shelf strata. The graptolite biozonation, which is well established in the Canadian Arctic Islands, allows the precise placement of the base of the conodont zones within a single graptolite zone, and ultimately ties the

conodont biozones into the standard chronostratigraphic divisions of the Silurian System. One conodont zone is new and is established on the presence of New genus new species. Its short range and distinctive morphology make it an excellent zonal fossil.

From the fauna, discrete, poorly understood and rare biofacies that represent the slope environment are recognised. The biofacies association of *Walliserodus*, *Dapsilodus*, and *Aspelundia* dominates much of the Llandovery, but is replaced in the Telychian by a much more diverse fauna, the latter of which is present in most late Llandovery sequences worldwide. In the Sheinwoodian Stage of the Wenlock, a low diversity fauna occurs, including the re-appearance of *Dapsilodus obliquicostatus* and New genus new species. Later Wenlock samples contain a low diversity fauna without key zonal species, which is typical of other sequences.

The Silurian is special because of the numerous biotic cycles that were eustatically and/or climatically controlled. Conodont bioevents, in which significant faunal turnovers occurred, are recognised in the *persculptus* graptolite Zone, the middle to late Rhuddanian, the early Telychian, and the early Wenlock. Of these, the first corresponds to the end-Ordovician glacially-linked extinction event. The Rhuddanian bioevent may be linked to a regional sequence boundary in the Arctic, while that in the Telychian could have been related to glaciation and/or a change to Primo episode oceanic and climate conditions. The step-wise extinction recognised over the Llandovery-Wenlock boundary is in agreement with other North American and detailed European studies and is also related to a major sequence boundary, glaciation, and carbon and oxygen isotope excursions.

Overall, the Cape Phillips Formation on Cornwallis Island preserves a diverse, moderately abundant, and exceptionally well preserved continuous conodont record. This is a substantial addition to conodont biostratigraphy and contributes to a greater understanding of the Lower Paleozoic. Additionally, it advances the science of conodont taxonomy and biogeography. The data further contribute to an integrated Lower Paleozoic conodont-graptolite parallel biostratigraphy together with important implications for regional correlations in the Canadian Arctic.

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***Plates and Plate Descriptions***

*Plate 1*

**Figures 1-8.** *Amorphognathus ordovicicus* Branson and Mehl (X65). All from CPS1.

1. Pa element, upper view (GSC120403).
2. Pb element, upper view (GSC120404).
3. Pb element, outer lateral view (GSC120405).
4. Sa element, lateral view (GSC120406).
5. Sb element, lateral view (GSC120407).
6. Sc element, lateral view (GSC120408).
7. Sd element, lateral view (GSC120409).
8. M element, inner lateral view (GSC120410).

**Figures 10-11.** *Belodina confluens* Sweet (X35). All from CM1.

10. compressiform element, lateral view (GSC120411).
11. grandiform element, lateral view (GSC120412).

**Figures 9, 12-14.** *Besselodus borealis* Nowlan and McCracken (X80). All from CPS1.

9. Sb? element, lateral view (GSC120413).
12. M element, inner lateral view (GSC120414).
13. Sb element, lateral view (GSC120415).
14. Pa (f) element, lateral view (GSC120416).

**Figures 15-17.** *Coelocerodontus trigonius* Ethington (X70). All from CPS1.

15. tetragoniform element, outer lateral view (GSC120417).
16. symmetrical trigoniform element (GSC120418).
17. tetragoniform element, inner lateral view (GSC120419).

**Figures 18-20.** *Drepanoistodus suberectus* (Branson and Mehl) (X40). All from CPS1.

18. oistodiform element, inner lateral view (GSC120420).
- 19-20. homocurvatiform elements, inner lateral views (GSC120421, (GSC120422).

**Figures 21-23.** *Paroistodus? nowlani* Zhen, Webby and Barnes (80X). All from CPS1.

21. M element, outer lateral view (GSC120423).
22. Sb element, outer lateral view (GSC120424).
23. Sc element, inner lateral view (GSC120425).

**Figures 24-27.** *Pseudobelodina? dispansa* (Glenister) (All X80 except Figure 24 X55). All from CPS1 except Figure 27 from CM1.

24. large, unbowed, acostate, unfurrowed element (GSC120426).
25. outer lateral view, slightly bowed, unicostate element (GSC120427).
26. outer lateral view, strongly bowed, unicostate element (GSC120428).
27. inner lateral view, bicostate element (GSC120429).

**Figure 28.** *Pseudooneotodus mitratus* (Moskalenko) (X35). From CPS1.

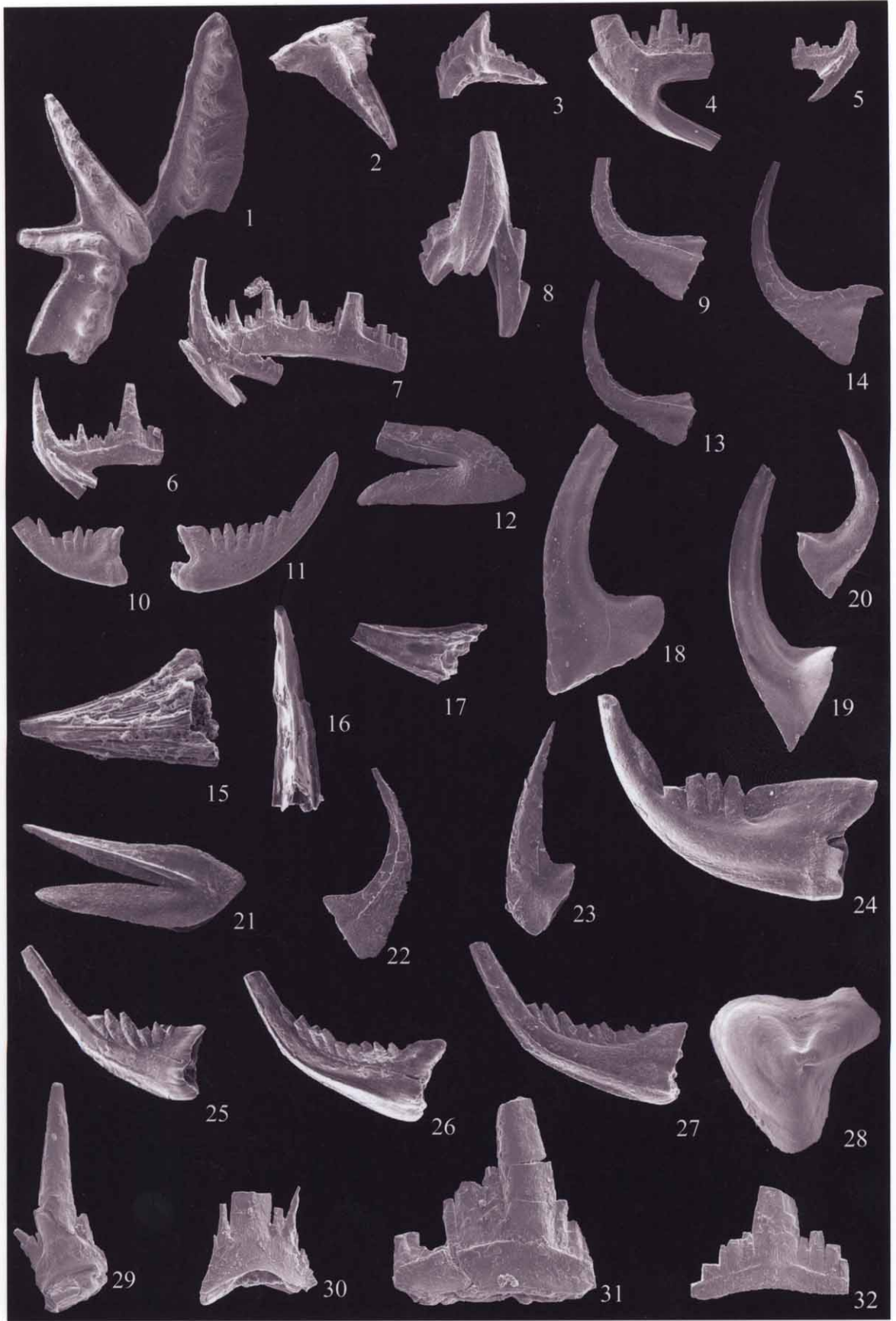
28. upper view (GSC120430).

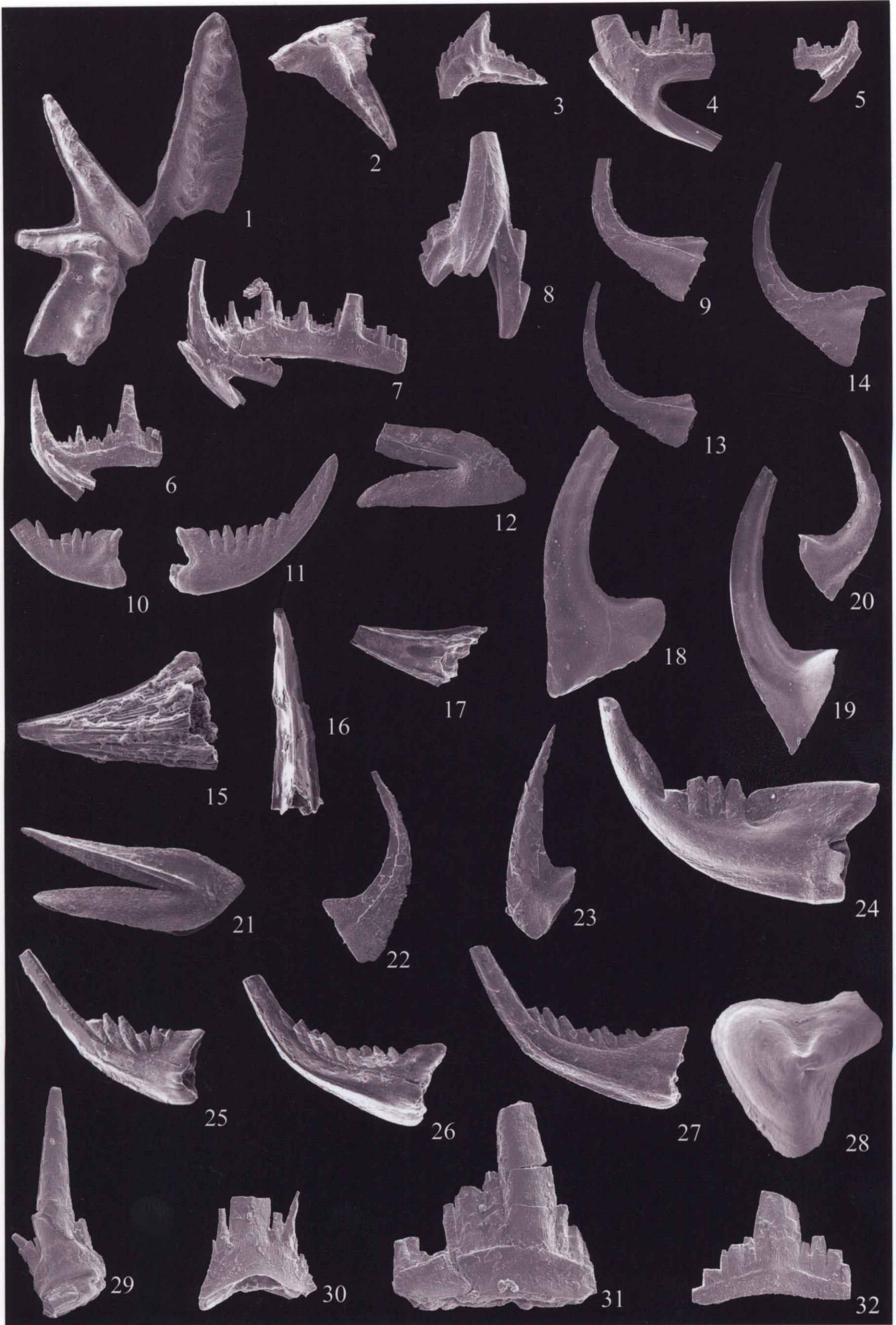
**Figures 29-30.** *Eocarniodus gracilis* (Rhodes) (X100). From CPS1.

29. lateral view of element with fractured cusp (GSC120431).
30. lateral view of element with broken cusp (GSC120432).

**Figures 31-32.** *Amorphognathus ordovicicus* Branson and Mehl "carniodiform" elements (X100). From CPS1.

31. lateral view of broken bar (GSC120433).
32. lateral view of broken bar (GSC120434).





*Plate 2*

**Figures 1-4.** *Apsidognathus tuberculatus* Walliser (X55). All from CP 17 except Figure 7 from CP27.

1. Pa element, upper view (GSC120433).
2. lyriform element, upper view (GSC120434).
3. ambalodiform element, upper view (GSC120435).
4. lenticular element, upper view (GSC120436).

**Figure 7.** *Apsidognathus* n. sp. 3 McCracken (X55). From CP27.

7. Pa element, upper view (GSC120437).

**Figures 5-6.** *Apsidognathus?* sp. (X55). Figure 5 from CP17, Figure 6 from CP26.

5. unknown element, upper view (GSC120438).
6. unknown element, upper view (GSC120439).

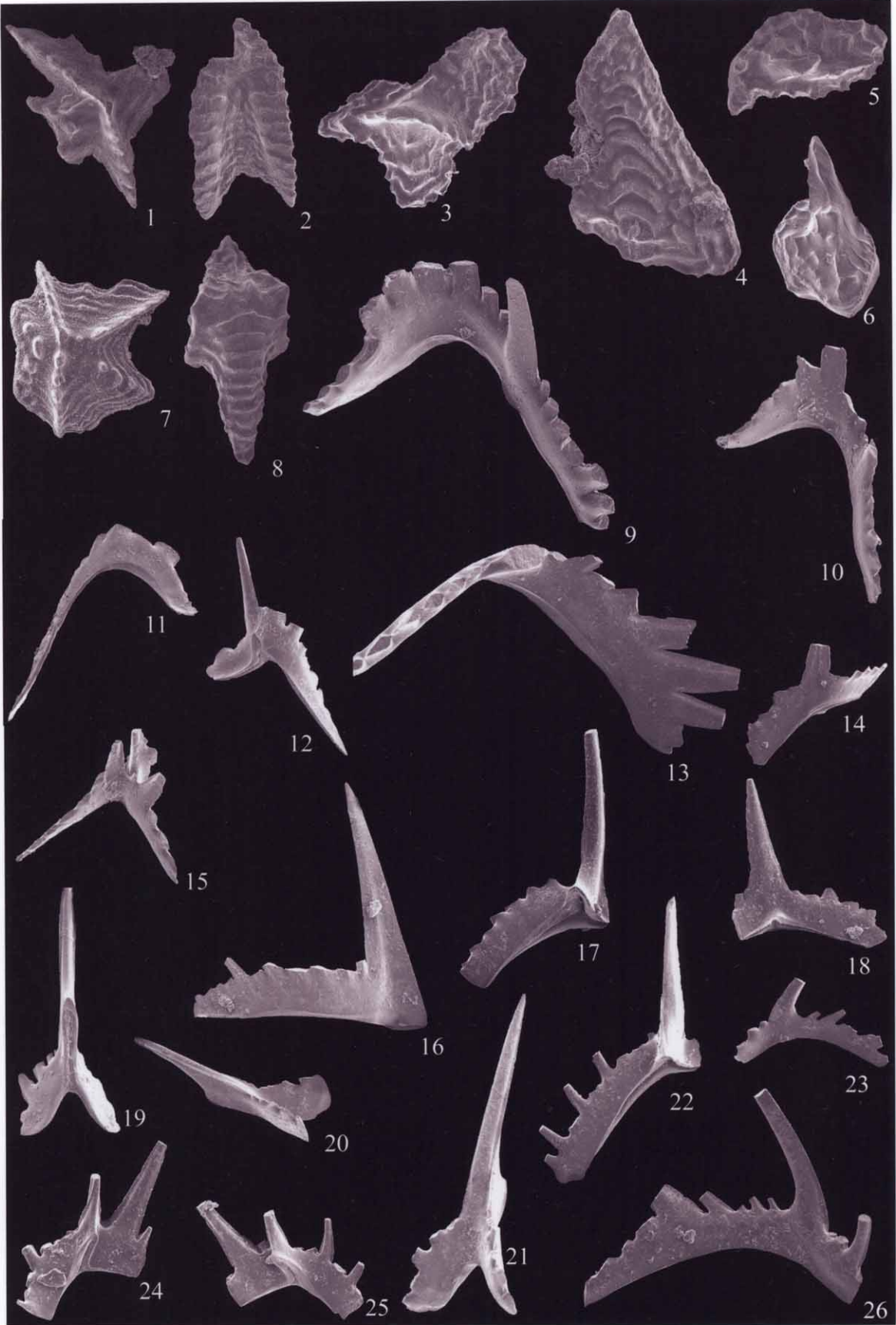
**Figure 8.** *Apsidognathus* cf. *A. walmsleyi* Aldridge (X55). From CP17.

8. lyriform element, top view (GSC120440).

**Figures 9-26.** *Aspelundia fluegeli* (Walliser) (X65). All from ARE1.

9. Pa element, upper-anterior view (GSC120441).
10. Pa element, upper-anterior view (GSC120442).
11. Pa element, aboral-posterior view (GSC120443).
12. Pa element, aboral-posterior view (GSC120444).
13. Pb element, upper inner-lateral view (GSC120445).
14. Pb element, inner lateral view (GSC120446).
15. Pa element, upper-anterior view (GSC120447).
16. M<sub>1</sub> element, inner lateral view (GSC120448).
17. M<sub>3</sub> element, inner lateral view (GSC120449).
18. M<sub>2</sub> element, inner lateral view (GSC120450).
19. Sa element, postero-lateral view (GSC120451).
20. Sa element, upper antero-lateral view (GSC120452).
21. Sa element, upper antero-lateral view (GSC120453).
22. M<sub>3</sub> element, inner lateral view (GSC120454).
23. Sc element, inner lateral view (GSC120455).
24. Sb element, posterior view (GSC120456).

25. Sb element, posterior view (GSC120457).
26. Sc element, inner lateral view (GSC120458).



*Plate 3*

**Figures 1-10.** *Aspelundia petila* (Nicoll and Rexroad) (X75). All from CM2C-7 except Figure 1, from CM2B-1.

1. early *A. petila*? M element, inner lateral view (GSC120459).
2. Pa element, antero-upper view (GSC120460).
3. Pa element, posterior view (GSC120461).
4. Pb element, inner lateral view (GSC120462).
5. Pb element, outer lateral view (GSC120463)
6. M element, inner lateral view (GSC120464).
7. Sa element, antero-lateral upper view (GSC120465).
8. Sa element, postero-lateral view (GSC120466).
9. Sb element, posterior view (GSC120467).
10. Sc element, inner lateral view (GSC120468).

**Figures 11-23.** *Aspelundia cf. A. borenorensis* Bischoff (All X75 except Figure 23, X65). All from ARE1.

11. denticulated Pa element, posterior view (GSC120469).
12. denticulated Pa element, upper lateral view (GSC120470).
13. broken? denticulated Pa element (GSC120471).
14. denticulated Sa element, upper anterior view (GSC120472).
15. denticulated Sa element, lateral view (GSC120473).
16. denticulated asymmetrical element, upper anterior view (GSC120474).
17. denticulated M element, inner lateral view (GSC120475).
18. undenticulated asymmetrical element, upper view (GSC120476).
19. undenticulated asymmetrical element, lower view (GSC120477).
20. denticulated asymmetrical element, lateral view (GSC120478).
21. denticulated Sa element, antero-lateral view (GSC120479).
22. denticulated Sa element, posterior view (GSC120480).
23. large, denticulated M element, inner lateral view (GSC120481).



*Plate 4*

**Figure 1.** *Pterospathodus eopennatus* ssp. 2 Männik (X55). From CM3-4.

1. Pa element, inner lateral view (GSC120482)

**Figures 1-4, 5-8.** *Aulacognathus bullatus* (Nicoll and Rexroad) (X55). Figures 4 from CM3-4, Figures 2, 3, 6 from CP17.

2. Pa element, upper view (GSC120483).
3. Sb/Sc element, inner lateral view (GSC120485).
6. Sb/Sc element, inner lateral view (GSC120488).

**Figures 4, 5, 8.** *Oulodus* sp. (X55). All from CP17.

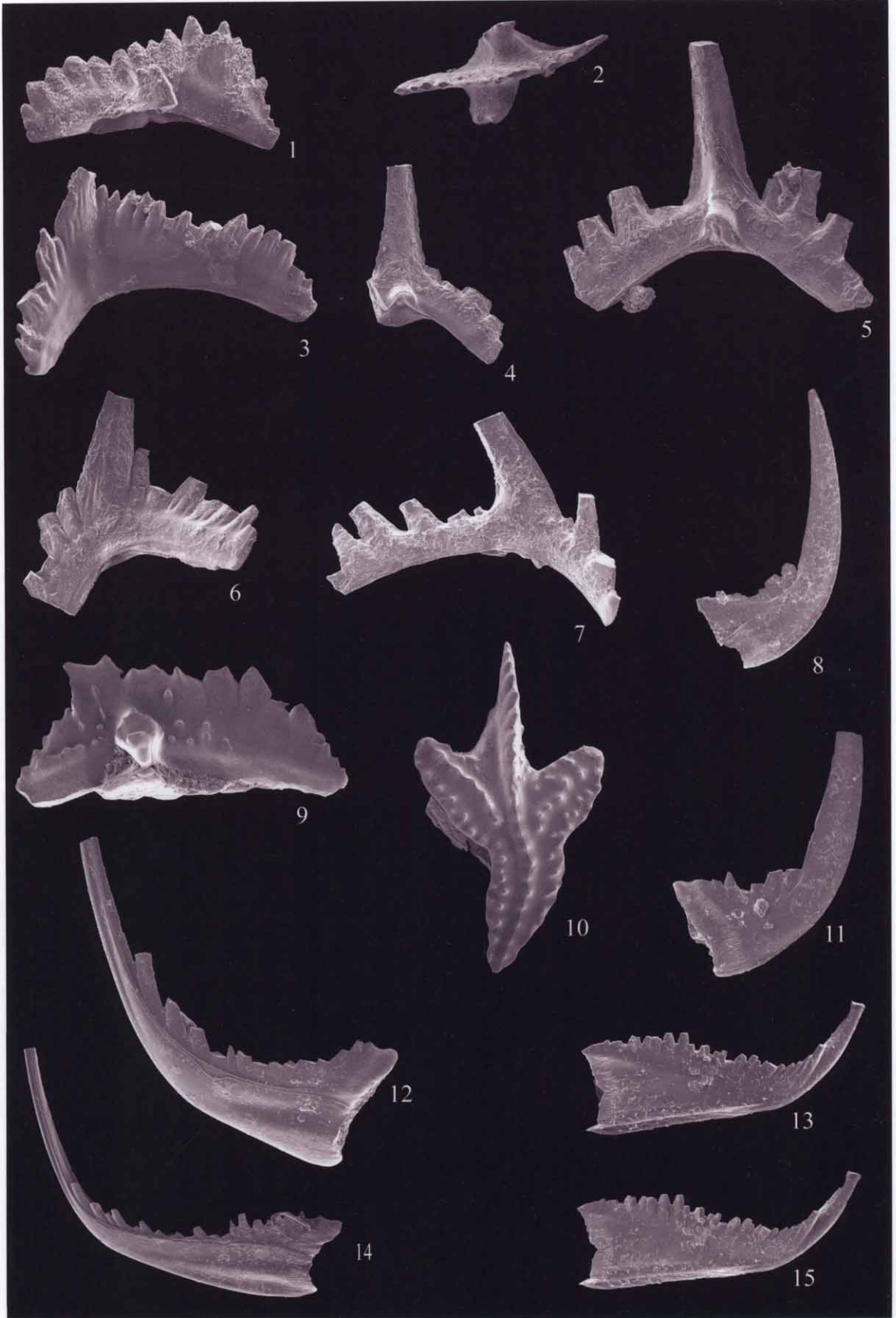
4. Sa element (broken), posterior view (GSC120486).
5. Sa element, posterior view (GSC120487).
8. Sc element, inner lateral view (GSC120489).

**Figures 9, 10.** *Aulacognathus chapini* (Savage) (X35). Both from ARE6.

9. Pb element, lateral view (GSC120490).
10. Pa element, upper view (GSC120491).

**Figures 9, 12-16.** *Belodella* sp. A Miller (X100). All from ARE1.

8. M element, lateral view of furrowed face (GSC120492).
11. M element, lateral view of unfurrowed face (GSC120493).
12. Sc element, outer lateral view (GSC120494).
13. Sb element, inner lateral view (GSC120495).
14. Sc element, outer lateral view (GSC120496).
15. Sb element, outer lateral view (GSC120497).



*Plate 5*

**Figures 1-3.** *Dapsilodus obliquicostatus* (Branson and Mehl) (X55). All from CP55.

1. Sb element lateral view (GSC120498).
2. Sb lateral view (GSC120499).
3. M element, lateral view (GSC120500).

**Figures 4-9, 13.** *Decoriconus fragilis* (Branson and Mehl) (X110). Figures 8, 13 from CPS10, Figure 9 from CPS16, Figures 4-7 from CM2B-1.

4. Sb element (GSC120501).
5. Sc element with anticusp, inner lateral view (GSC120502).
6. Sc element with anticusp, outer lateral view (GSC120503).
7. Sb element, lateral view (GSC120504).
8. Sa element, lateral view (GSC120505).
9. Sc? element, lateral view (GSC120506).
13. Sc element without anticusp, inner lateral view (GSC120507).

**Figures 10-12, 14, 17.** *Distomodus kentuckyensis* (Branson and Branson) (X40 except Figure 10, X20). All from CM2B-1.

10. Pa element, top view (GSC120508).
11. M element, inner lateral view (GSC120509).
12. M element, top view (GSC120510).
14. Sb element, lateral view (GSC120511).
17. Sa element, posterior view (GSC120512).

**Figures 15, 16, 18-20.** *Distomodus staurognathoides* (Walliser) (X35). All from ARE5 except Sa element, from ARE6.

15. Pa element, top view (GSC120513).
16. M element, lateral view (GSC120514).
18. Sa element, postero-lateral view (GSC120515).
19. Sc element, outer lateral view (GSC120516).
20. Sb element, postero-lateral view (GSC120517).



*Plate 6*

**Figures 1-2, 4. *Kockelella absidata absidata*** Barrick and Klapper (X40). All from 3ARW12.

1. Pa element, lateral view (GSC120518).
2. M element, inner-lateral view (GSC120519).
4. Sb element, posterior view (GSC120520).

**Figure 3. *Kockelella patula*** Walliser (X30). From 2ARW1.

3. Pa element, top view (GSC120521).

**Figures 5-10. *Kockelella ranuliformis*** (Walliser) (X65). Figures 5, 7, 9 from CP47, Figure 6 from CP51. Figures 8, 10 from CP49A.

5. Pa element, lateral view (GSC120522).
6. Pb element, lateral view (GSC120523).
7. M element, inner lateral view (GSC120524).
8. Sa element, posterior view (GSC120525).
9. Sb element, posterior view (GSC120526).
10. Sc element, inner lateral view (GSC120527).

**Figures 11-14. *Kockelella* sp.** (X75). All from CP25 except Figure 11 from CP23.

- 11, 12. Pa elements, lateral view (GSC120528, GSC120529).
13. Sa element, posterior view (GSC120530).
14. Sb element, posterior view (GSC120531).

**Figure 17. *Oulodus equirectus*** Kleffner (X60). From 3ARW12.

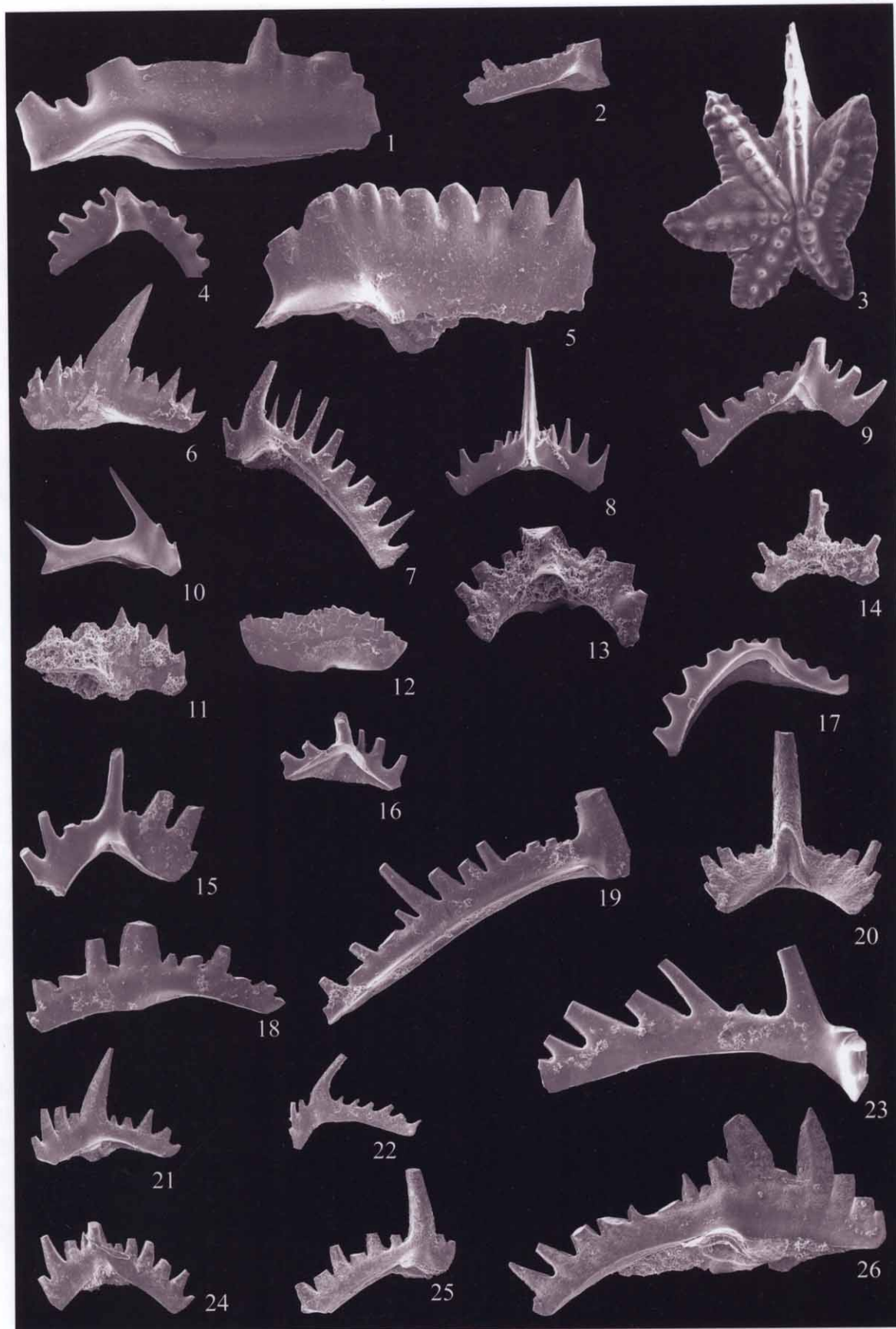
17. Pa element, posterior view (GSC120532).

**Figures 15-16, 18-20, 23. *Oulodus? kentuckyensis*** (Branson and Branson) (X50). All from CM2b-1 except Figure 17 from CPS 10.

15. Sb element, posterior view (GSC120533).
16. Pb element, inner lateral view (GSC120534).
18. Pa element, outer lateral view (GSC120535).
19. M element, posterior view (GSC120536).
20. Sa element, posterior view (GSC120537).
23. Sc element, inner lateral view (GSC120538).

**Figures 21-22, 24-26.** *Oulodus? nathani* McCracken and Barnes (X50). All from CPS 7.

21. Pb element, inner lateral view (GSC120539).
22. Sc element, inner lateral view (GSC120540).
24. Sb element, posterior view (GSC120541).
25. M element, posterior view (GSC120542).
26. Pa element, inner lateral view (GSC120543).



*Plate 7*

**Figure 1.** *Ozarkodina clavula* (Uyeno) (X65). From CM2C-11.

1. Pa element, lateral view (GSC1205544).

**Figures 2-5.** *Ozarkodina confluens* (Branson and Mehl) (X45). All from ARW12.

2. Pa element, lateral view (GSC120545).
3. Pb element, outer lateral view (GSC120546).
4. Sa element, posterior view (GSC120547).
5. Sb element, posterior view (GSC120548).

**Figures 6-10, 13.** *Ozarkodina excavata excavata* (Branson and Mehl) (X65). All from ARE6.

6. Pa element, outer lateral view (GSC120549).
7. Pb element, inner lateral view (GSC120550).
8. M element, posterior view (GSC120551).
9. Sc element, posterior view (GSC120552).
10. Sa element, posterior view (GSC120553).
13. Sb element, posterior view (GSC120554).

**Figures 11-12, 14-17.** *Ozarkodina hadra* (Nicoll and Rexroad) (X65). All from ARE6.

11. M element, posterior view (GSC120555).
12. Sa element, posterior view (GSC120556).
14. Pb element, inner lateral view (GSC120557).
15. Sb element, posterior view (GSC120558).
16. Pa element, lateral view (GSC120559).
17. Sc element, inner lateral view (GSC120560).

**Figures 18-22, 26.** *Ozarkodina hassi* (Pollock, Rexroad and Nicoll) (X65). All from CM2B-1.

18. Sb element, posterior view (GSC120561).
19. M element, posterior view (GSC120562).
20. Pa element, lateral view (GSC120563).
21. Pb element, outer lateral view (GSC120564).
22. Sa element, posterior view (GSC120565).
26. Sc element, inner lateral view (GSC120566).

**Figures 23-25.** *Ozarkodina oldhamensis* (Rexroad) (X65). All from CM2B-2.

23. Pa element, lateral view (GSC120567).
24. Pb element, lateral view (GSC120568).
25. M element, posterior view (GSC120569).



## Plate 8

**Figures 1-2.** *Pseudooneotodus tricornis* Drygant (X100). Both from ARE6.

1. slender, conical element (GSC120570).
2. squat, tri-denticulate element (GSC120571).

**Figures 3-4.** *Pseudooneotodus* sp. (X100). Figure 3 from CPS7, Figure 4 from CM2C-9.

3. lateral view of simple cone element (GSC120572).
4. lateral view of simple cone element (GSC120573).

**Figure 5.** *Pseudooneotodus bicornis* Drygant (X100). From CP47.

5. bi-denticulate element, top view (GSC120574).

**Figure 6.** *Pseudooneotodus beckmanni* (Bischoff and Sannemann) (X100). From CM2C-11.

6. top view (GSC120575).

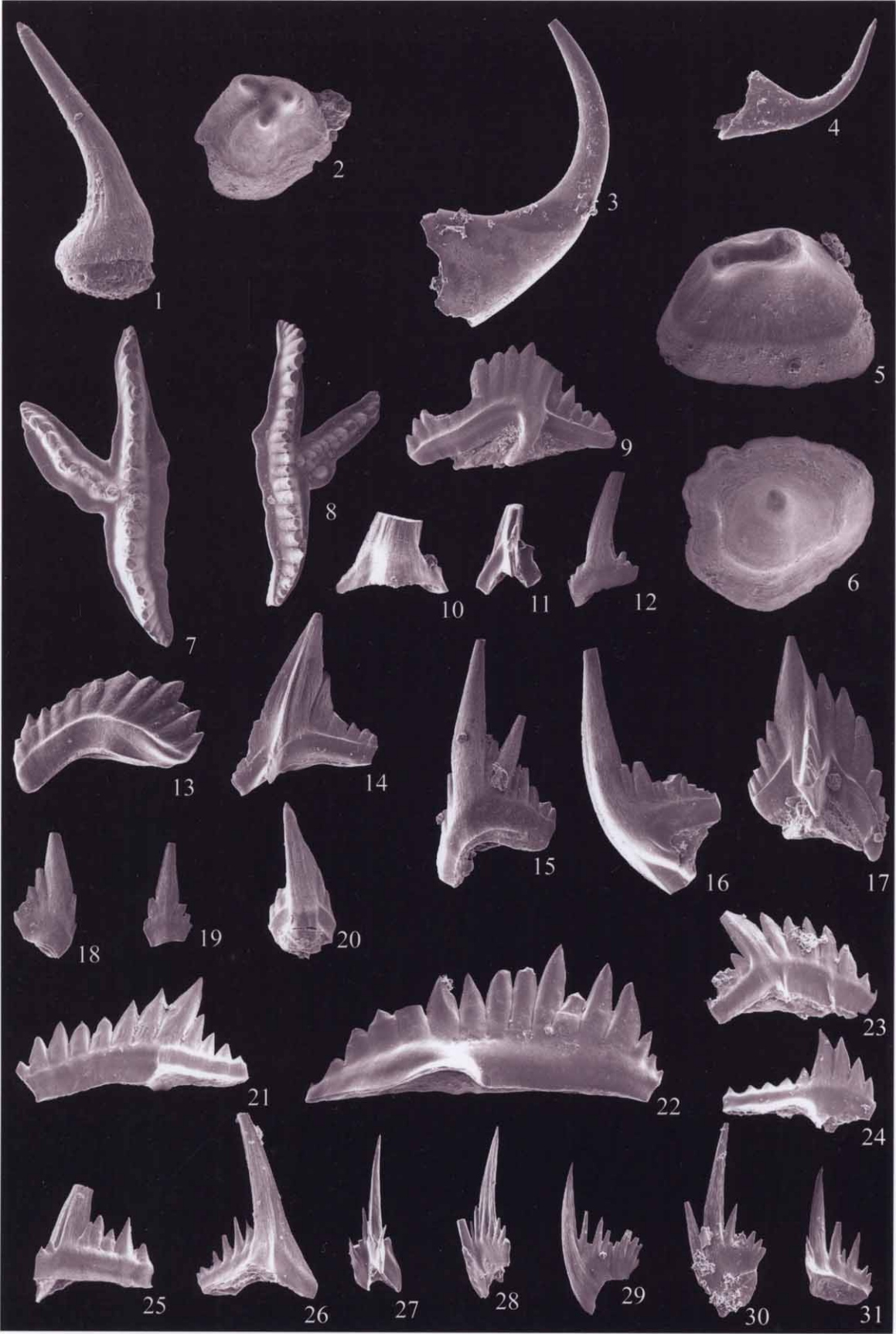
**Figures 7-20.** *Pterospathodus amorphognathoides amorphognathoides* Walliser (X55 except Figures 7-9 X35). All from ARE5.

7. Pa element lacking bifurcated lateral process, top view (GSC120576).
8. Pa element with bifurcated lateral process, top view (GSC120577).
9. Pb<sub>1</sub> element, outer lateral view (GSC120578).
10. M element, inner lateral view (GSC120579).
11. Sa element, posterior view (GSC120580).
12. cf<sub>2</sub> element, outer lateral view (GSC120581).
13. Pb<sub>2</sub> element, outer lateral view (GSC120582).
14. Pc element, lateral view (GSC120583).
15. Sc<sub>1</sub> element, outer lateral view (GSC120584).
16. Sc<sub>2</sub> element, lateral view (GSC120585).
17. modified carnuliform element, posterior view (GSC120586).
18. carnuliform (cf)? element, lateral view (GSC120587).
19. carnuliform (cf) element, lateral view (GSC120588).
20. curved element, outer lateral view (GSC120589).

**Figures 21-31.** *Pterospathodus celloni* (Walliser) (X70). All from CP13.

21. Pa element, lateral view (GSC120590).
22. Pa element, lateral view (GSC120591).

23. Pb<sub>1</sub> element, outer lateral view (GSC120592).
24. Pa? element, lateral view (GSC120593).
25. PC element, lateral view (GSC120594).
26. M element, posterior view (GSC120595).
27. Sa/Sb element, posterior view (GSC120596).
28. Sb element, postero-lateral view (GSC120597).
29. Sc<sub>2</sub> element, outer lateral view (GSC120598).
30. Sc<sub>3</sub> element, inner lateral view (GSC120599).
31. carniciform (ccf) element, posterior view (GSC120600).



**Plate 9**

**Figures 1-15.** *Pterospathodus pennatus procerus* (Walliser) (X100, except Figure 12b X250 and Figure 16b X500). 1-4, 6, 11 from ARE6; 5, 7-10, 12-15 from ARE 3.

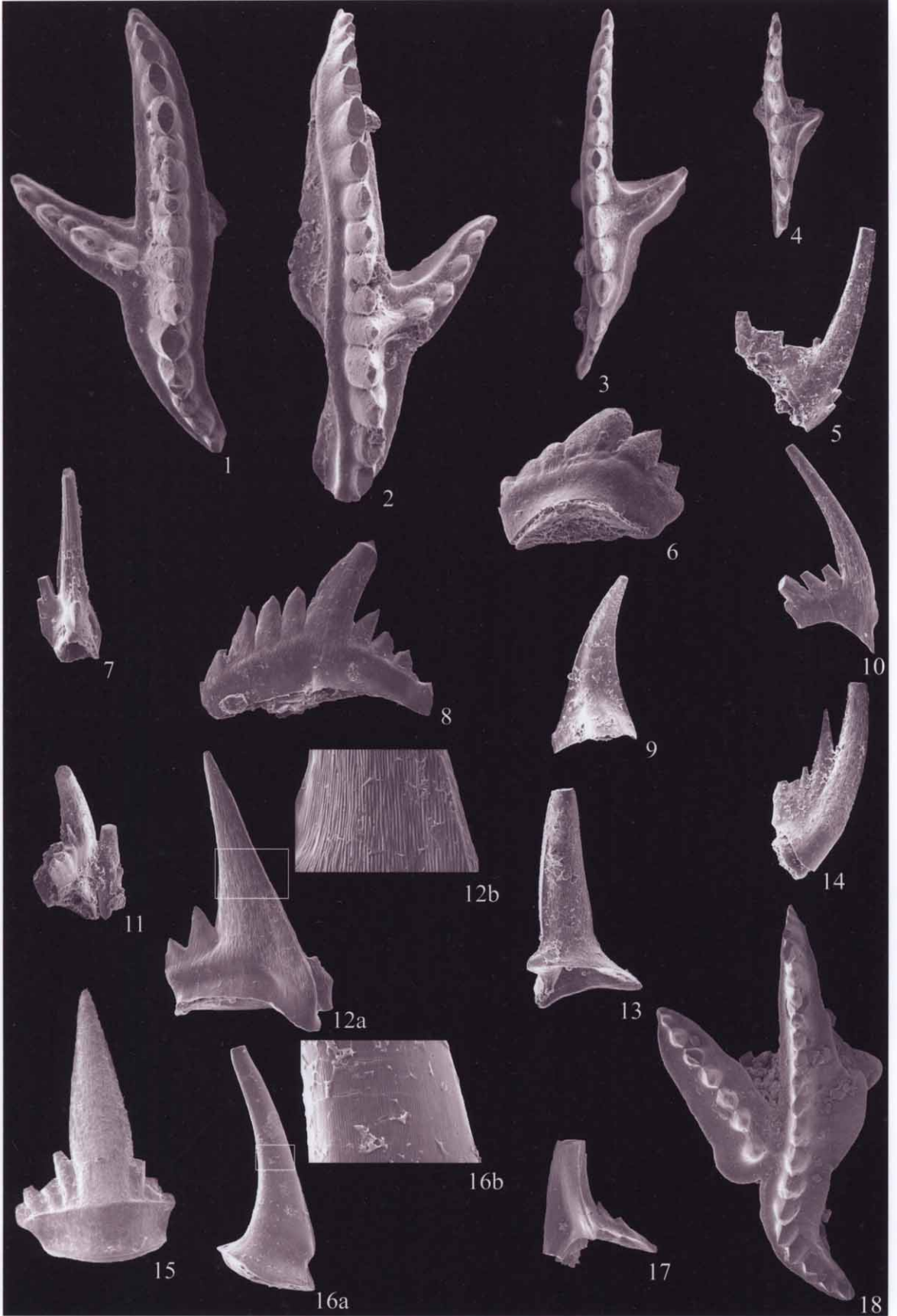
1. Pa element top view (GSC120601).
- 2-4. Pa element, growth series, top view (GSC120602, GSC120603, GSC120604).
5. Sc<sub>1</sub> element (GSC120605).
6. Pb<sub>2</sub> element, outer lateral view (GSC120606).
7. Sb<sub>1</sub> element, posterior view (GSC120607).
8. Pb<sub>2</sub> element, outer lateral view (GSC120608).
9. M<sub>1</sub> element, posterior view (GSC120609).
10. Sc<sub>2</sub> element, outer lateral view (GSC1206010).
11. Sb<sub>2</sub> element, posterior view (GSC120611).
- 12a. PC element, lateral view (GSC120612).
- 12b close-up of PC element showing fine longitudinal striae (GSC120612).
13. M<sub>2</sub> element, aboral-inner-lateral view (GSC120613).
14. Sc<sub>3</sub>, lateral view (GSC120614).
15. carnuliform element (GSC120615).

**Figures. 16 a, b.** 'Suberectiform element' (16a X100, 16b X500). From ARE1.

- 16a. suberectiform element, lateral view (GSC120616).
- 16b. close-up of suberectiform element showing lack of striae (GSC120616).

**Figures 17-18.** *Pterospathodus rhodesi* (Savage) (X50). Both from ARE1.

17. M element, posterior view (GSC120617).
18. Pa element, top view (GSC120618).



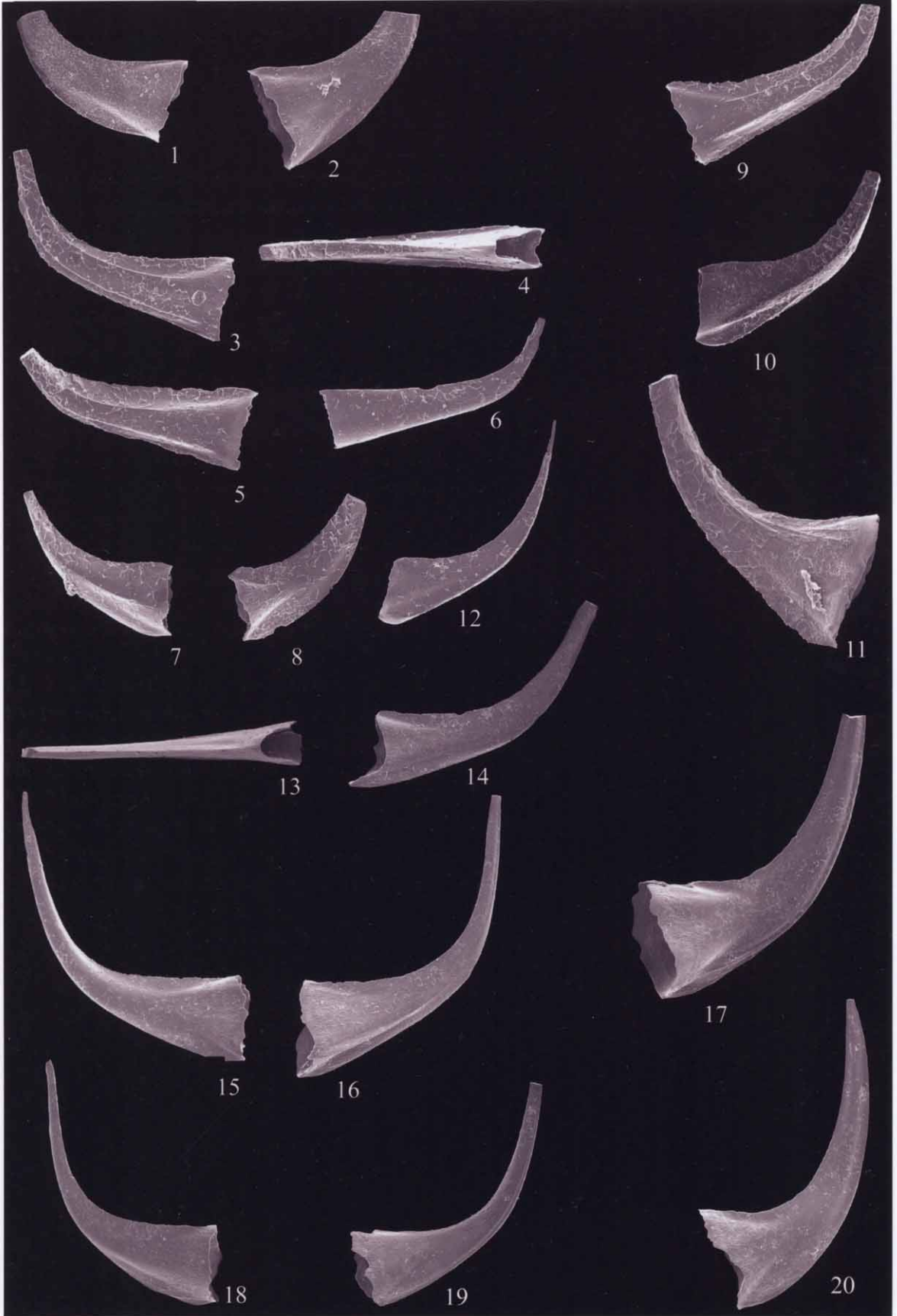
*Plate 10*

**Figures 1-12.** *Walliserodus curvatus* (Branson and Branson) (X85). Figures 1-9 from CM2C-18, Figures 10-12 from CM2C-11, Figure 13 from CM2C-13.

1. M element, outer lateral view (GSC120619).
2. M element, inner lateral view (GSC120620).
3. Sa element, lateral view (GSC120621).
4. Sa element, upper view (GSC120622).
5. Sb element, inner lateral view (GSC120623).
6. Sb element, outer lateral view (GSC120624).
7. Sc element?, outer lateral view (GSC120625).
8. Sc element, inner lateral view (GSC120626).
9. multicostatiform element, lateral view of bicostate face (GSC120627).
10. multicostatiform element, lateral view (GSC120628).
11. Sc element, inner lateral view (GSC120629).
12. slender M? element, lateral view (GSC120630).

**Figures 13-20.** *Walliserodus* cf. *W. sancticlairi* Cooper (X70). All from ARE1.

13. Sa element, upper view (GSC120631).
14. Sa element, lateral view (GSC120632).
15. Sb element, outer lateral view (GSC120633).
16. Sb element, inner lateral view (GSC120634).
17. M element, inner lateral view (GSC120635).
18. Sc element, outer lateral view (GSC120636).
19. Sc element, inner lateral view (GSC120637).
20. M element, outer lateral view (GSC120638).



*Plate 11*

**Figures 1-10.** *Panderodus unicostatus* (Branson and Mehl) (X100). All from ARE1.

1. asymmetrical graciliform element, inner lateral view (GSC120639).
2. asymmetrical graciliform element, outer lateral view (GSC120640).
3. compressiform element, outer lateral view (GSC120641).
4. compressiform element, inner lateral view (GSC120642).
5. arcuatiform element, outer lateral view (GSC120643).
6. arcuatiform element, inner lateral view (GSC120644).
7. tortiform element, outer lateral view (GSC120645).
8. truncatiform element, inner lateral view (GSC120646).
9. aequaliform element, lateral view (GSC120647).
10. subsymmetrical graciliform element?, lateral view (GSC120648).

**Figure 11. gen. and sp. indet. 1** (X55). From CP25.

11. lateral view (GSC120649).

**Figure 12. gen. and sp. indet. 5** (X100). From CP27.

12. aboral-lateral view of platform? element (GSC120650).

**Figure 13. gen. and sp. indet. 2** (X100). From CP27.

13. top view of platform element (GSC120651).

**Figure 14. gen. and sp. indet. 3** (X70). From ARE1.

14. top view of platform element (GSC120652).

**Figure 15. gen. and sp. indet. 4** (X55). From ARE5.

15. top view (GSC120653).

**Figure 16. gen. and sp. indet. 6** (X35). From ARE1

16. inner lateral view (GSC120654).

**Figures 17-18.** *Astropentagnathus?* sp. (X55). From CM2C-16.

17. inner lateral view of Sc element (GSC120655).

18. posterior view of Sa element (GSC120656).



*Plate 12*

**Figures 1-5. New genus, new species (X100).** From CP49A.

1. conical element, lateral view (GSC120657).
2. conical element, lateral view (GSC120658).
3. conical element, upper view (GSC120659).
4. conical element, lateral view (GSC120660).
5. conical element with attached radiolarian, lateral view (GSC120661).



### *Appendix A: Conodont Distribution Charts*

In the following, the distribution of conodont elements by species is recorded for each section. Included are element totals, height above base of section, mass, percent dissolution of the samples, and the yield per kg.

Appendix A, Table 1. Conodont distribution data for Cape Phillips South Section.

| CAPE PHILLIPS SOUTH               |                                 |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |     |
|-----------------------------------|---------------------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| Species                           | Sample Number                   | CPS1 | CPS2 | CPS3 | CPS4 | CPS5 | CPS6 | CPS7 | CPS8 | CPS9 | CPS10 | CPS11 | CPS12 | CPS13 | CPS14 | CPS16 | CPS17 | Total |     |
|                                   | Height from base (m)            | 19.7 | 22.5 | 25.2 | 26.3 | 27.0 | 28.0 | 29.0 | 30.0 | 31.0 | 32.0  | 33.0  | 34.0  | 35.0  | 37.2  | 41.0  | 43.7  |       |     |
|                                   | Sample Mass (g)                 | 3.2  | 3.4  | 3.2  | 3.2  | 3.0  | 3.2  | 3.0  | 3.0  | 3.0  | 3.0   | 3.2   | 3.0   | 3.0   | 3.1   | 3.1   | 3.1   |       | 3.6 |
|                                   | % Dissolution                   | 52   | 49   | 80   | 58   | 69   | 63   | 95   | 80   | 29   | 74    | 87    | 43    | 89    | 56    | 47    | 76    |       |     |
| <i>Amorphognathus ordovicicus</i> | Pa                              | 7    | 6    | 1    |      |      |      |      |      |      |       |       |       |       |       |       |       | 14    |     |
|                                   | Pb                              | 10   |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 10    |     |
|                                   | M                               | 3    | 1    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 4     |     |
|                                   | Sa                              | 1    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 1     |     |
|                                   | Sb                              | 2    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 2     |     |
|                                   | Sc                              | 5    | 1    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 6     |     |
|                                   | Sd                              | 4    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 4     |     |
| 'carniodiform' element            | 72                              | 5    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 77    |     |
| <i>Aspelundia</i> sp.             | M                               |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 1     |       | 1     |     |
| <i>Besselodus</i>                 | M                               | 12   | 3    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 15    |     |
|                                   | Sa                              | 1    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 1     |     |
|                                   | Sb                              | 6    | 4    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 10    |     |
|                                   | Sd/f                            | 8    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 8     |     |
| <i>Coelocerosodus trigonius</i>   | trigoniiform                    | 2    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 2     |     |
|                                   | tetragoniiform                  | 3    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 3     |     |
|                                   | basal funnel                    | 3    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 3     |     |
| <i>Dapsilodus obliquicostatus</i> | Sa                              |      |      |      |      |      |      | 1    |      |      |       |       |       |       |       |       |       | 1     |     |
|                                   | Sb                              |      |      |      |      |      |      | 5    |      |      |       |       |       | 5     |       |       |       | 10    |     |
|                                   | M                               |      |      |      |      |      |      | 3    |      |      |       |       |       |       |       |       |       | 3     |     |
| <i>Decoriconus fragilis</i>       | Sa                              |      | 1    |      |      |      | 1    | 1    |      | 2    | 1     |       |       | 4     | 4     |       |       | 14    |     |
|                                   | Sb                              |      | 1    |      |      |      |      | 3    |      | 4    |       |       |       | 5     | 8     |       |       | 21    |     |
|                                   | Sc                              |      |      |      |      | 1    | 1    | 9    |      |      | 1     |       |       | 6     | 4     |       |       | 22    |     |
| <i>Distomodus kentuckyensis</i>   | Pa                              |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 1     |       | 1     |     |
|                                   | Pb                              |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 1     |       | 1     |     |
|                                   | M                               |      |      |      |      |      |      | 1    |      |      |       |       |       |       |       | 1     |       | 2     |     |
|                                   | Sa                              |      |      |      |      |      |      |      | 2    |      |       |       |       |       |       | 3     |       | 5     |     |
|                                   | Sb                              |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 3     |       | 3     |     |
|                                   | Sc                              |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 2     |       | 2     |     |
| <i>Drepanoistodus suberectus</i>  | oistodiform                     | 1    | 1    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 2     |     |
|                                   | homocurvatiform                 | 8    | 3    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 11    |     |
|                                   | suberectiform                   | 1    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 1     |     |
| <i>Eocarniodus gracilis</i>       |                                 | 16   |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 16    |     |
| <i>Oulodus ? kentuckyensis</i>    | Pa                              |      |      |      |      |      |      |      |      |      | 0     |       |       |       |       |       |       | 0     |     |
|                                   | Pb                              |      |      |      |      |      |      | 7    |      |      | 4     |       |       |       |       |       |       | 14    |     |
|                                   | M                               |      |      |      |      |      |      | 2    |      |      | 2     | 1     |       |       | 1     |       |       | 6     |     |
|                                   | Sa                              |      |      |      |      |      |      | 4    |      |      | 3     | 1     |       |       | 3     | 1     |       | 12    |     |
|                                   | Sb                              |      |      |      |      |      |      | 6    |      |      | 2     |       |       |       | 3     | 2     |       | 13    |     |
|                                   | Sc                              |      |      |      |      |      |      | 3    |      |      | 11    | 4     |       |       | 4     |       |       | 22    |     |
| <i>Oulodus ? nathani</i>          | Pa                              |      |      |      |      |      |      | 7    |      |      |       |       |       |       |       |       |       | 7     |     |
|                                   | Pb                              |      |      |      |      |      |      | 7    |      |      |       |       |       |       |       |       |       | 7     |     |
|                                   | M                               |      |      |      |      |      |      | 3    |      |      |       |       |       |       |       |       |       | 3     |     |
|                                   | Sa                              |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 0     |     |
|                                   | Sb                              |      |      |      |      |      |      | 2    |      |      |       |       |       |       |       |       |       | 2     |     |
|                                   | Sc                              |      |      |      |      |      |      | 13   |      |      |       |       |       |       |       |       |       | 13    |     |
| <i>Ozarkodina hassi</i>           | Pa                              |      |      |      |      |      |      |      |      |      | 2     |       |       |       |       | 8     |       | 10    |     |
|                                   | Pb                              |      |      |      |      |      |      |      |      |      | 5     | 3     |       |       |       | 8     |       | 19    |     |
|                                   | M                               |      |      |      |      |      |      |      |      |      | 4     | 2     |       |       | 10    |       |       | 16    |     |
|                                   | Sa                              |      |      |      |      |      |      | 1    |      |      | 5     | 1     |       |       | 6     |       |       | 13    |     |
|                                   | Sb                              |      |      |      |      |      |      |      |      |      | 2     | 2     |       |       | 7     |       |       | 11    |     |
|                                   | Sc                              |      |      |      |      |      |      | 4    |      |      | 3     | 10    |       |       | 7     |       |       | 24    |     |
| <i>Panderodus unicostatus</i>     | aequaliform                     | 7    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 7     |     |
|                                   | tortiform                       | 4    | 13   | 1    |      |      |      |      |      |      |       |       |       |       |       | 12    |       | 30    |     |
|                                   | subsym. graciliform             |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 7     |       | 7     |     |
|                                   | asym. graciliform               | 26   | 28   | 5    |      |      |      |      |      |      |       | 1     |       |       | 32    |       |       | 92    |     |
|                                   | truncatiform                    | 5    | 1    |      |      |      |      |      |      |      |       |       |       |       | 4     |       |       | 10    |     |
|                                   | arcuatiform                     | 14   | 4    |      |      |      |      |      |      |      |       |       |       |       | 21    |       |       | 39    |     |
| compressiform                     | 14                              | 5    |      |      |      |      |      |      |      |      |       |       |       | 14    |       |       | 33    |       |     |
| <i>Panderodus</i> sp.             |                                 | 24   | 31   |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 55    |     |
| <i>Paroistodus ? nowlani</i>      | M                               | 21   | 1    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 22    |     |
|                                   | Sa                              | 0    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 0     |     |
|                                   | Sb                              | 3    | 1    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 4     |     |
|                                   | Sc                              | 5    | 3    |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 8     |     |
| <i>Pseudobelodina dispansa</i>    | unbowed, acostate               | 1    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 1     |     |
|                                   | bowed, unicostate               | 11   |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 11    |     |
|                                   | bowed, bicostate                |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 0     |     |
| <i>Pseudooneotodus mitratus</i>   |                                 | 5    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 5     |     |
| <i>Pseudooneotodus tricornis</i>  | slender, conical tridenticulate |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 13    |       | 13    |     |
| <i>Pseudooneotodus</i> sp.        | cone element                    |      |      |      |      |      |      | 2    |      |      | 1     | 1     |       |       |       |       |       | 4     |     |
| <i>Walliserodus curvatus</i>      | M                               | 2    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 3     |     |
|                                   | Sa                              | 1    |      |      |      |      |      |      |      |      |       |       |       |       |       | 1     |       | 2     |     |
|                                   | Sc                              | 3    |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       | 3     |     |
| Total Elements                    |                                 | 310  | 114  | 7    | 0    | 1    | 2    | 89   | 0    | 0    | 50    | 28    | 0     | 0     | 33    | 183   | 0     | 817   |     |
| Elements/kg                       |                                 | 185  | 68   | 3    | 0    | 0    | 1    | 31   | 0    | 0    | 21    | 11    | 0     | 0     | 19    | 124   | 0     |       |     |

Appendix A, Table 2. Conodont distribution data for Cape Manning Section 1.

| CAPE MANNING                      |                      |     |      |      |      |      |      |       |
|-----------------------------------|----------------------|-----|------|------|------|------|------|-------|
| Species                           | Sample Number        | CM1 | CM2  | CM3  | CM4  | CM5  | CM6  | Total |
|                                   | Height from base (m) | 9.5 | 11.9 | 12.8 | 13.5 | 14.4 | 15.0 |       |
|                                   | Sample Mass (g)      | 3.0 | 3.0  | 3.0  | 3.0  | 3.0  | 3.0  |       |
|                                   | % Dissolution        | 56  | 27   | 10   | 15   | 41   | 36   |       |
| <i>Belodina confluens</i>         | grandiform           | 12  |      |      |      |      |      | 12    |
|                                   | compressiform        | 7   |      |      |      |      |      | 7     |
| <i>Besselodus borealis</i>        | M                    | 4   |      |      |      |      |      | 4     |
| <i>Drepanoistodus suberectus</i>  | suberectiform        |     |      |      |      |      |      | 0     |
|                                   | homocurviform        | 10  |      |      |      |      |      | 10    |
|                                   | oistodiform          | 2   |      |      |      |      |      | 2     |
| <i>Panderodus unicastatus</i>     | aequaliform          | 1   |      |      |      |      |      | 1     |
|                                   | tortiform            | 2   |      |      |      |      |      | 2     |
|                                   | subsym. graciliform  | 18  |      |      |      |      |      | 18    |
|                                   | asym. graciliform    |     |      |      |      |      |      | 0     |
|                                   | truncatiform         | 2   |      |      |      |      |      | 2     |
|                                   | arcuatiform          | 5   |      |      |      |      |      | 5     |
|                                   | compressiform        | 6   |      |      |      |      |      | 6     |
| <i>Panderodus sp.</i>             |                      | 13  |      |      |      |      |      | 13    |
| <i>Paroistodus ? nowlani</i>      | M                    | 2   |      |      |      |      |      | 2     |
|                                   | Sa                   | 1   |      |      |      |      |      | 1     |
| <i>Protopanderodus insculptus</i> | a/b                  | 6   |      |      |      |      |      | 6     |
|                                   | c                    | 1   |      |      |      |      |      | 1     |
|                                   | e                    | 1   |      |      |      |      |      | 1     |
| <i>Pseudobelodina dispansa</i>    | unbowed, acostate    | 2   |      |      |      |      |      | 2     |
|                                   | bowed, unicastate    | 3   |      |      |      |      |      | 3     |
|                                   | bowed, bicostate     | 2   |      |      |      |      |      | 2     |
| <i>Walliserodus curvatus</i>      | M w/o outer costae   | 2   |      |      |      |      |      | 2     |
|                                   | Sb                   | 1   |      |      |      |      |      | 1     |
|                                   | Sd                   | 1   |      |      |      |      |      | 1     |
| Total Elements                    |                      | 104 | 0    | 0    | 0    | 0    | 0    | 104   |
| Elements/kg                       |                      | 62  | 0    | 0    | 0    | 0    | 0    |       |



Appendix A, Table 4. Conodont distribution data for Cape Manning Section 3.

| CAPE MANNING                                     |                          |       |       |       |       |       |       |       |       |       |        |        |        |        |       |
|--------------------------------------------------|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|-------|
| Species                                          | Sample Number            | CM3-1 | CM3-2 | CM3-3 | CM3-4 | CM3-5 | CM3-6 | CM3-7 | CM3-8 | CM3-9 | CM3-10 | CM3-11 | CM3-12 | CM3-13 | Total |
|                                                  | Height from base (m)     | 0.0   | 5.0   | 10.0  | 15.1  | 20.0  | 30.0  | 40.0  | 49.0  | 56.7  | 79.0   | 90.0   | 101.5  | 110.0  |       |
|                                                  | Sample Mass (g)          | 3.0   | 3.0   | 3.0   | 3.1   | 3.0   | 3.0   | 3.0   | 3.1   | 3.0   | 3.0    | 3.0    | 3.0    | 3.1    |       |
|                                                  | % Dissolution            | 47.9  | 59.1  | 69.9  | 53.4  | 23.4  | 46.7  | 31.4  | 27.1  | 22.5  | 77.7   | 37.2   | 27.5   | 29.8   |       |
| <i>Aspelundia fluegeli</i>                       | Pb                       |       |       |       |       |       |       |       |       |       |        | 1      |        |        | 1     |
|                                                  | M <sub>1</sub>           |       |       |       |       |       |       |       |       |       | 1      |        |        |        | 1     |
|                                                  | Sc                       |       |       |       |       |       |       |       |       |       | 3      |        |        |        | 3     |
| <i>Aspelundia petila</i>                         | Pb                       |       |       | 2     |       |       |       |       |       |       |        |        |        |        | 2     |
|                                                  | M                        |       |       | 1     |       |       |       | 2     |       |       |        |        |        |        | 3     |
|                                                  | Sb                       |       |       | 3     |       |       |       | 1     |       |       |        |        |        |        | 4     |
|                                                  | Sc                       |       |       | 4     |       |       |       | 1     |       |       |        |        |        |        | 5     |
| <i>Pterospathodus eopennatus</i> ssp. 2          | Pa                       |       |       |       | 1     |       |       |       |       |       |        |        |        |        | 1     |
| <i>Aulacognathus bullatus</i>                    | Sb/Sc                    |       |       |       | 1     |       |       |       |       |       |        |        |        |        | 1     |
| <i>Aspelundia</i> cf. <i>A. borenoensis</i>      | sym. denticulated        |       |       |       |       |       |       |       |       |       |        | 1      |        |        | 1     |
|                                                  | asym. denticulated       |       |       |       |       |       |       |       |       |       | 3      |        |        |        | 3     |
|                                                  | denticulated S           |       |       |       |       |       |       |       | 1     |       |        | 1      | 1      |        | 3     |
| <i>Distomodus staurogathoides</i>                | Pa                       |       |       |       | 1     |       |       |       |       |       |        |        |        |        | 1     |
|                                                  | Sa                       |       |       |       | 1     |       |       |       |       |       |        |        |        |        | 1     |
|                                                  | Sc                       |       |       |       | 1     |       |       |       |       |       |        |        |        |        | 1     |
| <i>Panderodus recurvatus</i>                     |                          |       |       | 1     |       |       |       |       |       |       |        |        |        |        | 1     |
| <i>Panderodus unicostatus</i>                    | aequaliform              |       |       |       |       |       |       | 1     |       |       |        | 1      |        |        | 2     |
|                                                  | tortiform                |       |       |       |       |       |       |       |       |       |        |        |        |        | 0     |
|                                                  | subsyzmetric graciliform |       |       | 1     |       |       |       |       |       |       |        |        |        |        | 1     |
|                                                  | asymetric graciliform    |       |       | 1     | 2     |       |       |       |       |       | 3      | 3      |        |        | 9     |
|                                                  | truncatiform             |       |       |       |       |       |       |       |       |       |        |        |        |        | 0     |
|                                                  | arcuatiform              |       |       |       | 1     |       |       |       | 1     |       | 2      | 1      |        |        | 5     |
|                                                  | compressiform            |       |       |       |       |       |       | 2     |       |       | 2      |        |        |        | 4     |
| <i>Pseudooneotodus beckmanni</i>                 | unidenticulate           |       |       |       |       |       | 4     |       |       |       |        |        |        |        | 4     |
| <i>Pterospathodus celloni</i>                    | Pa                       |       |       |       |       |       | 1     |       |       |       | 1      | 1      |        |        | 3     |
|                                                  | Pb <sub>1</sub>          |       |       |       |       |       | 2     | 1     |       |       |        |        |        |        | 3     |
|                                                  | Pc                       |       |       |       |       |       |       |       |       |       |        |        | 1      |        | 1     |
|                                                  | Sc <sub>3</sub>          |       |       |       |       |       |       |       |       |       | 1      |        |        |        | 1     |
| <i>Pterospathodus a. amorphognathoides</i>       | Pa                       |       |       |       |       |       |       |       |       |       |        | 1      |        |        | 1     |
|                                                  | Pb <sub>1</sub>          |       |       |       |       |       |       |       |       |       |        | 2      |        |        | 2     |
|                                                  | Pb <sub>2</sub>          |       |       |       |       |       |       |       |       |       |        | 1      |        |        | 1     |
| <i>Walliserodus</i> c.f. <i>W. sancticlairei</i> | M                        |       |       |       |       |       |       |       |       |       | 3      |        | 1      |        | 4     |
|                                                  | Sa                       |       |       |       |       |       |       |       | 2     |       |        |        | 1      |        | 3     |
|                                                  | Sb                       |       |       |       |       |       |       |       |       |       | 1      | 1      | 1      |        | 3     |
|                                                  | Sc                       |       |       |       |       |       |       |       | 1     |       | 2      | 6      | 5      | 1      | 15    |
| Total Elements                                   |                          | 0     | 0     | 12    | 9     | 0     | 0     | 14    | 6     | 0     | 22     | 20     | 10     | 1      | 94    |
| Elements/kg                                      |                          | 0     | 0     | 6     | 6     | 0     | 0     | 15    | 7     | 0     | 9      | 18     | 12     | 1      |       |

**Table 5. Conodont distribution data for Cape Phillips North Section (in back pocket envelope).**

Appendix A, Table 6. Conodont distribution data for Abbott River East  
(continued on next page)

| ABBOTT RIVER EAST                            |                                      |       |       |       |       |      |       |       |       |       |
|----------------------------------------------|--------------------------------------|-------|-------|-------|-------|------|-------|-------|-------|-------|
| Conodonts                                    | Sample Number                        | ARE1  | ARE2  | ARE3  | ARE4  | ARE5 | ARE6  | ARE7  | ARE8  | Total |
|                                              | Height from base (m)                 | 0.0   | 4.0   | 8.0   | 12.0  | 13.6 | 16.0  | 18.0  | 19.1  |       |
|                                              | Sample Mass (g)                      | 3.563 | 3.607 | 3.327 | 2.929 | 3.6  | 3.078 | 2.979 | 3.712 |       |
|                                              | % Dissolution                        | 62.8  | 64.8  | 57.9  | 33.3  | 60.7 | 65.0  | 25.7  | 39.5  |       |
| <i>Apsidognathus tuberculatus</i>            | lyriform                             |       |       |       |       | 2    |       |       |       | 2     |
|                                              | clavohamulus-like                    |       |       |       |       | 1    |       |       |       | 1     |
| <i>Apsidognathus</i> sp.                     |                                      |       |       |       |       | 1    |       |       |       | 1     |
| <i>Aspelundia fluegeli</i>                   | Pa                                   | 24    |       |       |       |      |       |       |       | 24    |
|                                              | Pb                                   | 39    | 4     | 2     |       | 7    |       |       |       | 52    |
|                                              | M <sub>1</sub>                       | 31    | 1     | 4     |       | 8    |       |       |       | 44    |
|                                              | M <sub>2</sub>                       | 1     |       |       |       |      |       |       |       | 1     |
|                                              | M <sub>3</sub>                       | 65    |       | 5     |       | 2    |       |       |       | 72    |
|                                              | Sa                                   | 39    | 6     | 5     |       | 3    |       |       |       | 53    |
|                                              | Sb                                   | 27    | 2     |       |       | 1    |       |       |       | 30    |
|                                              | Sc                                   | 66    | 12    | 11    |       | 16   |       |       |       | 105   |
| <i>Aspelundia</i> cf. <i>A. borenorensis</i> | sym. dentic.                         | 7     |       | 2     |       | 1    |       |       |       | 10    |
|                                              | asym. dentic.                        | 52    | 11    | 13    |       | 10   |       |       |       | 86    |
|                                              | adentic. asym                        | 25    | 8     | 2     |       | 3    |       |       |       | 38    |
|                                              | dentic. Sb                           | 3     |       | 1     |       | 1    |       |       |       | 5     |
|                                              | dentic. Pa                           | 10    | 1     | 2     |       | 3    |       |       |       | 16    |
|                                              | M <sub>2</sub> ? (post.dent.process) | 16    | 2     | 3     |       | 3    |       |       |       | 24    |
|                                              | Sc w. process                        |       |       |       |       |      |       |       |       | 0     |
| <i>Aulacognathus chapini</i>                 | Pa                                   |       |       |       |       | 2    |       |       |       | 2     |
|                                              | Pb                                   |       |       |       |       | 3    |       |       |       | 3     |
| <i>Belodella</i> sp. A                       | Sa                                   | 3     |       |       |       | 2    | 1     |       |       | 6     |
|                                              | Sb                                   | 8     |       |       |       |      |       |       |       | 8     |
|                                              | Sc                                   | 10    |       |       |       | 2    |       |       |       | 12    |
|                                              | M                                    | 6     |       |       |       |      |       |       |       | 6     |
| <i>Decoriconus fragilis</i>                  | Sb                                   |       |       |       |       |      | 1     |       |       | 1     |
| <i>Distomodus staurognathoides</i>           | Pa                                   |       |       |       |       | 1    |       |       |       | 1     |
|                                              | Pb                                   |       |       |       |       |      |       |       |       | 0     |
|                                              | M                                    |       |       |       |       | 3    | 1     |       |       | 4     |
|                                              | Sa                                   |       |       |       |       |      | 1     |       |       | 1     |
|                                              | Sb                                   |       |       |       |       | 5    |       |       |       | 5     |
|                                              | Sc                                   |       |       |       |       | 2    |       |       |       | 2     |
| Indeterminate 3                              | Pa                                   | 4     |       |       |       |      |       |       |       | 4     |
| Indeterminate 4                              |                                      |       |       |       |       | 1    |       |       |       | 1     |
| <i>Kockellella absidata</i>                  |                                      |       |       |       |       |      |       |       |       | 0     |
| <i>Ozarkodina excavata excavata</i>          | Pa                                   |       |       |       |       |      | 2     |       |       | 2     |
|                                              | Pb                                   |       |       |       |       |      | 2     |       |       | 2     |
|                                              | M                                    |       |       |       |       |      | 3     |       |       | 3     |
|                                              | Sa                                   |       |       |       |       |      | 3     |       |       | 3     |
|                                              | Sb                                   |       |       |       |       |      | 3     |       |       | 3     |
|                                              | Sc                                   |       |       |       |       |      | 5     |       |       | 5     |
| <i>Ozarkodina hadra</i>                      | Pa                                   | 2     |       |       |       | 3    |       |       |       | 5     |
|                                              | Pb                                   | 6     |       |       |       | 1    |       |       |       | 7     |
|                                              | M                                    | 1     |       |       |       | 2    |       |       |       | 3     |
|                                              | Sa                                   | 4     |       |       |       | 3    |       |       |       | 7     |
|                                              | Sb                                   | 7     |       |       |       | 2    |       |       |       | 9     |
|                                              | Sc                                   | 2     |       |       |       | 1    |       |       |       | 3     |
| <i>Panderodus recurvatus</i>                 | aequaliform                          |       |       | 4     |       |      | 1     |       |       | 5     |
|                                              | symmetrical acostatiform             |       |       |       |       |      |       |       |       | 0     |
|                                              | asymmetrical acostatiform            |       |       |       |       |      |       |       |       | 0     |
|                                              | subspherical graciliform             |       |       |       |       |      |       |       |       | 0     |
|                                              | asymmetrical graciliform             | 3     |       | 5     |       |      |       |       |       | 8     |
|                                              | arcuatiform                          | 2     |       |       |       | 4    | 1     |       |       | 7     |
|                                              | compressiform                        | 21    |       |       |       | 9    |       |       |       | 30    |
|                                              | truncatiform                         | 3     |       |       |       |      |       |       |       | 3     |
| <i>Panderodus unicosatus</i>                 | aequaliform                          | ???   | 1     | 22    |       | 5    |       |       |       | 28    |
|                                              | tortiform                            | 25    | 1     | 8     |       | 3    | 3     |       |       | 40    |
|                                              | subspherical graciliform             | 91    |       |       |       | 5    | 3     |       |       | 99    |
|                                              | asymmetric graciliform               | 114   |       | 20    |       | 14   | 1     |       |       | 149   |
|                                              | truncatiform                         | 5     |       |       |       | 3    |       |       |       | 19    |
|                                              | arcuatiform                          | 122   | 3     | 20    |       | 10   | 1     |       |       | 156   |
|                                              | compressiform                        | 181   | 2     | 87    |       | 42   | 8     |       |       | 320   |
| <i>Panderodus</i> sp.                        |                                      |       | 1     | 12    |       | 20   | 1     |       |       | 34    |

| ABBOTT RIVER EAST                        |                       |       |       |       |       |      |       |       |       |       |
|------------------------------------------|-----------------------|-------|-------|-------|-------|------|-------|-------|-------|-------|
| Conodonts                                | Sample Number         | ARE1  | ARE2  | ARE3  | ARE4  | ARE5 | ARE6  | ARE7  | ARE8  | Total |
|                                          | Height from base (m)  | 0.0   | 4.0   | 8.0   | 12.0  | 13.6 | 16.0  | 18.0  | 19.1  |       |
|                                          | Sample Mass (g)       | 3.563 | 3.607 | 3.327 | 2.929 | 3.6  | 3.078 | 2.979 | 3.712 |       |
|                                          | % Dissolution         | 62.8  | 64.8  | 57.9  | 33.3  | 60.7 | 65.0  | 25.7  | 39.5  |       |
| <i>Pseudooneotodus beckmanni</i>         | undenticulate         |       |       |       |       |      | 1     |       |       | 1     |
| <i>Pseudooneotodus tricornis</i>         | slender conical       |       |       |       |       | 10   |       |       |       | 10    |
|                                          | squat tri-denticulate |       |       |       |       | 2    |       |       |       | 2     |
| <i>Pt. a. amorphognathoides</i>          | Pa                    | 1     |       |       |       | 5    |       |       |       | 6     |
|                                          | Pb <sub>1</sub>       |       |       |       |       | 2    |       |       |       | 2     |
|                                          | Pb <sub>2</sub>       |       |       |       |       | 2    |       |       |       | 2     |
|                                          | Pc                    |       |       |       |       | 1    |       |       |       | 1     |
|                                          | M <sub>1</sub>        |       |       |       |       | 1    |       |       |       | 1     |
|                                          | Sc <sub>1</sub>       |       |       |       |       | 4    |       |       |       | 4     |
|                                          | Sc <sub>2</sub>       |       |       |       |       | 5    |       |       |       | 5     |
|                                          | Sc <sub>3</sub>       |       |       |       |       | 0    |       |       |       | 0     |
|                                          | Sb <sub>1</sub>       |       |       |       |       | 0    |       |       |       | 0     |
|                                          | Sb <sub>2</sub>       |       |       |       |       | 0    |       |       |       | 0     |
|                                          | Sa                    |       |       |       |       | 1    |       |       |       | 1     |
|                                          | cf                    |       |       |       |       | 5    |       |       |       | 5     |
|                                          | Sc?                   |       |       |       |       | 4    |       |       |       | 4     |
|                                          | ccf                   |       |       |       |       |      |       |       |       | 0     |
|                                          | mcf                   |       |       |       |       | 2    |       |       |       | 2     |
| curved                                   |                       |       |       |       | 5     |      |       |       | 5     |       |
| <i>Pt. pennatus procerus</i>             | Pa                    | 19    |       | 4     |       | 9    | 6     |       |       | 38    |
|                                          | juvenile Pa           | 5     |       |       |       |      | 5     |       |       | 10    |
|                                          | Pb <sub>1</sub>       | 5     |       | 2     |       | 7    | 4     |       |       | 18    |
|                                          | Pb <sub>2</sub>       | 5     |       | 2     |       | 2    |       |       |       | 9     |
|                                          | Pc                    | 8     |       |       |       | 1    |       |       |       | 9     |
|                                          | M <sub>1</sub>        | 13    |       | 2     |       | 1    | 1     |       |       | 17    |
|                                          | M sharp costae        |       |       |       |       |      |       |       |       | 0     |
|                                          | M <sub>2</sub>        |       |       |       |       | 1    |       |       |       | 1     |
|                                          | Sc <sub>1</sub>       | 3     |       | 1     |       | 4    |       |       |       | 8     |
|                                          | Sc <sub>2</sub>       | 7     |       | 4     |       |      |       |       |       | 11    |
|                                          | Sc <sub>3</sub>       |       |       | 3     |       |      | 2     |       |       | 5     |
|                                          | Sb <sub>1</sub>       |       |       |       |       |      | 1     |       |       | 1     |
|                                          | Sb <sub>2</sub>       | 4     |       | 2     |       |      |       |       |       | 6     |
|                                          | Sa                    |       |       |       |       |      |       |       |       | 0     |
|                                          | cf,a                  | 5     |       | 2     |       |      |       |       |       | 7     |
|                                          | mcf?                  |       |       |       |       |      |       |       |       | 0     |
|                                          | ccf                   |       |       |       |       |      |       |       |       | 0     |
| curved                                   | 1                     |       |       |       |       |      |       |       | 1     |       |
| 'subrectiform' element                   | 10                    |       |       |       |       | 5    |       |       |       | 15    |
| <i>Pterospirifer rhodesi</i>             | Pa                    | 3     |       |       |       |      |       |       |       | 3     |
|                                          | M                     | 1     |       |       |       |      |       |       |       | 1     |
| <i>Walliserodus cf. W. sancticlairei</i> | M                     | 63    |       | 1     |       | 0    |       |       |       | 64    |
|                                          | Sa                    | 14    | 1     | 0     |       | 0    | 1     |       |       | 16    |
|                                          | Sb                    | 31    | 1     | 0     |       | 0    | 4     |       |       | 36    |
|                                          | Sc                    | 202   |       | 6     |       | 0    |       |       |       | 208   |
| Indeterminate 6                          | 1                     |       |       |       |       |      |       |       |       | 1     |
| Total Elements                           |                       | 1426  | 57    | 268   | 0     | 289  | 66    | 0     | 0     | 2106  |
| Elements/kg                              |                       | 637   | 24    | 139   | 0     | 132  | 33    | 0     | 0     |       |

Appendix A, Table 7. Conodont distribution data for Abbott River West Section 1.

| ABBOTT RIVER WEST                             |                          |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |
|-----------------------------------------------|--------------------------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|
| Conodonts                                     | Sample Number            | ARW1 | ARW2 | ARW3 | ARW4 | ARW5 | ARW6 | ARW7 | ARW8 | ARW9 | ARW10 | ARW11 | ARW12 | ARW13 | ARW14 | Total |
|                                               | Height from base (m)     | 0.0  | 4.6  | 8.0  | 12.0 | 16.0 | 20.0 | 24.0 | 28.0 | 32.0 | 35.5  | 40.0  | 44.0  | 48.0  | 52.0  |       |
|                                               | Mass (g)                 | 3.0  | 3.0  | 2.9  | 3.0  | 3.1  | 3.0  | 3.0  | 3.0  | 3.0  | 4.0   | 3.1   | 3.0   | 3.1   | 3.1   |       |
|                                               | % Dissolution            | 68.6 | 7.5  | 52.8 | 8.2  | 71.2 | 95.8 | 5.1  | 3.1  | 3.0  | 4.2   | 97.0  | 71.6  | 74.4  | 51.1  |       |
| <i>Belodella</i> sp. A Miller                 | Sa                       |      |      | 2    |      | 5    |      |      |      |      |       |       |       |       |       | 7     |
|                                               | Sb                       |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 0     |
|                                               | Sc                       |      |      |      |      | 4    |      |      |      |      |       |       |       |       |       | 4     |
|                                               | M                        |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 0     |
| <i>Dapsilodus obliquicostatus</i>             | Sa                       | 1    |      |      |      |      | 1    |      |      |      | 0     | 0     |       |       |       | 2     |
|                                               | Sb/Sc                    | 10   |      | 2    |      | 1    | 8    |      |      |      | 14    | 1     | 6     | 1     |       | 43    |
|                                               | M                        | 2    |      | 2    |      |      | 3    |      |      |      | 10    | 0     | 2     |       |       | 19    |
| <i>Decoriconus fragilis</i>                   | Sa                       |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 0     |
|                                               | Sb                       |      |      |      |      | 3    |      |      |      |      |       |       |       |       |       | 3     |
|                                               | Sc                       |      |      |      |      | 1    |      |      |      |      |       |       |       |       |       | 1     |
| <i>Ozarkodina excavata excavata</i>           | Pa                       | 2    |      |      |      |      | 3    |      |      |      | 2     | 1     | 4     | 1     |       | 13    |
|                                               | Pb                       |      |      |      |      | 2    | 3    |      |      |      | 2     |       |       | 1     |       | 8     |
|                                               | M                        |      |      |      |      |      | 2    |      |      |      |       | 2     |       | 1     |       | 5     |
|                                               | Sa                       |      |      |      |      |      | 0    |      |      |      | 1     |       |       |       |       | 1     |
|                                               | Sb                       |      |      |      |      | 1    | 15   |      |      |      |       | 2     | 4     |       |       | 22    |
|                                               | Sc                       |      |      |      |      | 2    | 7    |      |      |      | 2     | 2     |       |       |       | 13    |
| <i>Panderodus unicosatus</i>                  | aequaliform              |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 0     |
|                                               | tortiform                |      |      |      |      |      | 1    |      |      |      | 1     |       | 1     |       |       | 4     |
|                                               | subsyzmetric graciliform |      |      |      | 1    |      |      |      |      |      |       |       | 1     |       |       | 2     |
|                                               | asymmetric graciliform   |      |      |      | 1    |      |      | 2    |      |      |       |       | 4     |       |       | 7     |
|                                               | truncatiform             |      |      |      |      |      |      |      |      |      |       |       | 7     |       |       | 7     |
|                                               | arcuatiform              |      |      |      | 4    |      |      | 3    |      |      | 2     |       | 5     | 2     |       | 16    |
|                                               | compressiform            |      |      |      | 4    |      |      | 2    |      |      | 1     | 1     | 4     |       |       | 12    |
| <i>Panderodus</i> sp.                         |                          |      |      | 2    |      |      | 1    |      |      |      | 1     |       | 6     | 1     |       | 11    |
| <i>Pseudooneotodus beckmanni</i>              |                          |      |      |      |      |      |      |      |      |      |       |       | 2     |       |       | 2     |
| <i>Pseudooneotodus bicornis</i>               | slender conical          |      |      |      |      |      | 1    |      |      |      |       |       |       |       | 1     | 2     |
|                                               | squat bi-denticulate     |      |      |      |      |      |      |      |      |      |       |       |       |       |       | 0     |
| <i>Walliserodus</i> cf. <i>W. sancticlaei</i> | M w/o costae             |      |      |      |      |      |      |      |      |      |       |       |       | 2     |       | 2     |
| Total Elements                                |                          | 15   | 0    | 20   | 0    | 19   | 52   | 0    | 0    | 0    | 36    | 9     | 46    | 10    | 0     | 206   |
| Elements/kg                                   |                          | 7    | 0    | 13   | 0    | 9    | 18   | 0    | 0    | 0    | 9     | 4     | 21    | 6     | 0     |       |

Appendix A, Table 8. Conodont distribution data for ARW2.

| ABBOTT RIVER WEST                 |                          |       |       |       |       |       |       |       |       |
|-----------------------------------|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Conodonts                         | Sample Number            | 2ARW1 | 2ARW2 | 2ARW3 | 2ARW4 | 2ARW5 | 2ARW6 | 2ARW7 | Total |
|                                   | Height from base (m)     | 0.0   | 4.0   | 8.0   | 12.0  | 16.0  | 20.0  | 24.0  |       |
|                                   | Mass (g)                 | 3.0   | 3.0   | 3.0   | 3.0   | 3.0   | 3.0   | 3.0   |       |
|                                   | % Dissolution            | 57.3  | 3.4   | 53.8  | 25.6  | 3.1   | 43.2  | 16.8  |       |
| <i>Dapsilodus obliquicostatus</i> | Sa                       |       |       | 1     |       |       |       |       | 1     |
|                                   | Sb/Sc                    |       |       | 2     | 2     |       |       |       | 4     |
|                                   | M                        |       |       | 2     |       |       |       |       | 2     |
| <i>Kockelella absidata</i>        | Pa                       | 2     |       |       |       |       |       |       | 2     |
|                                   | Pb                       |       |       |       |       |       |       |       | 0     |
|                                   | M                        |       |       |       |       |       |       |       | 0     |
|                                   | Sa                       | 1     |       |       |       |       |       |       | 1     |
|                                   | Sb                       |       |       |       |       |       |       |       | 0     |
|                                   | Sc                       | 3     |       |       |       |       |       |       | 3     |
| <i>Kockelella patula</i>          | Pa                       | 1     |       |       |       |       |       |       | 1     |
| <i>Ozarkodina confluens</i>       | Pa                       | 1     |       | 1     |       |       |       |       | 2     |
| <i>Ozarkodina e. excavata</i>     | Pa                       | 3     |       |       |       |       |       |       | 3     |
| <i>Ozarkodina hadra</i>           |                          |       |       |       |       |       |       |       | 0     |
| <i>Panderodus unicastatus</i>     | aequaliform              |       |       |       |       |       |       |       | 0     |
|                                   | tortiform                |       |       |       | 2     |       |       |       | 2     |
|                                   | subsyzmetric graciliform |       |       |       |       |       |       |       | 0     |
|                                   | asymmetric graciliform   | 2     |       | 2     | 7     |       |       |       | 11    |
|                                   | truncatiform             | 1     |       |       |       |       |       |       | 1     |
|                                   | arcuatiform              | 3     |       |       | 3     |       |       |       | 6     |
| compressiform                     | 2                        |       | 1     | 4     |       |       |       | 7     |       |
| <i>Panderodus sp.</i>             |                          | 2     |       | 1     | 3     |       |       |       | 6     |
| <i>Pseudooneotodus beckmanni</i>  |                          |       |       |       |       |       |       |       | 0     |
| <i>Pseudooneotodus bicornis</i>   | slender conical          | 1     |       |       | 1     |       |       |       | 2     |
|                                   | squat bi-denticulate     |       |       |       | 1     |       |       |       | 1     |
| Total Elements                    |                          | 22    | 0     | 10    | 23    | 0     | 0     | 0     | 55    |
| Elements/kg                       |                          | 13    | 0     | 6     | 30    | 0     | 0     | 0     |       |

Appendix A, Table 9. Conodont distribution data for Abbott River West Section 3.

| ABBOTT RIVER WEST                 |                          |       |       |       |       |       |       |       |        |       |        |        |       |        |        |        |        |       |
|-----------------------------------|--------------------------|-------|-------|-------|-------|-------|-------|-------|--------|-------|--------|--------|-------|--------|--------|--------|--------|-------|
| Conodonts                         | Sample Number            | 3ARW1 | 3ARW2 | 3ARW3 | 3ARW4 | 3ARW8 | 3ARW5 | 3ARW9 | 3ARW10 | 3ARW6 | 3ARW11 | 3ARW12 | 3ARW7 | 3ARW34 | 3ARW37 | 3ARW13 | 3ARW41 | Total |
|                                   | Height from base (m)     | 0.5   | 4.5   | 8.0   | 10.4  | 13.5  | 15.0  | 16.6  | 19.0   | 20.0  | 21.0   | 23.5   | 25.4  | 35.0   | 38.0   | 40.0   | 41.5   |       |
|                                   | Mass (g)                 | 3.0   | 3.0   | 3.0   | 3.0   | 3.0   | 3.0   | 3.2   | 3.1    | 3.0   | 3.1    | 3.4    | 3.1   | 0.5    | 3.0    | 3.3    | 2.8    |       |
|                                   | % Dissolution            | 95.3  | 98.3  | 65.6  | 91.9  | 7.9   | 71.5  | 65.5  | 24.3   | 39.9  | 37.9   | 73.5   | 58.1  | 91.2   | 75.5   | 66.7   | 55.5   |       |
| <i>Dapsilodus obliquicostatus</i> | Sa                       |       | 5     |       |       |       | 2     | 1     |        |       |        |        |       |        |        | 2      |        | 10    |
|                                   | Sb                       | 1     | 52    |       | 3     |       | 3     | 6     |        |       |        |        |       | 1      | 29     | 3      |        | 98    |
|                                   | M                        | 1     | 28    |       | 3     |       |       |       |        |       |        | 1      |       |        |        | 1      |        | 35    |
| <i>Kockelella absidata</i>        | Pa                       |       |       |       |       |       |       |       |        |       |        |        | 6     |        |        |        |        | 7     |
|                                   | Pb                       |       |       |       |       |       |       |       |        |       |        |        | 2     |        |        |        |        | 2     |
|                                   | M                        |       |       |       |       |       |       |       |        |       |        |        | 3     |        |        |        |        | 3     |
|                                   | Sa                       |       |       |       |       |       |       |       |        |       |        |        | 3     |        |        |        |        | 3     |
|                                   | Sb                       |       |       |       |       |       |       |       |        |       |        |        | 2     |        |        |        |        | 2     |
|                                   | Sc                       |       |       |       |       |       |       |       |        |       |        |        | 4     |        |        |        |        | 4     |
| <i>Kockelella</i> sp.             | Pa                       |       |       |       | 3     |       |       |       |        |       |        |        |       |        |        |        |        | 3     |
|                                   | Sa                       |       |       |       | 3     |       |       |       |        |       |        |        |       |        |        |        |        | 3     |
|                                   | Sc                       |       |       |       | 5     |       |       |       |        |       |        |        |       |        |        |        |        | 5     |
| <i>Oulodus equirectus</i> ?       | Pa                       |       |       |       |       |       |       |       |        |       |        | 2      |       |        |        |        |        | 2     |
| <i>Ozarkodina confluens</i>       | Pa                       |       |       |       |       |       |       |       |        |       |        | 10     |       |        |        | 12     |        | 22    |
|                                   | Pb                       |       |       |       |       |       |       | 1     |        |       |        | 1      |       |        |        | 2      |        | 4     |
|                                   | M                        |       |       |       |       |       |       |       |        |       |        |        |       |        |        | 3      |        | 3     |
|                                   | Sa                       |       |       |       |       |       |       |       |        |       |        |        | 1     |        |        | 1      |        | 2     |
|                                   | Sb                       |       |       |       |       |       |       |       |        |       |        |        | 1     |        |        |        |        | 1     |
|                                   | Sc                       |       |       |       |       |       |       |       |        |       |        |        |       |        |        | 3      |        | 3     |
| <i>Ozarkodina e. excavata</i>     | Pa                       |       |       |       | 1     |       |       | 4     | 1      |       |        | 14     |       | 1      | 5      | 3      |        | 29    |
|                                   | Pb                       |       |       |       |       |       | 2     | 2     |        |       |        | 9      |       | 2      | 4      |        |        | 19    |
|                                   | M                        |       |       |       |       |       | 3     | 2     |        |       |        | 6      |       | 2      | 3      |        |        | 16    |
|                                   | Sa                       |       |       |       |       |       |       | 0     |        |       |        | 3      |       | 5      | 2      |        |        | 10    |
|                                   | Sb                       |       |       |       | 1     |       | 2     | 3     |        |       |        | 7      |       | 4      | 5      |        |        | 22    |
|                                   | Sc                       |       |       |       | 3     |       | 1     | 3     |        |       |        | 14     |       | 5      | 10     |        |        | 36    |
| <i>Panderodus unicastatus</i>     | aequaliform              |       |       |       | 1     |       |       |       |        |       |        |        |       |        |        |        |        | 1     |
|                                   | tortiform                |       |       |       |       |       |       |       |        |       |        |        |       |        |        |        | 1      | 1     |
|                                   | subsymmetric graciliform |       |       | 1     |       |       |       |       |        |       |        |        |       |        |        |        | 4      | 5     |
|                                   | asymmetric graciliform   | 10    |       |       | 4     |       | 1     |       |        |       |        | 3      |       | 4      | 3      | 5      |        | 30    |
|                                   | truncatiform             |       |       |       |       |       |       |       |        |       |        | 1      |       |        |        | 2      |        | 3     |
|                                   | arcuatiform              | 3     |       | 3     | 8     |       |       |       |        |       |        | 3      |       |        | 6      | 9      |        | 32    |
| <i>Panderodus</i> sp.             | compressiform            | 11    |       | 3     | 11    |       | 1     |       |        |       |        | 5      |       | 1      | 3      | 9      |        | 44    |
|                                   |                          | 22    |       | 2     | 23    |       | 1     |       |        |       |        |        |       | 1      |        | 10     |        | 59    |
| <i>Pseudooneotodus beckmanni</i>  |                          |       |       |       |       | 2     |       |       |        |       |        |        |       |        |        |        | 1      | 3     |
| <i>Pseudooneotodus bicornis</i>   | slender conical          |       |       |       |       | 2     |       |       |        |       |        |        |       |        |        |        |        | 2     |
|                                   | squat bi-denticulate     |       |       |       |       | 1     |       |       |        |       |        |        |       |        |        |        |        | 1     |
| <i>Walliserodus</i>               | Sc                       |       |       |       |       |       | 1     |       |        |       |        |        |       |        |        |        |        | 1     |
| Total Elements                    |                          | 48    | 85    | 9     | 74    | 0     | 17    | 22    | 1      | 0     | 0      | 101    | 0     | 27     | 73     | 69     | 0      | 526   |
| Elements/kg                       |                          | 17    | 28    | 5     | 26    | 0     | 8     | 10    | 1      | 0     | 0      | 40     | 0     | 62     | 33     | 31     | 0      |       |

### *Appendix B: Section Descriptions*

A description of logged sections follows with lithologies and location of conodont samples. Except for Abbott River West Section 3, sample numbers follow consecutively up section from older to younger strata. Section locations are shown in Figure 3 and graphic logs in Appendix C.

*Cape Phillips South*

75°32'30"N, 94°31'48"W

Cape Phillips South section is exposed as two weathered sections on the crests of two ridges approximately 120 m apart. The lower and upper parts of the sections are exposed on the north and south ridges, respectively, and overlap 0.5 m (27.5-28.0 m). The base of the section, which is within the *fastigatus* Zone, lies at the top of a thick covered interval, below which is exposed massive limestone of the basal Cape Phillips "Allen Bay tongue" and the "cliff member". Conodont collecting began near the top of the *fastigatus* Zone beds, immediately prior to the Late Ordovician conodont extinction events, and continued across the Ordovician-Silurian boundary. The section covers the first three graptolite zones of the Llandovery.

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                  |
|-----------------------|---------------|---------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.0                   | 4.5           |               |                   | Calcareous shale grading upwards into lime wackestone; large orthoconic nautiloids, trilobites ( <i>Pseudogygites</i> ); <i>fastigatus</i> Zone graptolites. |
| 5.5                   | 1.0           |               |                   | Lime wackestone: medium-thick bedded, medium brown.                                                                                                          |
| 11.5                  | 6.0           |               |                   | Lime wackestone: rubbly, thin-medium bedded; trilobite <i>Pseudogygites</i> .                                                                                |
| 13.7                  | 2.2           |               |                   | Lime wackestone: light brown-grey, medium-bedded.                                                                                                            |
| 16.5                  | 2.8           |               |                   | Covered interval.                                                                                                                                            |
| 20.5                  | 4.0           | CPS1          | 19.7              | Dolostone: medium-bedded, light brown.                                                                                                                       |
| 23.0                  | 2.5           | CPS2          | 22.5              | Shale: calcareous, dark brown-grey; <i>pacificus</i>                                                                                                         |

## Zone graptolites.

|                                     |         |                                                                   |                                                              |                                                                                                                                                                                                |
|-------------------------------------|---------|-------------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 24.1                                | 1.1     |                                                                   |                                                              | Dolostone: medium-bedded, light grey-brown, medium crystalline.                                                                                                                                |
| 24.7                                | 0.6     |                                                                   |                                                              | Dolostone: thin-medium-bedded, light grey, trilobites.                                                                                                                                         |
| 25.2-<br>25.5                       | 0.5-0.8 | CPS3                                                              | 25.2                                                         | As above but contains large vugs infilled with reddish brown, sandy sediment (possibly paleokarst surface).                                                                                    |
| 25.2-<br>25.5<br>(where<br>present) | 0.3     |                                                                   |                                                              | (Where present—may be infill of eroded paleokarst surface) Mudstone: calcareous, dark brown-grey.                                                                                              |
| 28.5                                | 3.0     | CPS4<br>CPS5<br>CPS6                                              | 26.25<br>27.0<br>28.0                                        | Mudstone: calcareous, platy, laminated, black mudstones interbedded with fissile, black, calcareous shales; platy oblate concretions begin at 26.0 m; " <i>persculptus</i> " Zone graptolites. |
| 38.6                                | 10.1    | CPS7<br>CPS8<br>CPS9<br>CPS10<br>CPS11<br>CPS12<br>CPS13<br>CPS14 | 29.0<br>30.0<br>31.0<br>32.0<br>33.0<br>34.0<br>35.0<br>37.2 | As above, but larger more spherical, laminated and may be massive rather than platy at 1-2m concretions, <i>acuminatus</i> Zone graptolites.                                                   |
| 39.5                                | 0.9     | CPS15                                                             | 39.2                                                         | Dolowackestone: finely crystalline, light brown, rubbly.                                                                                                                                       |
| 40.5                                | 1.0     |                                                                   |                                                              | Mudstones: calcareous, laminated, platy, rare concretions; no visible graptolites.                                                                                                             |
| 41.0                                | 0.5     | CPS16                                                             | 41.0                                                         | Mudstone: calcareous, medium-bedded, dark brown.                                                                                                                                               |
| 41.3                                | 0.3     |                                                                   |                                                              | Dolostone: finely crystalline, medium brown-grey.                                                                                                                                              |

|      |     |       |      |                                                                                              |
|------|-----|-------|------|----------------------------------------------------------------------------------------------|
| 41.5 | 0.2 |       |      | Covered interval.                                                                            |
| 43.7 | 2.2 | CPS17 | 43.7 | Shale: black, rare concretions; <i>atavus</i> and possibly <i>acinaces</i> Zone graptolites. |
| 44.0 | 0.3 |       |      | Dolostone: nodular, vuggy, bituminous.                                                       |
| 44.5 | 0.5 |       |      | Shale: black, concretionary; graptolites of <i>atavus</i> or <i>acinaces</i> Zone.           |
| 52.4 | 7.9 |       |      | Dolostone: medium-bedded, medium brown, nodular, vuggy, bituminous.                          |

**Cape Manning**  
**75°26'N, 94°20'W**

SECTION 1: ORDOVICIAN-SILURIAN BOUNDARY

The lowest section at Cape Manning is continuous and spans the Ordovician-Silurian boundary. It is located along with the lower part of Cape Manning Section 2 in a small creek that runs into a larger, unnamed river.

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                        |
|-----------------------|---------------|---------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0                     | 6.5           |               |                   | Dolostone: thin-medium-bedded, medium brown, wackestone with lesser mudstone, rarely laminated; <i>fastigatus</i> Zone graptolites, trilobite, <i>Pseudogygites</i> , and gastropods in lower 2 m. |
| 6.7                   | 0.2           |               |                   | Dolomudstone: laminated, argillaceous, dark brown-grey; <i>pacificus</i> Zone graptolites.                                                                                                         |
| 7.1                   | 0.4           |               |                   | Lime wackestone: massive, medium brown-grey.                                                                                                                                                       |
| 7.3                   | 0.2           |               |                   | Dolomudstone: laminated, argillaceous, dark brown-grey, platy-shaly beds.                                                                                                                          |
| 7.4                   | 0.1           |               |                   | Dolomudstone: irregular, concretionary bed.                                                                                                                                                        |
| 8.4                   | 1.0           |               |                   | Dolomudstone: argillaceous, dark, laminated; <i>pacificus</i> Zone graptolites.                                                                                                                    |
| 8.5                   | 0.1           |               |                   | Shale: dolomitic, burrowed, grades upward to massive, burrowed dolowackestone.                                                                                                                     |
| 10.3                  | 1.8           | CM1           | 9.5               | Dolowackestone-mudstone: medium-thick bedded, medium brown-grey.                                                                                                                                   |

|       |      |     |      |                                                                                                                                                                                                                                 |
|-------|------|-----|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10.5  | 0.2  |     |      | Shale: dolomitic, silty, dark grey, shaly-platy.                                                                                                                                                                                |
| 11.9  | 1.4  | CM2 | 11.5 | Siltstone: greenish, brown, dolomitic, beds coarsen and thicken slightly upward; platy-flaggy near base to thin-bedded at top; topmost beds are medium grey.                                                                    |
| 11.92 | 0.02 |     |      | Dolomudstone: irregular, dark shaly.                                                                                                                                                                                            |
| 12.0  | 0.08 |     |      | Shale: black, fissile, friable.                                                                                                                                                                                                 |
| 12.06 | 0.06 |     |      | Dolomudstone: chocolate brown.                                                                                                                                                                                                  |
| 12.1  | 0.04 |     |      | Clay-shale: friable, orange-brown.                                                                                                                                                                                              |
| 12.4  | 0.3  |     |      | Mudstone: calcareous, cherty, shaly; " <i>persculptus</i> " Zone graptolites.                                                                                                                                                   |
| 15.3  | 2.9  | CM3 | 12.8 | Interbedded shale and mudstone: calcareous shales and black, platy, argillaceous lime mudstones; platy concretions at 14.5 and 15.0 m with; " <i>persculptus</i> " Zone and <i>acuminatus</i> Zone graptolites begin at 12.9 m. |
|       |      | CM4 | 13.5 |                                                                                                                                                                                                                                 |
|       |      | CM5 | 14.5 |                                                                                                                                                                                                                                 |
|       |      | CM6 | 15.0 |                                                                                                                                                                                                                                 |

## SECTION 2

Cape Manning Section 2 begins approximately 140 m downstream from Cape Manning Section 1. Based on the graptolite faunas, the basal 1 m overlaps with Section 1.

| Height Above Base (m) | Thickness (m) | Sample Number              | Sample Height (m)    | Description                                                                                                                                                                                                                         |
|-----------------------|---------------|----------------------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.6                   | 4.6           | CM2-(-1)<br>CM2-1<br>CM2-3 | 0.5<br>1.0<br>4.0    | Interbedded black, calcareous shales and black, platy argillaceous lime mudstones; platy concretions as in Section 1 at 14.5 and 15.0 m; <i>persculptus</i> Zone graptolites up to 0.6 m, <i>acuminatus</i> Zone graptolites above. |
| 15.6                  | 11.0          |                            |                      | Covered interval                                                                                                                                                                                                                    |
| 16.1                  | 0.5           | CM2B-1                     | 16.1                 | Dolostone: medium brown-grey, crystalline, vuggy, nautiloids and bitumen.                                                                                                                                                           |
| 18.3                  | 2.2           |                            |                      | Shale: black, dolomitic, poorly-moderately developed concretions; <i>atavus</i> Zone and possibly <i>acinaces</i> Zone graptolites.                                                                                                 |
| 20.0                  | 1.7           | CM2B-2                     | 19.3                 | Interbedded dolostone and shale: dolostone is thin-bedded, medium-brown, vuggy, nodular, bituminous interbedded with black, dolomitic shale.                                                                                        |
| 29.2                  | 9.2           | CM2C-1<br>CM2C-2<br>CM2C-3 | 21.7<br>24.7<br>27.7 | Dolostone: thin-medium-bedded, light-medium brown, vuggy, nodular, bituminous, thicker and lighter beds near top of unit.                                                                                                           |
| 30.5                  | 1.3           | CM2C-4                     | 30.3                 | Shale: dolomitic/calcareous, some concretions and lime mudstone beds 10 cm thick; <i>cyphus</i> Zone graptolites; sample from concretion.                                                                                           |
| 35.7                  | 5.2           | CM2C-5                     | 33.2                 | Interbedded shale and lime mudstone: shale                                                                                                                                                                                          |

|      |     |                             |                      |                                                                                                                                                                                                                                                                                   |
|------|-----|-----------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      |     |                             |                      | is black, calcareous-to-dolomitic, lime mudstone beds are laminated, tabular and concretionary; some pelmatozoan-rich turbiditic beds present; thin cherty beds and dolomitic content increase toward top of unit; <i>cyphus</i> Zone graptolites; sample mainly from concretion. |
| 37.7 | 2.0 | CM2C-6                      | 36.2                 | As above, but less common concretions and completely dolomitic, grades into overlying unit; sample mainly from concretion.                                                                                                                                                        |
| 39.1 | 1.4 |                             |                      | Dolostone: medium-thick-bedded, fine-medium crystalline, vuggy, mottled bituminous, some pelmatozoan-rich layers near base, wavy-laminated near top.                                                                                                                              |
| 39.2 | 0.1 | CM2C-7                      | 39.2                 | Dolomudstone: brown, pelmatozoan fragments.                                                                                                                                                                                                                                       |
| 39.8 | 0.6 |                             |                      | Covered interval.                                                                                                                                                                                                                                                                 |
| 49.3 | 9.5 | CM2C-8<br>CM2C-9<br>CM2C-10 | 42.1<br>45.0<br>49.0 | Interbedded shale and lime mudstone: shale is black, calcareous; lime mudstone is black, argillaceous and contains abundant large (1 m) concretions; <i>curtus</i> Zone graptolites; CM2C-8 from lime mudstone; CM2C-9, 10 from concretions.                                      |
| 51.4 | 2.1 |                             |                      | as above, smaller concretions (0.4 m); possibly <i>convolutus</i> Zone graptolites.                                                                                                                                                                                               |
| 51.7 | 0.3 | CM2C-11                     | 51.4                 | Limestone: thick turbidite bed, some grading and parallel lamination in lower part, cross-lamination and white chert in middle, and laminated lime mudstone in upper part.                                                                                                        |
| 59.5 | 8.1 | CM2C-12<br>CM2C-13          | 55.0<br>58.7         | Interbedded shale and lime mudstone: shale is black, calcareous; mudstone is laminated, black; abundant concretions (0.1-0.3 m), some beds, especially 54-57 m composed of laterally coalesced concretions; <i>convolutus</i> Zone graptolites; both samples from concretions.    |

|       |      |                                                     |                                        |                                                                                                                                                                                                             |
|-------|------|-----------------------------------------------------|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 65.0  | 5.5  | CM2C-14<br>CM2C-15                                  | 62.0<br>65.0                           | Interbedded dolomitic mudstone and shale: mudstone is thin-bedded, medium dark brown-grey; shale interbeds are thin; some bitumen and chert; both samples from dolomitic mudstone.                          |
| 66.0  | 1.0  |                                                     |                                        | Dolostone: flaggy-thin-bedded, light brown, laminated, silty-sandy texture.                                                                                                                                 |
| 68.0  | 2.0  |                                                     |                                        | Dolostone: thin-medium-bedded, brown, laminated, sandy texture, grades into overlying unit.                                                                                                                 |
| 69.5  | 1.5  |                                                     |                                        | Dolostone: flaggy-thin-bedded, medium-brown, laminated, silty-sandy texture.                                                                                                                                |
| 70.0  | 0.5  | CM2C-16                                             | 70.0                                   | Mudstone: wavy-irregularly laminated to thin-bedded, dolomitic; also argillaceous dolomudstones, some grey chert; sample from concretion.                                                                   |
| 78.9  | 8.9  | CM2C-17<br>CM2C-18<br>CM2C-19                       | 73.0<br>75.9<br>78.5                   | Interbedded shale and lime mudstone: shale is black, calcareous; mudstone thin-bedded, cherty; concretions common towards top; CM2C-17 from turbidite bed; CM2C-18 from concretion; CM2C-19 from mudstone.  |
| 82.1  | 3.2  |                                                     |                                        | Covered interval.                                                                                                                                                                                           |
| 87.0  | 4.9  | CM2C-20<br>CM2C-21                                  | 82.5<br>85.1                           | Interbedded calcareous shale and lime mudstone: mudstones thin-bedded, cherty, concretions common; both samples partly from concretions.                                                                    |
| 88.0  | 1.0  | CM2C-22                                             | 88.0                                   | Lime mudstone: thin-medium wavy-bedded, medium grey, some cherty layers.                                                                                                                                    |
| 91.1  | 3.1  |                                                     |                                        | Covered interval                                                                                                                                                                                            |
| 107.5 | 16.4 | CM2C-23<br>CM2C-24<br>CM2C-25<br>CM2C-26<br>CM2C-27 | 92.0<br>95.2<br>98.0<br>100.8<br>104.1 | Interbedded thin lime mudstones and calcareous shales: mudstones dark grey, laminated to wavy-bedded, argillaceous; shales black; sparse lime concretions (<0.3 m in diameter); beds tend to be thinner and |

|       |     |         |       |                                                                                                                                                         |
|-------|-----|---------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |     | CM2C-28 | 107.0 | shalier towards top; all samples partly from concretions.                                                                                               |
| 112.0 | 4.5 | CM2C-29 | 112.0 | Interbedded lime/dolomitic mudstone and shale: mudstones very thin-bedded (5-20 mm) "ribbon limestones", dark brown; shale black; sample from mudstone. |
| 114.0 | 2.0 | CM2C-30 | 114.0 | Interbedded mudstones and calcareous shales: mudstones medium-dark grey, wavy-bedded to nodular; shales thin; sample from mudstone                      |

## SECTION 3

A covered interval separates Cape Manning Section 2 from Section 3, which occur about 150 m apart on the same side of the stream (the latter being downstream from the other). This covered interval represents the upper part of the *guerichi* graptolite Zone and presumably the entire *turriculatus* graptolite Zone.

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                                                                                                                         |
|-----------------------|---------------|---------------|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3.0                   | 3.0           | CM3-1         |                   | Laminated brown-grey dolomudstone: thinly bedded. The lowest graptolite sample, at 2.0 m, contains <i>crispus</i> Zone graptolites.                                                                                                                                                                 |
| 6.0                   | 3.0           | CM3-2         |                   | Dolomudstone and interbedded limestone: brown-grey dolomudstone with cherty horizons; limestone is thin-bedded.                                                                                                                                                                                     |
| 56.8                  | 50.8          | CM3-3         | 10.0              | Dolomudstone and interbedded lime mudstone: dolomudstone is laminated; limestone is medium bedded and vaguely concretionary. The highest sample that is demonstrably <i>crispus</i> graptolite Zone was recovered from the 10.2-10.6 m interval, whereas the first <i>griestoniensis</i> graptolite |
|                       |               | CM3-4         | 15.1              |                                                                                                                                                                                                                                                                                                     |
|                       |               | CM3-5         | 20.0              |                                                                                                                                                                                                                                                                                                     |
|                       |               | CM3-6         | 30.0              |                                                                                                                                                                                                                                                                                                     |
|                       |               | CM3-7         | 40.0              |                                                                                                                                                                                                                                                                                                     |
|                       |               | CM3-8         | 49.0              |                                                                                                                                                                                                                                                                                                     |
|                       |               | CM3-9         | 56.7              |                                                                                                                                                                                                                                                                                                     |

Zone identification was placed at 23.5 m. The intervening strata contain undiagnostic graptolites.

|       |      |                  |               |                                                                                                                                                                                                                                                                                          |
|-------|------|------------------|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 75.0  | 18.2 |                  |               | Covered interval.                                                                                                                                                                                                                                                                        |
| 90.0  | 15.0 | CM3-10           | 79.0          | Dolomudstone interbedded with lime mudstone: dolomudstone laminated; lime mudstone interbeds are more limy than underlying strata.                                                                                                                                                       |
| 102.5 | 12.5 | CM3-11<br>CM3-12 | 90.0<br>101.5 | Interbedded laminated dolomudstone and lime mudstone as previous; lime mudstone beds have large vague concretions. Sample CM3-11 contained vague lens-like concretions as well as bioclasts and mudchips that remained after dissolution.                                                |
| 130.7 | 28.2 | CM3-13           | 110.0         | Interbedded laminated dolomudstone and lime mudstone: lime mudstone interbeds are less frequent and thinner than underlying strata. Sample CM3-13 contained cherty interbeds that remained after dissolution. The base of the <i>sakmaricus</i> graptolite Zone was recorded at 116.0 m. |
| 147.0 | 16.7 |                  |               | Fining upwards sequences approximately 1.5 m thick of mudstone with rip-up clasts at base followed by mudstone and laminated mudstone (first begins at 140.3 m).                                                                                                                         |
| 169.9 | 22.9 |                  |               | Interbedded laminated mudstone and medium and thick-bedded lime mudstone. Scattered large concretions.                                                                                                                                                                                   |

*Cape Phillips North*

75°37'N, 94°30'W

Cape Phillips North, the type section for the Cape Phillips Formation, outcrops near the northernmost point of the island. It begins near the point where the slope hill becomes a coastal cliff and is approached from the south. The entire section outcrops along the beach of Wellington Channel, opposite Devon Island. North of the base of this section, the beds become folded and faulted and can no longer be traced laterally.

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                                                                                                                                       |
|-----------------------|---------------|---------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16.0                  | 16.0          | CP1           | 0.0               | Interbedded calcareous shale and lime mudstone: shales are thin; lime mudstones 0.1-0.2 m thick (laminated or massive), some more nodular beds; very small concretions abundant, some chert pebbles; <i>crispus</i> and/or <i>griestoniensis</i> Zone graptolites; samples from lime mudstone.                    |
|                       |               | CP2           | 5.0               |                                                                                                                                                                                                                                                                                                                   |
|                       |               | CP3           | 8.0               |                                                                                                                                                                                                                                                                                                                   |
|                       |               | CP4           | 12.0              |                                                                                                                                                                                                                                                                                                                   |
|                       |               | CP5           | 15.4              |                                                                                                                                                                                                                                                                                                                   |
| 35.0                  | 19.0          | CP6           | 19.6              | Lime mudstone and shale: mudstone laminated and massive; shaly partings and thin shale interbeds; some nodular beds, lime grainstones that thicken towards top, mudchip conglomerates and cherty beds; concretions uncommon, <i>crispus</i> and/or <i>griestoniensis</i> Zone graptolites; samples from mudstone. |
|                       |               | CP7           | 25.4              |                                                                                                                                                                                                                                                                                                                   |
|                       |               | CP8           | 30.1              |                                                                                                                                                                                                                                                                                                                   |
| 40.0                  | 5.0           | CP10          | 39.9              | Interbedded lime mudstone and calcareous shale: mudstone thinner and laminated; concretions common; <i>griestoniensis</i> Zone graptolites.                                                                                                                                                                       |
| 59.0                  | 19.0          | CP11          | 45.3              | Calcareous shales: small concretions and some thin limestone beds, becomes cherty                                                                                                                                                                                                                                 |
|                       |               | CP12          | 50.4              |                                                                                                                                                                                                                                                                                                                   |

|       |      |                                      |                                        |                                                                                                                                                                                                                                                                                                    |
|-------|------|--------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |      | CP13                                 | 55.5                                   | towards top; samples from concretions.                                                                                                                                                                                                                                                             |
| 65.0  | 6.0  | CP14                                 | 59.7                                   | Limestone: thin-medium bedded, shaly partings, some bioclastic, some mottled mudstone, some concretionary; bioclastic sample.                                                                                                                                                                      |
| 84.0  | 19.0 | CP15<br>CP16<br>CP17                 | 65.0<br>70.6<br>78.7                   | Lime mudstone and calcareous shale: mudstone laminated, platy and argillaceous, some bioclastic; CP16 pelmatozoan-rich with some coral, others from lime mudstone.                                                                                                                                 |
| 106.0 | 22.0 | CP18<br>CP19<br>CP20<br>CP21<br>CP22 | 85.0<br>90.0<br>94.3<br>100.0<br>105.0 | Interbedded calcareous shale and lime mudstone: mudstone platy to thin-bedded, cherty, some concretions becoming more common in upper 2 m; <i>sakmaricus</i> Zone graptolites begin at ~90 m; CP20 from concretion and has some pelmatozoan debris, other samples, others from laminated mudstone. |
| 115.4 | 9.4  | CP23                                 | 110.0                                  | Interbedded calcareous shale and lime mudstone: shaly and massive laminated lime mudstone dominate; some nodular beds and mudchip conglomerates, chert less common; some slumping and wavy beds with uncompressed graptolites; <i>sakmaricus</i> Zone graptolites; sample from mudstone.           |
| 120.0 | 4.6  | CP24                                 | 166.7                                  | Interbedded calcareous shale and thin, laminated lime mudstone; concretions uncommon; sample from partly laminated mudstone.                                                                                                                                                                       |
| 122.5 | 2.5  | CP25                                 | 120.0                                  | Lime mudstone: laminated, platy to medium bedded.                                                                                                                                                                                                                                                  |
| 124.0 | 1.5  |                                      |                                        | Calcareous shale; some thin, laminated lime mudstone beds, concretions uncommon.                                                                                                                                                                                                                   |
| 127.0 | 3.0  | CP26                                 | 126.1                                  | Lime mudstone: laminated, platy to medium-bedded.                                                                                                                                                                                                                                                  |
| 133.0 | 6.0  |                                      |                                        | Lime mudstone: thin-medium-bedded, shaly                                                                                                                                                                                                                                                           |

|       |      |                                                              |                                                                      |                                                                                                                                                                                                                                                                                                                                                |
|-------|------|--------------------------------------------------------------|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |      |                                                              |                                                                      | partings, small concretions.                                                                                                                                                                                                                                                                                                                   |
| 138.0 | 5.0  | CP27                                                         | 137.5                                                                | Limestone: platy, small concretions.                                                                                                                                                                                                                                                                                                           |
| 145.5 | 7.5  | CP28<br>CP29                                                 | 141.0<br>145.4                                                       | Lime mudstone/grainstone: thin-medium-bedded, shaly partings, uncommon small concretions, some slumping; both samples from non-laminated mudstone.                                                                                                                                                                                             |
| 162.5 | 17.0 | CP30<br>CP31<br>CP32<br>CP33                                 | 149.5<br>155.6<br>158.0<br>161.0                                     | Lime mudstone: platy to thin-bedded, laminated, shaly partings; some irregularly bedded lime grainstone with uncompressed graptolites, concretions common and abundant near top; CP31 has some rip-up clasts, other samples from mudstones.                                                                                                    |
| 163.2 | 0.7  |                                                              |                                                                      | Calcareous shale, abundant concretions.                                                                                                                                                                                                                                                                                                        |
| 166.3 | 3.1  | CP34<br>*CP36                                                | 163.5<br>165.5                                                       | Lime mudstone: (less limy than below or more indurated), platy to thin-bedded, shaly parting, no concretions; both samples laminated.                                                                                                                                                                                                          |
| 171.0 | 4.7  | CP35<br>CP37                                                 | 167.5<br>169.5                                                       | Lime mudstone and lime siltstones: flaggy-platy laminated, abundant fish macrofossils; <i>insectus</i> Zone graptolites.                                                                                                                                                                                                                       |
| 196.0 | 25.0 | CP38<br>CP39<br>CP40<br>CP41<br>CP42<br>CP43<br>CP45<br>CP46 | 171.5<br>173.0<br>175.0<br>178.0<br>180.0<br>182.0<br>184.0<br>189.0 | Interbedded lime mudstone and calcareous shale: mudstone shaly to platy, laminated, med-dark grey, some thick (0.1 m) beds; base of <i>centrifugus</i> Zone at 169.6 m; base of <i>murchisoni</i> Zone at 172.0 m; base of <i>instrenuus-kolobus</i> Zone at 175.5 m; CP41-43 from oily shale/mudstone, CP45-46 graptolite-rich shaly mudstone |
| 199.0 | 3.0  | CP47                                                         | 196.0                                                                | As above, but some 0.2-0.5 m thick concretionary units; <i>instrenuus-kolobus</i> Zone; sample from concretions.                                                                                                                                                                                                                               |
| 203.5 | 4.5  | CP48                                                         | 200.0                                                                | As above, but no concretions; <i>instrenuus-kolobus</i> Zone; sample from organic rich mudstone/shale.                                                                                                                                                                                                                                         |
| 220.0 | 16.5 | CP49A                                                        | 206.6                                                                | As above, but with concretions; <i>instrenuus-</i>                                                                                                                                                                                                                                                                                             |

|       |      |       |       |                                                                                                                                                                   |
|-------|------|-------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |      | CP49B | 213.0 | <i>kolobus</i> Zone; CP49A, CP50-51 from concretions, CP49B from mudstone                                                                                         |
|       |      | CP50  | 216.0 |                                                                                                                                                                   |
|       |      | CP51  | 219.9 |                                                                                                                                                                   |
| 231.0 | 11.0 | CP52  | 227.2 | As above, but no concretions; <i>instrenuus-kolobus</i> Zone and/or <i>perneri-opimus</i> zone; sample from isolated concretions.                                 |
| 234.0 | 3.0  | CP53  | 232.7 | As above, but with concretions; <i>perneri-opimus</i> Zone?; sample from concretions.                                                                             |
| 240.5 | 6.5  | CP54  | 238.5 | As above, but no concretions; <i>perneri-opimus</i> Zone; sample from thinly-bedded mudstone/shale.                                                               |
| 256.5 | 16.0 | CP55  | 245.2 | As above, but with concretions; <i>perneri-opimus</i> Zone; both samples from concretions.                                                                        |
|       |      | CP56  | 250.9 |                                                                                                                                                                   |
| 293.0 | 36.5 | CP57  | 256.5 | As above, no concretions except for a single thick concretionary bed at 283.5 m; <i>perneri-opimus</i> Zone; CP57 from concretions, the remainder from mudstones. |
|       |      | CP58  | 262.5 |                                                                                                                                                                   |
|       |      | CP59  | 268.3 |                                                                                                                                                                   |
|       |      | CP60  | 277.5 |                                                                                                                                                                   |
|       |      | CP61  | 283.5 |                                                                                                                                                                   |
|       |      | CP62  | 288.0 |                                                                                                                                                                   |
|       |      | CP63  | 292.0 |                                                                                                                                                                   |

\*numbers out of order in the field

*Abbott River East*

75°13'40"N, 95°32'06"W

The Abbott River East Section is exposed along the side of a small, unnamed creek that runs into the Abbott River. The base of the section was placed at the top of ice and snow covered strata, but intermittent exposure was present below this (hence negative measurements).

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                                                  |
|-----------------------|---------------|---------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -3.5                  | 3.0           |               |                   | Interbedded calcareous shales and lime mudstone: shales wavy-bedded, some mudchip conglomerates; massive limestone beds, some mudchip conglomerates; uncommon graptolites, probably lower <i>sakmaricus</i> Zone.            |
| 0.0                   | 3.5           |               |                   | Covered interval                                                                                                                                                                                                             |
| 5.0                   | 5.0           | ARE1<br>ARE2  | 0.0<br>4.0        | Laminated, calcareous shales to platy argillaceous lime mudstone with concretionary horizons every 0.1-0.5 metres; <i>sakmaricus</i> Zone graptolites; ARE1 includes concretions and mudstone; sample ARE2 from concretions. |
| 5.5                   | 0.5           |               |                   | Shales: calcareous, recessive; <i>sakmaricus</i> Zone graptolites common.                                                                                                                                                    |
| 8.0                   | 2.5           | ARE3          | 8.0               | Laminated, calcareous shales to platy, argillaceous lime mudstones, with concretionary horizons every 0.1-0.5 metres; <i>sakmaricus</i> Zone graptolites common; sample from concretions.                                    |
| 13.0                  | 5.0           | ARE4          | 12.0              | As above, but uncommon concretions, large concretions horizon at 12.5 m, graptolites                                                                                                                                         |

|      |     |                      |                      |                                                                                                                                                                                            |
|------|-----|----------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      |     |                      |                      | uncommon, <i>sakmaricus</i> Zone; sample from concretion.                                                                                                                                  |
| 14.2 | 1.2 | ARE5                 | 13.6                 | As above, but no concretions, graptolites uncommon, <i>sakmaricus</i> or <i>insectus</i> Zone; sample from lime mudstone.                                                                  |
| 15.2 | 1.0 |                      |                      | Covered interval                                                                                                                                                                           |
| 19.3 | 4.1 | ARE6<br>ARE7<br>ARE8 | 16.0<br>18.0<br>19.1 | Interbedded lime mudstones and calcareous shales: mudstones platy to flaggy, some up to 0.1 m thick; no concretions; <i>insectus</i> Zone graptolites common; samples from lime mudstones. |
| 19.9 | 0.6 |                      |                      | Covered interval                                                                                                                                                                           |
| 20.2 | 0.3 |                      |                      | Interbedded lime mudstones and calcareous shales: mudstones platy to flaggy, some up to 0.1 m thick; <i>centrifugus</i> Zone graptolites common.                                           |
| 22.0 | 1.8 |                      |                      | Covered interval                                                                                                                                                                           |

*Abbott River West*

Located about 8 km from Abbott River East, the Abbott River West section is exposed as three continuous sections outcropping as steep cliffs along the banks of an unnamed tributary that runs north into Abbott River. Sections 1 (the stratigraphically lowest section) and 3 are exposed along the west side of the tributary. Section 2 is exposed along the east side, and covers the interval intermediate in age between sections 1 and 3. The three sections span mid-Wenlock to earliest Ludlow time. Section 1, the southernmost, is within the mid-Wenlock *perneri-opimus* Zone. Section 2 and the basal 10 m of Section 3 are within the *testis-lundgreni* Zone. The Wenlock/Ludlow boundary occurs between 33.5-40.0 m. A. Lenz (pers. comm. 2000) indicates that the lower and upper Homeric graptolite extinctions occur in section 3. The lower (*lundgreni* Event) is between 14.5-17.5 m, and the upper (*ludensis* Event) is at ~37 m.

SECTION 1.

75°14'47N", 95°43'12"W

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                                        |
|-----------------------|---------------|---------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8.0                   | 8.0           | ARW1<br>ARW2  | 0.0<br>4.6        | Calcareous shale with concretions; ARW1 from concretion contains sponge spicules, ARW2 from shale; <i>perneri</i> graptolite Zone.                                                                                 |
| 16.0                  | 8.0           | ARW3<br>ARW4  | 8.0<br>12.0       | Interbedded lime mudstone and calcareous shale: rare poorly-sorted bioclastic limestone beds with pelmatozoans, brachiopods, nautiloids, sponge spicules, concretions common; ARW3 from mudstone, ARW4 from shale. |
| 16.5                  | 0.5           | ARW5          | 16.0              | as above, but with very large concretion horizon (0.5 m diameter concretions);                                                                                                                                     |

|      |      |       |      |                                                                                                                                                                                                                                                                       |
|------|------|-------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|      |      |       |      | sample from large concretion.                                                                                                                                                                                                                                         |
| 21.0 | 4.5  | ARW6  | 20.0 | Lime mudstone: concretion-rich, medium to thick-bedded, argillaceous; sample from concretionary lens contains fish microfossils, brachiopods and radiolarians.                                                                                                        |
| 35.5 | 14.0 | ARW7  | 24.0 | Mudstone: indurated or non-calcareous, medium bedded, laminated, concretions absent.                                                                                                                                                                                  |
|      |      | ARW8  | 28.0 |                                                                                                                                                                                                                                                                       |
|      |      | ARW9  | 32.0 |                                                                                                                                                                                                                                                                       |
| 38.0 | 2.5  | ARW10 | 35.5 | Lime mudstone: bioclastic, lens-like, pinches out laterally; sample from concretion contains brachiopods, fish microfossils and radiolarians.                                                                                                                         |
| 40.0 | 2.0  |       |      | Lime mudstone: medium-bedded, laminated.                                                                                                                                                                                                                              |
| 40.5 | 0.5  | ARW11 | 40.0 | Bioclastic mudstone; sample from concretion.                                                                                                                                                                                                                          |
| 52.0 | 11.5 | ARW12 | 44.0 | Calcareous shale, platy, with bioclastic limestone beds intercalated more frequently, some medium-bedded indurated shaly limestone, some pyrite-rich beds; all samples from concretions ARW14 may be bioclastic bed; <i>lundgreni</i> graptolite Zone begins at 52 m. |
|      |      | ARW13 | 48.0 |                                                                                                                                                                                                                                                                       |
|      |      | ARW14 | 52.0 |                                                                                                                                                                                                                                                                       |

## SECTION 2

75°14'N, 95°42'30"W

All strata of Section 2 are within the *lundgreni* graptolite Zone (lower Homerian).

| Height Above Base (m) | Thickness (m) | Sample Number  | Sample Height (m) | Description                                                                                                                  |
|-----------------------|---------------|----------------|-------------------|------------------------------------------------------------------------------------------------------------------------------|
| 0.4                   | 0.4           | 2ARW1          | 0.0               | Bioclastic lime mudstone: sample contains pelmatozoans, brachiopods, ostracods, fish microfossils, sponge spicules.          |
| 7.5                   | 7.1           | 2ARW2          | 4.0               | Calcareous shale: platy, poorly exposed.                                                                                     |
| 8.0                   | 0.5           | 2ARW3          | 7.8               | Bioclastic lime mudstone: sample contains brachiopods and ostracods.                                                         |
| 18.0                  | 10.0          | 2ARW4<br>2ARW5 | 12.0<br>16.0      | Calcareous shale: platy, thin-bedded, laminated, hard concretions, pyrite; sample 2ARW4 contains prolific fish microfossils. |
| 26.0                  | 8.0           | 2ARW6<br>2ARW7 | 20.0<br>24.0      | Shaly carbonate: indurated, large (>1 m diameter) vague dolomitic concretions, pyrite.                                       |

## SECTION 3

75°14'03"N, 95°42'30"W

| Height Above Base (m) | Thickness (m) | Sample Number | Sample Height (m) | Description                                                                                                                                                                                                                                                                                                                                  |
|-----------------------|---------------|---------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 12.0                  | 12.0          | 3ARW1         | 0.5               | Shaly limestone with interbedded limestone: indurated, medium grey weathered, dark grey fresh concretions (0.2-0.5 m) abundant; limestone bioclastic, slumpy medium to thick-bedded, approximately 0.1-0.5m thick beds every >1 m, poorly sorted, coarse-grained, pelmatozoan-rich, chocolate brown fresh; <i>lundgreni</i> graptolite Zone. |
|                       |               | 3ARW2         | 4.5               |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW3         | 8.0               |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW4         | 10.0              |                                                                                                                                                                                                                                                                                                                                              |
| 25.0                  | 13.0          | 3ARW8         | 14.0              | Shaly carbonate: shalier and fewer concretions than underlying unit, moderately indurated, medium-thin-bedded, cliff forming; graded beds with shelly turbidites with shell hash at base, each approximately 0.3 m thick; <i>deubeli</i> graptolite Zone begins between 14.5-17.5 m.                                                         |
|                       |               | 3ARW5         | 15.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW9         | 17.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW10        | 19.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW6         | 20.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW11        | 21.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW12        | 24.0              |                                                                                                                                                                                                                                                                                                                                              |
| 3ARW7                 | 25.0          |               |                   |                                                                                                                                                                                                                                                                                                                                              |
| 42.0                  | 17.0          | 3ARW34        | ~35.0             | Calcareous shale interbedded with lime mudstone: shale platy, weathers yellow, dark grey/brown fresh; lime mudstone bioclastic, interbedded ~ every 4 m, medium-bedded, medium brown fresh; 'highest Wenlock fauna' at 33 m, <i>ludensis</i> Event occurs between 33.5 and 40.0 m.                                                           |
|                       |               | 3ARW37        | ~37.0             |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW13        | 40.0              |                                                                                                                                                                                                                                                                                                                                              |
|                       |               | 3ARW41        | ~41.0             |                                                                                                                                                                                                                                                                                                                                              |

*Appendix C: Stratigraphic Sections and Conodont Ranges.*

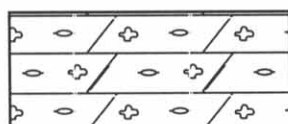
In the following series of nine figures, the stratigraphic sections are presented with the conodont ranges integrated into the graptolite zonation for the Canadian Arctic Island. The lithological symbols are identified on the following page.



*Dolostone*



*Interbedded limestone and calcareous shale*



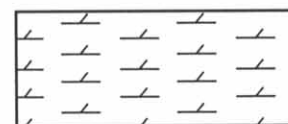
*Nodular and vuggy dolostone*



*Shale*



*Dolomitic siltstone*



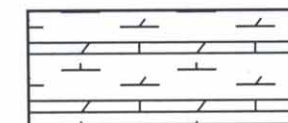
*Dolomitic shale*



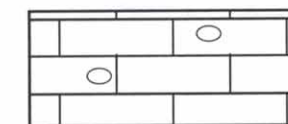
*Laminated dolostone*



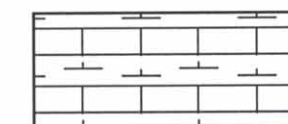
*Thinly bedded limestone and calcareous shale*



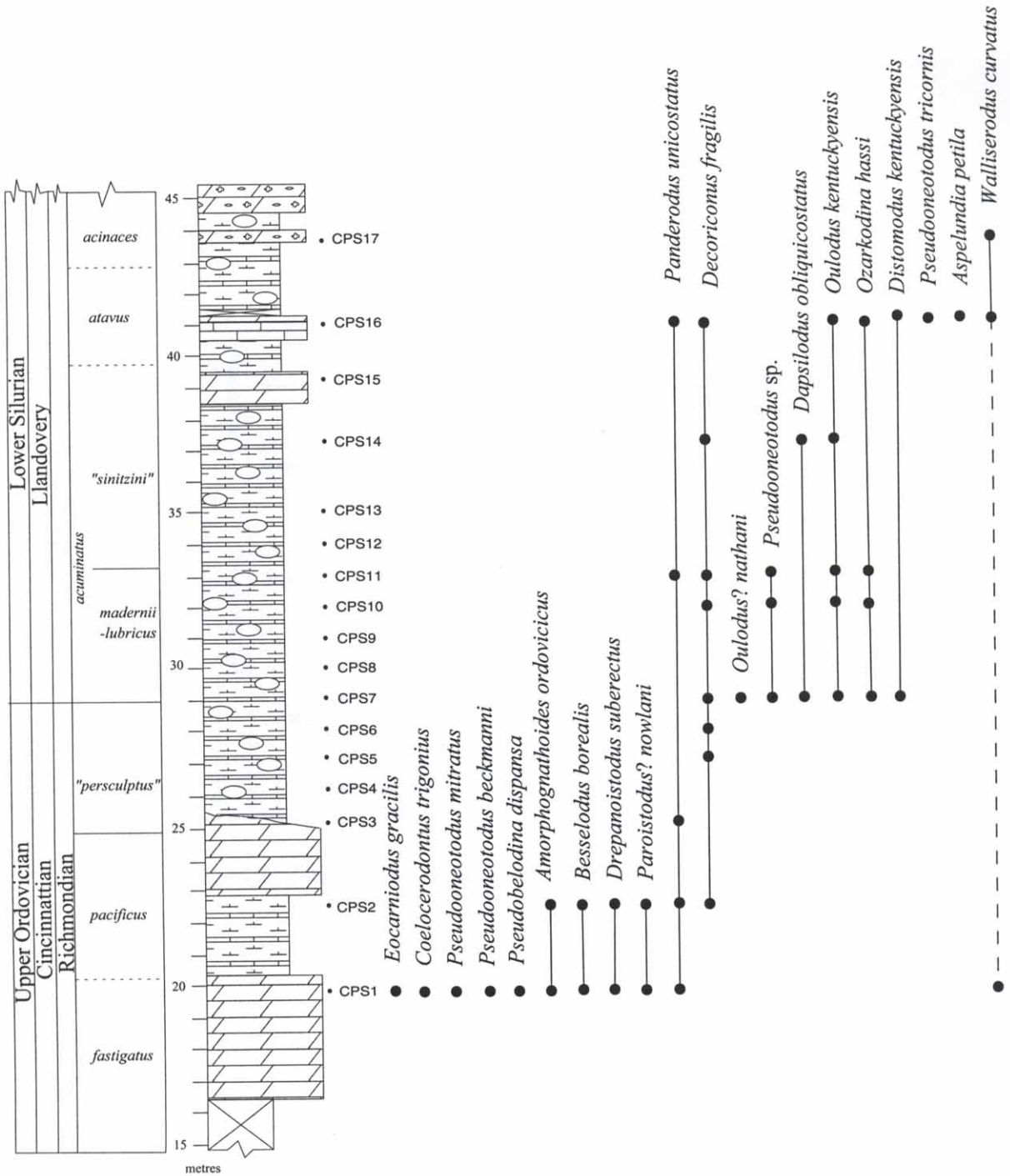
*Interbedded dolomitic limestone and dolomitic/calcareous shale*



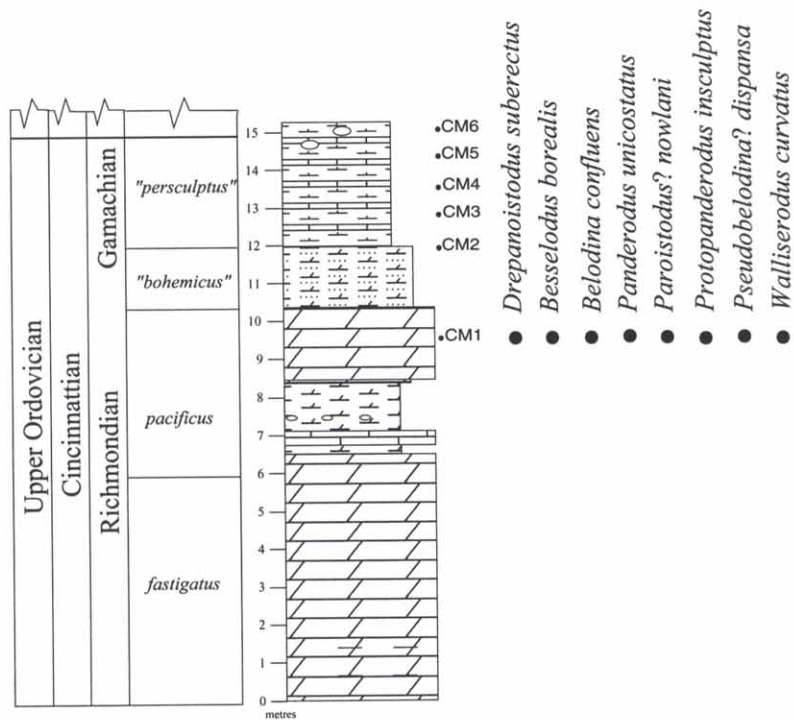
*Limestone (concretionary)*



*Interbedded shale and med-thick bedded limestone*

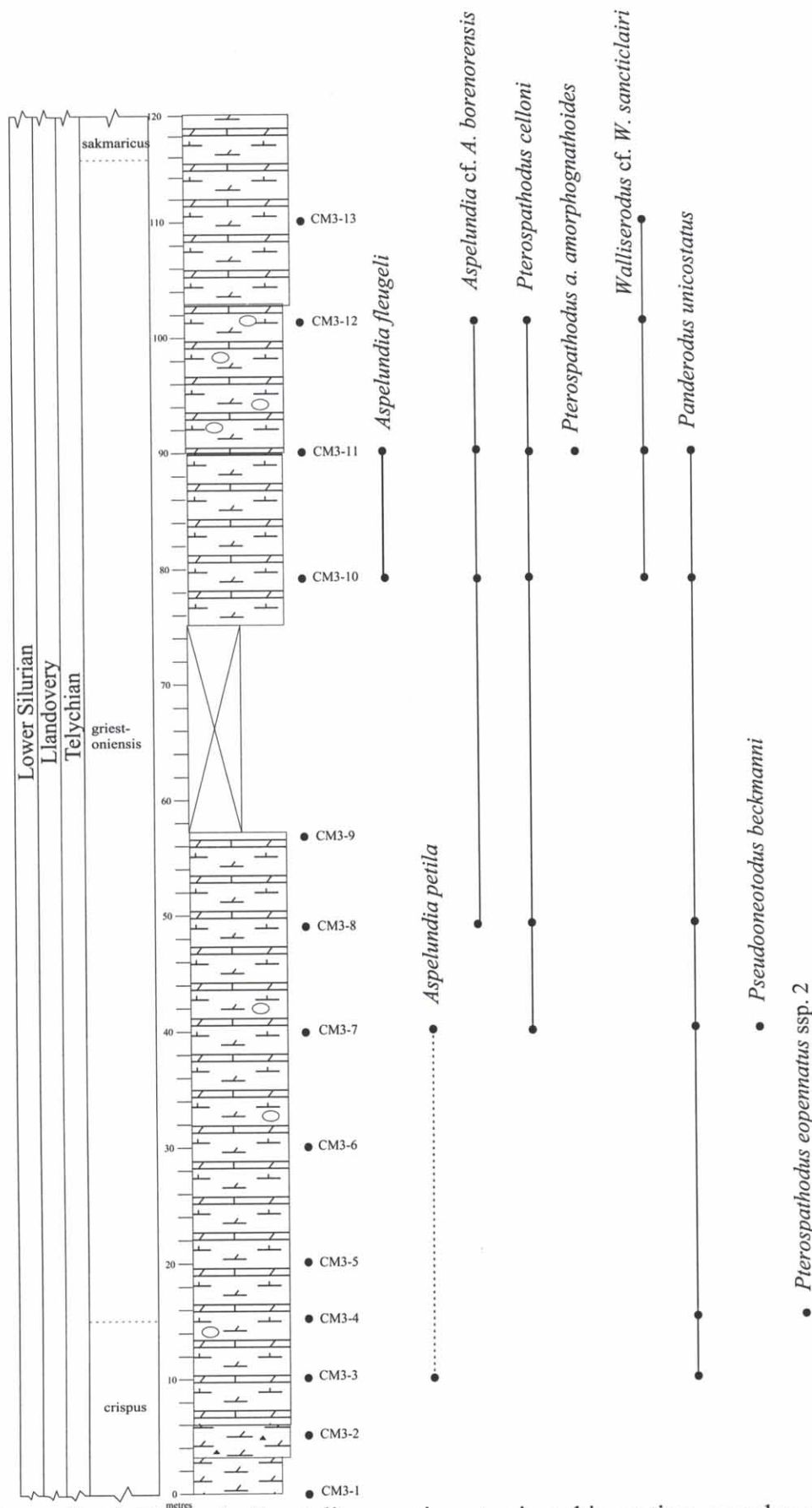


Appendix C, Figure 1. Graptolite zonation, stratigraphic section, samples and conodont ranges for Cape Phillips South.



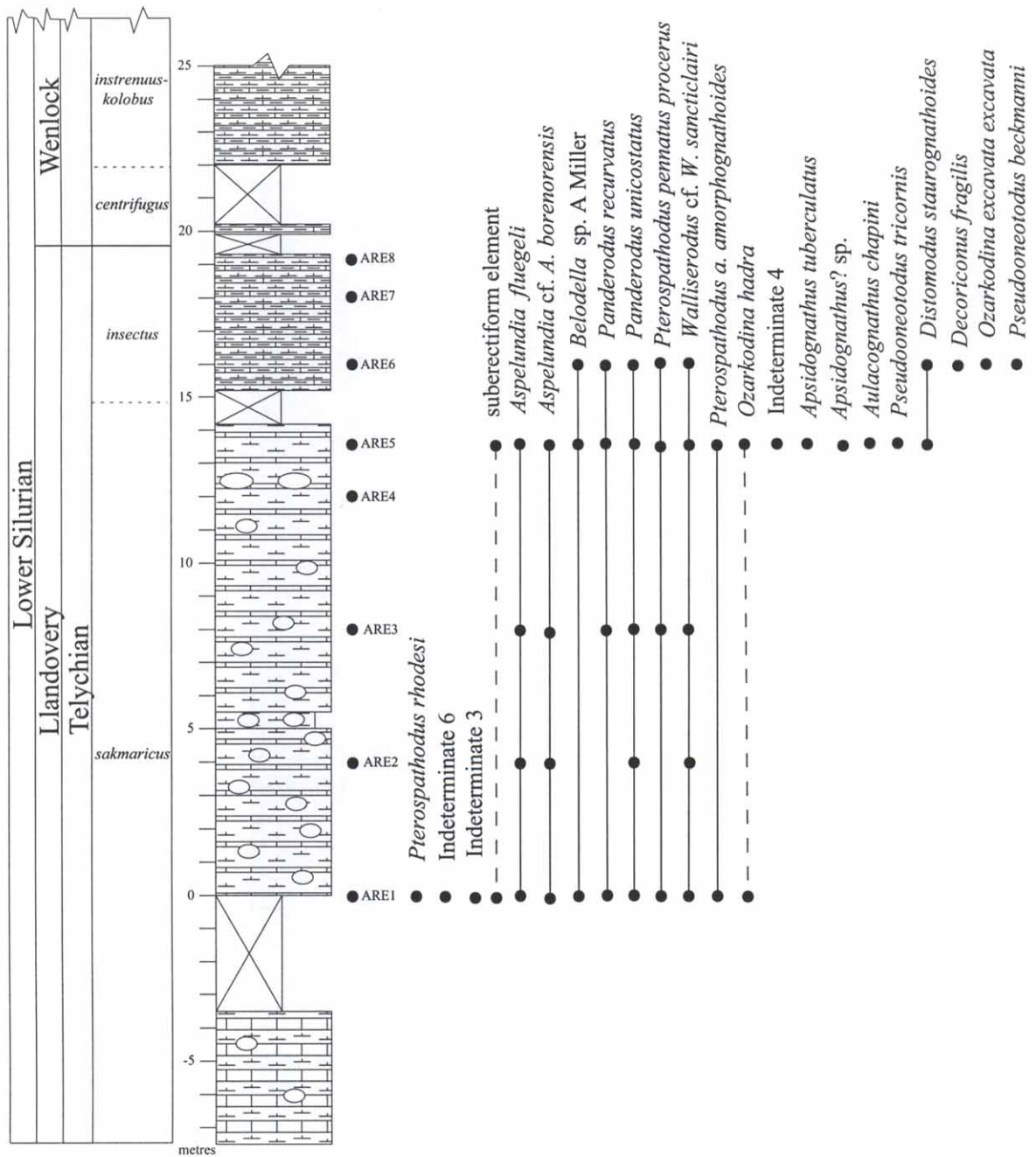
Appendix C, Figure 2. Graptolite zonation, stratigraphic section, samples and conodont ranges for Cape Manning Ordovician-Silurian boundary section.

**Appendix C, Figure 3. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Cape Manning Section 2 (in back pocket envelope).**

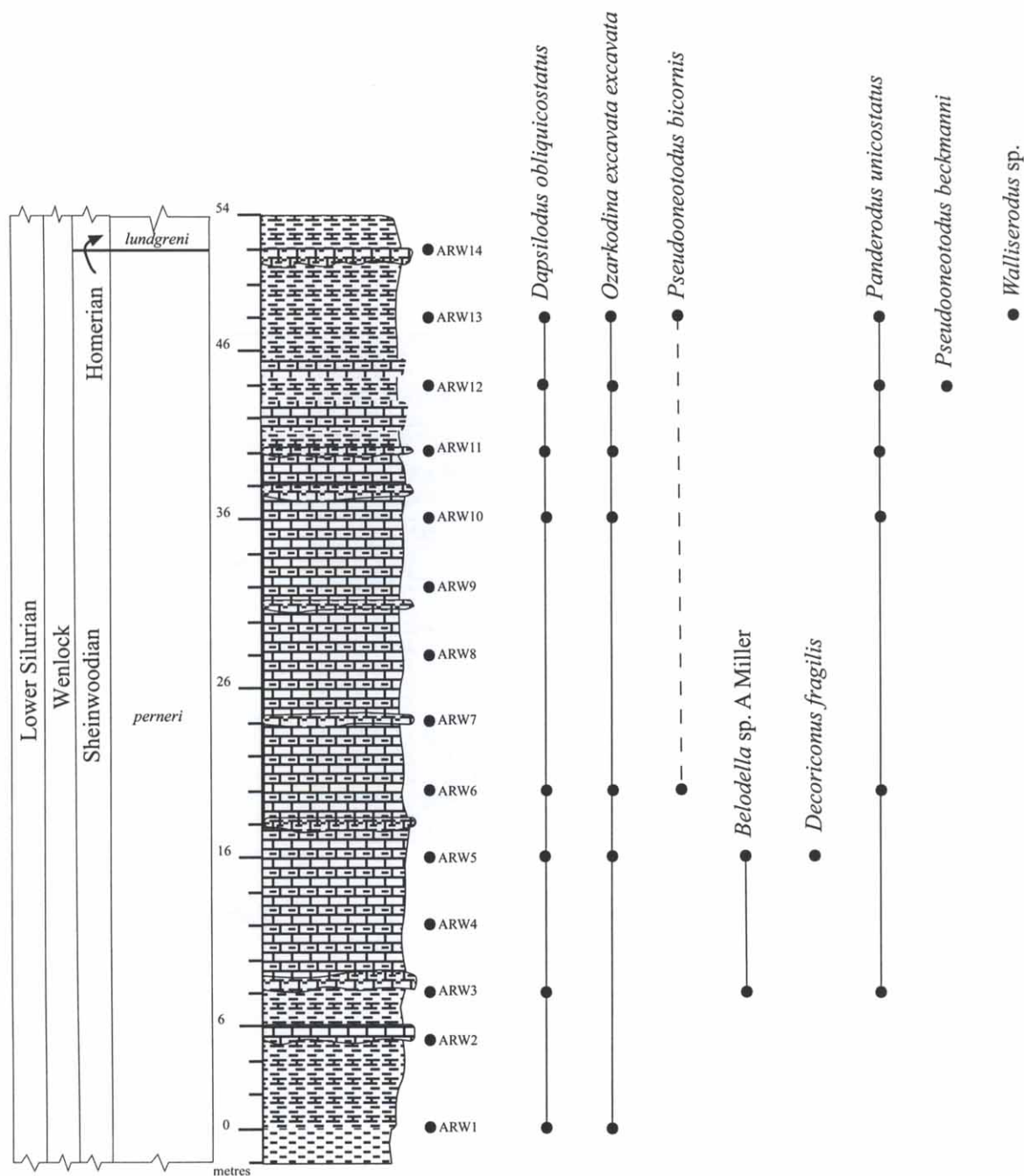


Appendix C, Figure 4. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Cape Manning Section 3.

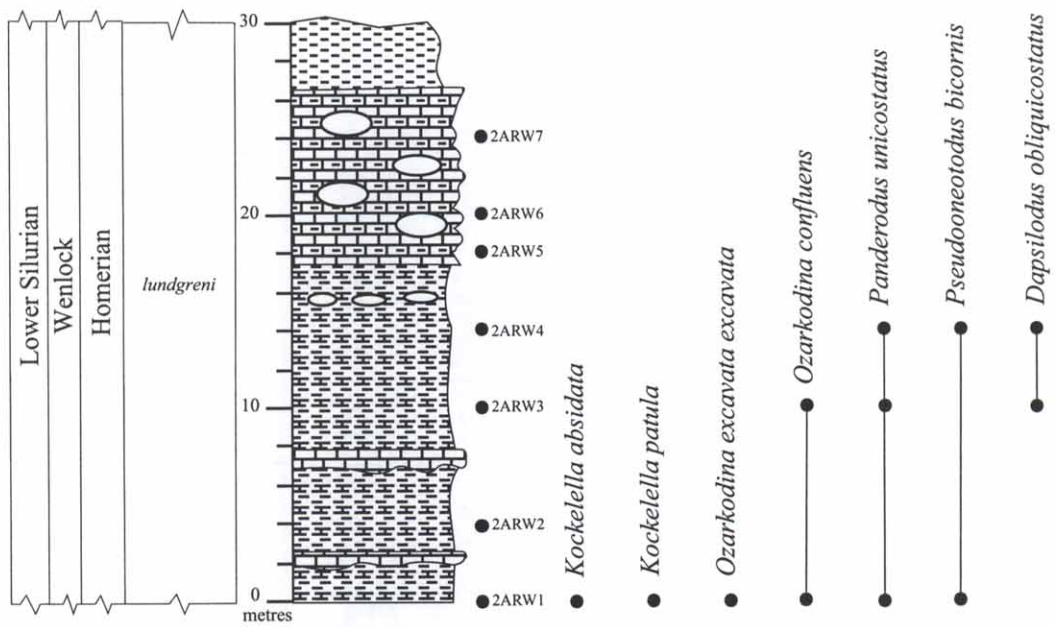
**Appendix C, Figure 5. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Cape Phillips North Section (in back pocket envelope).**



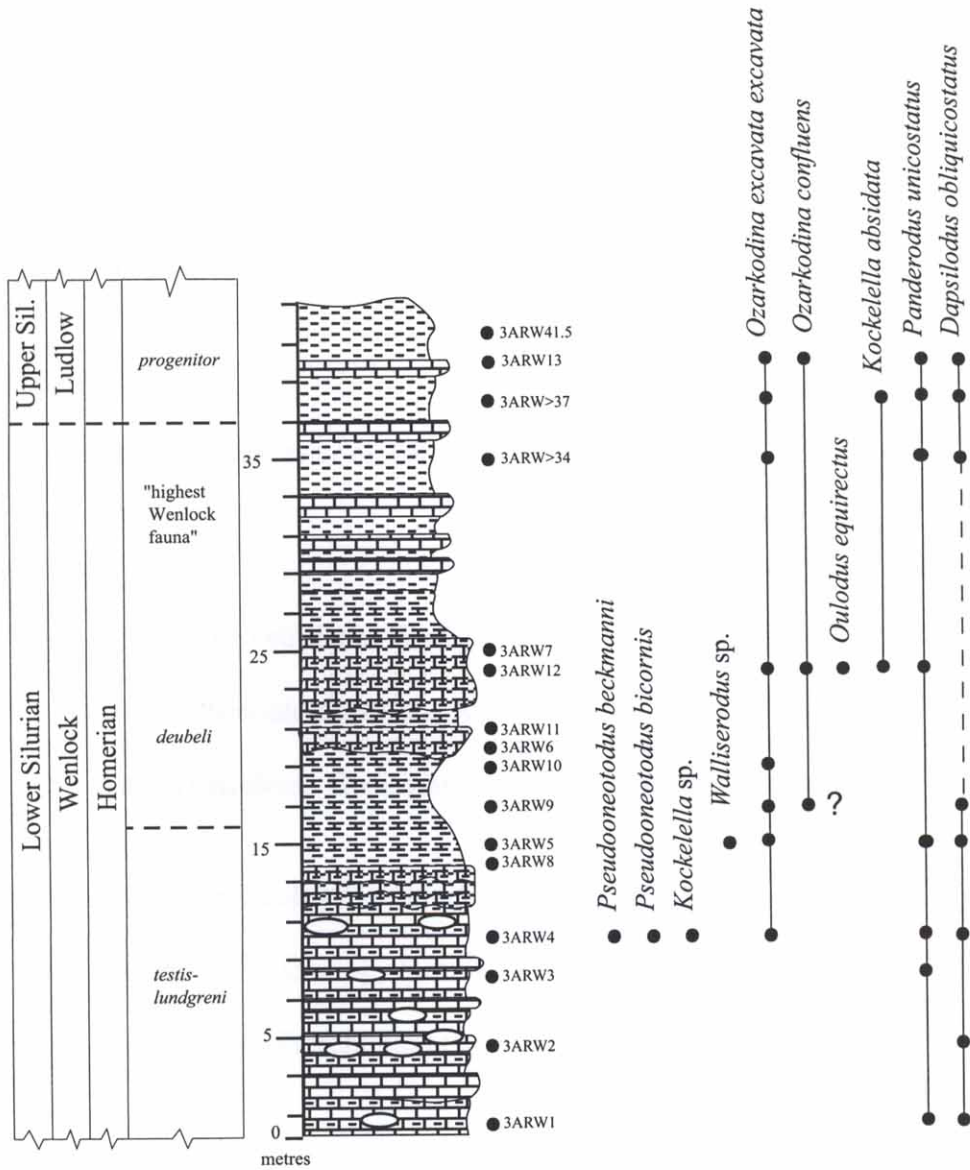
Appendix C, Figure 6. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Abbott River East section.



Appendix C, Figure 7. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Abbott River West Section 1.

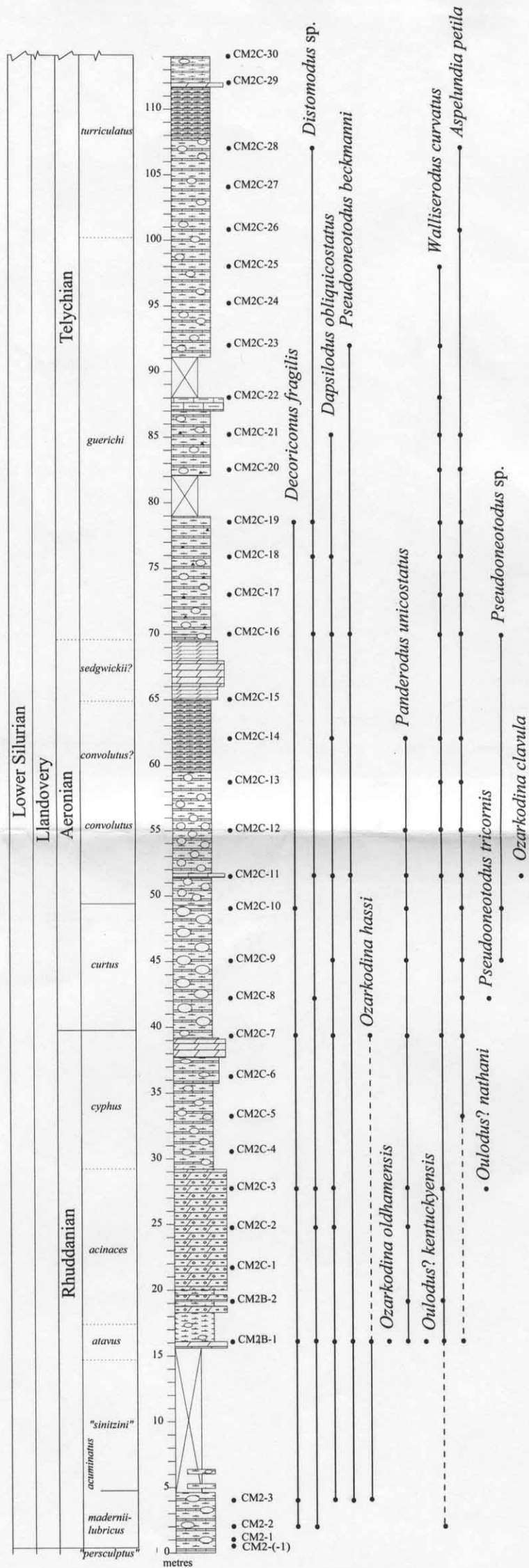


Appendix C, Figure 8. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Abbott River West Section 2.

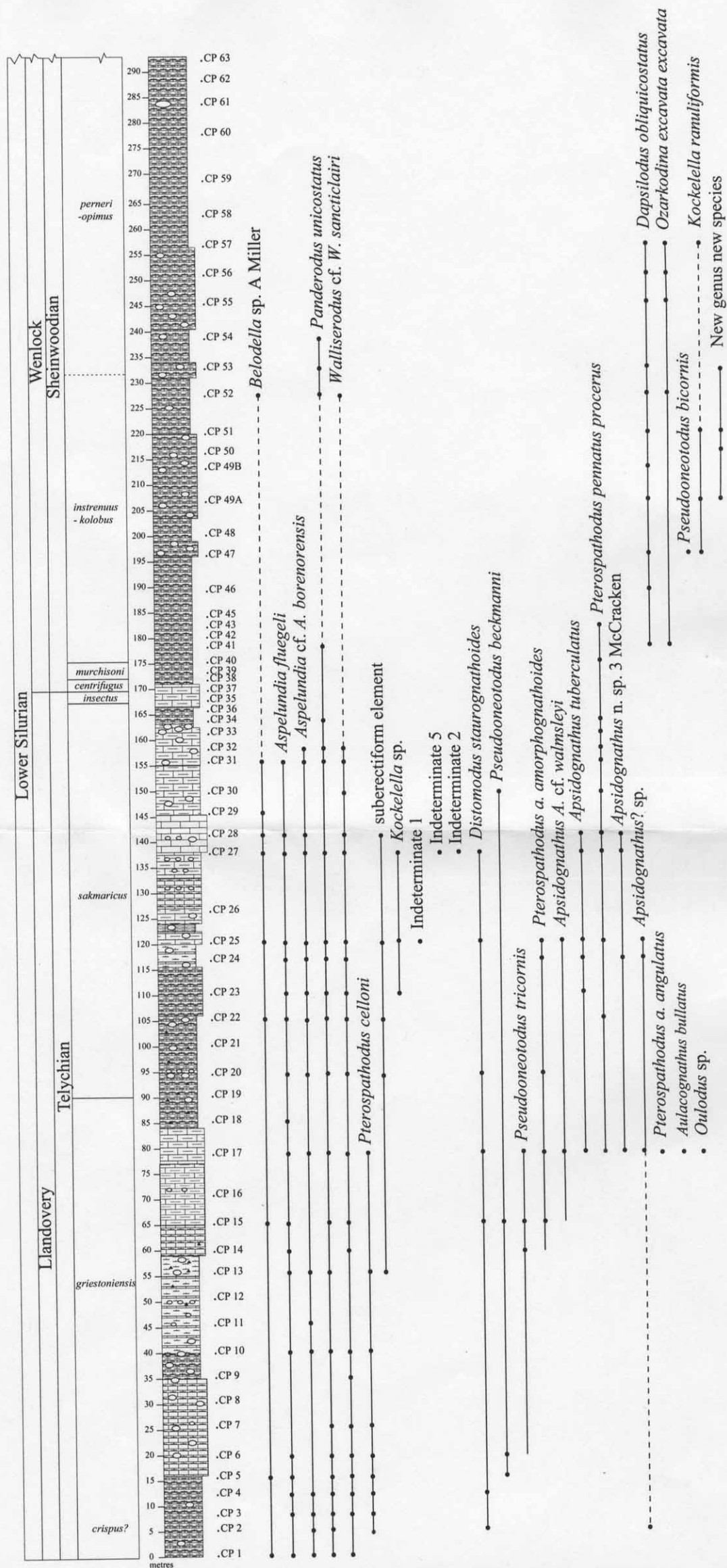


Appendix C, Figure 9. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Abbott River West Section 3.





Appendix C, Figure 3. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Cape Manning Section 2.



Appendix C, Figure 5. Graptolite zonation, stratigraphic section, samples, and conodont ranges for Cape Phillips North section.