CONODONTS FROM THE COBBS ARM FORMATION (MIDDLE ORDOVICIAN), NORTH-CENTRAL NEWFOUNDLAND

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by

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FRONTISPIECE

View south-west over Cobbs Arm

ABSTRACT

On New World Island, north central Newfoundland, the Middle Ordovician Cobbs Arm Formation constitutes only a small proportion of the dominantly volcanic and volcaniclastic strata of the island arc terrains characteristic of the Dunnage Zone. The Cobbs Arm Formation is predominantly composed of limestones that are dark grey in colour when mixed with volcanic detritus and light grey and more coarsely crystalline when purely carbonate. The purer carbonate accumulations of the formation would appear to have been deposited in an environment free of terrigenous detritus between emergent volcanics and shallow water volcanic sandstones to the north, and trench deposits to the south. The result was a carbonate grainstone barrier that subdivided parts of the Middle Ordovician coastline into a landward restricted lagoonal environment and an oceanward open marine environment.

Because of the presently deformed nature of the New World Island rocks, several small incomplete sections of the Cobbs Arm Formation were measured and sampled. Detailed investigation of the lithologies of the samples revealed a sedimentological pattern indicative of a slightly erratic transgressive phase of deposition. It is possible that the emergence of the arc terrains, which preceded the deposition of the Cobbs Arm Formation, and the subsequent subsidence of the island arc terrains, which accompanied and succeeded Cobbs Arm Formation deposition, was the fore and aftermath of a ridge-trench interaction. The transgression resulted in a landward shift of oceanward facies, now recorded in the verticle sequences of the Cobbs Arm Formation.

The conodont fauna of the Cobbs Arm Formation appears to be

divisible into two species associations. One relates well with sediments of the proposed restricted environment and the other relates well with sediments of a more open marine environment. On a finer scale, there appears to be a relationship between substratum characteristics and certain conodont species. Because of this apparent ecological control on many of the conodont species, the conodont zones and subzones of the Middle Ordovician were difficult to accurately apply.

Conodonts are found in relative abundance in the Cobbs Arm Formation and are represented by 39 multielement species and five residual forms, including 8 new species and 2 new genera. The two new genera are described on the basis of the two new species Pseudobelodina n. sp. A and New Genus A n. sp. A. The fauna is dominantly of North Atlantic Province affinity yet the most abundantly represented species is more commonly found in the Midcontinent Province, i.e. Panderodus gracilis (Branson and Mehl). This species, along with Periodon aculeatus Hadding, Pygodus anserinus Lamont and Lindstrom, Baltoniodus variabilis (Bergstrom), Protopanderodus varicostatus (Sweet and Bergstrom), and Pygodus serrus (Hadding) constitutes more than 75 percent of the total number of recovered conodont elements. Other important conodont species include: Baltoniodus prevariabilis-B. variabilis transition, Distacodus venustus (Stauffer), Drepanoistodus n. sp. A, Eoplacognathus lindstroemi (Hamar), E. robustus Bergstrom, Scalpellodus cavus (Webers), Strachanognathus parvus Rhodes, Walliserodus ethingtoni (Fahraeus), Walliserodus nakholmensis (Hamar) and Walliserodus n. sp. A.

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INTRODUCTION

1.1 Acknowledgements.

This thesis was supervised by L.E. Fahraeus whose keen interest, advice and critism aided immensely in the completion of the project. L.E. Fahraeus' conodont collections and his paleontology library were extremely useful. Laboratory and field support was funded by a National Research Council of Canada grant to L.E. Fahraeus. Personal financial assistance was provided by a Memorial University Fellowship. It is gratefully acknowledged.

I am indebted to the Geology Department as a whole for providing excellent laboratory and office conditions. W. Marsh provided immeasurable photography assistance, R. Hiscock aided in drafting and A. Thompson gave useful instruction on the use of the JEOL JXA microprobe and scanning electron microscope. Foster, Jerry, Lloyd and Pat kindly offered numerous forms of assistance whenever it was needed.

Special thanks go to fellow students S. Stouge for fruitful discussions on taxonomy and to D.F Baker for interesting discussions about everything else. I also extend a great deal of thanks to my parents and siblings for spiritual and financial assistance, especially during the final phases of the project.

1.2 Location and Access.

The carbonate sediments of the Middle Ordovician Cobbs Arm Formation outcrop on New World Island in the volcanogenic environment of the Dunnage Zone, in north central Newfoundland (Fig. 1). Type locality

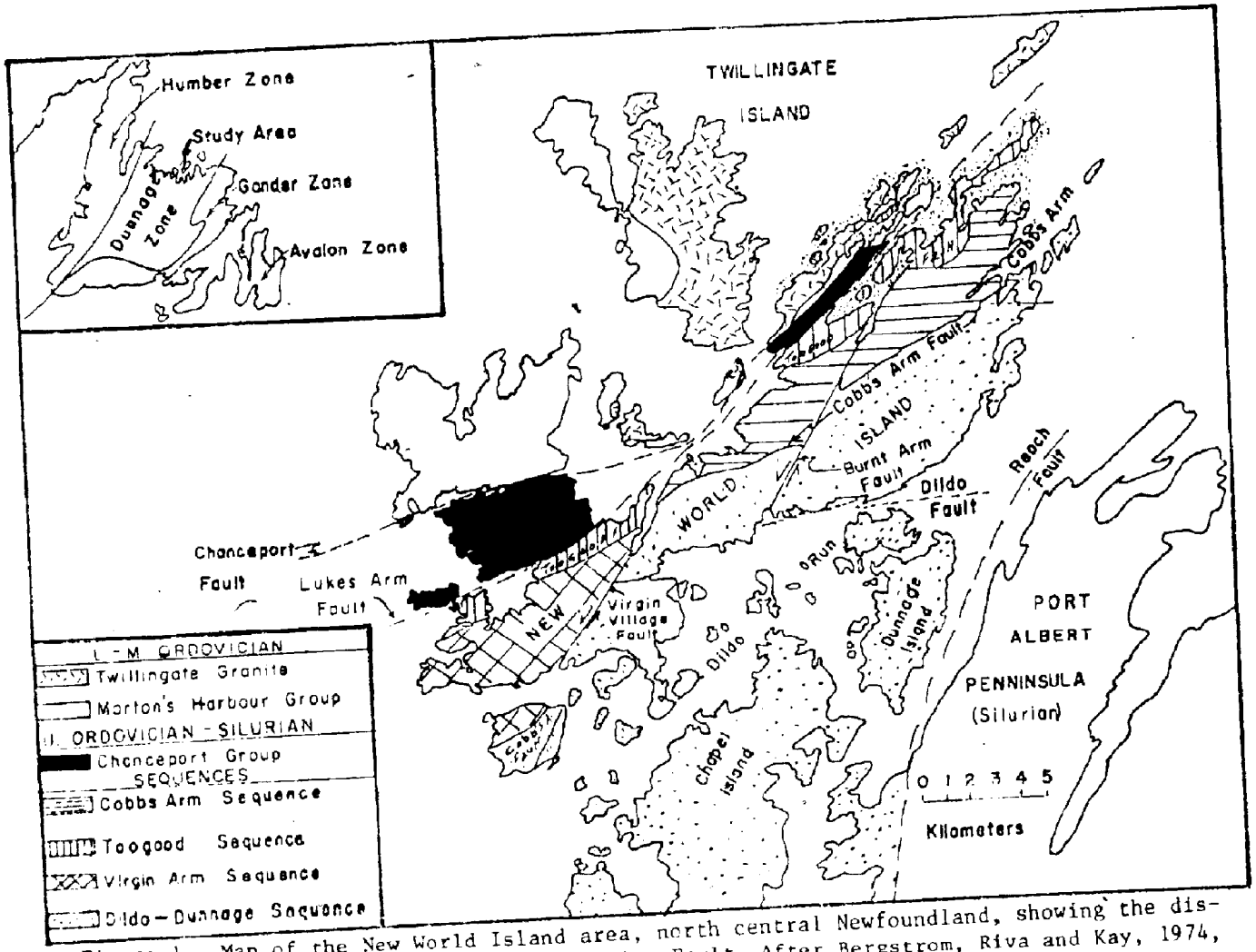

Figure 1. Map of the New World Island area, north central Newfoundland, showing the distribution of sequences south of the Lukes Arm Fault. After Bergstrom, Riva and Kay, 1974, and Dean and Strong, 1976b.

of this formation occurs within Cobbs Arm, north eastern New World Island, at latitude 49° 37' and longitude 54° 35'(Fig. 1). A series of fault bounded quarries, at the head of Cobbs Arm, offer excellent exposures of typical Cobbs Arm Formation lithologies, yet fail to give a true indication of the formation thickness. A more complete section can be seen north of Cobbs Arm at Quarry Cove (Fig. 2), (pocket in back of thesis).

A paved highway permits easy access to the study area from mainland Newfoundland. It transverses New World Island from Summerford, in the south west, to Twillingate Island, in the north east, and from it a gravel road leads to Cobbs Arm and other coastal villages (Fig. 2).

1.3 Previous Work.

Geological investigation of New World Island began with the early visit of Murray and Howley (1881). Much later, Heyl (1936) conducted a study mainly within the Bay of Exploits, but he included also the south west portion of New World Island. Twenhofel and Shrock (1937), and Twenhofel (1947), examined and described the sedimentary strata in the north eastern part of New World Island, and Baird (1953) undertook a reconaissance study of north eastern New World Island and Twillingate Islands.

Modern studies of the New World Island area commenced with mapping by Williams (1963). He compiled a one-mile-to-the-inch geologic map of New World and Twillingate Islands and recognized fifteen unnamed lithologic units. Kay and Williams (1963), and Harris (1966), outlined the relationships of New World Island geology on a smaller scale.

Kay (1967) summarized New World Island geology and introduced a system of stratigraphic nomenclature. Subsequent papers have accounted for revisions to the stratigraphic nomenclature and refinement of the

understanding of the structural complexity of New World Island and other parts of Notre Dame Bay (i.e. Kay, 1969c, 1970, 1976; Horne and Helwig, 1969; Horne, 1970; Bergstrom, Riva and Kay, 1974; Dean and Strong, 1977).

Twenhofel and Shrock (1937), Williams (1963), and Horne (1970), contributed much information pertaining to the distribution and composition of Orodvicion and Silurian faunas of New World Island, but these data were largely used for stratigraphic purposes. Neuman (1968, 1971, 1972, 1976), discussed, in more detail, the paleogeographic distribution and possible paleoecology of Arenigian and Llanvirnian brachiopods from New World Island and other northern Appalachian localities. Dean (1971, 1973) outlined the taxonomic composition and possible affinities of Arenigian, Llanvirnian and Llandeilan trilobites from two localities on New World Island. In addition he (1971), provided a list of conodont genera and species obtained from a single sample of limestone from Squid Cove (Fig. 2), and identified by T.T. Uyeno, Geological Survey of Canada. Bergstrom, Riva and Kay (1974), gained additional information about the timing of Ordovician sedimentation and volcanism on New World Island from their collections of graptolites and conodonts. McKerrow and Cocks (1977), located the proto Atlantic suture in central Newfoundland, as indicated by the composition of brachiopod and trilobite faunas on New World Island and further to the southeast of the Reach Fault (Fig. 1).

1.4 Present Study.

The incentive for the present study evolved from the work of Bergstrom, Riva and Kay (1974), who clearly demonstrated the richness and significance of the New World Island conodont fauna. The main objective is to describe in detail the conodonts and the stratigraphy of the

Middle Ordovician Cobbs Arm Formation from New World Island. Detailed investigation of sample lithologies and an analysis of the distribution and frequencies of various conodont species has lead to formulated conclusions about the sedimentology of the Cobbs Arm Formation and paleoecological characteristics of some conodont species. Supplementary to this, the possible nature of the conodont animal is discussed.

CHAPTER 2

METHODS OF STUDY

2.1 Collection of Samples.

The original nature of the Cobbs Arm Formation lithologies has been masked by the processes of pressure solution and recrystallization, and disaggregated by Silurian and Devonian faulting and folding. As a consequence of the latter events, a complete section of the Cobbs Arm Formation does not appear to exist. As a consequence of the forementioned processes the sedimentological characteristics of the sections that are exposed, are difficult to distinguish.

Therefore, 76 samples, for lithological and conodont studies, were collected from seven incomplete sections in an effort to get examples of the complete range of the represented sedimentary facies of the Cobbs Arm Formation.

Ten samples of limestone, or limy tuff, were collected from localities within the Summerford Group on New World Island. Additional samples were collected for interest from localitites in the Bay of Exploits, Badger Bay, and Lushes Bight, Long Island (Fig. 2). Details of these isolated samples are given in Appendix A.

Prior to collecting, sections were measured and lithologies noted. Samples weighing in excess of 5 kilos were taken for processing. See Figure 2 for the sample locations.

2.2 Processing of Samples.

In the laboratory, samples were crushed to walnut-sized fragments and placed in a 15 percent solution of Glacial Acetic Acid. Total

digestion required as few as ten days for purer limestone and as many as twenty days for impure limestone.

The resultant residues were washed through a 200 micron mesh sieve, dried and separated in Tetrabromethane (sp. gr. 2.88), with the conodonts settling in the heavy fraction, by one of two methods: 1) gravity settling, for periods of 12 hours or more; and 2) centrifugal separation, for a period of twenty minutes at 250 revolutions per minute.

Most samples were separated by the first method, but, because of the impure nature of many samples, some very large residues were recovered. In order to speed up separation of such samples, a centrifugal method was used. Residue was placed into Tetrabromethane in four 5 centimetre diamater test tubes, which were necked at their mid-length, and rotated at a slow speed of 250 revolutions per minute for twenty minutes. When rotation was completed the light fraction was poured off the top half of the test tubes while the heavy fraction was held back by a thick glass rod in the necked portion of the tube. The heavy fraction then was washed into another filter paper. This was cleaned with acetone and inspected under a binocular microscope for conodonts.

Gravity settling for periods of at least 12 hours proved the superior method.

CHAPTER 3

GEOLOGICAL SETTING

The field work for this study concentrated on the investigations and sampling of the carbonate Cobbs Arm Formation on New World Island, but additional collection was conducted in the Bay of Exploits, Badger Bay and on Long Island, all within Notre Dame Bay (Fig. 2). On a regional scale, this area lies within the north-central portion of the Dunnage Zone, one of the four divisions proposed by Williams (in press), for Newfoundland geology.

The rock succession of the westernmost of these four zones (Humber Zone), is interpreted to have formed at a stable continental margin, underlain by Precambrian metasedimentary and igneous rocks. Destruction of this continental margin in the latest Early Ordovician apparently resulted in the transportation and emplacement of packages of outer marginal mainly siliciclastic sediments and classic ophiolites onto the shallower water generally carbonate strata of the original continental margin platform (Stevens, 1970; Williams and Stevens, 1974; Williams et al., 1974).

The significance of the easternmost Gander and Avalon Zones (Fig. 1) is presently less well known compared to the Dunnage and Humber Zones to the west. The metasediments of the Gander Zone appear to lie on basement and may represent outer continental margin sediments, mirroring similar sediments in the Humber Zone.

The late Precambrian volcanic and sedimentary rocks of the Avalon Zone may have originated during an orogeny earlier than that displayed in the Humber and Dunnage Zones (Williams, in press). The Precambrian strata of the Avalon Zone is unconformably overlain by terrig-

enous sediments representative of a time interval comparable to the platformal sediments of the Humber Zone. These Lower Paleozoic sediments comprise a basal quartzite unit, basinal shales of Cambrian age, and intertidal-supratidal sands, silts and muds of Early Ordovician age. This indicates that the Avalon Zone was gently subsiding to stable during the earliest Paleozoic.

The main component of the Ordovician geology of Notre Dame Bay, and the rest of the Dunnage Zone, is interpreted as in situ oceanic crust (i.e. Lushes Bight Group and lowermost Mortons Harbour Group (Fig. 2)), with overlying thick volcanic arc sequences (i.e. Cutwell Group, Wild Bight Group, lower half of the Exploits Group and Summerford Group (Fig. 2)). The chaotic Dunnage Melange, to the southeast, may represent the vestige of an ancient oceanic trench adjacent to the volcanic arcs (Williams and Hibbard, 1976).

In the Cobbs Arm Sequence on New World Island (Fig. 1), the volcanics and sediments of the Summerford Group are locally overlain by the carbonates of the Cobbs Arm Formation. Elsewhere in the New World Island area, the arc volcanics, the Dunnage Melange and the Cobbs Arm Formation are all overlain by an extensive yet condensed unit of Caradocian black shales. In the western part of Notre Dame Bay, this unit usually consists of carbonaceous and cherty argillites (Dean and Strong, 1976f,g).

These Caradocian shales mark a definite end to volcanism and melange development in the Ordovician of Notre Dame Bay, and apparently represent rapid subsidence in the areas south of the Lobster Cove-Chanceport Fault System (Fig. 2). The shales are in turn conformably overlain

everywhere by the Upper Ordovician to Silurian Sansom Greywacke. The sediments of this formation are dominantly volcaniclastic in composition, of probable turbidite origin (Horne, 1970), and generally grade upwards into the coarser sediments of the Goldson Conglomerate. This formation likewise exhibits sedimentary structures that suggest a fluxo-turbidite origin (Horne, 1970). The most likely source area, for both of these sedimentary units, is the dominantly volcanic terrains north of the Lobster Cove-Chanceport Fault System.

On the Fortune Harbour Peninsula and in an area further west in Notre Dame Bay, the Sansom Greywacke is overlain by sedimentary and volcanic strata of probable Silurian age (Cottrels Cove Group and Roberts Arm Group, respectively (Fig. 2)). The basal unit of these packages of strata is composed of a complex sedimentary-volcanic slump melange that contains lenses of Goldson type conglomerate (Dean and Strong, 1976f,g). The Chanceport Group, of New World Island, lies north of the Lukes Arm Fault (Fig. 2), and is considered to be a correlative of the Cottrels Cove and Roberts Arm Groups to the west (Dean and Strong, 1976h).

The top of all three of these groups is faulted to the north against older strata along the Lobster Cove-Chanceport Fault System (Fig. 2). This low angle south-easterly directed Silurian thrust is the most prominent such feature in Notre Dame Bay (Dean and Strong, 1977). Thrusts trending east-north-east-west-south-west, of similar style but smaller displacement, are most evident south of the Lobster Cove-Chanceport Fault System on New World Island, where several low angle thrusts have forced older strata to the surface over younger strata. These thrusts now have a vertical attitude.

Consequently the thrusts and the Ordovician and Silurian strata were both likely folded during the Acadian orogeny (Dean and Strong, 1977).

North-east-south-west trending post-Acadian faults transect the stratigraphic pattern created by the low angle Silurian thrusts on New World Island to produce the present geometry of isolated blocks; each with a stratigraphy slightly different from the next. Williams (1963), recognized two, Kay (1967), recognized three and Bergstrom et al. (1974), recognized four of these dissimilar fault-bounded structural-stratigraphic sequences to the south of the Lukes Arm Fault on New World Island (Fig. 1).

The Virgin Arm Sequence (Bergstrom et al., 1974), was defined to include the Ordovician and Silurian rocks of south-west New World Island and the north-west part of Farmers Island (Fig. 1). It is bounded to the north by the Toogood Fault (Kay, 1967), on the east by the post-Acadian Virgin-Village Fault and to the south on Farmers Island by the Cobbs Arm Fault (Horne and Helwig, 1969). The geology of this part of New World Island was interpreted by Horne (1970) to include the Summerford Group, the Sansom Greywacke (Heyl, 1936), and the Goldson Conglomerate (Twenhofel and Shrock, 1937). The Summerford Group, in this sequence, ranges in age from the Tremadocian to the Ashgillian. It is composed of more than 1000 metres of volcanics and sedimentary rocks and has been subdivided into six mappable units lettered Z,A,B,C,D,E (Horne, 1970). The Summerford Group is conformably overlain by the clastic sediments of the Upper Ordovician-Lower Silurian Sansom Greywacke, which shows a tendency to coarsen and become more volcanic upward to where it is conformably succeded by the Silurian Goldson Conglomerate.

The Summerford Group, in the Cobbs Arm Sequence, is represented

by about 300 metres of basic lava flows, agglomerates, tuffs and volcanic sandstones of Middle Ordovician age. It is overlain by the sedimentary Hillgrade Group, which includes the Cobbs Arm and Rogers Cove Formations. The Cobbs Arm Formation (Bergstrom et al., 1974), consists of up to 45 metres of light grey, medium to coarsely crystalline limestone, with minor dark argillaceous limestone, and is capped with possible unconformity by approximately 30 metres of the black siliceous shale of the Rogers Cove Formation. The Hillgrade Group is conformably overlain by the Sansom Greywacke and the Goldson Conglomerate.

The Toogood Sequence consists predominantly of the Silurian Goldson Conglomerate, which in this sequence has been subdivided into three formations; Herring Head Formation, Burnt Island Formation and Mix Cove Formation (Kay 1969c, 1976). The Goldson Conglomerate lies unconformably on either the Sansom Greywacke, or on the tuffs or shales of the Hillgrade Group. The Ordovician stratigraphy of the Toogood Sequence is similar to that of the Cobbs Arm Sequence, but is not as well represented (Horne and Helwig, 1969).

Strata of the Dildo-Dunnage Sequence are possibly as old as Middle Cambrian (Kay and Eldridge, 1968). The Dunnage Melange, a bouldery mudstone-melange, is the oldest unit of this sequence and may be as thick as 10,000 metres (Williams and Hibbard, 1976). It is bounded by the Reach Fault toward the east and youngs northward to where it is succeeded by the conglomerates of the Cheneyville Formation. Succeeding this are Caradocian black shales of the Dark Hole Formation, the Sansom Greywacke and the Goldson Conglomerate.

CHAPTER 4

LITHOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE COBBS ARM FORMATION

4.1 Introduction.

The Cobbs Arm Formation constitutes the lower of the two formations of the Middle Ordovician Hillgrade Group; a package of sedimentary strata that is defined within, and generally restricted to, the Cobbs Arm Sequence of New World Island (Fig. 1). The outcrop pattern of the Cobbs Arm Sequence is strongly fault and fold controlled such that the presently exposed sections have a near vertical to overturned attitude. The base of the formation is seen to lie on the tholeitic volcanics of the Summerford Group at several localities, but the top of the formation is seen with some certainty only at the Squid Cove locality (Fig. 2), although even here, the actual contact between the Cobbs Arm Formation and the overlying Caradocian black shale of the Rogers Cove Formation is buried beneath beach rubble.

When examined in the field, the Cobbs Arm Formation appears to be lithologically variable, but only two members need to be distinguished: a dark grey impure limestone and a light grey, medium to coarsely crystalline pure limestone.

Examination of thin sections and acetate peels of numerous samples shows that the dark grey limestone contains appreciable insoluble volcanic detritus that is generally of silt to mud size. This insoluble material is the cause of the dark colouration, as both texturally coarse and texturally fine limestones can have the dark colouration.

Extensive and complex pressure solution processes have resulted in concentrations of this insoluble material into major solution surfaces

that roughly parallel the original bedding. Pressure solution is most evident in the dark grey limestones where the concentrations of insoluble material appear as irregular one centimetre thick beds, a characteristic that is herein referred to as anastomosis "bedding". In addition to this, the dark grey limestones have undergone slight recrystallization. The original nature of the sediment was nonetheless easily distinguished.

The light grey pure limestones have very little insoluble material and are therefore lighter in colour and lack the anastomosis "bedding" that is characteristic of the dark grey limestones. Samples of the light grey limestone vary texturally from grainstones to mudstones as classified according to Dunham (1962). The grainstones characteristically have well developed syntaxial overgrowth cement that appears to have retarded recrystallization. The texturally finer samples, however, are partially to extensively altered by aggrading neomorphism. In the latter cases, observations of the abundance and variety of fossil fragments and the density of crinoid grains were made to ensure that the original sediment had indeed been texturally fine. Crinoidal and other fossil fragments are little altered by the aggrading neomorphism; therefore such observations were deemed trustworthy.

In addition to the dark grey and light grey limestone members, the Cobbs Arm Formation has a calcareous tuff component in several instances. These tuffs are generally green in colour because of the chloritized nature of the constituent volcanic fragments.

Appendix B illustrates some of the characteristic components and textures of the Cobbs Arm Formation sediments.

4.2 Lithostratigraphy.

In an attempt to investigate as much of the conodont composition and sedimentology of the Cobbs Arm Formation as possible, seven incomplete sections were measured and sampled. The thicknesses, sample locations and sedimentological characteristics of six of the seven sections are illustrated in Figures 5,6,7,12 and 14. The distribution and frequencies of the numerically more abundant conodont species are shown alongside each of the sections in these figures. See Figure 2 for strike and dip data and the locations of the sections and Tables 1a and 1b (pocket in back) for the complete distribution of the conodont species in each section.

4.2.1 Cottles Island Section.

The Cottles Island section (Fig. 2), comprises 46.2 metres of relatively homogenous and pure coarsely crystalline grey limestone (Fig. 3). The lower few metres of the limestone section is covered and the upper contact of the section is faulted. A total of 19 samples, for conodont and lithological study, were taken at 2 to 3 metre intervals through the section. The main fossil components and textural properties of each of these samples is diagramatically illustrated in Figure 5.

The four textural classes used in the diagramatic representation of the sedimentology of the section illustrate the wave kinetic energy of the environment of deposition. The grainstones would be deposited in a sedimentary environment with a high wave kinetic energy release and the mudstones in a sedimentary environment with a low wave kinetic energy release. The cyclic sedimentology of the Cottles Island section would thus seem to be a response to alternating conditions of high and

Figure 3. View eastward of the Cottles Island section. Base of the section is to the right (arrow). The left arrow marks the faulted top of the measured section.

Figure 4. Exposure of the uppermost part of the Squid Cove section. The hammer at the right marks the top of the limestone. The hammer at the left marks the base of the black shales of the Rogers Cove Formation.

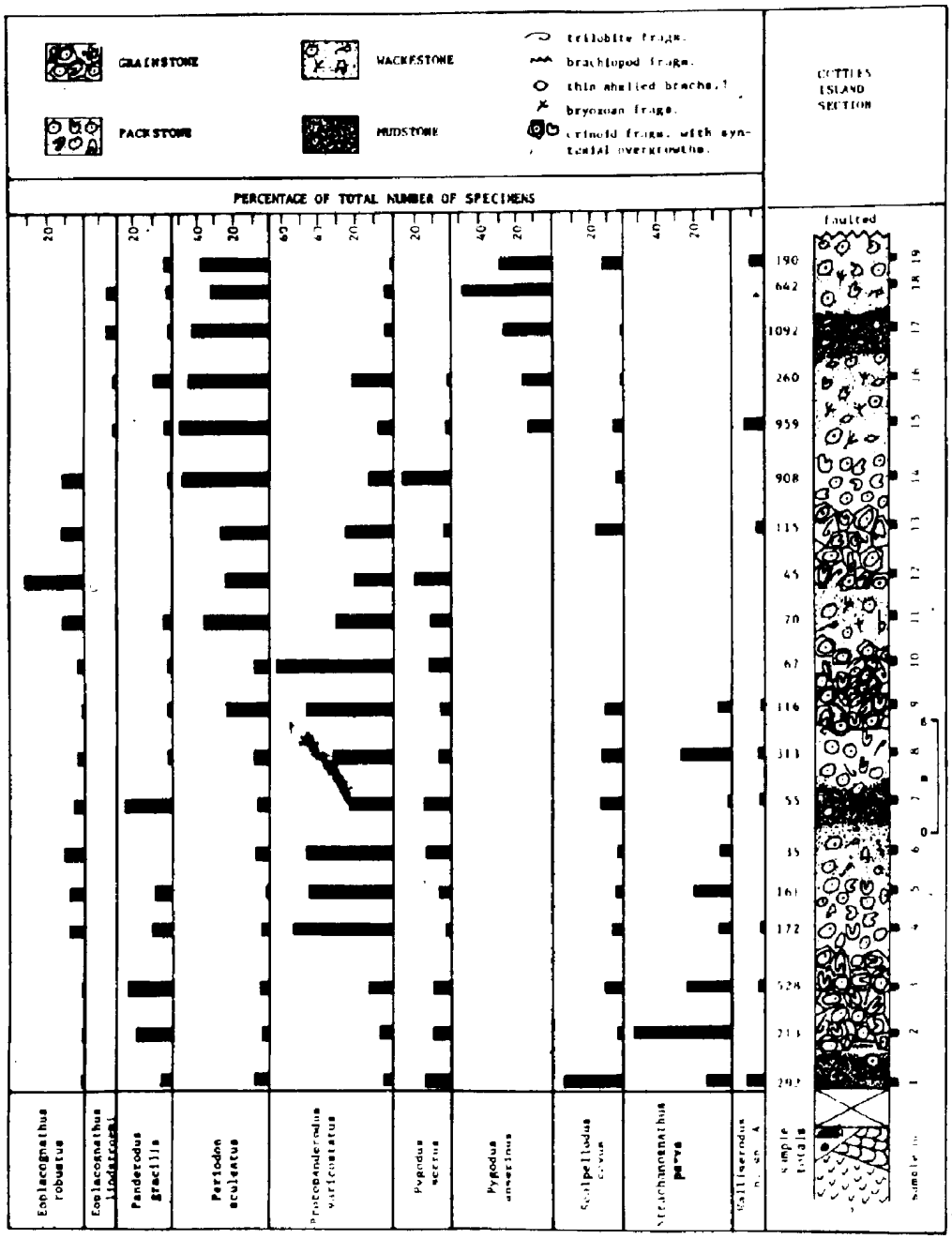

Figure 5. Sedimentology of the Cottles Island section and the distribution and relative abundance of some common conodont species.

low wave kinetic energy.

4.2.2 Squid Cove Section.

On the southeastern shore of Squid Cove (Fig. 2), there are three thin beds of limestone in a section of dominantly calcareous tuff (Fig. 4). The limestone beds were deposited under conditions of relatively low wave kinetic energy release and contain abundant insoluble volcanic detritus except for in the uppermost part of the section. The true nature of the contact between the uppermost limestone and the overlying black shale of the Rogers Cove Formation is unknown because that part of the sequence is covered (Figs. 4,6).

4.2.3 Hillgrade Section.

Approximately 37 metres of carbonate grainstones rich in volcanic detritus and relatively pure lime mudstones were measured and sampled near the village of Hillgrade (Figs. 2,8). The textural classification of each sample suggests that the lower two-thirds of the sediments were deposited under conditions of high wave kinetic energy release, whereas the upper one-third of the sediments appear to represent conditions of low wave kinetic energy release (Fig. 7).

4.2.4 Cobbs Arm Road Section.

A small section of approximately 22 metres was measured along a roadcut on the Cobbs Arm road 1.1 kilometres east of the head of Burnt Arm (Fig. 2). The sediments of this section have a high percentage of volcanic detritus and are thus dark grey in colour (Fig. 9). Sediments of the lower and upper parts of the section were deposited under conditions of relatively low wave kinetic energy release, whereas the sediments of the middle two-thirds of the section represent conditions of

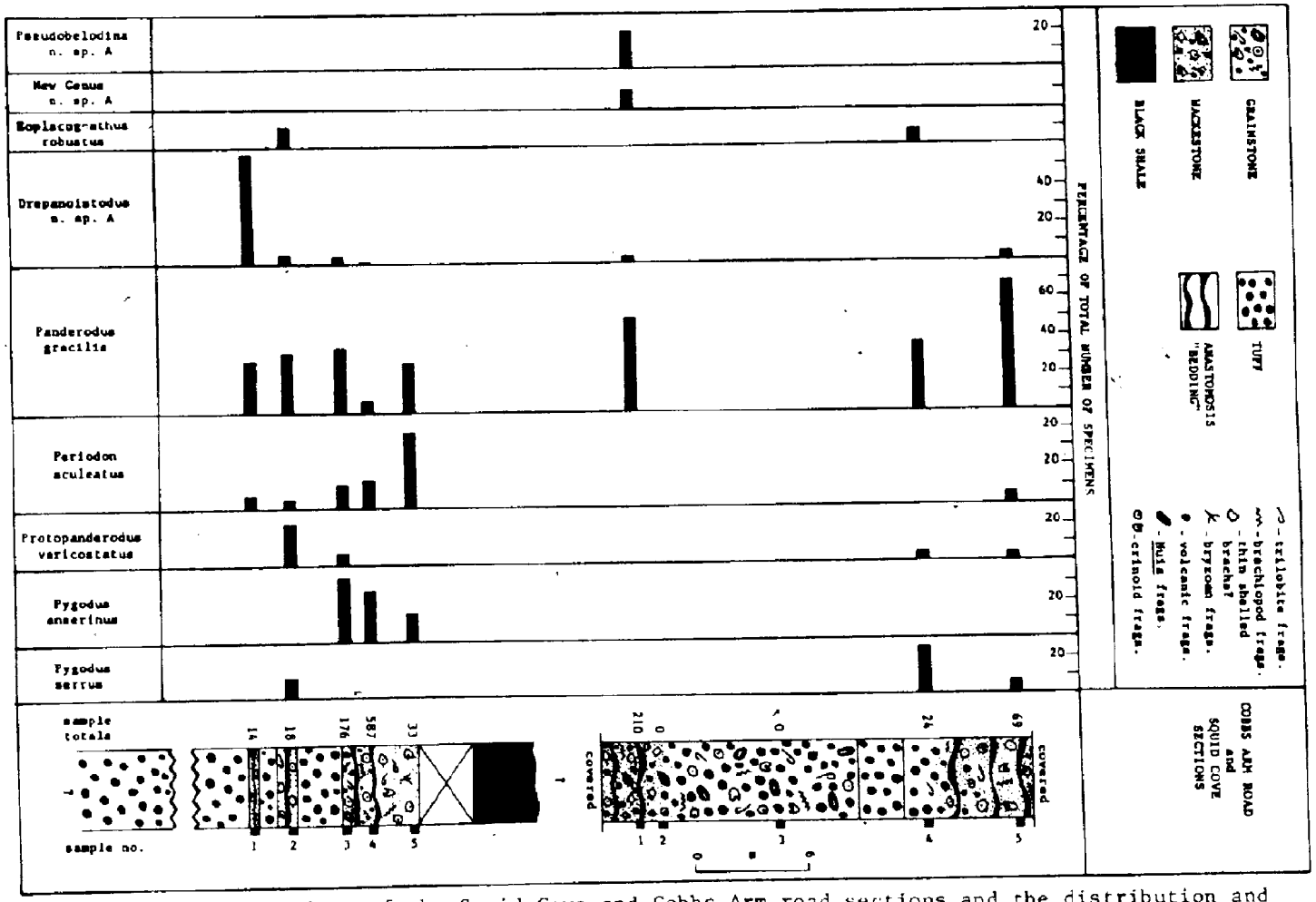

Figure 6. Sedimentology of the Squid Cove and Cobbs Arm road sections and the distribution and relative abundance of some of the common conodont species.

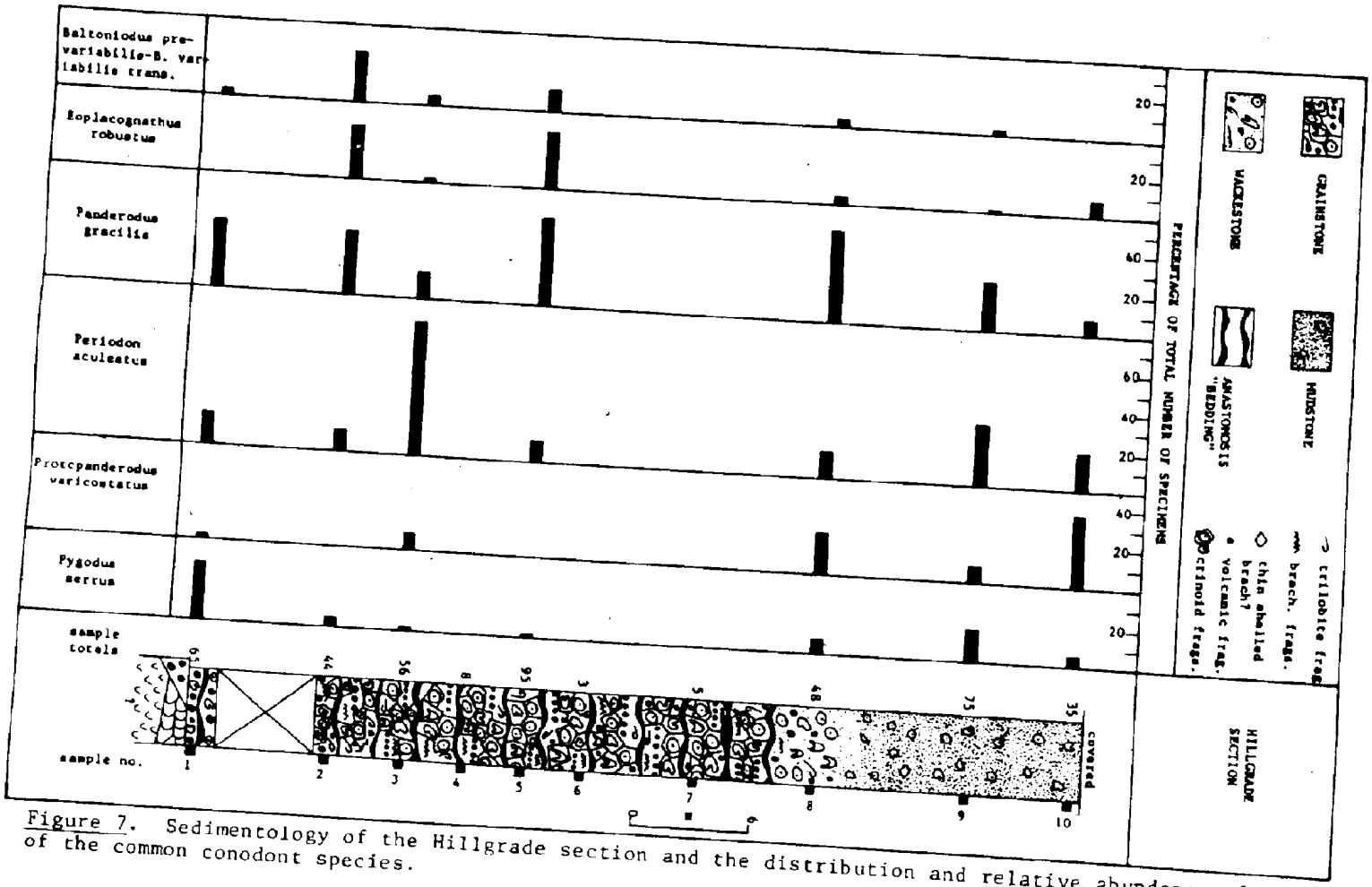

Figure 7. Sedimentology of the Hillgrade section and the distribution and relative abundance of some of the common conodont species.

Figure 8. View southward of the Hillgrade section. Tree covered volcanics are to the right and overturned and barren limestones are to the left.

Figure 9. View west of the Cobbs Arm road locality.

high wave kinetic energy release, very near a source of terrigenous-clastic sediment (Fig. 6).

4.2.5 Cobbs Arm Section (Middle Quarry Face).

This section is located within the main quarry at the head of Cobbs Arm (Fig. 2). It comprises approximately 27 metres of sediments that were primarily deposited under conditions of low wave kinetic energy release, however, there are three zones within the section that represent conditions of high wave kinetic energy release (Fig. 12). Parts of the sections have a fairly high percentage of insoluble terrigenous detritus and thus exhibit the anastomosis "bedding" characteristic of the dark grey limestone. The remaining sediments are relatively pure limestone. In outcrop, this section is viewed as alternating beds of light and dark grey limestone (Fig. 10).

4.2.6 Cobbs Arm Section (Western Quarry Face).

Five samples were collected from the 13 metre thick section of light grey crystalline limestone of the westernmost escarpment in the Cobbs Arm quarry (Figs. 2,11). For the sample spacings, and a summary of the distribution of the conodont species, see Figure 13 and Tables 1a and 1b respectively. Detailed examinations of lithology were not done on the samples from this small section.

4.2.7 Quarry Cove Section.

The Quarry Cove section of the Cobbs Arm Formation (Fig. 2), is divisible into two members: a 4 metres thick lower member composed of dark grey limestone with anastomosis "bedding", and a 34 metres thick upper member composed of light grey medium to coarsely crystalline limestone (Fig. 15). The lower contact of the measured section is faulted and

Figure 10. View southward of the overturned Cobbs Arm section (middle quarry face). Note the interbedded nature of the dark grey and light grey limestones.

Figure 11. View southward of the overturned Cobbs Arm section (west quarry face). Note the calcareous tuff bed (arrow).

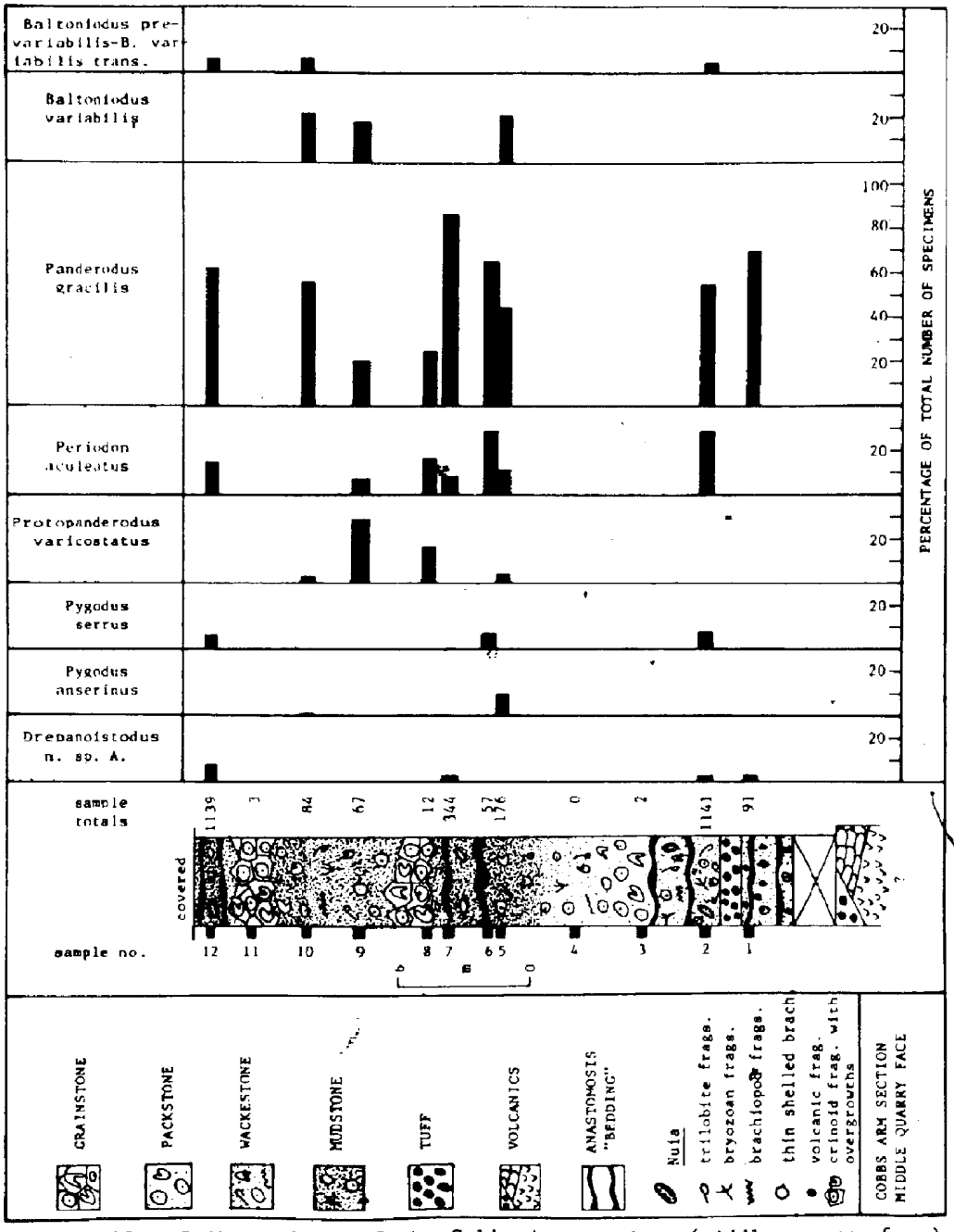

Figure 12. Sedimentology of the Cobbs Arm section (middle quarry face), and the distribution and relative abundance of some common conodont species.

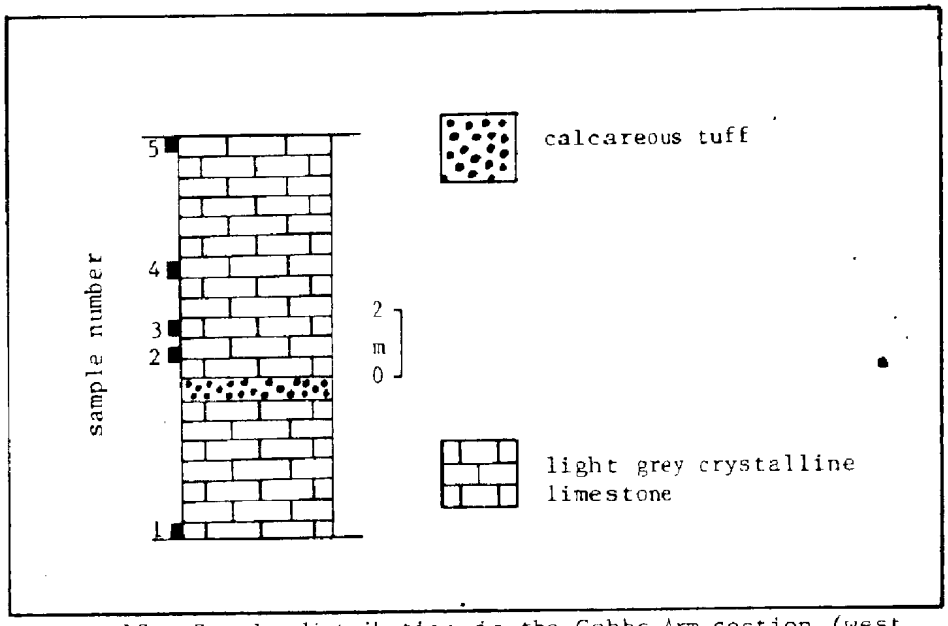

Figure 13. Sample distribution in the Cobbs Arm section (west quarry face).

the upper contact is covered by water. A total of 19 samples for conodont and lithological study were collectedat 2 metre intervals through the section. An additional sample was collected close to the volcanic-limestone contact.

The main paleontological components and lithological classification of each of the 20 samples are diagramatically illustrated in Figure 14. The presence of the calcareous algae Hedstroemia in sample 20 suggests water depths of 0 to 10 metres (Moore, 1977). Girvanella (matrix) in samples 1 and 2 suggests depths of 10 to 50 metres (Moore, 1977).

The cyclic sedimentation of the Quarry Cove section is considered to be the result of alternating conditions of high and low wave kinetic energy release.

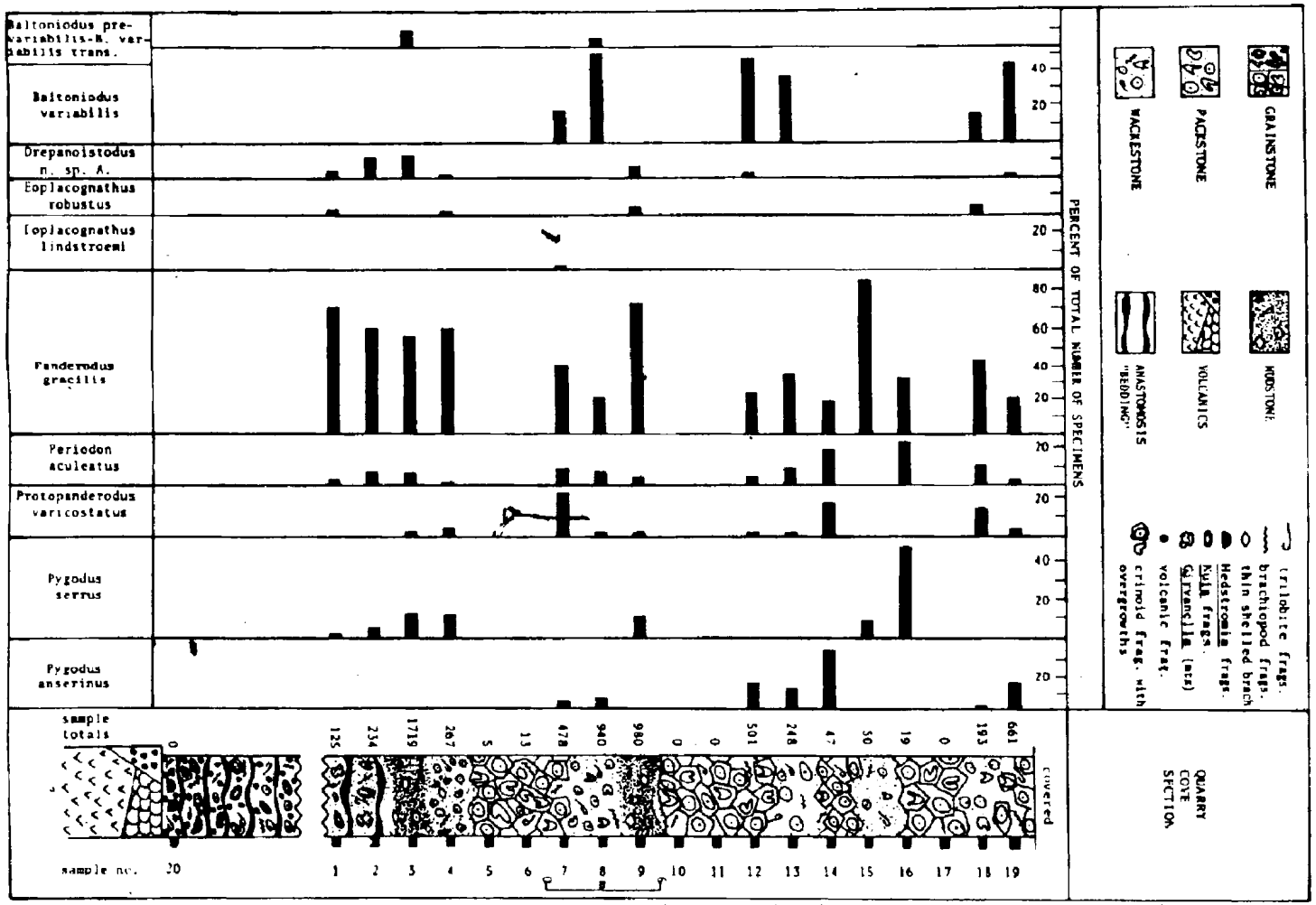

Figure 14. Sedimentology of the Quarry Cove section and the distribution and relative abundance of some of the common conodont species.

Figure 15. View eastward of the Quarry Cove section. The base of the section is approximately marked by the left arrow; top of the section is marked by the right arrow.

Figure 16. Limestone lens (outlined) in the Summerford Group volcanics near Tilt Cove.

4.3 Sedimentology of the Cobbs Arm Formation.

The Middle Ordovician volcanism in the Cobbs Arm area is thought to have been very active because the volcanics of the Summerford Group are dominated by basic flows and submarine pillow basalts with only minor interlayered tuffs and agglomerates (Harris, 1966). However, in the Squid Cove-Tilt Cove area (Fig. 2), the volcanic stratigraphy of the Summerford Group comprises a larger proportion of calcareous tuffs, which have yielded late Arenigian shallow-water-marine fossil assemblages described and discussed by Neuman (1976). Similar discoveries have also been made within calcareous tuffs of the Summerford Group in the Virgin Arm Sequence (Neuman, 1968, 1971, 1972). Evidence of short episodes of carbonate sedimentation within the Summerford Group is seen in the form of thin limestone lenses (i.e. Fig. 16).

In the later part of the Middle Ordovician, volcanism appears to have abated quite suddenly, allowing the development of volcaniclastic sandstones and the uninhibited organic production and deposition of unknown thicknesses of Cobbs Arm Formation limestone. Kidd, Dewey and Nelson (1977), suggest that volcanism terminated because of the attempted northwest subduction of a spreading ridge beneath the Summerford Group arc complex. They are also of the opinion that the Cobbs Arm Formation was deposited on the outer arc platform during the maximum arc uplift at the height of the ridge-arc interaction.

In the Cobbs Arm area, the slope of the volcanic substratum was probably fairly low since the generally carbonate sediments of the Cobbs Arm Formation appear to have been deposited in an environment with a high-low-high-low pattern of wave kinetic energy release. The Quarry Cove

section, for example, is underlain by massive volcanics and comprises a lower unit of carbonate grainstones rich in volcanic detritus that appear to grade upward into wackestones rich in volcanic detritus. These are in turn succeeded by a series of alternating mudstones or wackestones and grainstones, all of which are composed of relatively pure limestones. Presumably the purer carbonate sediments accumulated far enough oceanward to escape the influx of volcanic detritus from the emergent volcanic arc.

The vertical changes, in the sediment characteristics of the Quarry Cove section, are considered to be the result of transgression of the Middle Ordovician sea onto the arc volcanics. This is possibly the result of arc subsidence following a ridge-trench interaction (Kidd, Dewey and Nelson, 1977). The transgression superimposed oceanward facies over more landward facies in accordance with Walther's Law (Walther, 1894).

The cyclic nature of the grainstones and mudstones, in the upper two thirds of the section (Fig. 14), may be indicative of a stop-start condition of transgression, i.e. a sea level rise would cause a shoreward shift of a grainstone facies over a wackestone facies, but with a temporary cessation of the transgression, the grainstone facies would prograde seaward, followed also by a seaward shift of the more landward facies. Conceivably, the same effect could be produced by a fluctuation of sediment influx in an environment with a constant rate of transgression, but fluctuations in the in-situ production of carbonate sediment is a difficult process to assess.

The Cobbs Arm section (middle quarry face), appears to have been deposited under environment conditions similar to those of the

Quarry Cove section, but contains a higher proportion of lime mudstones (Fig. 12). It exhibits a transgressive sequence beginning with interbedded wackestones rich in volcanic detritus and calcareous tuff, which are succeeded by alternating high and low energy purer carbonate sediments. The influx of insoluble terrigenous mud into the lime mudstones, throughout the section, must herald the seaward progradation of the mixed terrigenous-carbonate facies. The lime mudstones of this section, and most probably those of the Quarry Cove section, are thus interpreted as lagoonal rather than basinal. Consequently, these two sections are considered to represent only the high-low-high portion of an environment with a high-low-high-low pattern of wave kinetic energy release.

A conceptual model for such an enviromnent is shown in Figure 17. It is noteworthy that the development of a narrow offshore barrier, as depicted in this model, would effectively partition the coastline and perhaps restrict circulation within the lagoon. The restricted circulation within the lagoon could in turn result in slightly raised temperatures and salinities.

Sediments of the Cobbs Arm road section (Fig. 6) are very rich in volcanic detritus, and consequently are most likely representative of a terrigenous and mixed carbonate-terrigenous facies (Fig. 17). Sediments of the Hillgrade section (Fig. 7) were presumably deposited within a mixed carbonate-terrigenous facies and a lagoonal lime mudstone facies.

Sediments of the Squid Cove section, however, may have been deposited under different environmental conditions than the other examined sections from the Cobbs Arm Sequence. The calcareous tuffs of the lower portion of the Squid Cove section most likely represent shallow

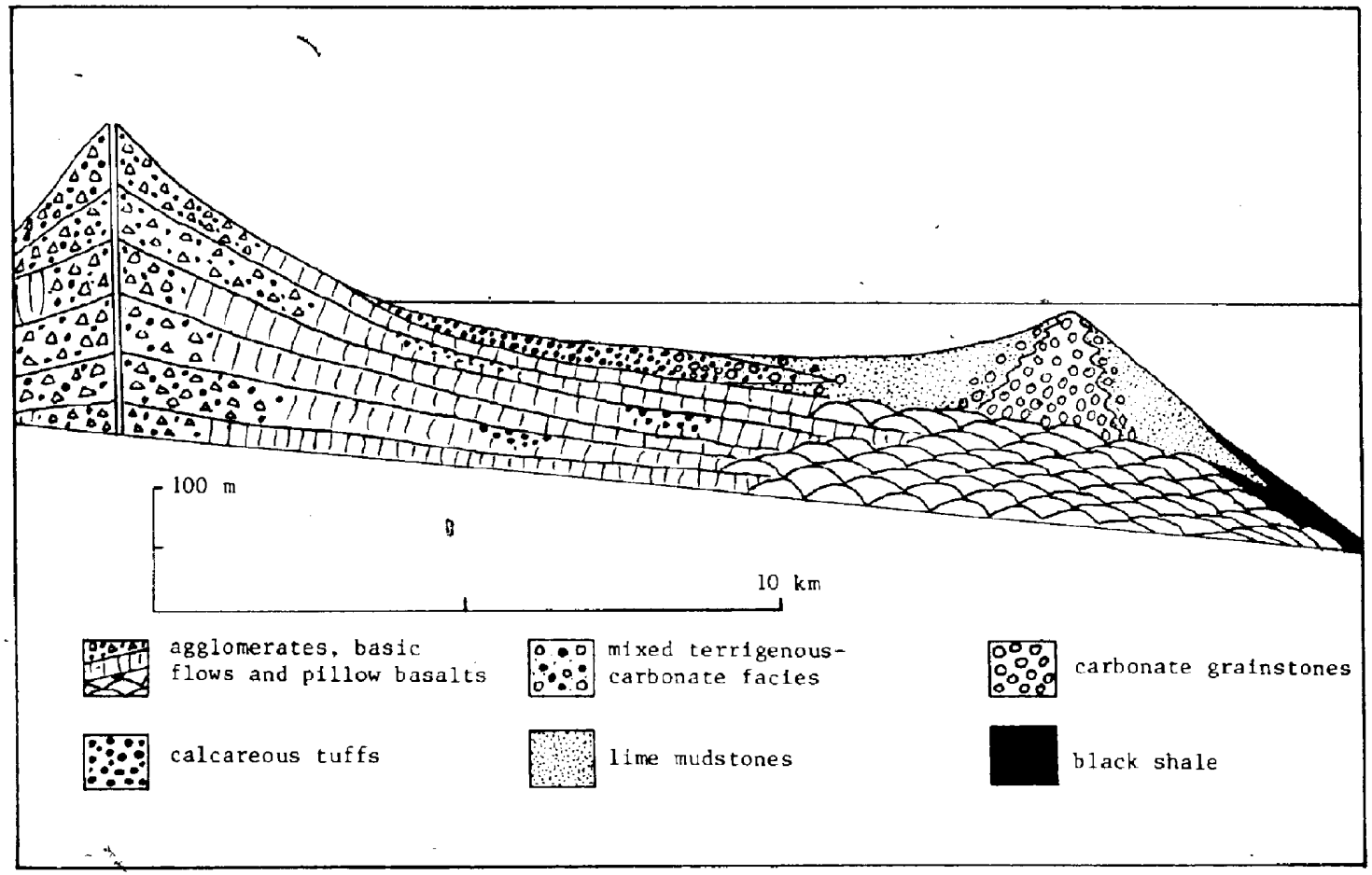

Figure 17. A conceptual model of the Cobbs Arm Formation sedimentation.

water near-shore volcanic sands and silts. These are interbedded with and overlain by carbonate wackestones rich in volcanic detritus, which are in turn overlain by purer carbonate muds. These lime mudstones appear to be succeeded by basinal shales. If this is indeed the case, the Squid Cove section must have been deposited under conditions of relatively high substratum slope, and thus in an open marine environment rather than in a restricted marine environment. Sediments of an open marine environment would exhibit a high-low pattern of wave kinetic energy release.

The only measured section of appreciable thickness occurring outside of the Cobbs Arm Sequence is located within the Toogood Sequence near Cottles Island, in the south western part of New World Island (Fig. 2). The conodont faunal and the sedimentological characteristics of this section are different than most of the sections in the Cobbs Arm Sequence. If it was similarly deposited in an environment with a high-low-high-low pattern of wave kinetic energy release, only the low-high-low portion of this is preserved in the section (Fig. 5). None of the sediments contain volcanic detritus and consequently are considered to represent an offshore area of carbonate sediment accumulation, i.e. far enough basinward to not contain volcanic detritus of the near shore high energy facies. It is noteworthy that the grainstones of this section were more fossiliferous than those of the Quarry Cove section (Figs. 5,14). The wave kinetic energy may thus have dissipated over a wider zone, more suitable for inhabitation, than the narrow barrier zone of the Quarry Cove section (Fig. 17).

The mudstones of the mudstone-grainstone cycles, in the lower part of the section, are considered analagous to those of the Quarry Cove section (i.e. lagoonal). The mudstones of the mudstone-grainstone cycles

in the upper part of the section, however, are interpreted as an ocean-ward facies rather than a shoreward lagoonal facies. This follows from the similar cyclic and transgressive nature of the Cottles Island and Cobbs Arm area sections. The basinal muds would develop when transgression began to outdistance the rate of sedimentation.

The most probable direction of Cobbs Arm Formation progradation was to the south or south east, between an emergent volcanic arc to the north and the trench deposits of the Dildo-Dunnage Sequence to the south. The Silurian low angle thrusts, on New World Island, have brought into close proximity at least three Ordovician and Silurian stratigraphic cross sections. The volcanics of the Summerford Group in the northernmost Too-good Sequence are overlain by pre-Caradocian volcaniclastics only. In the Cobbs Arm Sequence (Fig. 1), the volcanics of the Summerford Group are overlain by minor pre-Caradocian volcaniclastics and a fairly thick se-quence of carbonates which may have developed close to the trench margin. The Dildo-Dunnage Sequence to the south contains sediments that may have slumped from the trench margin.

CHAPTER 5

PALEONTOLOGY AND PALEOECOLOGY OF THE COBBS ARM FORMATION

5.1 Paleontology.

The total production of the carbonates of the Cobbs Arm Formation would have required vast organic productivity, and so the relatively shallow Middle Ordovician waters, that surrounded the central Newfoundland arc systems, must have been overflowing with marine life. Such a faunal diversity is not very evident, however, because of the generally poor preservation of the light grey limestones. Nonetheless, one sample of crystalline limestone from the Cottles Island section has proven to yield at least four trilobite genera: Nieskowskia, Illaenus, Sphaerexochus, and Proetus (Dr. Fortey, pers. comm.).

In the volcanic rich parts of the formation, where preservation is best, a more varied fauna has been found. Dean (1971), recognized 15 genera of trilobites from the calcareous tuffs that underly and are interbedded with the limestone beds of the Squid Cove section (Fig. 2). From the Cobbs Arm road section (Fig. 2), 11 species of bryozoans and 3 species of gastropods have been identified (Bergstrom et al., 1974). McKerrow and Cocks (1977), reported 5 species of brachiopods and 2 species of trilobites from the same locality.

Thin section and acetate peel analyses of both the dark grey and light grey limestones have also revealed an abundance of trilobite, brachiopod, bryozoan and calcareous algae fragments, but the most prolific group of fossil taxa were the crinoids. Fragments of these organisms constituted nearly 100 percent of some beds within the measured sections.

Abundant and generally well preserved conodonts were recovered

from most of the samples of the Cobbs Arm Formation.

5.2 Conodontophorid Paleoecology.

5.2.1 Introduction.

Paleoecological studies on benthic communities are possible because many of the benthic taxa have preservable hard parts that are, in some cases, found in or near life positions. Careful analysis of substratum association, of the sedimentary matrix and of the morphology of these fossil taxa, can lend ideas on the role and feeding habits of each individual taxon within the benthic community.

However, formulating conclusions of this nature about the conodont bearing animal is difficult, because the conodonts themselves only represent the disaggregated remains of assemblages that were once located within the soft tissue part of the organism. It is possible that the conodont bearing animal had, in addition to conodonts, a shell or a test, but these preservable remains would become disassociated upon death and decay of the soft parts of the animal. Thus, paleoecological analysis of conodonts is reduced to a study of common associations of particular conodont species with other conodont species and with the sedimentary matrix. In its strict sense, this should be termed conodontophorid autoecology.

Recently, Barnes and Fahraeus (1975), were able to recognize, within both the Midcontinent and North Atlantic Provinces, conodont associations or communities that show a lateral segregation in a sequence extending from nearshore into deeper water environments. This indicated to them that the majority of Ordovician conodontophorids were benthic or nektobenthic in habit. Conodonts of the Midcontinent Province were found

to be largely restricted to equatorial regions characterized by raised salinity and temperature. Conodonts of the North Atlantic Province were considered to represent a normal-marine, virtually cosmopolitan fauna. The only pelagic forms recognized, in both provinces, were the simple cone genera with a primitive symmetry transition series.

Bergstrom and Carnes (1976), analysed the relations between the distribution of various conodont species and the environments of deposition within the Middle Ordovician strata in eastern Tennessee. They discovered recurrent associations of conodont species (RSA) within four principal environments, namely mudflat, lagoon, bank with patch reefs and basinal environments. The conodonts in each of these environments were discussed separately within two distinct time zones, i.e. the Pygodus serrus Zone time and the Pygodus anserinus Zone time of the Middle Ordovician of Europe and eastern North America (Bergstrom, 1971, 1973c).

The mudflat environment was characterized by an impoverished association of mostly fibrous forms, the Leptochirognathus RSA, in both time zones. The recovered forms belong to the genera Panderodus, Leptochirognathus, Phragmodus, Belodina and Belodella.

In the Pygodus serrus Zone time, the shallow subtidal portion of the lagoonal environment hosted a relatively varied association of dominantly Midcontinent Province forms named the Belodella-Phragmodus-Polyplacognathus RSA. The deeper subtidal portion of the lagoon environment, and the basinal environment, were dominated by North Atlantic Province forms representing the Periodon-Pygodus RSA. This includes specimens of Periodon, Pygodus, Protopanderodus, Eoplacognathus, Polyplacognathus and Walliserodus.

The bank with patch reefs environment apparently developed in Pygodus anserinus Zone time and hosted a conodont fauna similar in composition to the Belodella-Phragmodus-Polyplacognathus RSA, but referred to as the Belodella-Phragmodus-Prioniodus(Baltoniodus) RSA. In this RSA, species of Polyplacognathus appear to have been replaced by forms of Baltoniodus and Eoplacognathus.

5.2.2 Conodontophorid Paleoecology of the Cobbs Arm Formation.

The conodont fauna of the Cobbs Arm Formation is most characteristically of a North Atlantic Province affinity, and is represented by at least 37 multielement species. However, more than 75 percent of the total number of recovered elements are represented by only the six most abundant species: Panderodus gracilis, Periodon aculeatus, Pygodus anserinus, Baltoniodus variabilis, Protopanderodus varicostatus and Pygodus serrus. All of these species exhibited high frequencies only under certain environmental conditions, to which they must have been so-attuned so as to flourish over the many other represented conodont species.

Except for forms of Belodina, Panderodus and Drepanoistodus, the conodont fauna most clearly resembles the Periodon-Pygodus RSA of Bergstrom and Carnes (1976), i.e. deeper subtidal and basinal environments. Both of these are essentially open marine environments and would thus represent conditions of normal marine temperatures and salinity, conditions considered essential for a North Atlantic Province conodont fauna (Barnes and Fahraeus, 1975).

Because of the paleogeographic position of the Middle Ordovician island arc terrain of central Newfoundland, in an open marine environment some distance east of the platformal deposits of eastern North

America, it is not surprising that the conodont fauna is of North Atlantic Province affinity. The sedimentology of the Cobbs Arm Formation is representative of reasonably shallow conditions of sedimentation, and the geometry of the sediment wedge, as depicted in Figure 17, suggests that parts of the coastline adjacent to the arc terrain, may have been subdivided into a nearshore lagoonal environment with possible conditions of restricted circulation and slightly raised temperatures and salinity, and a basinward open marine environment with normal marine temperatures and salinity. The distribution of conodonts, within the measured sections of the Cobbs Arm Formation, is somewhat in support of the probable existence of an open marine and restricted marine environment, and, in addition, suggests that there may be a relationship between substratum characteristics and conodont species.

The Quarry Cove section, for example, if deposited under conditions of a high-low-high-low pattern of kinetic energy release (Fig. 14), has preserved only the high-low-high (restricted) portion of this in the section. The distribution and frequency, of the 10 most abundant of the 29 represented species, shows that most samples are dominated by the presence of Panderodus gracilis or Baltoniodus variabilis (Fig. 14). The former dominates in the shoreward lower energy zone and the latter dominates in the relatively high energy zone basinward. Sediments of the highest energy zone were essentially barren. Within the same section, Pygodus serrus was mainly recovered from the lower energy sedements, whereas Pygodus anserinus was recovered from sediments representative of a higher wave kinetic energy zone.

The sedimentology of the Cottles Island section suggests that,

if sedimentation occurred in an environment with a high-low-high-low pattern of wave kinetic energy release, only the low-high-low portion of this is preserved in the measured section. Again the relative frequencies of many of the represented conodont species show dramatic changes through the length of the section (Fig. 5). For example Strachanognathus parvus is most abundant in the lower part of the section, Protopanderodus varicostatus and Eoplacognathus robustus in the middle and Periodon aculeatus, E. lindstroemi and Pygodus anserinus in the upper part of the section. Of these, S. parvus and P. varicostatus show their highest frequencies in the high energy grainstones and P. aculeatus and P. anserinus dominate in the low energy (basinward) sediments of the upper part of the section. These two species are much more prolific in the upper part of the Cottles Island section than in any other measured section of the Cobbs Arm Formation. These low energy sediments were the only ones considered basinal.

Of the two sections referred to above, the Quarry Cove section would appear to represent an environment of more restrictive circulation than the Cottles Island section. This is most evident by the high dominance of Panderodus gracilis in the lagoonal sediments. The fauna recovered from such sediment can be referred to as a recurring species association, in the sense of Bergstrom and Carnes (1976).

In addition to P. gracilis, the fauna of the restricted marine environment includes Drepanodus robustus, Drepanoistodus n. sp. A, Walliserodus nakholmensis, ?Acodus n. sp. A, New Genus A n. sp. A, New Genus n. sp. 1, Pseudobelodina n. sp. A and perhaps Distacodus venustus, Baltoniodus variabilis, Pygodus serrus and Eoplacognathus robustus. B. variabilis is most abundant in the sections of the Cobbs Arm area and may have been a

most specialized species, restricted to a relatively high energy environment shoreward of a barrier complex. P. serrus and E. robustus are normally found in sediments of normal marine non-restrictive waters but they may have been able to endure in the slightly higher saline waters in non-competition with the closely related and more normal marine species P. anserinus and E. lindstroemi. They also would have been blessed with the absence of the hypersaline forms common in the shallow Midcontinent Province to the west of the island arcs, isolated by a deep water mormal marine barrier. Only free swimming forms such as Panderodus and Drepanodus could have crossed such a barrier.

The fauna of the open marine environment is dominated by Periodon aculeatus and Pygodus anserinus, but also includes Eoplacognathus lindstroemi, Walliserodus ethingtoni and perhaps Protopanderodus varicostatus.

The distribution of many of the recovered conodont species, as they would appear superimposed on the model of Figure 17, is summarized in Figure 18. The solid lines are meant to show the species distributions as suggested by their highest occurrences. The dotted lines represent the expanded low frequency distributions of the species.

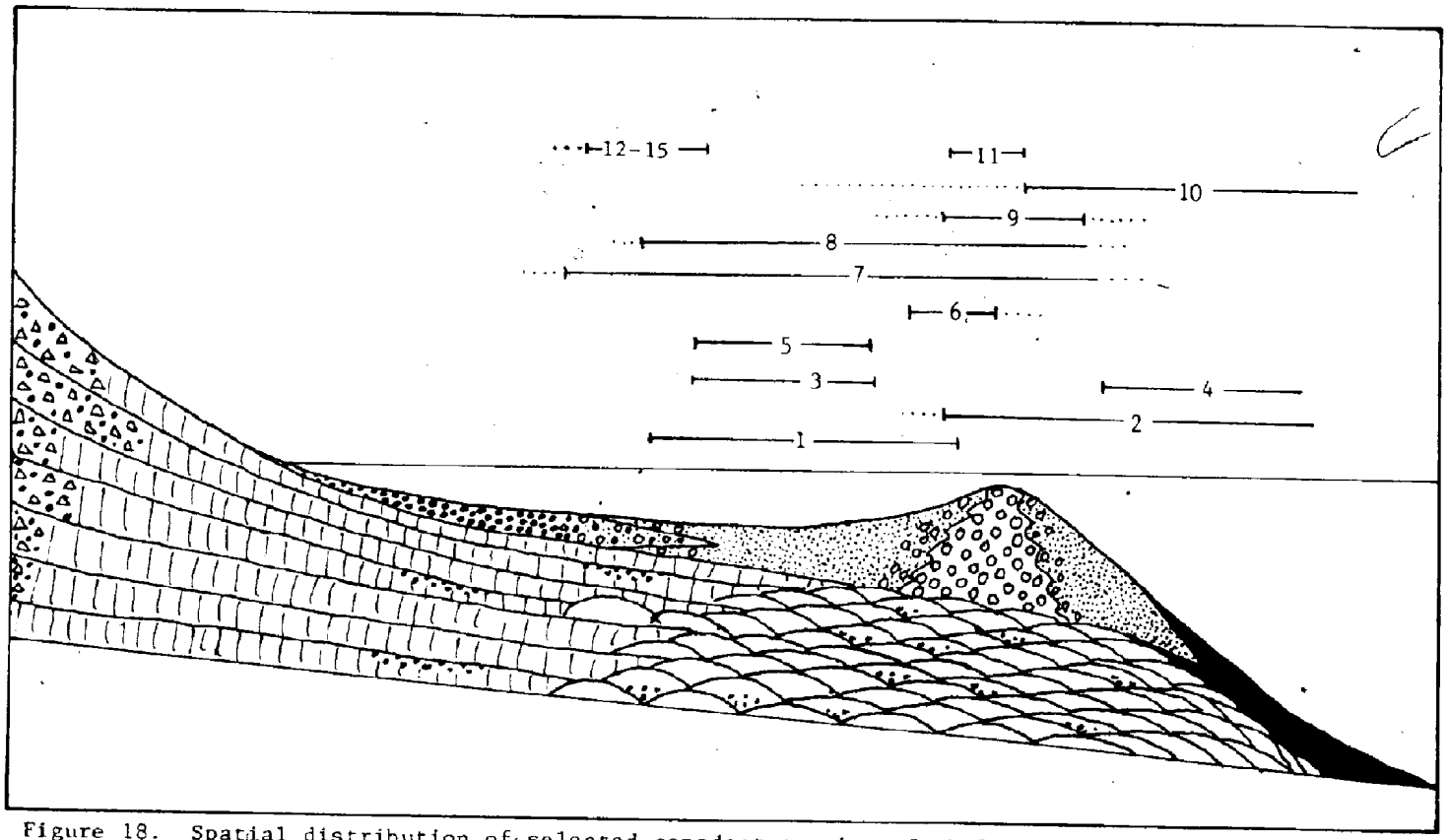

Figure 18. Spatial distribution of selected conodont species. Symbols are as in Figure 17. Numbers refer to the following species: (1) Pygodus serrus; (2) Pygodus anserinus; (3) Eoplacognathus robustus; (4) Eoplacognathus lindstroemi; (5) Baltoniodus prevariabilis-B. variabilis transition; (6) Baltoniodus variabilis; (7) Panderodus gracilis; (8) Drepanoistodus n. sp. A; (9) Protopanderodus varicostatus; (10) Periodon aculeatus; (11) Strachanognathus parvus; (12) ?Acodus n. sp. A; (13) New Genus A n. sp. A; (14) New Genus n. sp. 1; (15) Pseudobelodina n. sp. A.

CHAPTER 6

CHRONOSTRATIGRAPHY OF THE COBBS ARM FORMATION

6.1 Local Correlation.

Figure 19 summarizes the distribution of the biostratigraphically important conodont species, and attempts to illustrate the possible temporal relationships between six of the seven measured sections of the Cobbs Arm Formation. The sections are all drawn to scale and are positioned according to the first occurrence of *Pygodus anserinus* in the respective sections.

The distribution of these stratigraphically important conodont species seems to indicate that the Hillgrade, Cottles Island and Quarry Cove sections represent successively younger packages of strata. However, a close examination of the conodont distribution in the Quarry Cove section and the Cobbs Arm section (middle quarry face), in Figure 19, reveals that the occurrences of *Pygodus serrus* and *Pygodus anserinus* are mutually exclusive. They occur in alternating samples, or groups of samples, throughout the length of the sections; suggesting that the two obviously co-occurring species have different ecological amenities. A similar pattern is seen, to a lesser degree, for *Eoplacognathus robustus* and *E. lindstroemi* and *Baltoniodus prevariabilis-B. variabilis* transition and *B. variabilis*.

This kind of evidence, in conjunction with the discussions of the previous chapter, may indicate that the paleogeographic distribution of the biostratigraphically important conodont species is somewhat ecologically controlled, and, as a consequence, the various sections of the Cobbs Arm Formation may be more stratigraphically time equivalent than

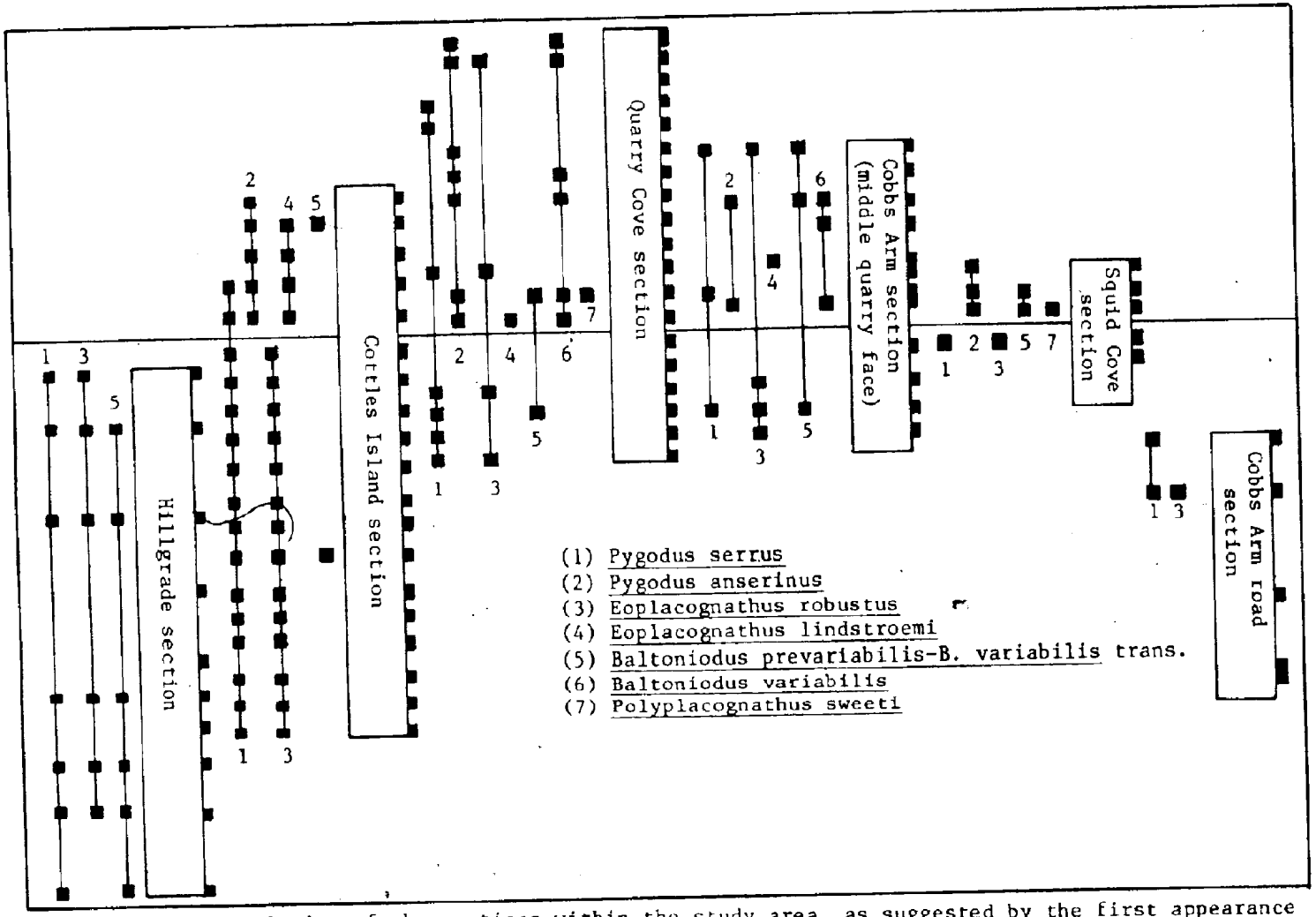

Figure 19. Correlation of the sections within the study area, as suggested by the first appearance of Pygodus anserinus.

previously thought. The sections could be representative of different portions of the overall sedimentation model of Figure 17, and the composition of the conodont fauna in any one portion would reflect the physical and chemical conditions of that sedimentary environment.

A limestone lens within green tuffs along the shore beneath the Anglican church southwest of Herring Neck (Fig. 2, Appendix A), yielded several conodont species including Eoplacognathus robustus (Table 1a, 1b; referred to as Back Cove Sample). This suggests an age in close proximity to that of the Cobbs Arm Formation.

Conodonts were recovered from two other limestone lenses: one in the Summerford Group volcanics near Tilt Cove (Figs. 2,16), yielded a few elements of Pygodus anserinus, and one from the Summerford Group volcanics of the Toogood Sequence near Newville (Fig. 2; Appendix A), yielded specimens of Eoplacognathus robustus. These two samples also suggest an age in close proximity to that of the Cobbs Arm Formation.

6.2 Regional Correlation.

From the discussions of the previous section, it is concluded that the conodont zones and subzones of the Middle Ordovician (Bergstrom, 1971, 1973c), cannot be applied, with the same degree of confidence, to the conodonts of the Cobbs Arm Formation, of north-central Newfoundland. In the absence of the apparent ecological control on many of the conodont species, the Cobbs Arm Formation seems to represent a time period from the upper part of the Pygodus serrus Zone into the upper half of the Pygodus anserinus Zone of the Middle Ordovician (Fig. 19). This would correspond to nearly all of the Glyptograptus teretuisculus graptolite Zone, and perhaps the base of the Nemagraptus gracilis Zone. This was

first suggested by Bergstrom et. al. (1974, figs. 7,10).

However, considering the apparent ecological control on many of the conodont species, the Cobbs Arm Formation could have been deposited in a shorter period of time; perhaps completely within the period represented by the Pygodus anserinus Zone.

This follows from the generally homogenous nature of the conodont fauna. For example, two species of Pygodus, two species of Eoplacognathus, Baltoniodus variabilis and the closely related Baltoniodus prevariabilis-B. variabilis transition, were all recovered from the Quarry Cove section (Fig. 14). It is highly conceivable that Pygodus serrus and Eoplacognathus robustus were able to inhabit the environments offered by the arc complexes far longer that the Middle Ordovician environments of Sweden and eastern North America, but it is less conceivable that Baltoniodus variabilis appeared in the volcanic environment very much earlier than elsewhere.

These same conclusions cannot be safely made, for the Cottles Island and Hillgrade sections, in the absence of Baltoniodus variabilis, in both sections, and Pygodus anserinus in the Hillgrade section. However, the occurrence of Baltoniodus prevariabilis-B. variabilis transition throughout may indicate a time interval near the evolutionary transition to Baltoniodus variabilis. In addition, the Cottles Island, Squid Cove Hillgrade and Quarry Cove sections all exhibit a style of sedimentation suggestive of transgression, which, in the case of the Squid Cove section, appears to have culminated with the appearance of black shale. It seems most probable that these sections were the product of a single transgressive phase and thus, for all intent and purpose, time equivalent.

CHAPTER 7

NATURE OF THE CONODONT ANIMAL

7.1 Composition and Growth.

Conodonts are composed mainly of a calcium phosphate mineral of the apatite group. This was first discovered by Ellison (1944), and subsequently confirmed by Hass and Lindberg (1946), and Phillip (in Rhodes, 1954). A more thorough investigation into the composition of conodonts was completed by Pietzner *et al*. (1968), who derived a complex formula for the phosphate mineral. Bradshaw *et al*. (1973), conducted a series of neutron activation analyses of select conodonts and discovered common traces of Sodium, Manganese, Magnesium and Zinc among others.

X-ray analyses of *Panderodus gracilis*, in this study, simply confirmed the fluorapatite composition of conodonts. The X-ray peaks were rather small, suggesting that the mineral has a weakly crystalline molecular structure.

In addition to this, a few conodont specimens of *Panderodus gracilis* were microanalyzed with a JEOL JXA electron microprobe. Most analyses were taken from parts of the conodont specimens without white matter. The computed average of these analyses indicated a composition that consists of: 4.24 weight percent fluorine (F), 41.69 weight percent phosphate (P_2O_5), and 53.85 weight percent calcium (CaO); for a cumulative total of 99.78. A few analyses were also taken from parts with white matter, but these invariably produced low totals. This may indicate a slightly different composition of white matter, but more likely represents poor analyses because of the non-homogenous (porous) nature of white matter (Barnes *et al*., 1973).

Conodonts are built of a cone-in-cone series of lamellae that are added in an outward sequence, or centrifugally. This mode of growth can only occur if the conodont is surrounded by secreting tissue. Some conodonts are composed entirely of these lamellae, and, if well preserved, are amber in colour. These are referred to as hyaline. Other conodonts have white matter, which is generally concentrated in denticles and in the main cusp. White matter is considered to develop during growth, by the recrystallization of the inner (older) parts of the conodont.

7.2 Nature of the Conodont Apparatus.

All but a few species of Cambrian conodonts were of simple cone type and thus probably all subsequent conodont taxa originated from a simple cone apparatus. One of the most likely ancestral stocks to several of the important Ordovician simple cone genera is the Late Cambrian *Oneotodus* (Druce and Jones, 1971; Nowlan, 1976). Early species of this genus show variation in cusp curvature; a characteristic that is also seen in many later simple cone genera, noteably *Drepanoistodus* (Nowlan, 1976). Early Ordovician conodont apparatuses, of a more complex nature, are considered to have originated from a *Drepanoistodus* stock (McTavish, 1973; Dzik, 1976). Throughout the rest of the Ordovician, conodonts continued to diversify at a rapid pace.

Recently, Barnes *et al*. (1977) made an analysis of the diversity of Ordovician multielement genera, and were able to recognize 12 types of apparatuses belonging to five principal apparatus groups. All five principal apparatus groups were recognized among the conodont genera from the Cobbs Arm Formation.

Apparatus I was diagnosed to include simple cones with a

continuous symmetrical-asymmetrical symmetry transition series (Barnes et al., 1977). In order to classify some of the Cobbs Arm Formation conodont genera, however, this diagnosis had to be emended to include denticulated cones. Thus apparatus Ia includes simple cones only (i.e. Scalpellodus and Walliserodus); apparatus Ib includes denticulated cones (i.e. Belodella and New Genus A); and apparatus Ic includes genera with an apparatus similar to Ib, but with a fewer number of constituent forms (i.e. Pseudobelodina). Apparatus Ia and Ib, of the represented species from the Cobbs Arm Formation, commonly contained five constituent forms (i.e. Scalpelodus cavus, Fig. 33A-E; Walliserodus n. sp. A, Fig. 36A-E; and New Genus A n. sp. A, Fig. 32A-E).

Apparatus II includes cones and compound elements exhibiting a cordylodiform-zygognathiform-trichonodelliform symmetry transition series (IIa; i.e. Spinodus spinatus).

Apparatus III includes cones and denticulated cones that exhibit a curvature transition from proclined through erect to reclined forms. Conodont genera from the Cobbs Arm Formation also have a symmetrical-asymmetrical symmetry transition series superimposed on this (IIa; Protopanderodus, Panderodus and Drepanoistodus). Protopanderodus varicostatus (Fig. 27A-E), and Panderodus gracilis (Fig. 30A-E), have five constituent forms, each with three curvature forms. Drepanoistodus n. sp. A has at least four constituent symmetry forms, each with at least three curvature forms (Fig. 23A-E). This apparatus was difficult to work with because of the lack of characteristic element surface structure, and therefore, it may contain more constituent forms than shown. Apparatus III may be reduced to a smaller number of constituent forms (IIIb; i.e. Belodina).

Apparatus IV is regarded by Barnes et al. (1977) as two transition series: cordylodiform-zygognathiform-trichonodelliform (-tetraprioniodiform), and cyrtoniodiform-prioiodiform-blade (-platform); each with three or four elements (IVa; i.e. Amorphognathus, Baltoniodus, and Periodon). Baltoniodus variabilis appears to have six constituent forms (Fig. 40B,C,E-H), whereas Periodon aculeatus appears to have seven (Fig. 41A,B,D-H). Periodon aculeatus also appears to have a second morphotype (Fig. 41A-E,G,H). Pygodus serrus has a reduced second transition series (IVc; i.e. Fig. 37A-G).

Apparatus Va includes compound conodonts bearing the second transition only. This may by reduced to two elements (Vb; i.e. Eoplacognathus, Polyplacognathus and Rhodesognathus).

7.3 Were Conodonts Cephalopods?

Conodonts represent the disaggregated remains of an assemblage that occupied a position within the soft tissue of a highly successful Paleozoic group of organisms. Their mode of growth and morphology has led several workers to conclude that they developed within secreting tissue and were functionally involved in feeding, however, the true nature of the animal, from which the conodonts were derived still remains a mystery.

So far they have been taken to be gastropod radular teeth (Loomis, 1936) polychaete jaws (Zittel and Rohon, 1886; Du Bois, 1943; Rhodes, 1954), fish teeth (Pander, 1856; Ulrich and Bassler, 1926), jaws of chaetognath type (Rietschel, 1973) and lophophore support (Lindstrom, 1964, 1973, 1974). The inner structure, mode of growth, and, in a partial sense, the composition of conodonts has led Lindstrom (1964, 1973,

1974), to a well founded dismissal of the first four of the above five hypotheses. The last hypothesis, however, does appear to be one way of explaining growth, shape, symmetry and homology of conodonts.

Morris (1976), described an invertebrate, named Odontogriphus omalus Morris, from the Burgess shale (Cambrian) of British Columbia. It carries a horse-shoe shaped structure of teeth-like elements that are considered to have supported a lophophore. This indeed is an exciting find, and one that is somewhat in support of Lindstrom's hypothesis (Lindstrom, 1964, 1973, 1974), however, the lophophorate described by Morris is badly compressed and needs to be supported by additional discoveries.

The fossilized remains of a small soft bodied organism from the Bear Gulch Limestone (Carboniferous) in Montana, was found to contain conodont elements that are disoriented, variable in size and representative of incomplete known apparatuses. This organism was considered to be the conodont animal by Melton and Scott (1973), and Scott (1973), who referred it to the Conodontochordata, a new subphylum. Lindstrom (1974), supported the view that the conodontochordates were pelagic, or weakly necktonic, but considers them conodont preditors, rather than conodont animals. If the conodonts were eaten by the conodontochordates, the maximum size of the conodont animal could not have been much greater than about 10 millimetres.

However, interpreting the conodontochordates as swimmers does not necessarily mean they inhabited surface waters. It is conceivable that instead they scavenged the sediment surface for particles of organic material, and, in a manner familiar to many marine organisms, passed sediment through the primitive looking intestinal tract. In this way the

conodont elements could have been taken up from the bottom sediment.

Interpretation of the mode of life of the conodont animal will probably only be possible from examination of the nature of the conodonts themselves. It seems apparent, from the previous chapter, that the conodont animal was pelagic and/or nektonic as well as nektobenthic, and was thus likely able to have control over its movements. Most workers already agree that the conodont assemblage was contained within secreting tissue and used to assist in feeding; whether by seizing, grasping, rasping or carding of food is still unknown.

An active swimmer, with such an apparatus, would most likely be a carnivore or scavenger, and thus would occupy a higher position within the trophic structure than would its more prolific, diverse, and important food sources. The conodont animal may have preyed upon the myriad of planktonic, nektonic and benthic arthropods, larval forms of many other taxonomic groups, phytoplankton, zooplankton, better protected sessile organisms, or even other conodont animals. The mobility of such an animal may mean that its distribution did not rely entirely on temperature and chemical properties of the environment, but was probably also dependent on the distribution of palatable food.

It seems conceivable to this author, that the conodont apparatus could have been used to assist in the swallowing of food particles in a manner analogous to the radula of recent cephalopods. The individual conodont elements may have exhisted within pockets, in a tongue-like appendage, where they could have grown and functioned in the manner shown by Bengtson (1976, Figs. 11G-I, 12). In a plan view, different conodont apparatuses could have appeared as in Figure 20.

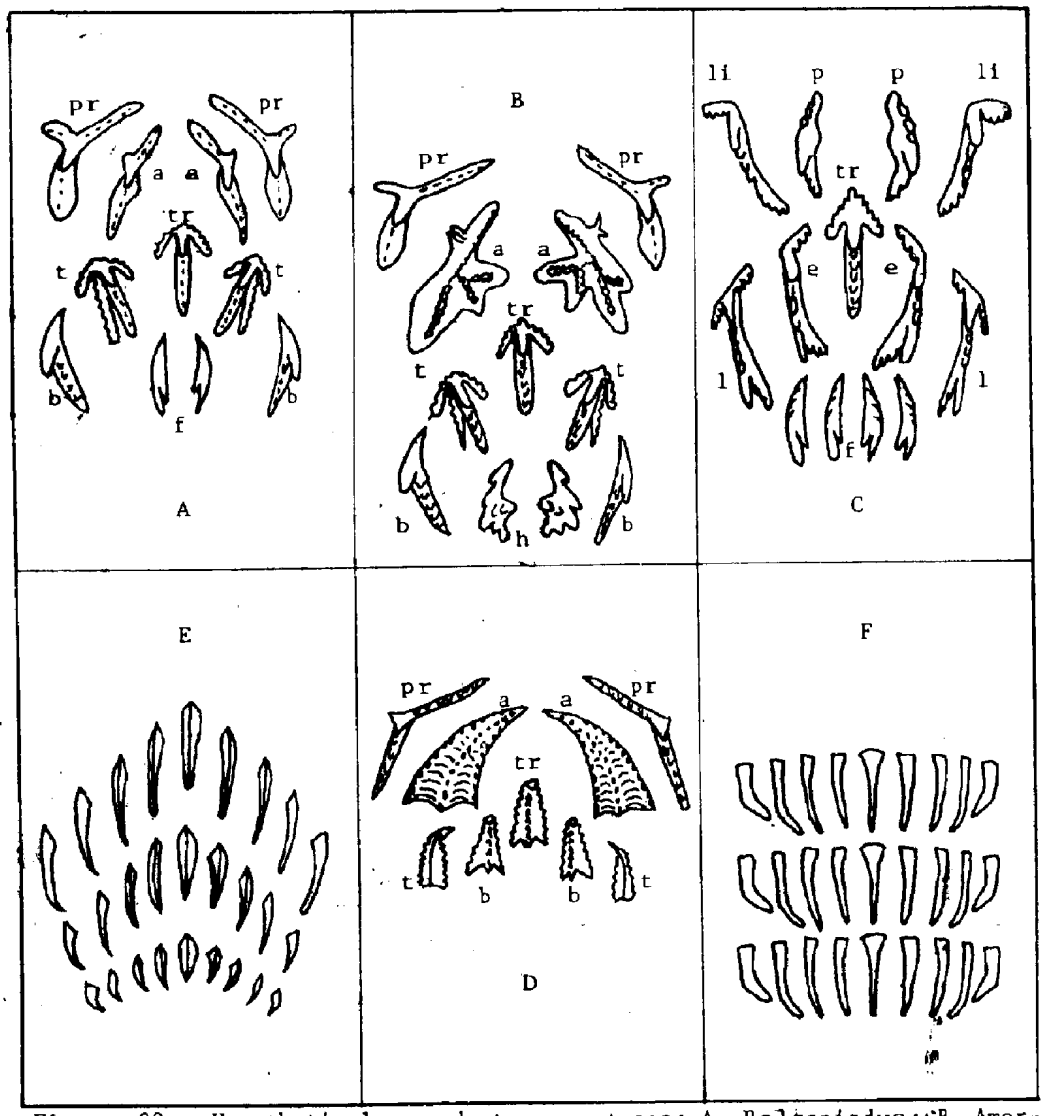

Figure 20. Hypothetical conodont apparatuses: A, Baltoniodus; B, Amorphognathus; C, Periodon; D, Pygodus; E, Panderodus; F, Scalpellodus. The meaning of the small letters is as follows: a = amorphognathiform; b = belodiform; e = eoligonodiniform; f = falodiform; h = holodontiform; l = loxognathiform; li = ligonodiniform; p = prioniodiniform; pr = prioniodiform; t = tetraprioniodiform; tr = trichonodelliform.

The shape of most elements of each apparatus has a directional nature to it, which is defined by the curvature and inclination of the cusp and denticles. In the sense of Figure 20, the posteriorly directed cusp and denticles point to the direction in which the food would be carried.

From Figure 20 (A,B), Baltoniodus and Amorphognathus are seen to have very similar apparatuses, except for the nature of the amorphognathiforms. Pygodus appears most similar to Amorphognathus but shows a drastic reduction in the size of elements within the first symmetry transition, and has lost the falodiforms (Fig. 20D). Such changes in the nature of the apparatus may be a response to changes in diet or to changes in preferred habitat. Periodon has a type IV apparatus, yet, from the numerical data of this study, appears to have seven, rather than six, structural elements (Fig. 20C). Panderodus and Scalpellodus are composed of simple cone elements and are representative of apparatuses IIIa and Ia respectively. Apparatus IIIa seems to have a finite number of structural elements, whereas the number of elements within an apparatus of type Ia is not indicated by the nature of the constituent forms. It could consist of one transverse row, or several.

The upper surface of the front part of the tongue of most recent cephalopods is covered by the radula, a conveyor-like chitonous ribbon with hundreds of transverse rows of teeth that are secreted by radular glands at the base of the radula. The teeth in each row exhibit a symmetrical-asymmetrical symmetry transition series. As an example, the symmetry transition exhibited by the recent squid Illex illicebrosis (Lesueur, 1821), can be seen in Plate 16, figures 12-15. Figure 16 of

Plate 16 gives a partial view of one of the longitudinal rows. The size of the individual radular teeth of Illex illicebrosis is similar to the size of many conodonts.

Recent cephalopods are exclusively marine, are found in oceans all over the world and range from inside the Arctic Circle to the edge of the Antarctic Continent. Octopuses are generally nektobenthic and can be found in very shallow waters (i.e. mudflat octopus), or in waters over a kilometre in depth. Shallow water forms lie await in ready made, or self made lairs and obtain prey by seizing, whereas deeper water forms generally lack strong appendages and radulae and therefore probably eat carrion, debris and plankton (Lang, 1960).

Squids inhabit more diverse environments. They may be pelagic, nektonic or benthonic and prey on food ranging from tiny plankton to fast powerful fish. Nektonic squids can live in surface waters or to great depths. Some of these occupy a narrow zone within the water column; others live in deep waters during the day and come to the surface at night. A few species show successfully shallower habitats during phylogeny (Dr. Lu, pers. comm.). The biggest control on nektonic squid distribution appears to be latitude.

In four separate reports, Lu and Clarke (1975a,b), and Clarke and Lu (1974, 1975), discuss the vertical distribution of squids as recorded at six different latitude stations between 11 degrees north and 60 degrees north. There were 39 species of squid at 11 degrees north, 40 species at 18 degrees north, 29 species at 30 degrees north, and 18 species at 40, 53, and 60 degrees north.

It is conceivable that the total habitat range of the conodont

animal differed little from that of recent cephalopods. Cephalopods and conodonts have often been found to occur together in the stratigraphic record, but this may only indicate a similarity of life environment (Lindstrom, 1973).

The only realistic similarities between conodonts and the radulae of recent cephalopods lies with the simple cone apparatuses. Nautilus, the recent representatives of the nautiloids, has a chitonous radula bearing many transverse rows of simple conical teeth. The radula of a Pennsylvanian nautiloid, Paleocadmus herdinae Solem and Richards, has the same structural pattern as the recent nautiloids, but with elements very similar to elements of some Ordovician and Silurian species of Panderodus. The similarities could be completely superficial, but in addition to showing similarity in form, the transverse rows of the radula in Paleocadmus herdinae, and recent species of Nautilis as well, each carries nine structural elements. This kind of apparatus appears to also be exhibited by conodont animals with a type Ia apparatus (i.e. Scalpellodus cavus, Fig. 20F). Most recent cephalopods have seven structural elements, however, some have only five teeth per row, and still others lack radulae altogether (Solem and Roper, 1976).

This evidence is far from conclusive, yet the size and functional similarities of the feeding appendages, and the possible ecological similarities between the Paleozoic conodont animals and recent cephalopods would tend to indicate some relationship between the two groups of organisms. If conodonts were indeed parts of Paleozoic cephalopods, there would have had to be a dramatic evolutionary change in the mode of radular growth, and in the composition of the individual elements.

CHAPTER 8

TAXONOMY

8.1 Preamble.

Taxonomical classification of the many and varied past forms of life is frequently complicated because of the difficulty in not always being able to relate these life forms with present day life forms. Paleontological classification is usually based on preserved hard-parts which may or may not directly relate to the at one time life sustaining soft part; organs that are frequently used by biologists for classification. The problem of taxonomy is compounded further in the case of conodonts where fossilized remains have not assuredly been related to the external or internal portion of the host organism let alone related to the nature of the possible life sustaining soft parts with which they were once associated.

Initially, it was assumed that conodonts were fish teeth, and, as such, differing forms of conodonts would represent differing species (Pander, 1856). Hinde (1879), proposed the multielement concept of the conodont species, suggesting that each animal contained a variety of elements. Multielement taxonomy in his time, however, was a near impossible project and may have made the study of conodonts appear too difficult since individual elements could not be named unless whole assemblages were found. Taxonomical progress, in the first part of this century, was slow and of a utilitarian nature. Papers by Hadding (1913), Bryant (1921), Roundy (1926), Ulrich and Bassler (1926), and Hibbard (1927) are examples. Nonetheless, the question of natural assemblages was once again brought to light.

Schmidt (1933, 1934), in Germany and Scott (1934, 1942), in the United States, described physically associated conodonts on shales of Carboniferous age as did Du Bois (1943), Cooper (1945) and Rhodes (1952). Lange (1968), was the first to report assemblages on the etched surface of limestone, and from digested limestone, Barnes (1967), Rexroad and Nicol (1964), Austin and Rhodes (1969), and Pollock (1969), reported fused conodonts that were also thought to represent assemblages or parts of assemblages.

Most conodont workers, however, continued to follow Pander's approach to conodont taxonomy by regarding discrete forms of conodonts as differing species. With improvements in laboratory techniques in the 1930's and 1940's, more and better preserved conodonts were being recovered. Boiling of soft shale allowed Branson and Mehl (1933, 1934) to safely screen or decant mud, leaving the conodonts along with other residual particles. Digesting of limestone with dilute acetic acid was a more delicate process that left a much more complete material. This method came into general use as early and 1941 (Graves and Ellison, 1941), and became standard after 1950.

This new practice of recovering conodonts by dissolving soluble rock in acid, destroyed any physical association of elements that may have been present in the rock. However, many more students were taking interest in conodontology and consequently the bank of information grew rapidly.

By the late 1950's conodont workers were drawing from this information bank, and attempting for the first time to reconstruct "natural" conodont assemblages based on discrete elements. Huckriede (1958), and

Walliser (1964), noted the presence of groups of associated element species with common ranges. Sweet and Bergstrom (1962), and Lindstrom (1964), considered members of a symmetry transition series to possibly represent elements of a single apparatus. Bergstrom and Sweet (1966), and Webers (1966), elaborated on earlier studies by recognizing assemblages based on frequent association, common structure, and symmetry transition. Kohut (1969) first applied a computer generated method of apparatus reconstruction that evaluated recurrent groups of conodont elements.

The undesireable situation of dual classification had, by this time, become entrenched within the literature. It did not have its beginning in the early 1960's with the ressurgence of the multielement concept; rather it arose with the discovery of the natural assemblages by Schmidt (1933, 1934) and Scott (1934, 1942). Schmidt (1934), followed the International Rules of Zoological Nomenclature and used the oldest available generic name for the apparatus, whereas Scott (1942) proposed a dual nomenclature, establishing a separate nomenclature for assemblages and continuing the nomenclature for discrete elements already in use. Moore and Sylvester-Bradley (1957), appealed to the International Commission on Zoological Nomenclature to legalize the dual systen of nomemclature, but the idea was rejected by the 15th International Zoological Congress in London in 1958. Conodont workers, nonetheless, continued to use separate systems for assemblages and elements.

The single element utilitarian taxonomy had proven useful for biostratigraphical purposes. The possibilities of disruption of exhisting zonal schemes, by the nomenclature problems that would result from

a restructure of conodont taxonomy was therefore unsettling to many workers. In a biological sense, however, utilitarian classification was not natural, for a natural classification should not only serve as a means of identification and communication, but should express evolutionary relations also. An utilitarian classification cannot possibly do this.

Conodont taxonomy could no longer be based on the gross morphology of individual elements, but had to incorporate the composition and morphology of the apparatus, as a whole, with information on evolutionary lineages. A suprageneric taxonomy, which used such criterion, was first attempted in 1970 by Lindstrom. It still leaves to be shown, however, that conodont taxonomy will require the use of higher categories and more subdivisions as the conodont apparatus becomes better understood.

This is more or less the foundation to the taxonomic approach taken in this study. Where possible, isolated elements were grouped, as assemblages, using the criterion of common association and macrostructural and, to a lesser extent, microstructural similarities. Subsequent to this, the true nature of the apparatus was inferred through a search of all possible varieties and interrelationships of the constituent forms. The inferred apparatus type and plausible evolutionary relationships with other apparatuses, both in the literature and in thus study, were used together for the taxonomical groupings.

The synonomies of the multielement species, in this study, are listed by author; first ordered chronologically and then alphabetically. Reports of form species and reports of multielement species are given equal consideration by this method. The page, plate and figure numbers,

of the reported species of interest are located alongside the author's name. The term "fig.", uncapitalized, refers to plates, whereas the term "Fig.", capitalized, refers to text figures. If the publication makes use of form taxonomy, the individual form species constituents, of the multielement species in question, are separated by semicolons. For a publication to be included in the synonomy, of a multielement species in this study, enough of its constituent elements had to be described and illustrated so as to leave as little doubt of its identity as possible.

Isolated multielement species are alphabetically listed as form taxa. These residuals, like the constituent elements of the multielement apparatuses, are treated as nouns by attaching the suffix "-iform" to the name of the (form) genus to which the element is referable. The term s.f. (sensu formo), is used whenever referring to form species.

The commonly used morphological terms are illustrated in Figure 21. It should be noted that not all conodont specimens are illustrated, as in Lindstrom (1955a), with the oral margin in a horizontal position.

The taxonomic descriptions of the simple cones were not based on discrete elements; rather they were structured so as to give an impression of the variability of form that defines the symmetry and curvature transitions. The conodont apparatuses composed of compound and platform elements, however, do not exhibit curvature transition. Furthermore, the symmetry transitions are defined by the presence of very distinct and easily isolated forms; consequently descriptions of these apparatuses are easier and more exact.

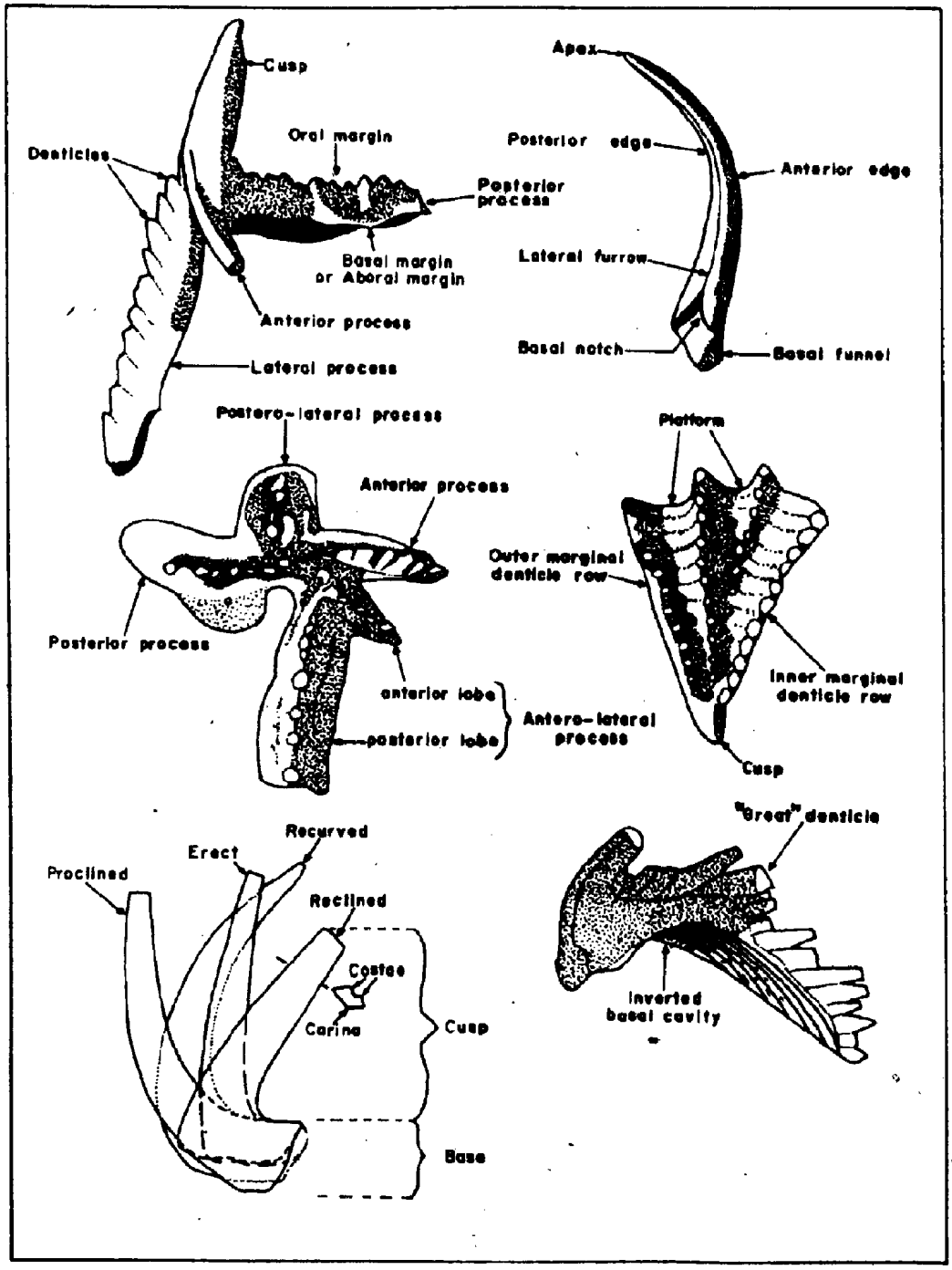

Figure 21. Commonly used conodont terminology.

8.2 Multielement Taxonomy.

Order CONODONTOPHORIDA Eichenberg, 1930

Superfamily DISTACODONTACEA (Bassler, 1925)

Family DISTACODONTIDAE Bassler, 1925

Discussion. Lindstrom (1971), placed the components of this family into two informal groups, i.e. the Drepanodus group consisting of Drepanodus Pander, 1856, and the Paltodus group consisting of Distacodus Pander, 1856, Drepanoistodus Lindstrom, 1971, Paltodus Pander, 1856 and Paroistodus lindstrom, 1971. This two fold division of Distacodontidae is, in essence, followed herein, but for the addition of the genus Protopanderodus in the Drepanodus group.

Dzik (1976), for no definite reason, considers Drepanodus a possible derivation from Semiacontiodus and consequently placed it within the superfamily Panderodontacea. Presumably this was done because of the mutual similarities between Drepanodus and Protopanderodus, both in the nature of their apparatuses and in their environmental preferences (i.e. North Atlantic Province), but upon close examination, the apparatuses of Drepanodus and Protopanderodus, on one hand, and Semiacontiodus, on the other, show considerable differences.

Drepanoistodus, Drepanodus and Protopanderodus are composed (at least in the early stages) of drepanodiforms and oistodiforms. In Drepanodus and Protopanderodus, the oistodiforms have very short bases and are usually modified, but are there. Semiacontiodus generally contains erect to proclined forms. All four genera show a curvature transition and thus may have evolved from an earlier simple cone stock exhibiting similar

characteristics, i.e. Oneotodus. If so, it would appear that Drepanoistodus, Drepanodus and Protopanderodus evolved separately from Semiacontiodus since early forms of this latter genus first appear in the Midcontinent Province and do not seem to be found in the North Atlantic Province until Drepanodus and Drepanoistodus are well established.

From comparisons of Figures 23 and 24, of this study, it would seem apparent that Drepanoistodus and Drepanodus are closely related. This is in agreement with Lindstrom (1970, 1971). From comparisons of Figures 24 and 27, it would likewise seem apparent that Drepanodus and Protopanderodus are closely related. Lindstrom (1973), agrees that Protopanderodus and Drepanodus were derived from a similar ancestor, but he points out that Protopanderodus has fine surface striations whereas Drepanodus does not. This was also discovered in this study, i.e. Plate 14 figs. 1, 1a, but this author is not convinced that the presence of very fine striations on Protopanderodus varicostatus is enough to place Protopanderodus and Drepanodus into different superfamilies.

Following Dzik (1976), the genus Drepanodus is placed close to Protopanderodus, but within Distacodontacea, rather than Panderodontacea.

The genera of the family Distacodontidae are incorporated into the two subfamilies: Drepanoistodinae Fahraeus and Nowlan, in press; and Protopanderodontinae Lindstrom, 1970.

Subfamily DREPANOISTODINAE Fahraeus and Nowlan, in press

Discussion. This subfamily includes the genera Drepanoistodus, Paltodus, Paroistodus and Distacodus, all of which have apparatuses with drepanodiforms and oistodiforms only. The drepanodiforms are non-costate

in Drepanoistodus and costate in Paltodus and Distacodus. In this study, the drepanodiform:oistodiform ratio appears to be 4:1 for Drepanoistodus, 1:2 for Distacodus and 1.5:1 for Paltodus. All three genera possibly have a type IIIa apparatus.

Genus DISTACODUS Pander, 1856

Type Species. Machairadus incurvus Pander, 1856

DISTACODUS VENUSTUS (Stauffer, 1935)

Pl. 1, figs. 1a-5b; Pl. 13, figs. 2,3; Fig. 22A-1

WEYANT 1968, p. 28, pl. 5, fig. 8; p. 46, pl. 5, figs. 9,11; p. 53, pl. 2, fig. 9.

Discussion. The oistodiform (Oistodus venustus s.f.), has been reported in many studies (i.e. Stauffer, 1935a; Rhodes, 1953; Ethington, 1959; Sweet and Bergstrom, 1962; Spassov and Teller, 1963), but has failed to show good association with any other form species. It has a relatively low occurrence and appears in only a few samples in this study, yet shows favourable association with co-occurring distacodiforms. This apparatus resembles that of other Distacodontidae.

Description. Drepanodiforms have long and slender sharp-edged cusps that are proclined to recurved. Bases are about twice as long as high and extend posteriorly only. Their basal cavities are shallow with an anteriorly directed apex beneath the centre of the cusp. Basal margins are generally convex in lateral view and slightly flared in aboral view. The antero-aboral angle is about 90 degrees in erect forms and about 20 degrees less in recurved or reclined forms. Symmetrical forms have equally developed postero-lateral costae that continue ~~from the~~ tip of the cusp to

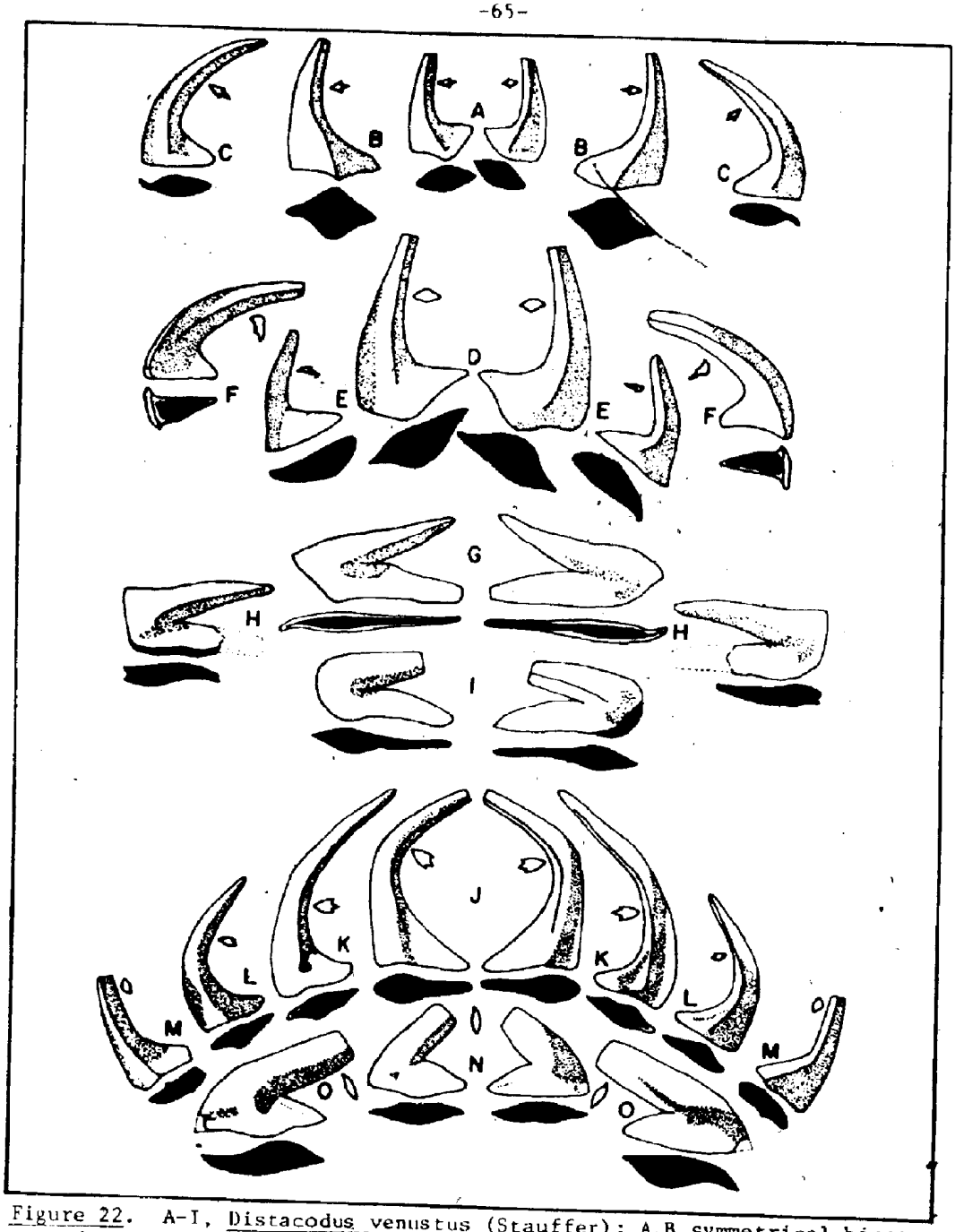

Figure 22. A-I, Distacodus venustus (Stauffer): A,B symmetrical bicostate drepanodiforms; C-F asymmetrical bicostate drepanodiforms; G-I oistodiforms. J-O, Paltodus semisymmetricus (Hamar): J symmetrical bicostate drepanodiform; K-M asymmetrical costate drepanodiforms; N,O oistodiforms. Inner lateral view left of centre; outer lateral view right of centre. Illustrations are all X52.

near the basal margin. Anteriorly the cusp faces are slightly concave. Asymmetric forms have planar to concave inner cusp faces and convex outer cusp faces, both of which are usually costate or carinate.

Oistodiforms have sharp-edged cusps and bases that are nearly equal in length. Lateral faces of the cusp are carinate, more conspicuously on the outer face. The nature of the basal margin and the antero-aboral angle is variable. In one extreme the basal margin anteriorly has a nearly right-angle upward bend and an antero-aboral angle of about 90 degrees. In these forms the cusp and base diverge at a low angle of about 20 degrees. Forms of the opposite extreme have an upward bend in the basal margin of about 60 degrees, approximating that of the antero-aboral angle. The cusp and base of these latter forms deverge at an angle of about 40 degrees.

Remarks. The constituent forms of this species show a morphological resemblance to the forms of Drepanoistodus n. sp. A, however, the limited material available for this species does not indicate the same drepanodiform:oistodiform ratio as does the material for D. n. sp. A. The two species, nonetheless, would appear to be taxonomically close together, since both exhibit characteristics of apparatus type IIIa.

Material. 218 specimens (77 drepanodiforms, 141 oistodiforms).

Genus DREPANOISTODUS Lindstrom, 1971

Type Species. Oistodus forceps Lindstrom, 1955

DREPANOISTODUS n. sp. A

Pl. 1, figs. 6-15b; Pl. 13, figs. 6-8; Fig. 23A-L

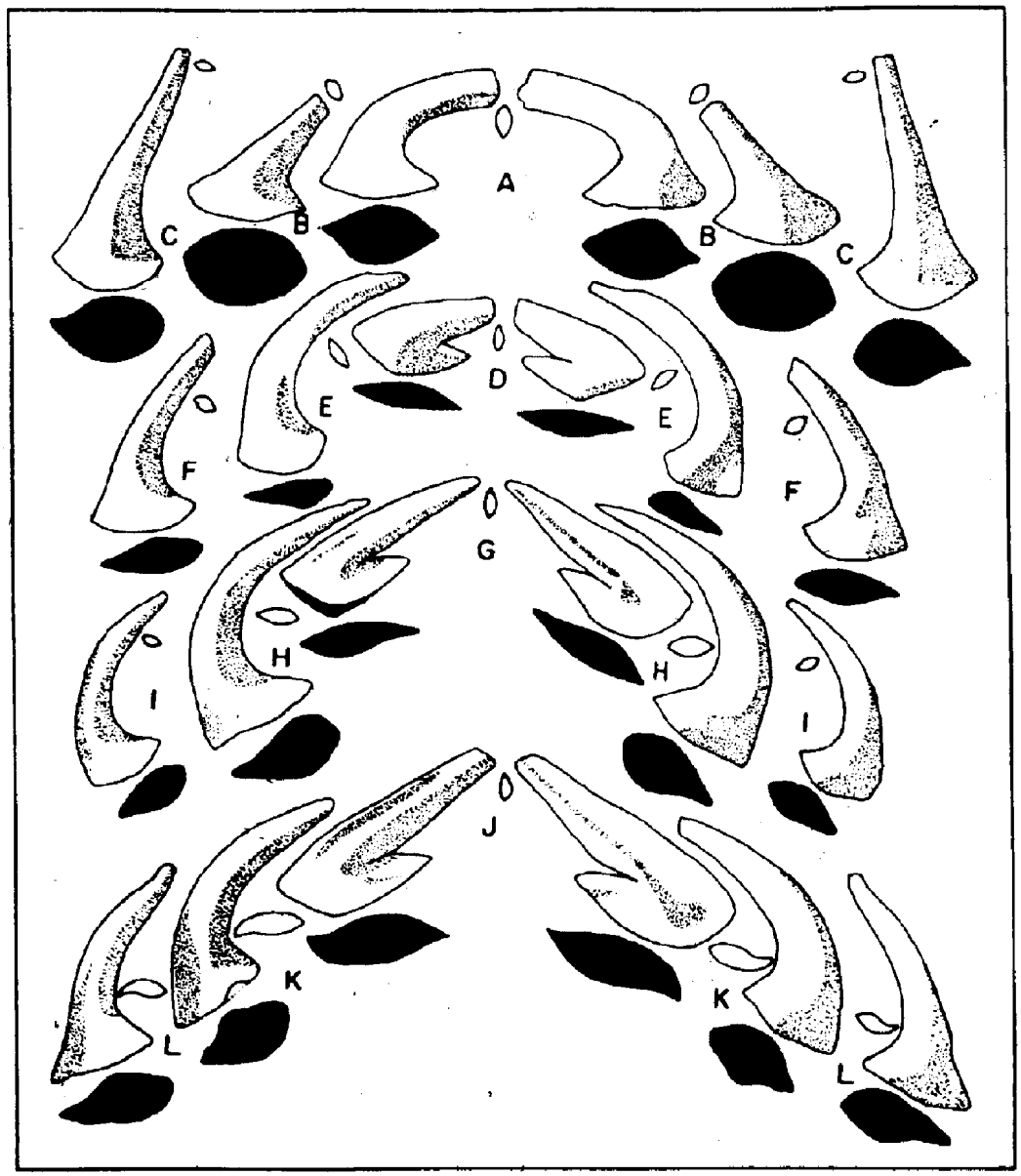

Figure 23. A-L, Drepanoistodus n. sp. A: A, symmetrical oistodiform; B,C, symmetrical drepanodiforms; D,G,J, asymmetrical oistodiforms; E,F,H,I,K,L, asymmetrical drepanodiforms. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X59.

Discussion. Form species considered belonging to the genus Drepanoistodus have been reported from strata ranging in age through most of the Ordovician in both the Midcontinent and North Atlantic Provinces (Branson and Mehl, 1933, 1934; Rhodes, 1953; Lindstrom, 1955a, Webers, 1966).

Lindstrom (1971), has differentiated the two species Drepanoistodus forceps and D. basiovalis, in the Lower Ordovician of the Balto-Scandic area, by the nature of the oistodiforms of the apparatus. Oistodiforms of D. forceps have a low and long base with a small undulation of the aboral margin. Oistodiforms of D. basiovalis have a relatively low and short base that is rounded anteriorly, almost eliminating the 90 degree antero-basal angle. Lindstrom (1973), suggests a range of lower Arenigian to lower Llanvirnian for D. forceps and a range of upper Arenigian to lower Llanvirnian for D. basiovalis. The microstructure of both shows abundant white matter in the cusp.

Midcontinent Province examples of Drepanoistodus, with a similar apparatus, are generally referred to D. suberectus. Oistodiforms of this species have a relatively high and very short base with an antero-basal angle of about 90 degrees and a postero-oral angle generally greater than 60 degrees. This species is recovered from Middle and Upper Ordovician strata (Webers, 1966; Dzik, 1976). The microstructure of this species shows little white matter if any at all (Barnes et. al. 1973).

The oistodiform of Drepanoistodus n. sp. A has a long straight cusp and relatively low and short base, with an antero-basal angle of 60 to 80 degrees. Anteriorly the element is somewhat pointed.

Except for the oistodiforms, the apparatuses of these four

species is very similar. One wonders whether the slight morphological differences of the oistodiforms alone is enough to differentiate on the species level. Van Wamel (1974) questions Lindstrom's (1971) differentiation of D. forceps and D. basiovalis and claims that any subdivision of Drepanoistodus would be possible only on the basis of biometric data and statistical methods.

Nonetheless, the oistodiforms of the Cobbs Arm Formation species of Drepanoistodus are rather uniform in their characteristics and are distinct from oistodiforms of the other three species mentioned. Considering also the relative age ranges of these three species it seems appropriate to, at least tentatively, place the Cobbs Arm Formation species of Drepanoistodus as a new species.

Description. This difficult apparatus of simple cone conodonts comprises drepanodiforms and oistodiforms.

The drepanodiforms have long and slender proclined to reclined cusps that are generally rather compressed laterally and sharp-edged. Bases are short and shallowly excavated. Symmetrical forms have a straight or slightly curved biconvex cusp and a broadly flared base. Asymmetrical forms have curved cusps with outward convex faces. The inner surfaces vary from weakly convex to planar to concave with increasing asymmetry of form. Basal margins only flare slightly.

Oistodiforms have a compressed, pointed and sharp-edged cusp that is about three times as long as the oral margin of the base. Basal margins are biconvex but flare more inward. This inward flare is stronger in some forms than in others. The postero-oral angle appears to vary

inversely with the magnitude of basal flaring. An oistodiform with a large flare has a postero-oral angle of about 20 degrees, whereas an oistodiform with a weak flare is nearly symmetrical and generally has a postero-oral angle of about 40 degrees.

Remarks. Within the Cobbs Arm Formation fauna there are about 500 elements referable to Drepanoistodus n. sp. A. These show a ratio of drepanodiforms:oistodiforms that supports Lindstrom's (1971) figure of 4:1. The homocurvatid drepanodiform:suberectid drepanodiform:oistodiform ratio is approximately 6:1:2.

The proposed Drepanoistodus apparatus has a simple symmetrical asymmetrical symmetry transition superimposed on a curvature transition of proclined or erect drepanodiforms through recurved or reclined drepanodiforms to oistodiforms. This is classed a type IIIa apparatus.

Material. 530 specimens (347 homocurvatid drepanodiforms, 63 suberectid drepanodiforms, 123 oistodiforms).

Genus PALTODUS Pander, 1856

Type Species. Paltodus subaequalis Pander, 1856

PALTODUS SEMISYMMETRICUS (Hamar, 1966)

Pl. I, figs. 16-21; Pl. 13, figs. 4,5; Fig. 22J-O

LINDSTROM 1960, Figs. 6:11, 7:10.

HAMAR 1966, p. 51, pl. 7, figs. 5,6, Fig. 3:6.

ETHINGTON and SCHUMACHER 1969, p. 450,452, pl. 67, figs. 21,22, Fig. 4c.

VIIRA 1974, p. 50, pl. 12, figs. 16, 17, Fig. 35; p. 97, pl. 11, figs. 13, 14, Fig. 117.

DZIK 1976, p. 435, Fig. 18a-f.

Description. Paltodus semisymmetricus is composed of drepanodiforms and oistodiforms.

The drepanodiforms have long and slender proclined to erect sharp-edged cusps that broaden into posteriorly extended bases. The anterior and basal margins meet at an angle of about 90 degrees whereas the oral and basal margins meet at an angle of about 30 degrees. Basal cavities are fairly shallow with apices anterior of the mid-point of the cusp about one-third of the distance up the base. Symmetrical drepanodiforms have equally developed postero-lateral costae that begin somewhat above the basal margin and continue to the tip of the cusp. Anteriorly, the cusp faces are convex. On slightly asymmetric forms the outer lateral costa originates much nearer to the basal margin than does its inner counterpart. Anteriorly, the outer lateral face is convex whereas the inner lateral face is planar. Strongly asymmetric forms have inward twisted cusps and asymmetrically arranged lateral costae. The outer lateral costae occupy posterior positions whereas the inner lateral costae are located more anteriorly.

The oistodiforms have long and slender compressed and sharp-edged cusps that are two to three times the length of their respective bases. Anterior and basal margins meet at an angle of about 60 degrees. Oral and basal margins form an angle of about 40 degrees and the posterior and oral margins form an angle of 50 to 60 degrees. Basal cavities are shallow and have their apices beneath the point at which the posterior margin of the cusp and the oral margin of the base join. The inner basal margin flares more in the posterior half of its length than in the

anterior half. The outer basal margin is smoothly convex. Oistodiforms with large inward flaring of the basal margin have a smaller postero-oral angle than do forms exhibiting less basal flaring.

Remarks. The limited amount of material from this study probably does not give full perspective to the nature of the apparatus of this species. The general morphology of the constituent elements is similar to those of the Distacodus venustus apparatus and thus the two species appear to be taxonomically close together. Therefore, P. semisymmetricus possibly has a type IIIa apparatus.

Material. 62 specimens (37 drepanodiforms, 25 oistodiforms).

Subfamily PROTOPANDERODONTINAE Lindstrom, 1970

Emended Diagnosis. Conodont apparatuses consisting of symmetrical and asymmetrical simple cone conodonts that are non-costate in early species, costate and non-costate to wholly costate in later species. Elements of the apparatus generally have an anterior and posterior edge, and can exhibit a high degree of variation. The elements can nonetheless be arranged into a simple symmetrical asymmetrical symmetry transition series and a curvature transition series, both of which are characteristic of a type IIIa apparatus.

Genus DREPANODUS Pander, 1856

Type Species. Drepanodus arcuatus Pander, 1856

Discussion. Lindstrom (1971), included four forms of non-costate elements in D. arcuatus and pin pointed its first appearance to the

latest Tremadocian. Previously (Lindstrom, 1955a), Acontiodus arcuatus s.f. and A. reclinatus s.f. were reported from middle Arenigian sections which also yielded D. arcuatus, but they occurred in small numbers.

A. arcuatus s.f. presumeably evolved from D. arcuatus s.f. during the early Arenigian. A. arcuatus s.f., D. arcuatus s.f. and forms transitional between these two were recovered from the Orthoceras Limestone, of the Paroistodus originalis Zone, on Bornholm, Denmark (S. Stouge, pers. comm.). Similarly, these forms were reported from the Llanvirnian of Sweden (Fahraeus, 1966).

The evolutionary trend, from an apparatus comprising exclusively non-costate forms to an apparatus with costate and non-costate forms, appears to have culminated in the Middle Ordovician with an apparatus comprising costate forms only. It is conceivable that apparatuses with costate and non-costate forms and apparatuses with only costate forms should be referred to new genera respectively.

DREPANODUS ROBUSTUS (Hadding, 1913)

Pl. 2, figs. 5-12; Pl. 13, figs. 9,10; Fig. 24A-J

DZIK 1976, p. 400, Fig. 17d,e,g, not f.

Description. D. robustus has symmetrical or nearly symmetrical bicostate drepanodiforms, symmetrical multicostate drepanodiforms, asymmetric bicostate drepanodiforms, weakly bicostate asymmetrical drepanodiforms and costate oistodiforms.

The symmetrical or nearly symmetrical bicostate drepanodiforms have a robust recurved cusp that is anteriorly sharp and posteriorly

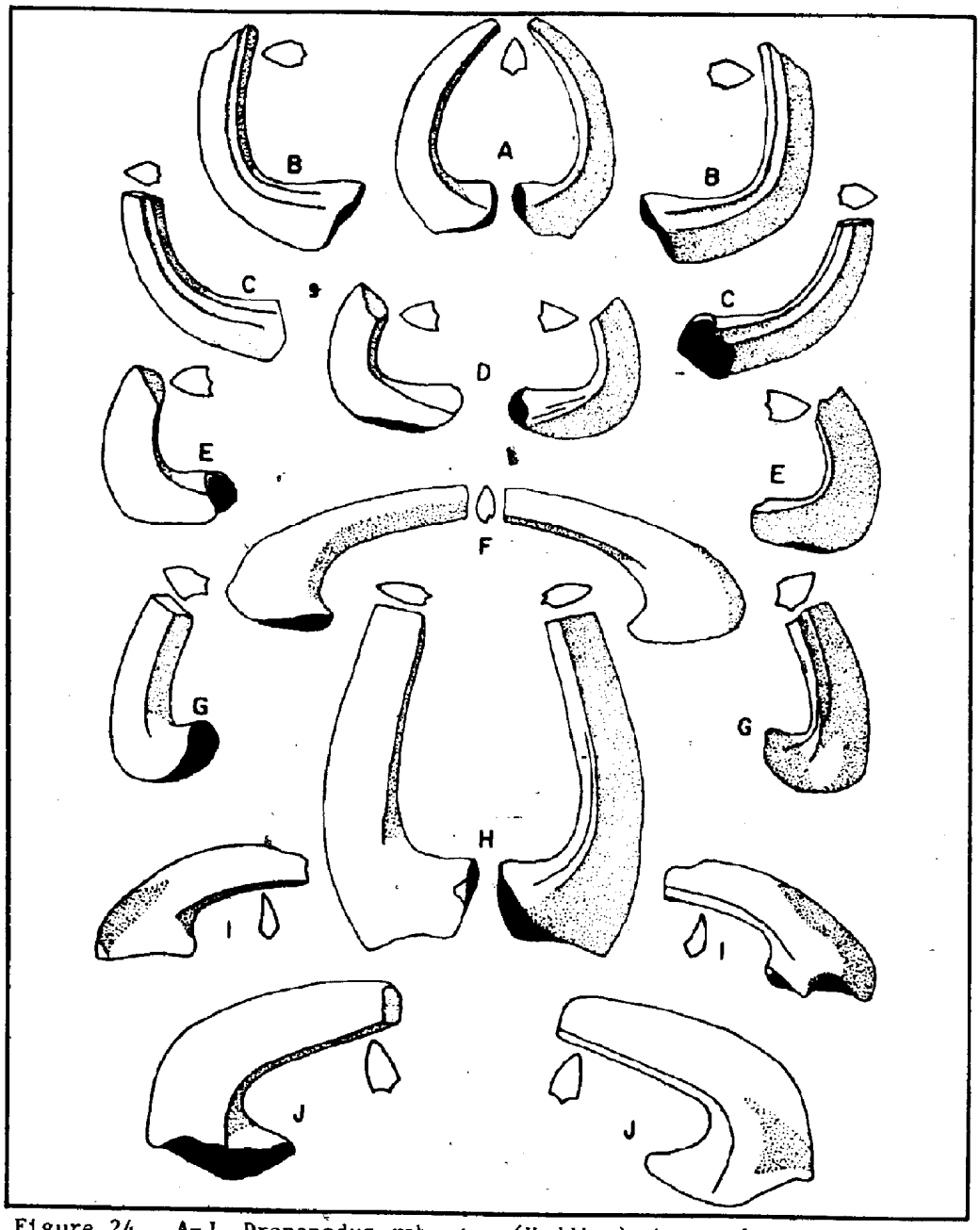

Figure 24. A-J, Drepanodus robustus (Hadding): A, nearly symmetrical bicostate drepanodiform; B,C, symmetrical multicostate drepanodiforms; D,E, asymmetrical bicostate drepanodiforms; F,H-J, weakly bicostate drepanodiforms; G, oistodiform. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X32.

costate. There is a single posterior costa on each lateral face, which begins near the basal margin and continues to the tip of the cusp.

The symmetrical multicostate drepanodiforms have proclined or erect cusps that bear two posterior costae on each lateral face. The costae begin near the basal margin.

The asymmetrical bicostate drepanodiforms have a single posterior costa on each lateral face of the cusp. Anterior of the costae, the outer cusp face is convex whereas the inner cusp face is near planar.

The weakly bicostate asymmetrical drepanodiforms have erect to reclined compressed cusps with postero-lateral costae that are well developed on the outer face and weak to absent on the inner face. Anterior edges are always sharp, whereas posterior edges are sharp or costate. The outer lateral cusp faces are convex, the inner faces slightly convex to concave with increasing asymmetry. The outer basal margin, of strongly asymmetric forms may have a rather pronounced undulation.

The oistodiforms have reclined robust cusps which are anteriorly sharp and posteriorly costate. The outer lateral face of the cusp is smoothly convex except where interrupted by a single posterior costa. The inner lateral face has a prominent carina developed posterior of its midline; anterior to this the inner lateral face is planar.

Remarks. The relatively low recovery of elements of this species makes it difficult to formulate any precise opinions about its apparatus. It does, however, show curvature transition and symmetry transition characteristic of a type IIIa apparatus.

Material. 161 specimens (16 symmetrical bicostate drepanodiforms,

12 symmetrical multicostate drepanodiforms, 47 asymmetrical bicostate drepanodiforms, 52 weakly bicostate asymmetrical drepanodiforms, 34 oistodiforms).

DREPANODUS sp. cf. D. ARCUATUS Pander, 1856

Pl. 3, figs. 1a-7; Pl. 13, figs. 11-13; Fig. 25A-H

Remarks. Only a few specimens, which possibly represent a derivative of D. arcuatus, were recovered from the Cobbs Arm Formation. This species appears to contain costate and non-costate drepanodiforms. Symmetrical costate drepanodiforms have one costa on each lateral face whereas asymmetrical costate drepanodiforms have a single costa on the outer face only. The remaining drepanodiforms, and the oistodiforms, are non-costate.

Material. 41 specimens (11 symmetrical bicostate drepanodiforms, 13 unicostate drepanodiforms, 13 non-costate drepanodiforms, 4 oistodiforms).

Genus PROTOPANDERODUS Lindstrom, 1970

Type species. Acontiodus rectus Lindstrom, 1955

PROTOPANDERODUS PESELEPHANTIS (Lindstrom, 1955)

Pl. 3, figs. 8-11; Pl. 13, fig. 17; Fig. 26G-J

LINDSTROM 1955a, p. 595, pl. 2, figs. 19,20, Fig. 3q.

VAN WAMEL 1974, p. 94-95, pl. 5, figs. 16,17.

VIIRA 1974, p. 124, Fig. 162.

DZIK 1976, Fig. 141.

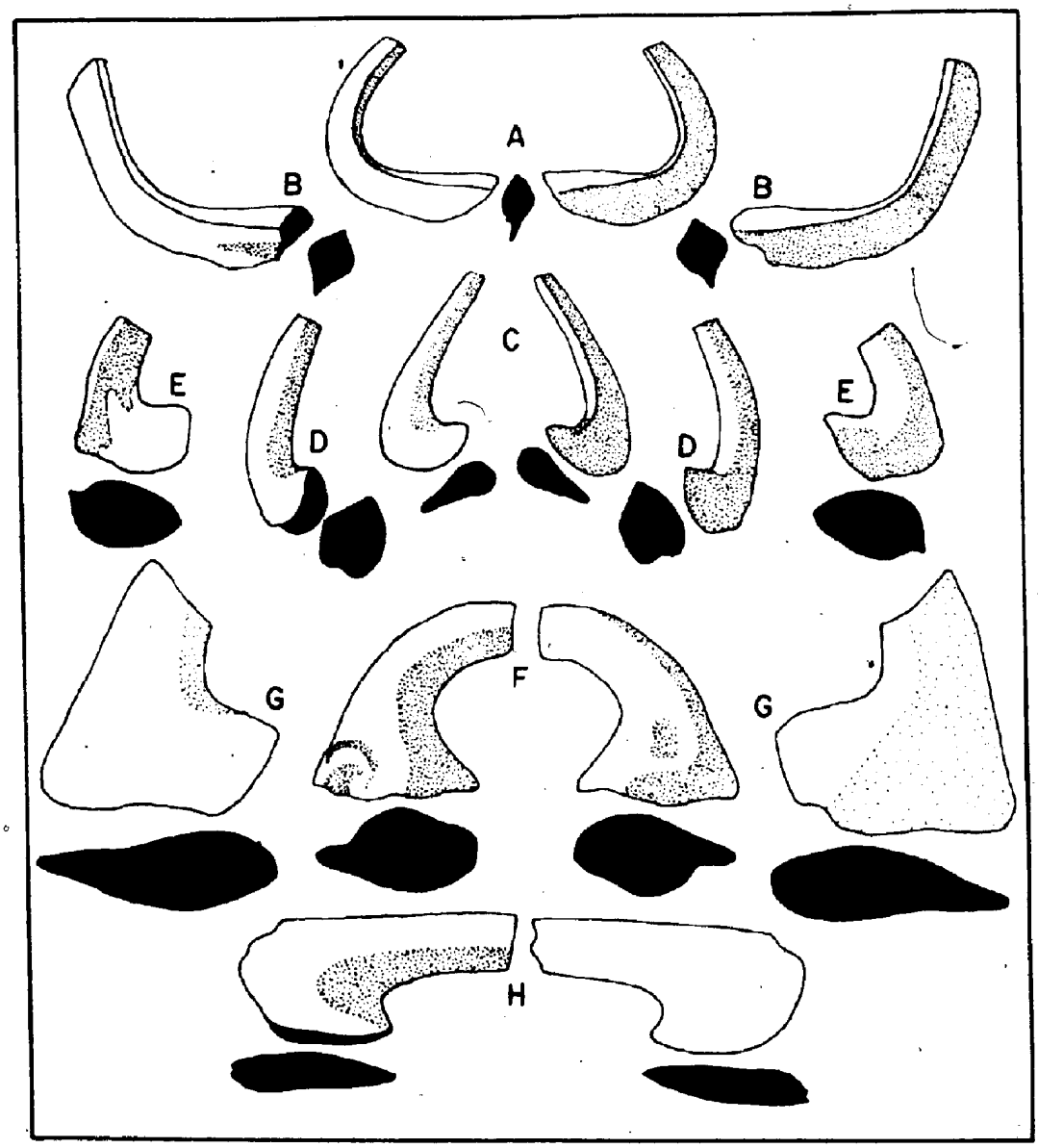

Figure 25. A-H, Drepanodus sp. cf. D. arcuatus Pander: A,B, symmetrical bicostate drepanodiforms; C, unicostate drepanodiform; F-H, acostate drepanodiforms; D, oistodiform; E, ?oistodiform. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X65.

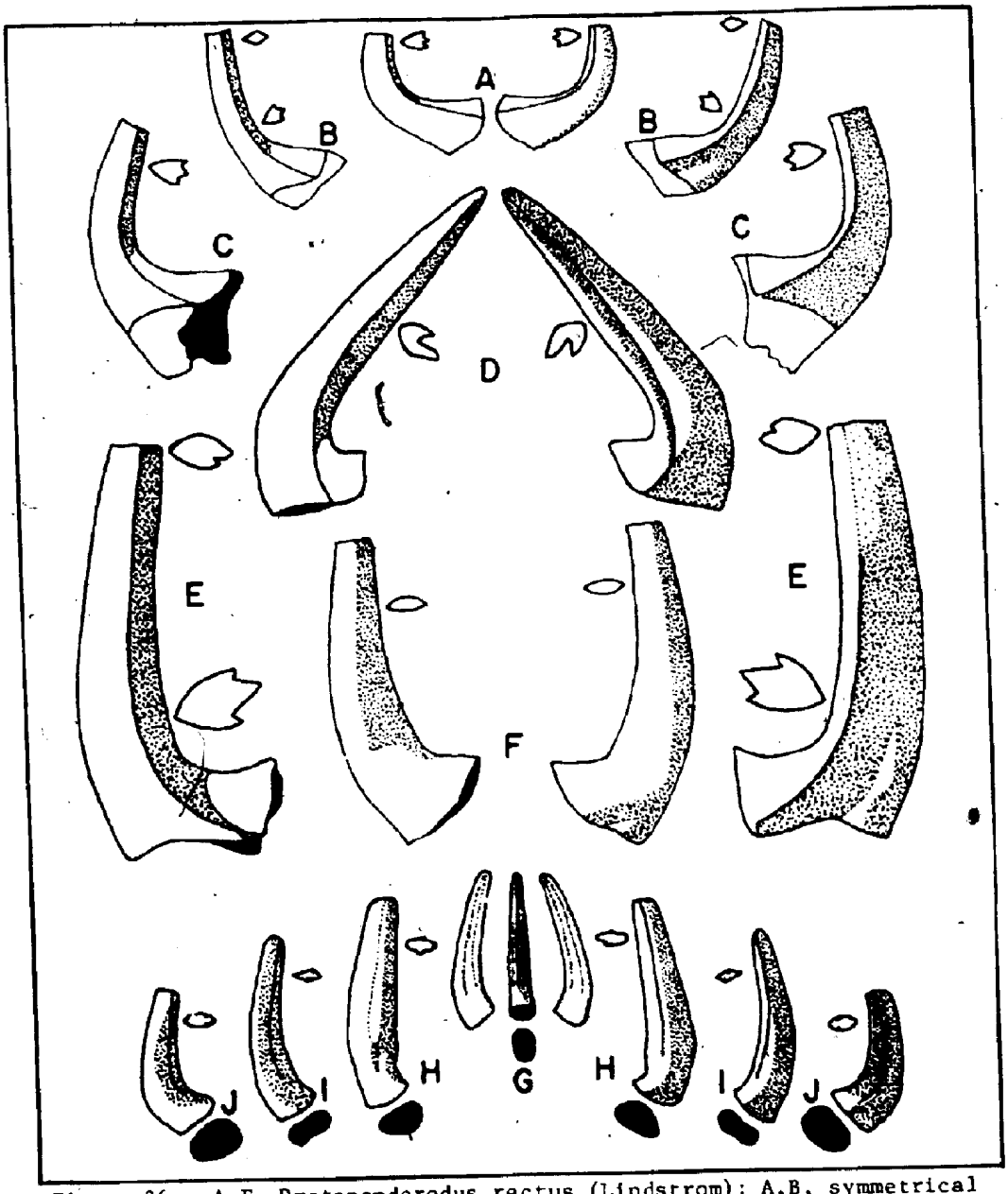

Figure 26. A-F, Protopanderodus rectus (Lindstrom): A,B, symmetrical costate drepanodiforms; C-E, asymmetrical costate drepanodiforms; F, scandodiform. G-J, Protopanderodus peselephantus (Lindstrom): G, symmetrical form; H-J, asymmetrical forms. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all x73.

Discussion. Conodonts of this species have sharp posterior and anterior margins, white matter and striated to definately costate lateral surfaces. There is a simple symmetrical asymmetrical symmetry transition,

The characteristics of this species best suit the genus Protopanderodus. It is consequently removed from Scolopodus where it was tentatively placed by Lindstrom (1955a).

Description. Constituent elements of P. peselephantis are small, nearly straight to curved and pin shaped. Cusps are pointed, generally compressed, sharp-edged and ornamented with lateral costae and coarse striations. Bases are small, circular or elliptical in shape and flared slightly all around. Basal cavities are relatively shallow.

Symmetrical elements have a subcircular cross section with sharp margins and two or three costae on each lateral face. Asymmetrical elements have compressed and sharp-edged cusps with single lateral costae that are centrally developed on nearly symmetrical forms and located more posteriorly on forms with strong inward deflection of the cusp. Strongly asymmetrical forms have costae in an outer postero-lateral position only. Some forms indicate the presence of a curvature transition.

Remarks. There are only a few elements of P. peselephantis preserved in the Cobbs Arm Formation and therefore any strong conclusions about the nature of its apparatus cannot be made. It would appear, however, that the apparatus is similar to other species of Protopanderodus.

Material. 26 specimens.

PROTOPANDERODUS RECTUS (Lindstrom, 1955)

Pl. 3, figs. 12-16b; Pl. 13, figs. 15,16; Fig. 26A-F

LINDSTROM 1955a, p. 549, pl. 2, figs. 7-11; p. 593, pl. 4, figs. 21-25, Fig. 3k;

WOLSKA 1961, p. 345, pl. 1, figs. 1,2.

SWEET and BERGSTROM 1962, p. 1221-1222, pl. 168, figs. 2,3, Fig. 1g; p. 1222, pl. 169. fig. 11, Fig. 1i; p. 1246, pl. 168, figs. 13,16.

HAMAR 1964, p. 257, pl. 1, figs. 6,7,14,?18, Fig. 4:5; p. 258, pl. 1, figs. 10,12,13,17, Figs. 4:4a,b; p. 282, pl. 2, figs. 6,7, Figs. 6:9,11.

FAHRAEUS 1966, p. 15, pl. 2, fig. 3b; p. 16, pl. 2, figs. 5a,b, Figs. 3e, f,g; p. 17, pl. 2, figs. 7a,b, Fig. 3b; p. 30, pl. 3, fig. 11, Fig. 2k.

VIIRA 1967, p. 321, Figs. 1:12,13.

BARNES and POPLAWSKI 1973, p. 782, pl. 3, figs. 1,4,5, pl. 4, fig. 15, not 18.

VIIRA 1974, p. 46, pl. 5, figs. 25,26, Figs. 25,26; p. 48, pl. 4, figs. 21-23, Fig. 29; p. 49, Figs. 30,31,34,?32,?33.

non DZIK 1976, Figs. 16a-d,i,l.

Description. P. rectus has bicostate drepanodiforms and non-costate scandodiforms.

The costate drepanodiforms have a long and slender proclined, suberect or reclined cusp with costae in a postero-lateral position. These costae begin near the basal margin, and continue to the tip of the cusp. On symmetrical drepanodiforms they are each posteriorly bounded by

a furrow. Asymmetrical forms have a furrow bounded costae on one lateral face only. The inner lateral faces have a costa or carina that is positioned more centrally and is bounded by a furrow near the base only. The disposition and distinctness of the lateral costae on different forms defines a symmetrical asymmetrical symmetry transition. Within each group there are proclined, near erect and reclined varieties.

Scandodiforms have a long and slender sharp-edged cusp with a broad central carina on the inner lateral face. The outer face is convex.

Remarks. The ratio of costate to non-costate forms is 5:1, but in this study the elements of P. rectus occur in low frequency. The costate to non-costate element ratio should probably approximate the 7:2 figure inferred for P. varicostatus since the two species are part of the same evolutionary lineage (Dzik, 1976).

P. rectus, from the Cobbs Arm Formation, agrees closely with specimens from the collections of Dr. L.E. Fahraeus of upper Llanvirnian conodonts from the Gullhogen Quarry, Sweden (Fahraeus, 1966), and with collections of S. Stouge of upper Arenigian conodonts from Bornholm, Norway (see Stouge, 1975). It would seem apparent that P. rectus was a very conservative animal to have survived from the middle Arenigian to at least middle LLandeilian times with no apparent change.

Material. 66 specimens (54 bicostate drepanodiforms, 12 scandodiforms).

PROTOPANDERODUS VARICOSTATUS (Sweet and Bergstrom, 1962)

Pl. 4, figs. 1a-7b; Pl. 14, figs. 1,1a; Fig. 27A-E

SWEET and BERGSTROM 1962, p. 1247, pl. 168, figs. 4-9, Figs. 1a,c,k; p. 1245, pl. 168, fig. 12, Fig. 1e.

HAMAR 1964, p. 284, pl. 1, figs. 1,2, Figs. 4:7a,b; p. 281-282, pl. 2, figs. 16,17; p. 282, pl. 2, figs. 10,11.

HAMAR 1966, p. 75, pl. 1, fig. 18, Fig. 2:1; p. 74, pl. 3, fig. 1, not 7.

VIIRA 1974, p. 123, pl. 5, figs. 23,24, Fig. 160; p. 119, pl. 5, fig. 30, Fig. 151.

non DZIK 1976, Figs. 16e-g.

Discussion. This species of Protopanderodus has numerous representatives in the Cobbs Arm Formation, and shows a definite apparatus consisting of four multicostate drepanodiforms and one non-costate scandodiform which herein show a ratio of 1:2:2:2:2. The costate forms thus outnumber the non-costate forms by a ratio of 7:2. P. varicostatus exhibits a simple symmetrical asymmetrical symmetry transition and a curvature transition characteristic of apparatus type IIIa.

Description. P. varicostatus has one symmetrical and three asymmetrical multicostate drepanodiforms and one asymmetrical non-costate scandodiform each with a curvature transition.

Symmetrical multicostate drepanodiforms have a sharp anterior margin and a costate posterior margin. On each lateral face there are two posterior costae, separated by a deep furrow that begins near the basal margin and continues to the tip of the cusp. The base is about

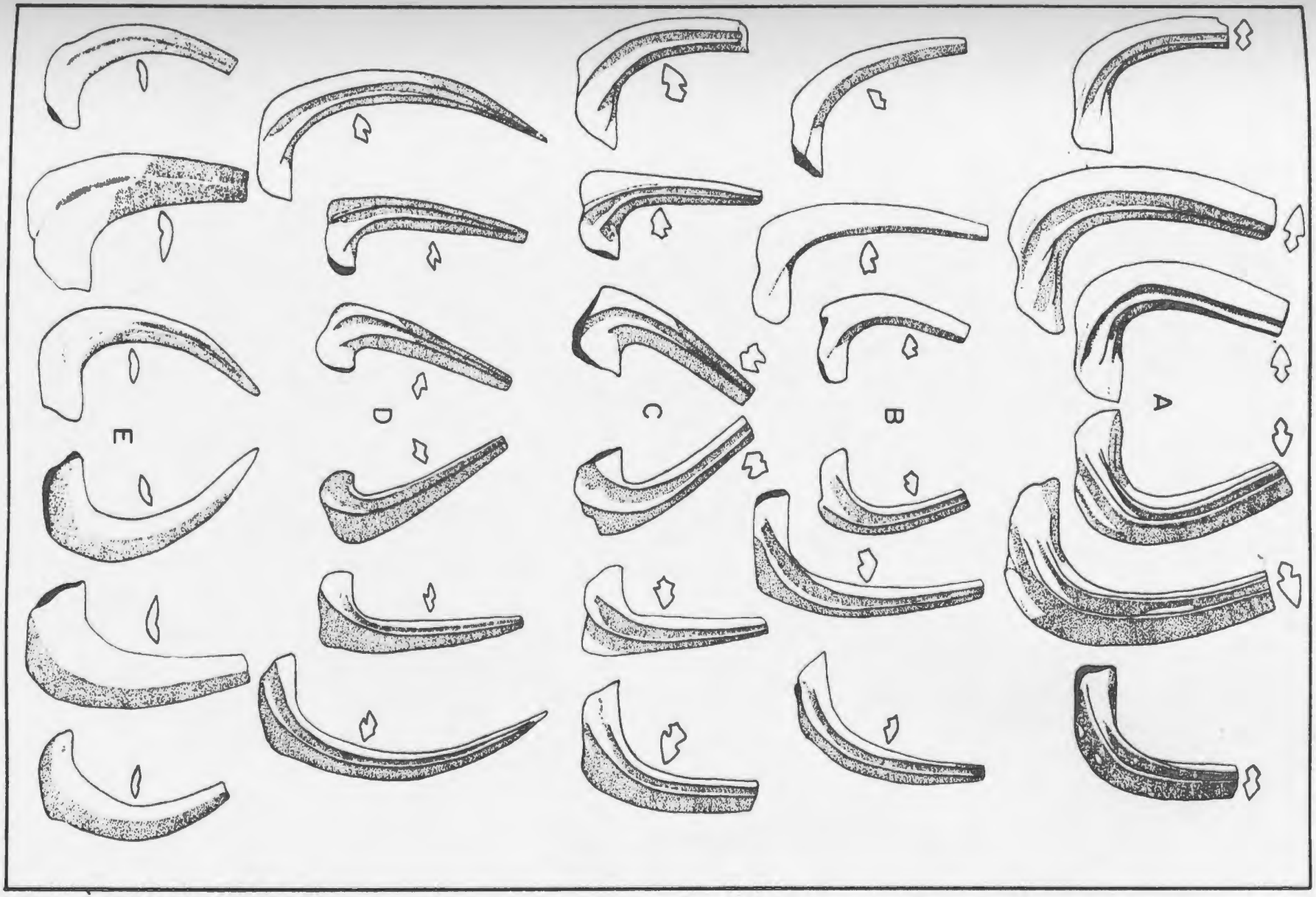

Figure 27. Protopanderodus varicostatus (Sweet and Bergstrom): A, symmetrical multicostate drepanodiforms; B, tricostate drepanodiforms; C,D, asymmetrical multicostate drepanodiforms; E, scandodiforms. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X45.

one third of the length of the cusp and has a slightly sinuous basal margin.

Tricostate drepanodiforms are similar to the symmetrical forms only in the fact that the cusps are long and slender, costate and not twisted out of the plane of the base, but differ in that one lateral face has two longitudinal costae; the other has one only. The bases are also proportionately shorter that those of the symmetrical multicostate drepanodiforms. Basal margins are slightly sinuous in proclined varieties and notched in reclined varieties.

The asymmetrical multicostate drepanodiforms constitute a rather uniform group that is divisible, upon close examination, into two end member forms. One of these has a sharp anterior and posterior margin and a distally twisted cusp with two low inner lateral costae. The outer lateral face has one well developed costa bounded by a furrow. Posterior to this a second costa is well developed on the base but generally becomes weaker further up the cusp.

The other asymmetrical multicostate drepanodiform is nearly identical with the last described drepanodiform, but has one well developed costa on the outer lateral face instead of two. The bases of the asymmetrical multicostate drepanodiforms are proportionately shorter than those of the tricostate drepanodiforms. Basal margins are not notched in proclined varieties.

The scandodiforms have a long and robust sharp-edged cusp that is laterally compressed and inward twisted out of the plane of the base. On the anterior half of the inner lateral face there is a shallow longitudinal groove that begins near the basal margin and continues to the

tip of the cusp. The outer lateral face is convex.

Remarks. P. varicostatus probably evolved from P. rectus, through the addition of auxiliary lateral costae, sometime in the upper Arenigian (Dzik, 1976). P rectus continued with minimal change until at least the middle Llandeilian and then ceased to exist whereas P. varicostatus, and its predecessors, underwent changes that culminated in the Ashgill with P. insculptus, an elongate protopanderodid having forms with double lateral costae.

Material. 1291 specimens (157 symmetrical multicostate drepanodiforms, 327 tricostate drepanodiforms, 581 asymmetrical multicostate drepanodiforms, 226 non-costate scandodiforms).

Family UNKNOWN

Genus STRACHANOGNATHUS Rhodes, 1955

Type Species. Strachanognathus parvus, Rhodes, 1955

Discussion. The affinities of this genus are not clear. It is of simple cone type but for the presence of a single large denticle directly in front of the cusp. It exhibits a simple symmetry transition from symmetrical to increasingly asymmetric forms. There is also some evidence for a slight curvature transition, but this is not conclusive enough to suggest that Strachanognathus has a type III apparatus. Edges of the elements are sharp, basal cavities are shallow and the surface of the forms lack any conspicuous fine microstructure.

There seem to be little doubt that Strachanognathus evolved directly from a distacodontid apparatus, but is is not possible at the

present time to assign this genus to any presently described family.

STRACHANOGNATHUS PARVUS Rhodes,1955

Pl. 2, figs. 1a-4b; Pl. 13, fig. 1; Fig. 28F-I

RHODES 1955, p. 132, pl. 7, fig. 16, pl. 8, figs. 1-4.

BERGSTROM 1962, p. 55-56, pl. 3, figs. 1-6, Figs. 2b,3h,i.

WOLSKA 1961, p. 358, pl. 5, figs. 6a,b.

SERPAGLI 1967, p. 71-72, pl. 29, figs. 4a-c,?5a-c.

BERGSTROM, RIVA and KAY 1974, pl. 1, fig. 7.

DZIK 1976, Figs. 14j,k.

Description. This species is composed of compound conodonts showing slightly differing forms, of basically the same kind of element, arranged in a simple symmetrical asymmetrical symmetry transition. Cusps are long, slender and sharp-edged and are followed anterior~~ly~~ by a very large denticle that is often near equal in length to the cusp and curved in towards the cusp. The anterior and posterior margins of the base are nearly parallel and sharp. Basal cavities are shallow, and flare slightly inward on asymmetrical forms. Symmetrical or nearly symmetrical forms are compressed and have both the cusp and anterior denticle in the same plane as the base. Asymmetric forms are concave inward and have an inward deflected cusp and anterior denticle.

Material. 687 specimens.

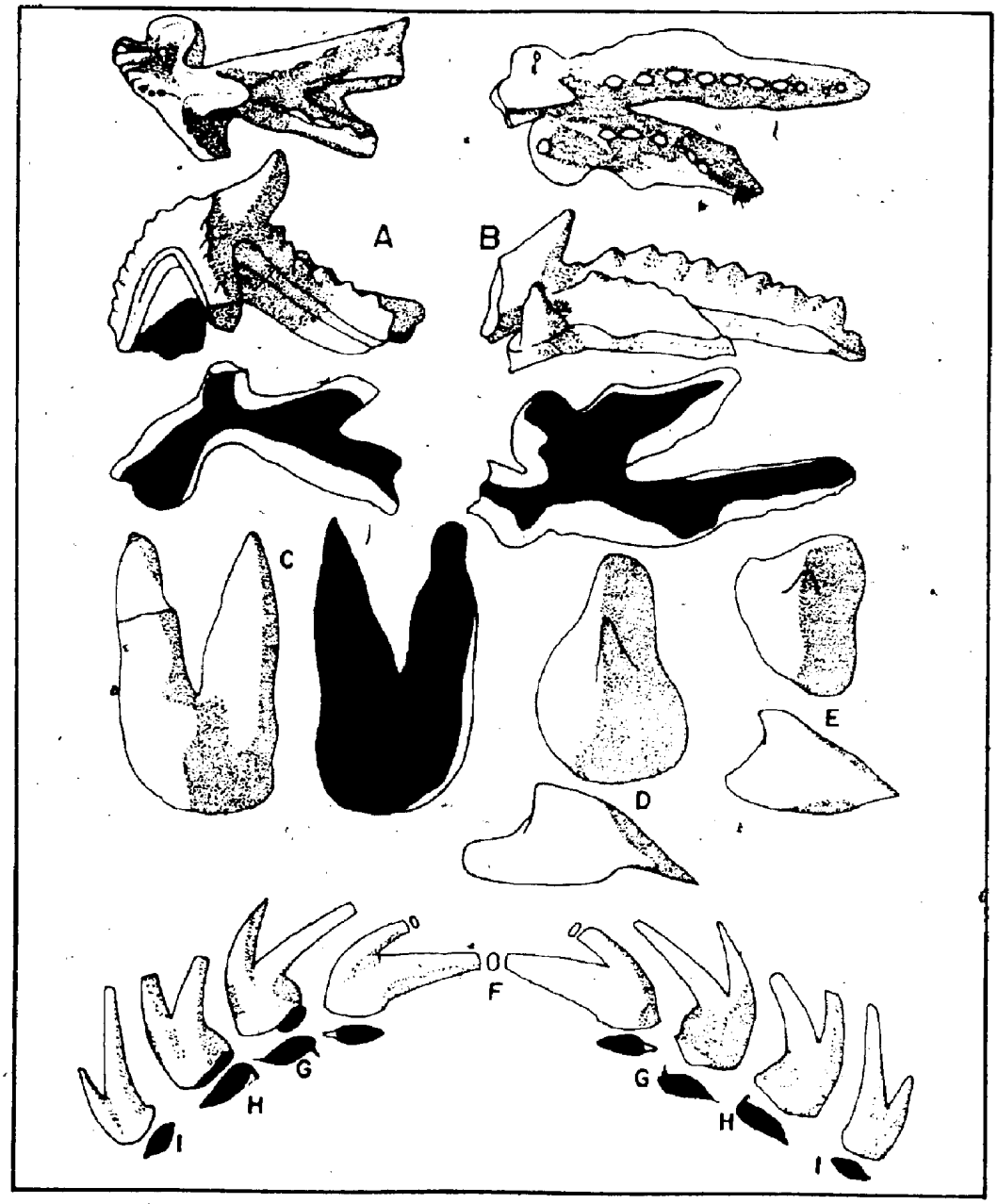

Figure 28. A, Rhodesognathus sp. cf. R. elegans polonicus Dzik: oral view, top; lateral view, centre; aboral view, bottom; X37. B, Amorphognathus sp. cf. A. inaequalis-A. kielcensis transition: oral view, top; lateral view, centre; aboral view, bottom; X37. C, Westergaardodina sp. cf. W. bicuspida Muller: oral view, left; aboral view, right; X53. D,E, ?Oneotodus mitratus (Moskalenko): oral views, top; lateral views, bottom; X53. F-I Strachanognathus parvus Rhodes;F,nearly symmetrical form; G-I, asymmetrical forms. Inner lateral views, left of centre; outer lateral views, right of centre; X53.

Superfamily PANDERODONTACEA Lindstrom, 1970

Discussion. Lindstrom (1970) proposed this superfamily for conodont species with apparatuses consisting of simple cone conodonts with or without lateral costae or carinae and for related species having forms with a row of denticles posteriorly. Important to Panderodontacea, by definition, is the presence of fine longitudinal striations on the cusps of the constituent elements.

Middle Ordovician taxon of Panderodontacea from the Cobbs Arm Formation exhibit a variation obvious of a large degree of evolutionary differentiation. There are 14 species belonging to 8 genera which herein are assigned to 2 families.

Dzik (1976) considers the genus Semiacontiodus Miller to be ancestral to Panderodontacea. It first appears in the lower Tremadocian, presumably a descendent of the Late Cambrian Oneotodus. From Semiacontiodus, the related genera Panderodus and Scalpellodus diverged. Panderodus is characterized by a type IIIa apparatus and has very noticeable surface striations. Scalpellodus has surface striations and a type Ia rather than a type III apparatus.

These gross characteristics are the foundation to the subdivision of the superfamily Panderodontacea into two families: Panderodontidae and Scalpellodontidae.

Family PANDERODONTIDAE Lindstrom, 1970

Discussion. Panderodontidae characteristically have a deep basal cavity, longitudinal striations and a lateral furrow. Some forms have a denticle row posteriorly.

The apparatus shows a simple symmetrical asymmetrical symmetry transition and a curvature transition, characteristic of type IIIa apparatuses. The apparatus may be reduced in number of elements (IIIb; i.e. Belodina).

Genus BELODINA Ethington, 1959

Type Species. Belodus grandis Stauffer, 1935

BELODINA SERRATA (Dzik, 1976)

Pl. 4, figs. 8a,b; Pl. 14, fig. 4; Fig. 29A

DZIK 1976, p. 422, Fig. 14f, pl. 41, Fig. 3.

Description. The characteristic form of this species is a long and slender inward bowed simple cone with a finely denticulated posterior margin. The element is continuously curved throughout its length and consequently cusp and base are not easily distinguished. The anterior margin is narrowly rounded whereas the posterior margin is distally and proximally sharp and centrally provided with about ten small sharp denticles. A carina is developed on the basal anterior part of the outer surface. Posterior to this, there is a hairline furrow that begins at a small notch in the base and continues to the tip of the cusp. The basal cavity is deep.

Remarks. Dzik (1976) considers B. serrata to be a descendent from Scalpellodus and consequently placed it within the genus Belodella, however, the resemblance of the elements of this species to elements of Panderodus and Belodina is outstanding and it appears to be an intermediate form between the two. It is possible that the remaining elements of this

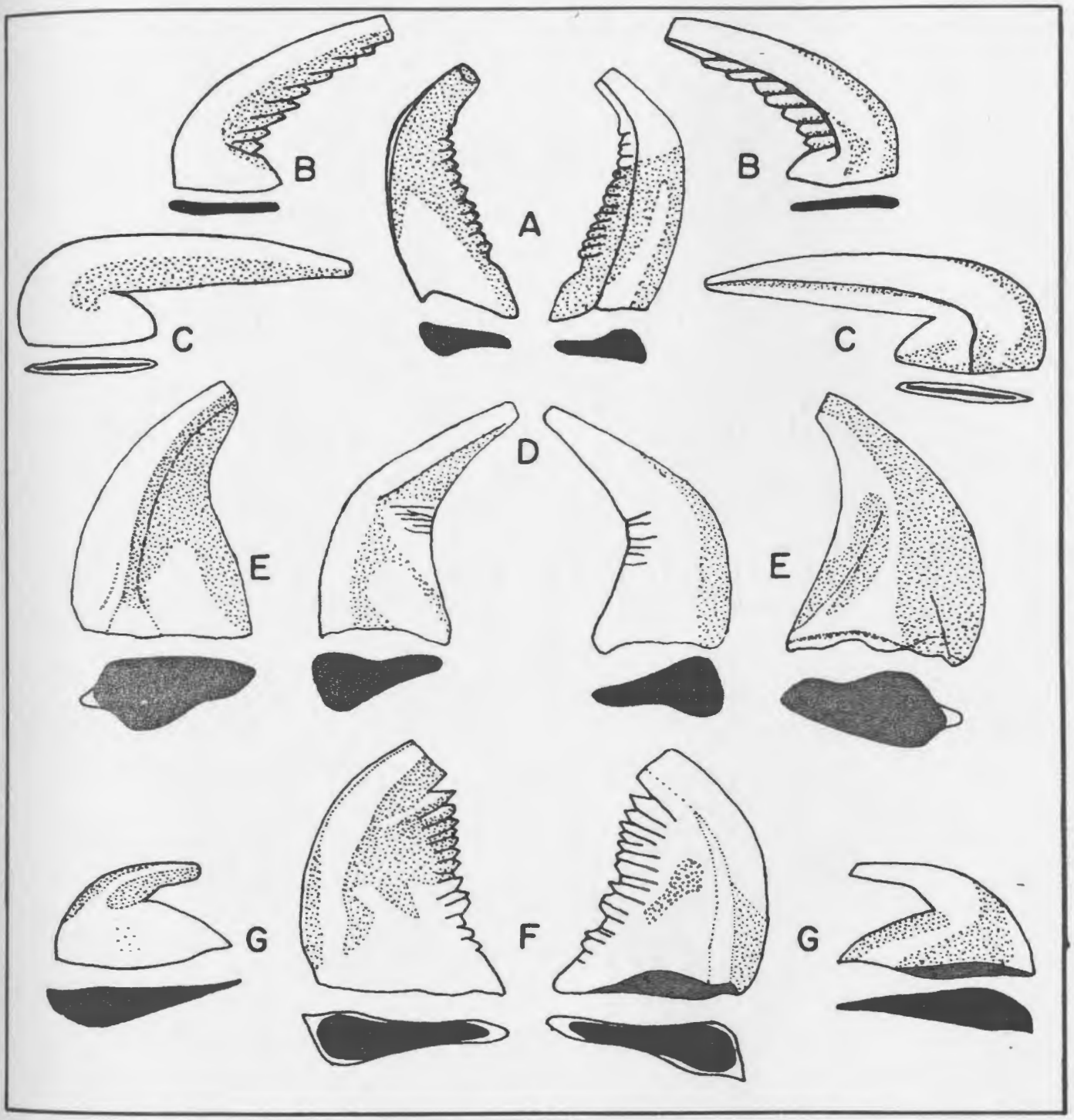

Figure 29. A, Belodina serrata (Dzik). B,C, Belodina n. sp. A: B, belodiniform; C, eobelodiniform. F,G, Pseudobelodina n. sp. A: F, belodelliform; G, oistodiform. D, Belodella n. sp. s.f. Barnes and Poplawski, 1973. E, non-denticulated belodelliform from the Belodella n. sp. A apparatus (Fig. 32). Note the similarities between Belodina serrata and the belodiniform of Belodina n. sp. A. Inner lateral views, left of centre; outer later views, right of centre. Illustrations are all X74.

apparatus represent non-denticulated panderodiforms.

Material. 3 specimens.

BELODINA n. sp. A

Pl. 4, figs. 9a,b,11a,b; Pl. 14, fig. 7; Fig. 29B,C

Description. Belodina n. sp. A appears to have a type IIIb apparatus comprising belodiniforms and eobelodiniforms.

The belodiniforms can be differentiated into erect and proclined forms; both with 7 to 9 denticles on the posterior margin that begin at the base of the cusp and continue upward for three quarters of its length. The remaining edges of the element are sharp. The basal cavity is triangular and penetrates one third the length of the element.

The eobelodiniforms are strongly compressed laterally and sharp edged. The straight posterior edge of the cusp is near parallel with, and more than twice the length of, the basal margin. The anterior edge is convex and continuously curved to the basal margin.

Both form elements have fine longitudinal striations on the lateral faces and a median furrow on the outer surface.

Remarks. Belodina n. sp. A has the general characteristics of Belodina compressa, but the belodiniforms of Belodina n. sp. A have smaller and more numerous denticles and are less robust than belodiniforms of B. compressa. The eobelodiniforms of Belodina n. sp. A have much longer cusps.

Material. 30 specimens (16 belodiniforms, 14 eobelodiniforms).

Genus PANDERODUS Ethington, 1959

Type Species. Paltodus unicostatus Branson and Mehl, 1933

PANDERODUS GRACILIS (Branson and Mehl, 1933)

Pl. 5, figs. 1a-7; Pl. 14, fig. 3; Fig. 30A-E

BRANSON and MEHL 1933, p. 108, pl. 8, figs. 20,21; p. 109, pl. 8, fig. 19; p. 42, pl. 3, fig. 3; p. 42, pl. 3, fig. 4.

STAUFFER 1935a, p. 150, pl. 12, figs. 17,26; p. 142, pl. 12, fig. 18; p. 142, pl. 12, fig. 16.

STAUFFER 1935b, p. 612, pl. 74, figs. 6,8,9; p. 612, pl. 74, figs. 1,2,11, 13-15,19; p. 612, pl. 74, figs. 4,7; p. 613, pl. 74, figs. 3,16.

STAUFFER 1940, p. 427, pl. 60, fig. 6; p. 427, pl. 60, fig. 10; p. 427, pl. 60, figs. 8,9; p. 428, pl. 60, figs. 5,12,13,17; p. 428, pl. 60, fig. 11.

BRANSON and MEHL 1943, p. 386, pl. 64, fig. 6; p. 386, pl. 64, figs. 7,8.

BRANSON 1944, pl. 11, figs. 3,34,35; pl. 12, figs. 20-23, 25-28.

BRANSON and BRANSON 1947, p. 554, pl. 82, figs. 6-8, 11-22; p. 554, pl. 82, figs. 1-5, 23,24.

BRANSON, MEHL and BRANSON 1951, p. 6, pl. 1, figs. 1-8; p. 7, pl. 1, figs. 16-22; p. 7, pl. 1, figs. 9-15.

RHODES 1953, p. 297, pl. 21, figs. 106-109, pl. 22, figs. 162, 165; p. 297, pl. 23, figs. 219,220; p. 298, pl. 21, figs. 84-88, pl. 22, figs. 155,156, pl. 23, figs. 214-216.

RHODES 1955, p. 127, pl. 10, figs. 11,12; p. 127, pl. 10, figs. 1,3.

GLENISTER 1957, p. 727, pl. 85, fig. 7; p. 728, pl. 85, fig. 11; p. 728, pl. 85, figs. 2-5; p. 728, pl. 85, fig. 10; ?p. 728, pl. 85, figs. 8,9; ?p. 729, pl. 85, fig. 6; ?p. 729, pl. 85, fig. 1.

ETHINGTON 1959, p. 284, pl. 39, fig. 4; p. 284, pl. 39, fig. 2; p. 285, pl. 39, fig. 1; p. 285, pl. 39, fig. 3.

ETHINGTON and FURNISH 1959, p. 541, pl. 73, figs. 8,9.

STONE and FURNISH 1959, p. 225, pl. 31, fig. 3; p. 225, pl. 31, fig. 2; p. 225, pl. 31, fig. 1; p. 226, pl. 31, fig. 4.

SWEET, TURCO, WARNER and WILKIE 1959, p. 1056, pl. 130. fig. 1; p. 1056, pl. 130, fig. 2; p. 1057, pl. 131, fig. 4; p. 1057, pl. 131, fig. 3.

WOLSKA 1961, p. 353, pl. 4, figs. 1a,b; p. 353, pl. 4, figs. 2a,b; p. 353, pl. 4, figs. 3a,b.

SWEET and BERGSTROM 1962, p. 1233, Fig. 1h; p. 1234, Fig. 1d.

BERGSTROM 1964, p. 30, Fig. 14,16,?15.

HAMAR 1964, p. 271-72, pl. 1, figs. 25,26, Figs. 6:2a,b; p. 272, pl. 1, figs. 28,29, Figs. 6:1a,b.

BARNET 1965, p. 72, pl. 1, fig. 19, pl. 2, fig. 17; p. 72, pl. 1, fig. 28; p. 72, pl. 1, fig. 32.

BERGSTROM and SWEET 1966, p. 355, pl. 35, figs. 1-6.

HAMAR 1966, p. 64, pl. 1, figs. 1-4, Figs. 3:8a-c; p. 66, pl. 7, figs. 22-24, Fig. 3:3; p. 67, pl. 1, fig. 6; pl. 1, fig. 7.

OBERG 1966, p. 140, pl. 15, fig. 8; p. 140, pl. 16, fig. 3; p. 140, pl. 15, fig. 17; p. 140, pl. 15, fig. 1.

SCHOPF 1966, p. 65, pl. 5, figs. 26,28; p. 65, pl. 5, fig. 23; p. 66, pl. 5, fig. 30; p. 66, pl. 5, figs. 22,24.

WEBERS 1966, p. 38, pl. 2, figs. 8a,b,9a,b; p. 38, pl. 2, figs. 19,11; p. 38, pl. 3, figs. 1a,b,2a,b; p. 39, pl. 3, figs. 10a,b,11a,b,12a,b; p. 39, pl. 2, figs. 1a,b,2a,b,3a,b,6a,b.

WINDER 1966, p. 58, pl. 9, fig. 23, Fig. 3:23; pl. 9, fig. 19, Fig. 3:19;

pl. 9, fig. 20, Fig. 3:20; pl. 9, fig. 24, Fig. 3:24; pl. 9, fig. 25, Fig. 3:25; pl. 9, fig. 26, Fig. 3:26; pl. 9, fig. 27, Fig. 3:27; pl. 9, fig. 28, Fig. 3:28.

ANDREWS 1967, p. 895, pl. 113, fig. 3; p. 896, pl. 113, fig. 9.

IGO and KOIKE 1967, p. 12, pl. 1, figs. 19a,b,20a,b, Fig. 4b; p. 15, pl. 1, figs. 3-5, Fig. 4j; p. 21, pl. 1, figs. 12,13a,b,14a,b, Fig. 5a; ?p. 18. pl. I, figs. 1,2, Fig. 5h.

SERPAGLI 1967, p. 56, pl. 6, figs. 4a-c,5a,b; p. 57, pl. 23, figs. 3a-5c; p. 59, pl. 23, figs. 1a-2c.

VIIRA 1967, Figs. 4:20,21-22.

WEYANT 1968, p. 55, pl. 5, fig. 7; p. 55, pl. 6, figs. 1,2; p. 56, pl. 5, fig. 4; p. 56, pl. 5, figs. 1,2; p. 57, pl. 5, figs. 5,6; p. 57, pl. 5, fig. 3; p. 58. pl. 5, fig. 13.

GLOBENSKY and JAUFFRED 1971a, p. 57, pl. 4, figs. 1,2.

MOSKALENKO 1973, pl. 1, figs. 13,14; p. 38-39, pl. 1, figs. 16,17; p. 37-38, pl. 1, fig. 15.

UYENO 1974, p. 15, pl. 3, figs. 7-14.

Discussion. Elements of this species have long been ignored because of its apparently long ranging nature and consequent unimportance for correlation purposes. The characteristics of the apparatus have thus not been thoroughly investigated.

P. gracilis, in this study, appears to have a simple symmetrical asymmetrical symmetry transition of five forms; four of which were previously referred to as Panderodus gracilis s.f. or Panderodus unicostatus s.f. and one previously referred to as Panderodus compressus s.f. Superimposed on the symmetry transition there is a curvature transition;

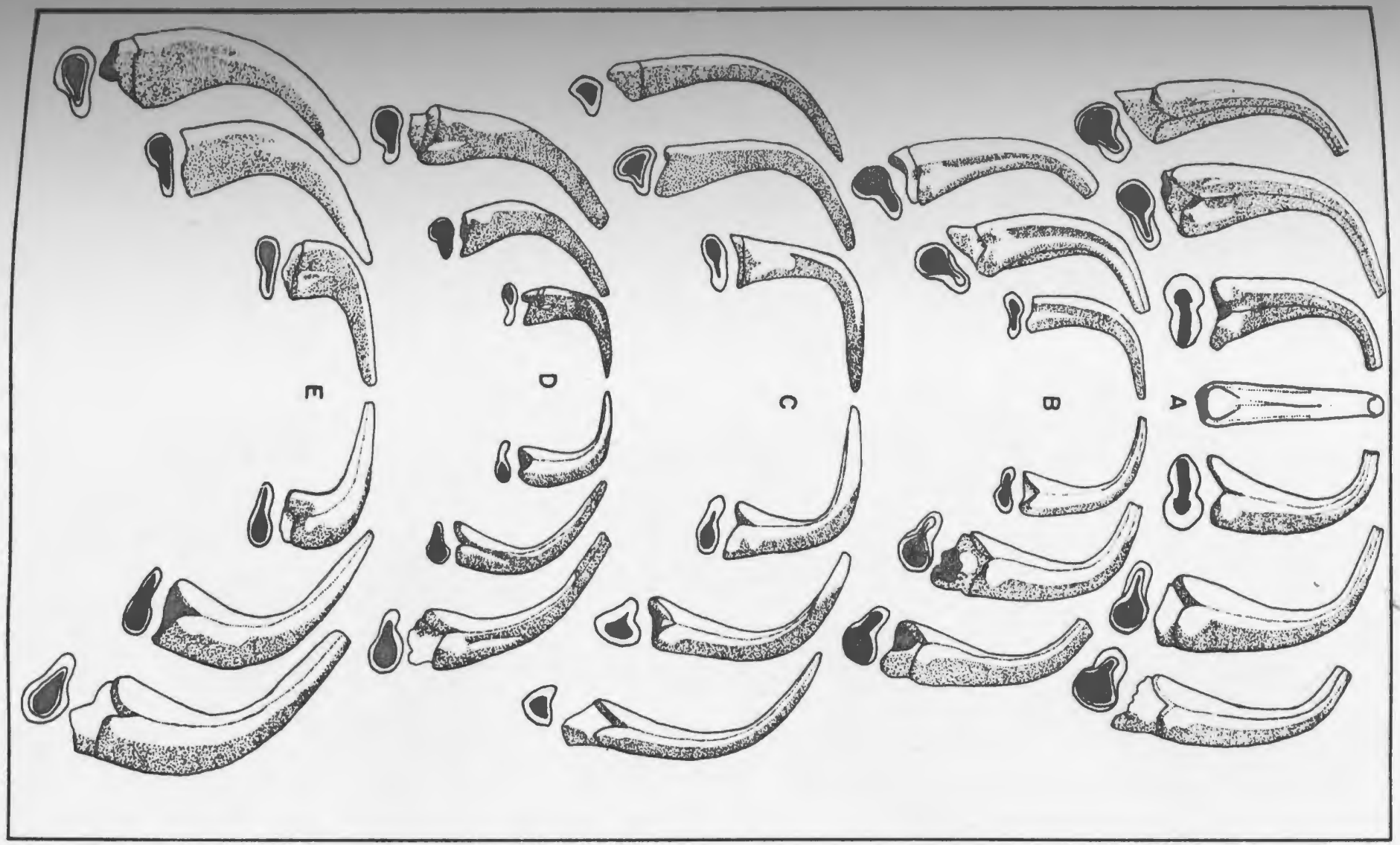

Figure 30. Panderodus gracilis (Branson and Mehl): A, symmetrical gracilid panderodiform; B,C,D, asymmetrical gracilid panderodiforms; E, compressid panderodiform. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X50.

characteristic of a type IIIa apparatus.

P. gracilis occurs in abundance in both the North Atlantic and Midcontinent Provinces (Branson and Mehl, 1933; Webers, 1966; Rhodes, 1953). A single species would have to have incredible environmental tolerance to be able to occupy both territories throughout the Ordovician, but no study has yet offered evidence to suggest otherwise. Presently, the true time range of P. gracilis and the temporal relationship it has with the Silurian(?) P. unicostatus is poorly understood. Solution to this kind of problem will, in the future, require many painstaking hours of observation of varied and prolific faunas in search of possible morphological changes in the apparatus of P. gracilis and related species.

In this study, the synonomy of P. gracilis includes only those works on Ordovician faunas in the North Atlantic and Midcontinent Provinces.

Description. P. gracilis, as interpreted herein, has five symmetry forms that are described in order from the symmetrical and asymmetrical gracilid panderodiforms to the most asymmetric compressid panderodiforms.

The cusp of the symmetrical gracilid panderodiforms has a smooth broadly rounded posterior margin. The oral edge of the base is sharp from the tip of the cusp to where it becomes rounded near the basal margin. Lateral costae are symmetrically disposed and run from near the basal margin to the tip of the cusp. Anteriorly, the element is smoothly convex. Posteriorly, the lateral faces are slightly concave and ornamented with fine longitudinal striations. Along the middle of each of the posterior lateral faces there is a narrow furrow which begins as a notch in the basal margin and continues to the tip of the cusp.

The nearly symmetrical gracilid panderodiforms are very similar to the symmetrical forms but lack an inner lateral furrow and basal notch. The sharp oral edge of the base occupies a slight outer lateral position and the lateral costae are not quite symmetrically disposed.

The slightly more asymmetrical gracilid panderodiform has an inward twisted cusp, such that the inner lateral costa of the base moves anteriorly to become a sharp anterior edge to the cusp. The sharp posterior edge of this form is positioned more outer laterally somewhat parallel to the furrow on the outer lateral face. A narrowly rounded outer lateral carina is developed on the base only.

The fourth group of gracilid panderodiforms have developed a sharp anterior edge at the expense of the inner lateral costa present on less asymmetric forms. The posterior edge of the element is very close and near parallel to the furrow on the outer lateral face. On the outer lateral face of the base there is a broadly rounded carina.

The compressid panderodiforms resemble the last described forms but have a narrowly rounded anterior margin, a wider base, and a smooth outer lateral face.

Remarks. Only about 1000 elements, from one sample, were examined in detail. Forms previously assigned to P. gracilis s.f. and P. unicostatus s.f. were easily separated into symmetrical, near symmetrical and distinctly asymmetrical form groups that were, along with P. compressus s.f., respectively represented by 76, 206, 459, and 228 specimens. The distinctly asymmetrical forms of P. gracilis s.f. and P. unicostatus s.f. were not easily subdivided and so end member varieties were used in the descriptions.

The apparatus appears to have five different form groups that exhibit a curvature transition series superimposed on the symmetry transition series, i.e. apparatus type IIIa. The proportions of the five forms respectively suggest the ratio 1:2:2:2:2.

Material. 5756 specimens (4612 gracilid panderodiforms, 1144 compressid panderodiforms).

PANDERODUS MUTATUS (Branson and Mehl, 1933)

Pl. 5, figs. 8a-12b; Pl. 14, figs. 6,7; Fig. 31A-J

BRANSON and MEHL 1933, p. 126, pl. 10, fig. 17.

ETHINGTON 1959, p. 275, pl. 39, fig. 8; p. 268, pl. 39, fig. 11.

BERGSTROM 1964, p. 9-10, Fig. 2.

HAMAR 1964, p. 256, pl. 1, fig. 3; p. 264-65, pl. 1, figs. 4,5, Fig. 4:1.

BERGSTROM and SWEET 1966, p. 303-305, pl. 35, figs. 7-9.

HAMAR 1966, p. 48, pl. 2, figs. 1,2,10, Figs. 4:1-3.

SCHOPF 1966, p. 51, pl. 5, fig. 1, Fig. 7b; p. 31, pl. 5, fig. 20, Fig. 7a.

WEBERS 1966, p. 21-22, pl. 3, figs. 5,6.

IGO and KOIKE 1967, p. 12, pl. 1, figs. 21,22, Fig. 4c; ?p. 15-16, pl. 1, figs. 6-11.

SERPAGLI 1967, p. 18-19, pl. 9, figs. 6a-11c; p. 13-14, pl. 6, figs. 1a,b, 6a,b.

DZIK 1976, p. 428, Figs. 15g-i.

Description. This species is an assemblage of simple cone conodonts, most of which are ornamented with lateral costae and longitudinal striations. The apparatus has a symmetry transition series of forms with

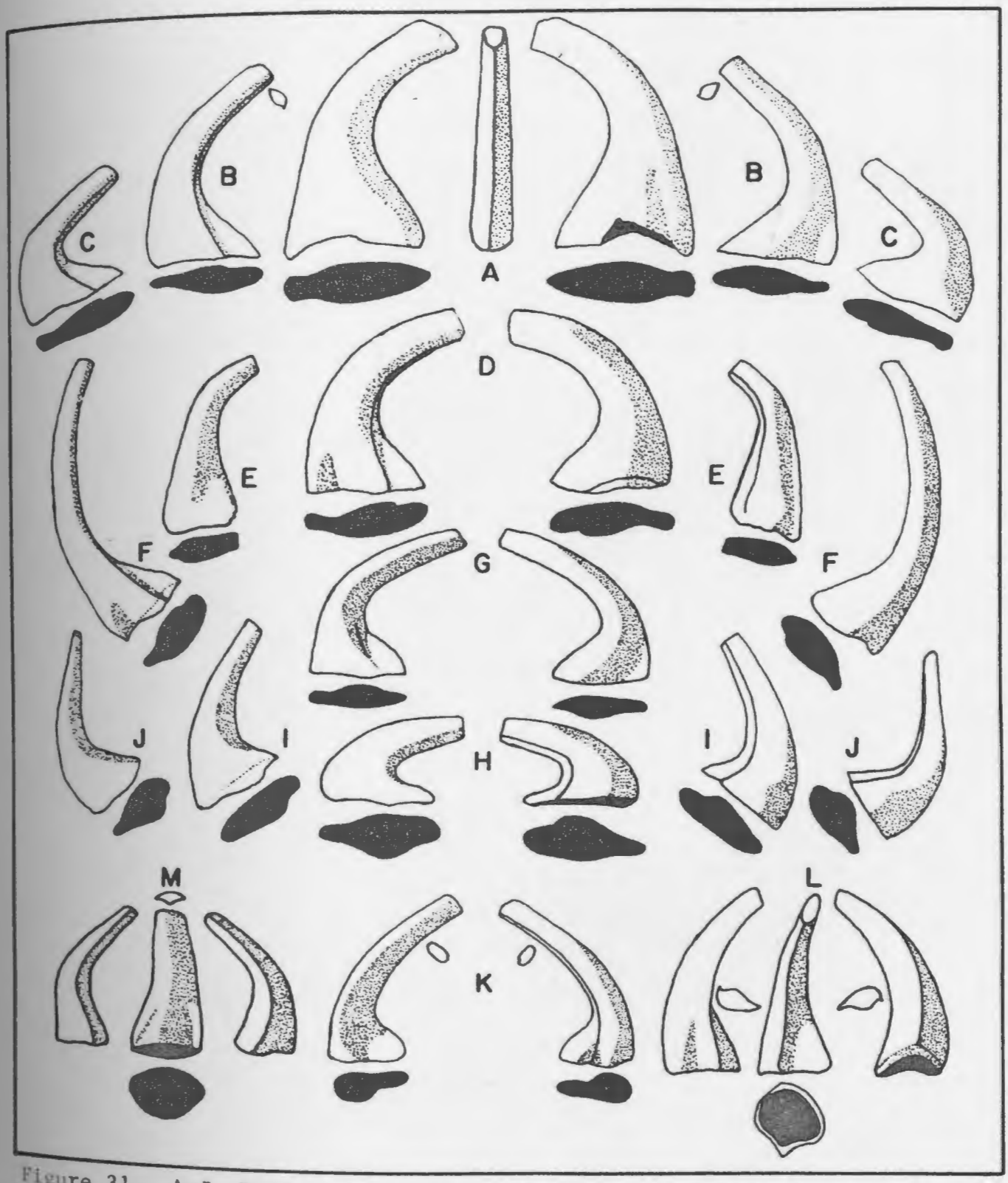

Figure 31. A-J, Panderodus mutatus (Branson and Mehl): A, symmetrical panderodiform; B-G, asymmetrical inner costate panderodiforms; H-J, asymmetrical outer costate panderodiforms. Inner lateral views, left of centre; outer lateral views, right of centre. L,M, ?Panderodus n. sp. A: M, symmetrical form; L, asymmetrical form (outer lateral view, to the left). K, panderodiform (residual). Illustrations are all X59.

coarsely striated surfaces and has, in addition, symmetrical forms with fewer and finer surface striations.

The coarsely striated forms have long proclined to erect sharp edged cusps that are continuously curved with the posteriorly extended bases. The basal cavities are deep with their apices near the anterior margin at the point of greatest element curvature. Symmetrical forms are non-costate and have no lateral furrows. Nearly symmetrical forms, and forms of intermediate symmetry, have a weakly developed carina on the outer face and a well developed costa on the inner face that is bounded posteriorly by a narrow furrow. Strongly asymmetric forms have a short costa that is present on the inner face of the base only.

The finely striated forms have a long robust cusp that is continuously curved, erect, sharp edged and laterally compressed. The outer face of the element carries a longitudinal furrow that runs the length of the element. The inner face is convex. The base is short, convex inward and flared slightly outward. The basal cavity has its apex near the anterior margin at the point of greatest element curvature.

Remarks. This species has a type IIIa apparatus, exhibited as a distinct curvature transition superimposed on a symmetry transition.

Material. 138 specimens.

?PANDERODUS n. sp. A

Pl. 4, figs. 10a-c,12a,b; Fig. 31L,M

Description. Two costate forms, possibly representing part of a *Panderodus* apparatus, were found. One is a nearly symmetrical simple cone

conodont with a rounded anterior margin, a costate posterior margin, and a well developed costa on each lateral face. The antero-posteriorly compressed cusp is more than half the length of the element. The basal cavity is deep and has a broad antero-posterior biconvex margin.

The other form is strongly asymmetrical and has a twisted cusp, such that the costae occupy a posterior and anterior position on the element.

Remarks. The two recovered specimens of this species probably are representative of a simple cone apparatus with a simple symmetrical asymmetrical transition series, and are herein tentatively brought to Panderodus. There is no way of knowing whether or not a curvature transition is also characteristic of the apparatus of this species.

This species does not have the lateral furrow characteristic of Panderodus, however, on the asymmetrical form there is a slight depression, on the outer face of the base, that is possibly a vestige of a furrow.

Material. 3 specimens.

Family SCALPELLODONTIDAE n. fam.

Diagnosis. Panderodontacea with deep basal cavities and a type I apparatus (i.e. simple symmetrical asymmetrical symmetry transition only). Surface striations may or may not be present. Early forms had no pronounced ornamentation other than surface striations. Some later forms have posterior denticles (Ib; i.e. Belodella), and posterior and anterior denticles (Ib; i.e. New Genus A). Other forms developed strong lateral

costae (Ia; i.e. Walliserodus).

Discussion. The genus Scalpellodus presumably was derived from Semiacontiodus (Dzik, 1976). From Scalpellodus, it is possible to derive the genus Belodella by the development of posterior denticles and the genus Walliserodus by the development of lateral costae. New Genus A could be derived from Belodella by the denticulation of the anterior margin of one or more of the constituent forms. The genus Pseudebelodina n. gen. has the compositional characteristics of Belodina, but, for reasons discussed below, it is considered a descendent from Scalpellodus.

Genus BELODELLA Ethington, 1959

Type Species. Belodus devonicus Stauffer, 1940

BELODELLA n. sp. A

Pl. 5, figs. 13a-16b; Pl. 14, figs. 8,9; Fig. 32F-I

SWEET and BERGSTROM 1962, p. 1244-45, Fig. 5.

ETHINGTON and SCHUMACHER 1969, p. 478-79, pl. 68, fig. 12, Fig. 4j.

FAHRAEUS 1970, Fig. 3o.

BARNES and POPLAWSKI 1973, p. 769, pl. 4, fig. 19,20.

SERPAGLI 1974, p. 38-39, pl. 8, figs. 7a,b, pl. 20, fig. 10.

Discussion. Belodella n. sp. s.f. and Scandodus mysticus from the Mystic Conglomerate in Quebec (Barnes and Poplawski, 1973), could belong to a species that should probably be brought to the genus Scalpellodus. These same forms also occur, with Belodella n. sp. A, in the Parson's Point Formation at Lushes Bight, north-central Newfoundland (Fig. 2). Some of the elements of the fore mentioned species show the vestiges of

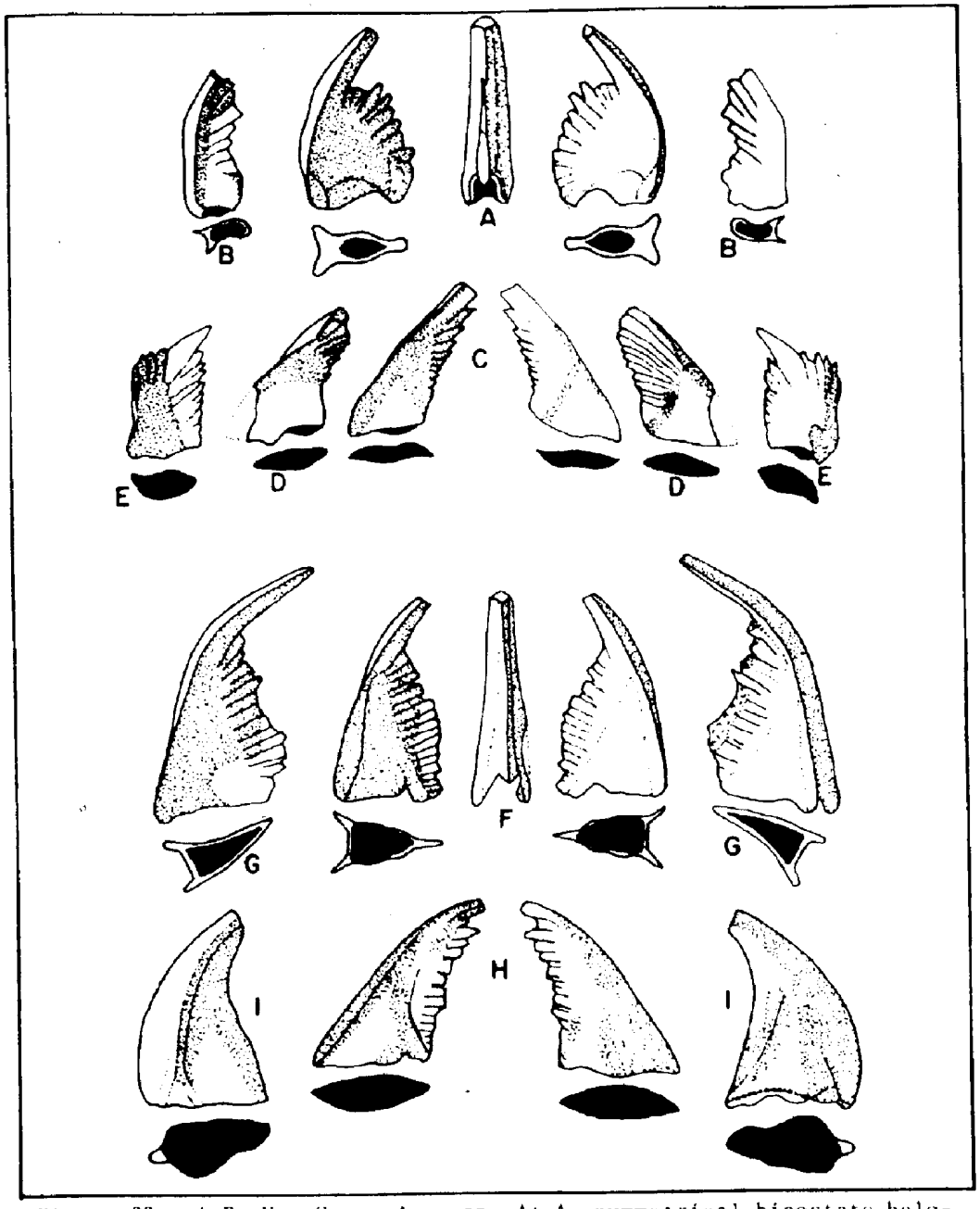

Figure 32. A-E, New Genus A n. sp. A: A, symmetrical bicostate belodelliform; B, asymmetrical bicostate belodelliform; C, unicostate belodelliform; D, acostate belodelliform; E, anteriorly denticulated belodelliform. F-I, Belodella n. sp. A: F, symmetrical bicostate belodelliform; G, asymmetrical bicostate belodelliform; H, acostate belodelliform; I, non-costate belodelliform. Inner later views, left of centre; outer lateral views, right of centre. Illustrations X61.

denticles on the posterior margin, and may consequently bear close affinity to the genus Belodella. The tendency for Scalpellodus to produce denticles can be seen, at a later stage in development, in the Middle Table Head Formation (Dr. L.E. Fahraeus, pers. comm.). A Middle Ordovician species of Scalpellodus occurs in the Cobbs Arm Formation, but shows no evidence of denticulation.

Description. Belodella n. sp. A has a simple symmetrical asymmetrical symmetry transition from symmetrical and asymmetrical bicostate belodelliforms through acostate belodelliforms to a non-denticulate belodelliform.

The denticulated elements have long and slender proclined cusps and deeply excavated bases. Posterior processes carry many rather uniformly sized, compressed, confluent and sharp chisel-like denticles. Symmetrical forms have two well developed sharp costae, on the cusp faces, that continue downward as thin costa-like processes. The thinly sheathed concave lateral faces enclose a triangular basal cavity. The anterior margin of the cusp is rounded whereas the posterior margin is sharp.

Asymmetrical bicostate belodelliforms have a slightly inward twisted cusp with a convex anterior margin and a narrowly rounded posterior margin. The posterior process is inward concave.

Acostate belodelliforms have an inward twisted cusp and a sharp posterior margin that is continuous with the sharp edges of the posterior denticles. The anterior margin of the element is sharp and curved slightly inward and posteriorly producing a convex outer surface. The basal margin is lanceolate.

Non-denticulate belodelliforms have very sharp posterior and

anterior margins and deep triangular basal cavities that have their apices at the point of maximum element curvature. Narrow carinae run the length of the element near the centre of each lateral face.

Remarks. Very few elements of this species were recovered and so it is unlikely that the nature of the whole apparatus is represented by the descriptions.

Belodella n. sp. s.f. (Barnes and Poplawski, 1973), from the Parson's Point Formation, Long Island (Fig. 2), is illustrated in Figure 29 along with a non-denticulated belodelliform from the possibly related Belodella n. sp. A.

Material. 26 specimens (5 symmetrical bicostate belodelliforms, 2 asymmetrical bicostate belodelliforms, 7 acostate belodelliforms, 12 non-denticulated belodelliforms).

Genus SCALPELLODUS Dzik, 1976

Type Species. Protopanderodus latus Van Wamel, 1974

SCALPELLODUS CAVUS (Webers, 1966)

Pl. 6, figs. 1a-7b; Pl. 14, figs. 2,2a; Fig. 33A-E

SWEET and BERGSTROM 1962, p. 1226, pl. 168, fig. 17.

WEBERS 1966, p. 28-29, pl. 2, figs. 4,5.

DZIK 1976, Fig. 14a-e.

Description. This species is composed of simple cone elements with a wide, compressed and proclined cusp and a deep triangular basal cavity that has its apex near the anterior margin at the point of maximum

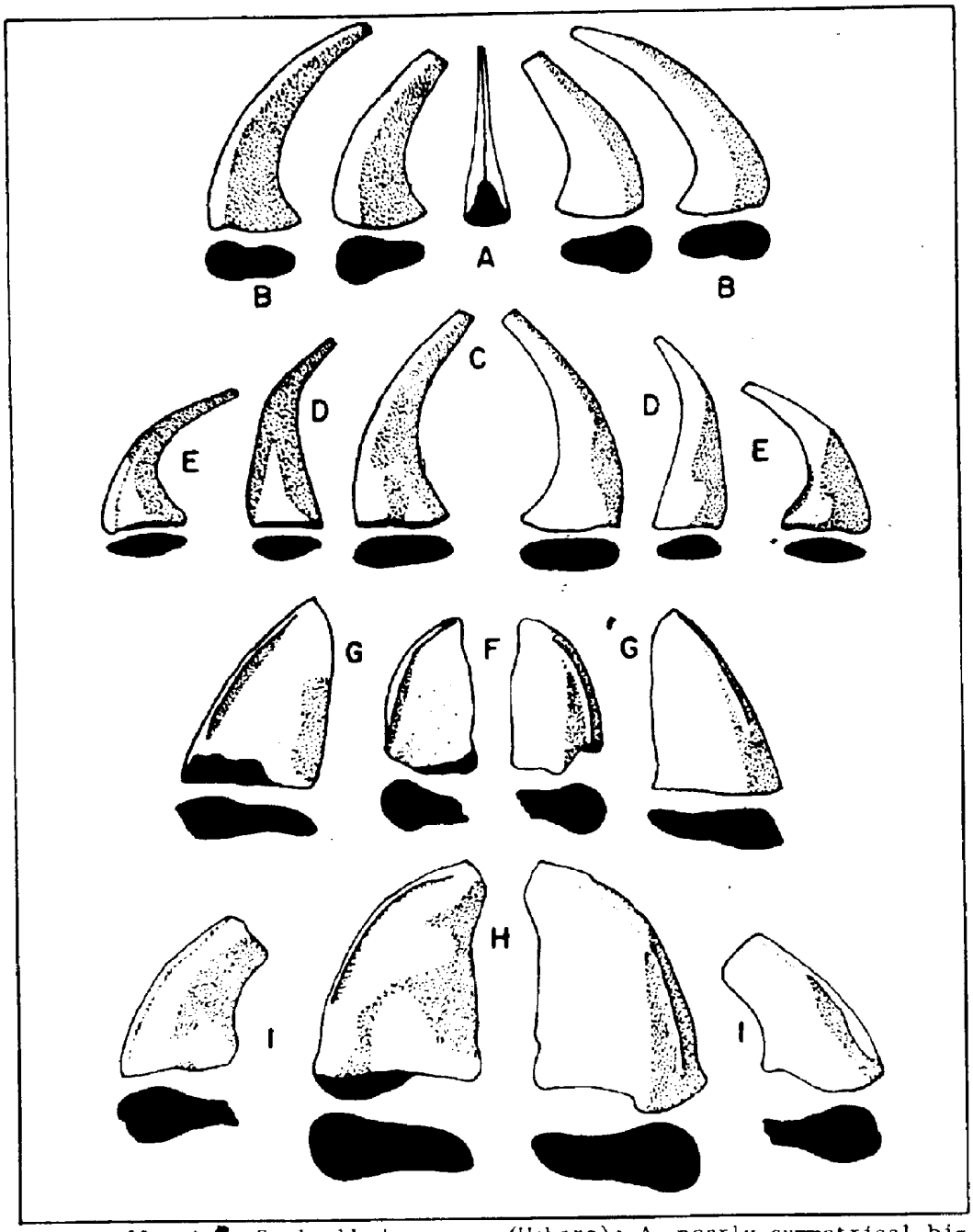

Figure 33. A-E, Scalpellodus cavus (Webers): A, nearly symmetrical bicarinate drepanodiform; B, unicarinate drepanodiform; C,D, non-carinate drepanodiforms; E, strongly bowed drepanodiform. F-I, Scalpellodus n. sp. A: F; near symmetrical drepanodiform; G-I, asymmetrical drepanodiforms. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X62.

curvature. The posterior margin is very sharp whereas the anterior margin is less sharp and may be narrowly rounded on the base. The sharp oral edge of the base is slightly concave but merges almost imperceptibly with the posterior edge of the cusp.

This species has a symmetry transition of symmetrical or nearly symmetrical bicarinate drepanodiforms to strongly bowed drepanodiforms, but differences between the individual form groups are small. The nearly symmetrical elements have near equally developed broad carinae on the anterior part of each lateral face. A second form group constitutes elements with a well developed carina on the inner face of the base only, and a slightly inward deflected cusp.

Non-carinate drepanodiforms have biconvex basal margins and inward deflected cusps. The cusp of most of these forms is inward deflected to the same degree as the unicarinate drepanodiforms, whereas the remainder show a noticeably stronger inward deflection of the cusp.

The most asymmetrical drepanodiforms have a lanceolate basal margin and a very strongly inward bowed cusp.

Material. 521 specimens (76 near symmetrical bicarinate drepanodiforms, 172 unicarinate drepanodiforms, 205 non-carinate drepanodiforms, 68 strongly bowed drepanodiforms).

SCALPELLODUS n.sp. A

Pl. 6, figs. 8a-10b; Pl. 14, fig. 10; Fig. 33F-I

Description. This species is composed of short and broad simple cone conodonts which have sharp posterior margins and generally narrowly

rounded anterior margins. The basal cavities are deep and triangular with apices near the anterior margin. A shallow trough runs the length of the element near the anterior margin of the lateral faces. The type la apparatus of this species shows a simple symmetry transition from near symmetrical forms through forms with increasing inward concavity.

The nearly symmetrical forms have a sharp posterior margin and a narrowly rounded anterior margin that is sharply bounded on both faces by a shallow trough. Anterior of the midline of the element, the basal margin flares biconvexly; more to one side than to the other. This lateral flaring is expressed, on the lower half of the element, as broadly rounded carinae.

Definately asymmetrical forms have a thin and sharp posterior margin that is straight to concave, generally with increasing asymmetry of form. The inner basal margin is slightly concave, whereas the outer basal margin is convex and slightly flared. Anterior of the midline of the element there is a broadly rounded carina on the outer face of the element.

Remarks. This species is represented by only a few specimens from widely separate samples but the forms are easily distinguished by the presence of the sharply bounded troughs adjacent to the anterior margin of the elements.

Material. 13 specimens.

Genus WALLISERODUS Serpagli, 1967

Type Species. Acodus curvatus Branson and Branson, 1947

Discussion. Cooper (1975, p. 995), when identifying Walliserodus debolti (Rexroad) emended the genus Walliserodus to include an acodiform and a suite of costate paltodiforms in a grading morphological series. He regarded the name of the two acodiforms to have age priority over the names of the other constituents of the apparatus and consequently chose one (Acodus curvatus s.f.), for the name of the species and type species of the genus Walliserodus.

The apparatuses of the three represented species of Walliserodus from the Cobbs Arm Formation also have a suite of paltodiforms plus one form which could be referred to as an acodiform or which would at least occupy a similar position in the apparatus as the acodiform.

WALLISERODUS ETHINGTONI (Fahraeus, 1966)

Pl. 6, figs. 11a-16b; Pl. 14, fig. 13; Fig. 34A-H

FAHRAEUS 1966, p. 26, pl. 3, figs. 5a,b.

BERGSTROM, RIVA and KAY 1974, pl. 1, fig. 12.

DZIK 1976, Figs. 14o,p

Description. This is an apparatus of strongly variable simple cone conodonts comprising both costate and non-costate forms; each with a deep, broad basal cavity with an apex near the anterior margin at the point of maximum element curvature. The cusps of these forms are erect to slightly proclined and only slightly longer that the high bases. Posterior margins are sharp throughout the length of the elements. Anterior margins of the

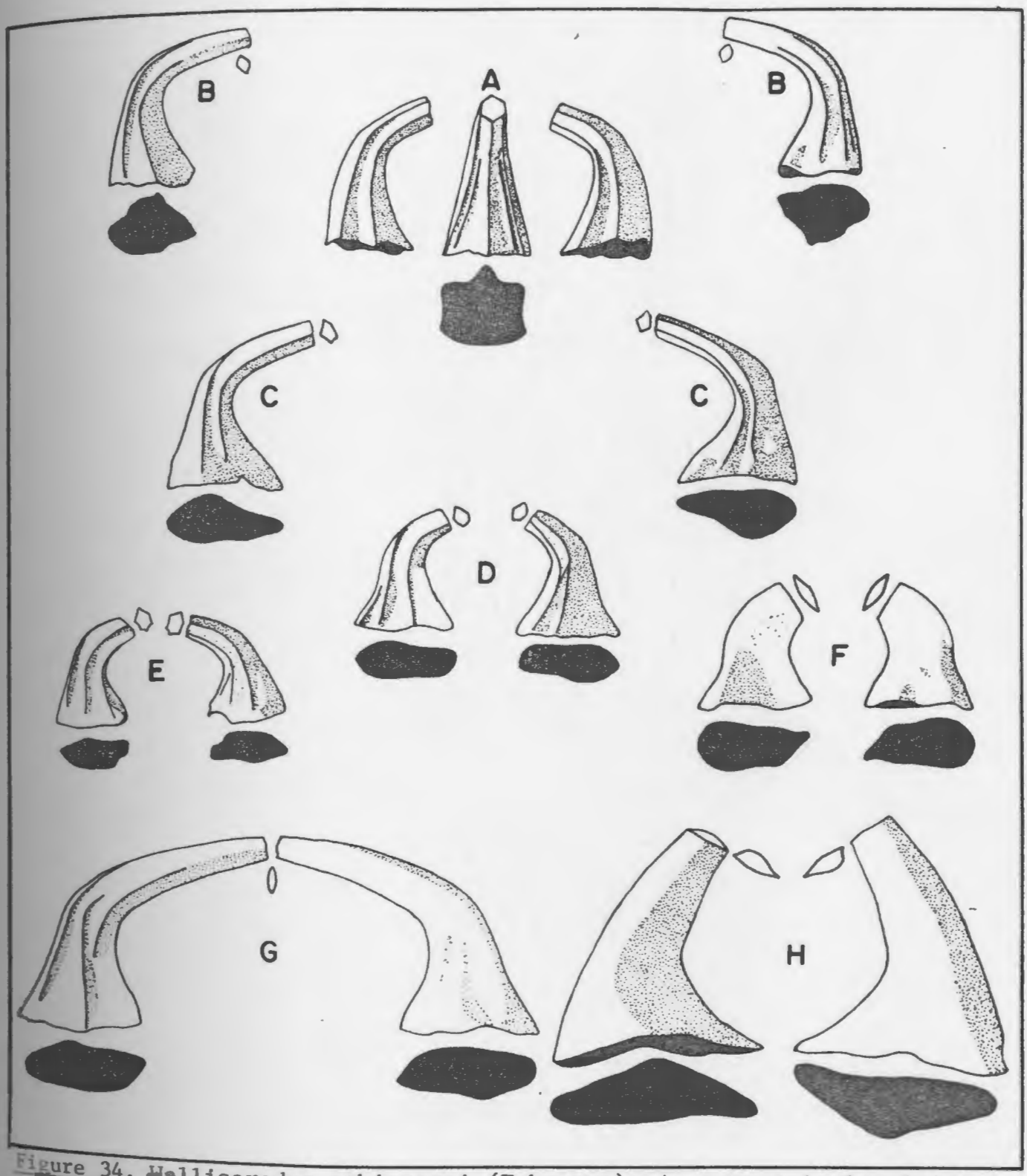

Figure 34. Walliserodus ethingtoni (Fahraeus): A, symmetrical multicostate drepanodiform; B-E,G, asymmetrical multicostate drepanodiforms; F, acostate drepanodiform; H, Inward bowed drepanodiform. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X46.

bases are smoothly convex whereas the anterior margins of the cusps may be convex or sharp.

Symmetrical multicostate drepanodiforms have a costate posterior margin, a convex anterior margin and carry two costae on each lateral face that run the length of the element.

Asymmetrical multicostate drepanodiforms were found to be quite variable. Nearly symmetrical forms have two costae on each lateral face but these become indistinct some distance up the cusp. Only the inner posterior lateral costa continues to the irregular basal margin. A second asymmetrical form has two or three costae on each lateral face. The inner anterior lateral costa of these forms merges with the anterior margin some distance up the element. Other asymmetrical forms may be costate on the inner side only or non-costate. The latter tend to have one lateral face that is near planar with the other broadly convex.

In addition to the above described forms the apparatus has non-costate forms with a robust, compressed and sharp-edged cusp that is strongly deflected inward. The inner cusp face is near planar whereas the outer face is convex. The deep wide basal cavity has a planar outer margin and a strongly flared inner margin.

Remarks. W. ethingtoni shows an inconsistent variation of form and is thus difficult to adequately describe, especially when present in low numbers as is the case in this study. It nonetheless appears to have a type Ia apparatus similar to Scalpellodus.

There does not appear to be longitudinal striations on W. ethingtoni.

Material. 81 specimens (5 symmetrical multicostate drepanodiforms, 45 asymmetrical multicostate drepanodiforms, 21 non-costate drepanodiforms, 10 strongly bowed drepanodiforms).

WALLISERODUS NAKHOLMENSIS (Hamar, 1966)

Pl. 7, figs. 1-5b; Pl. 14, fig. 12; Fig. 35A-E

HAMAR, 1966, p. 66, pl. 7, figs. 22-24, Fig. 3:3.

DZIK 1976, Figs. 14q-t.

Description. W. nakholmensis is an apparatus of simple cone conodonts most of which are characterized by lateral costae and fine longitudinal striations. This species has a type Ia apparatus that shows a simple symmetry transition from symmetrical multicostate drepanodiforms through tricostate and asymmetrical bicostate drepanodiforms to non-costate inward bowed drepanodiforms.

The costate elements have slender suberect to proclined cusps and deep basal cavities that have their apices near the anterior margin at the point of greatest element curvature. Posterior margins are sharp whereas the anterior margins are smoothly convex. Symmetrical multicostate drepanodiforms have two costae on each lateral face. One lies close to the anterior margin and becomes indistinct some distance up the element. The other is situated more or less centrally on the base and continues to the tip of the cusp.

Tricostate drepanodiforms have only one posterior lateral costa which is carried on the outer face. This outer costa and the inner anterior lateral costa continue to the tip of the cusp. The outer anterior lateral costa becomes indistinct some distance up the element.

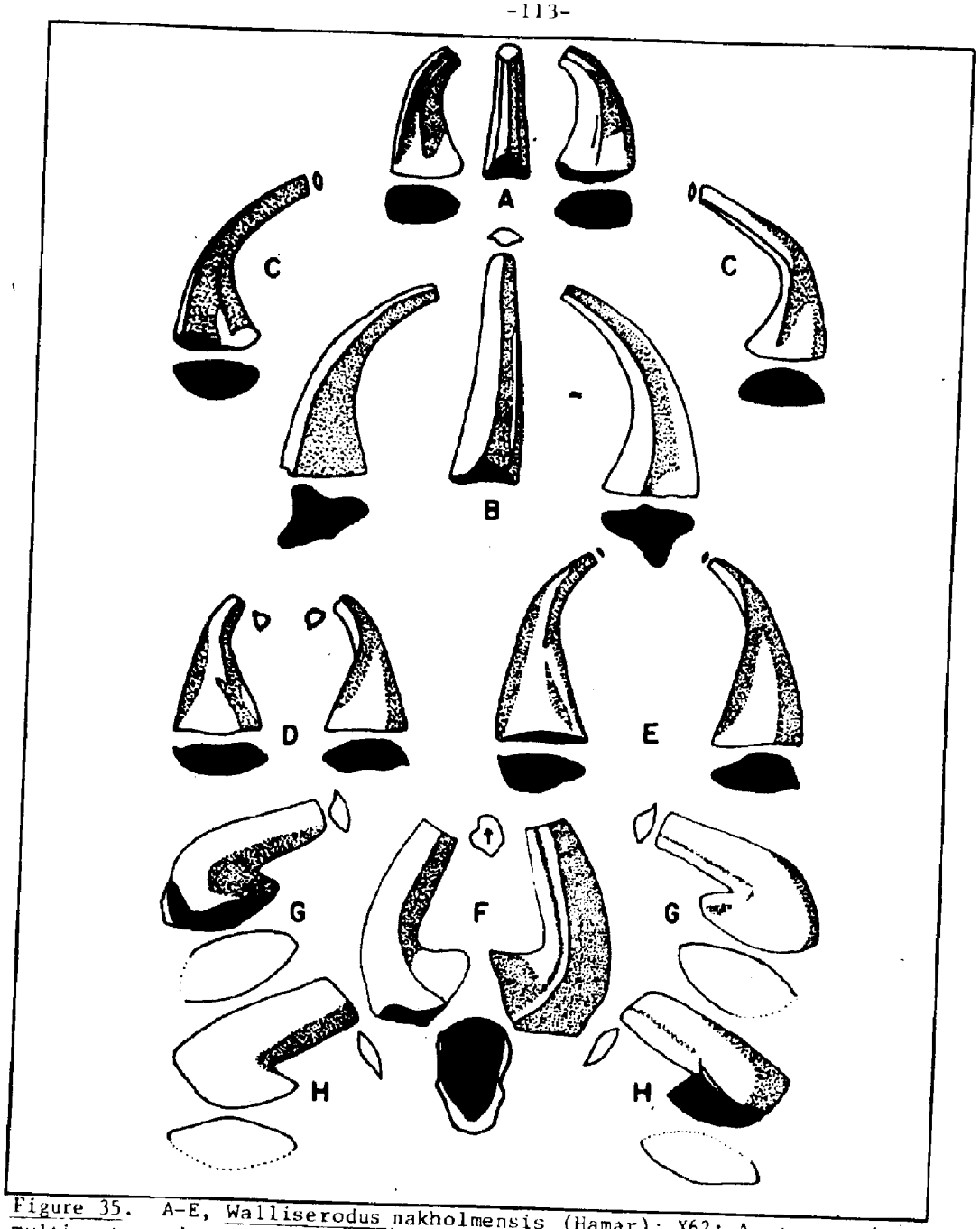

Figure 35. A-E, Walliserodus nakholmensis (Hamar); X62: A, symmetrical multicostate drepanodiform; B, tricostate drepanodiform; C, asymmetrical bicostate drepanodiform; D,E, inward bowed drepanodiforms. F, distacodiform (residual), X52. G,H, oistodiform 1 (residual), X62. Inner lateral views, left of centre; outer lateral views, right of centre.

Asymmetrical bicostate drepanodiforms have an inward twisted cusp, a convex outer surface and a planar to slightly convex inner surface of the base. The posterior margin of the cusp is broadly carinate from its tip to its base whereupon it becomes indistinct. The anterior margin is sharp and slightly curved posteriorly. An outer posterior costa begins near the basal margin and continues to the tip of the cusp. The sharp oral edge of the base is not continuous with the carinate posterior margin of the cusp, but rather it continues a short distance up the cusp between the posterior margin of the cusp and the outer lateral costa, to where it becomes indistinct. A short costa is often present on the inner face of the base.

The non-costate inward bowed drepanodiforms are convex outward and tapered their full length. The posterior margin of the cusp is narrowly rounded but becomes indistinct near its base. The oral edge of the base is sharp and swings outer laterally near the cusp base. It disappears after a short distance.

Remarks. This species is represented in relatively low numbers and thus the description of the apparatus is probably incomplete.

Material. 149 specimens (22 symmetrical multicostate drepanodiforms, 48 tricostate drepanodiforms, 56 asymmetrical bicostate drepanodiforms, 23 inward bowed drepanodiforms).

WALLISERODUS n. sp. A

Pl. 7, figs. 6a-10b; Pl. 14, fig. 11; Fig. 36A-E

Description. This species has a simple symmetrical asymmetrical

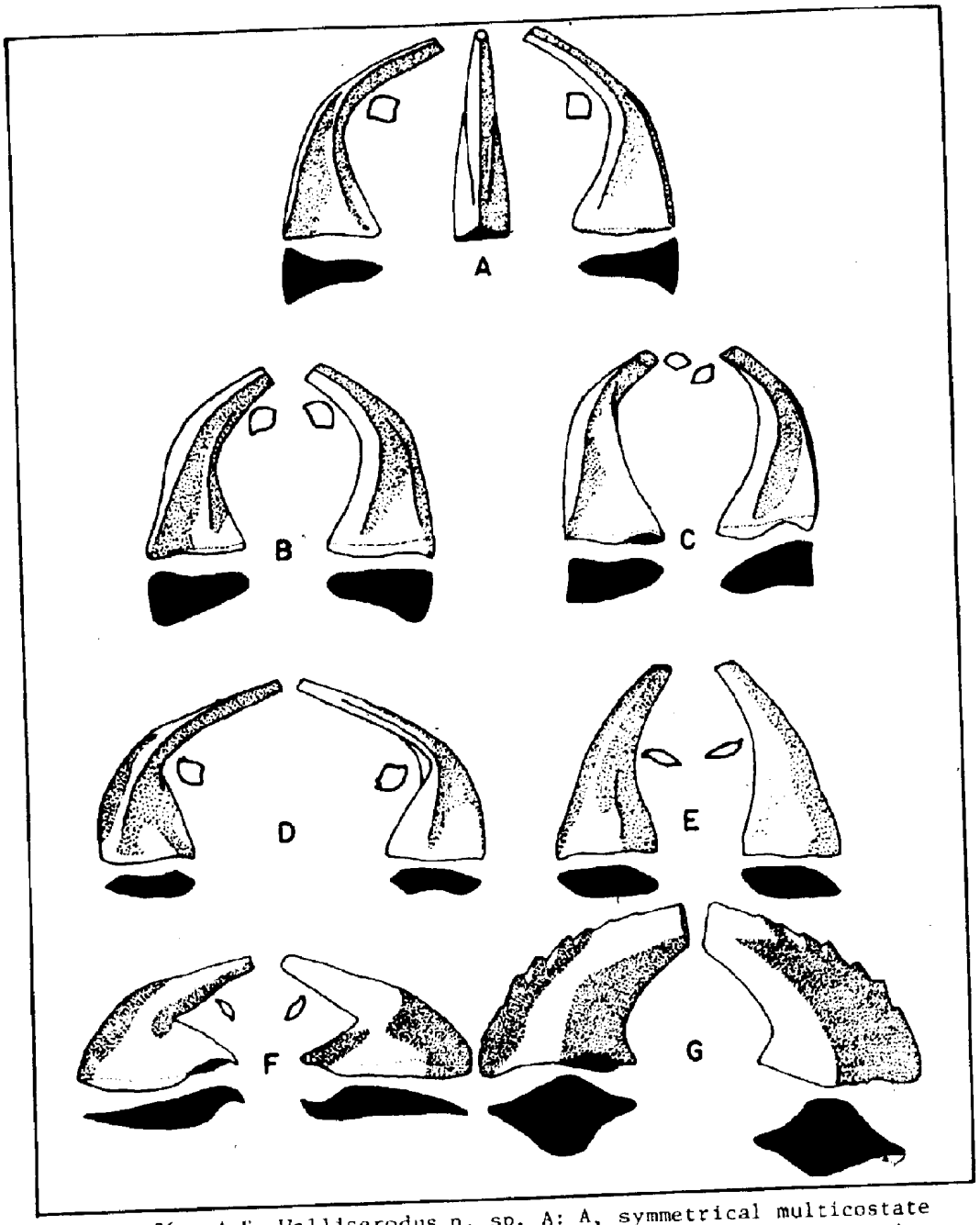

Figure 36. A-E, Walliserodus n. sp. A: A, symmetrical multicostate drepanodiform; B, asymmetrical multicostate drepanodiform; C, tricostate drepanodiform; D, asymmetrical bicostate drepanodiform; E, inward bowed drepanodiform. F, oistodiform 2 (residual). G, strachanognathiform (residual). Inner later views, left of centre; outer lateral views, right of centre. Illustrations are all X64.

symmetry transition comprising four multicostate drepanodiforms and one inward bowed and unicostate drepanodiform.

The multicostate drepanodiforms all have a slender erect or proclined cusp that is posteriorly costate or carinate and anteriorly convex. The triangular bases are deeply excavated, each with an apex near the anterior margin at the point of maximum element curvature. Symmetrical multicostate drepanodiforms bear five costae: one on the posterior margin and two on each lateral face. Posterior lateral costae run from near the basal margin along the centre of the cusp faces to its tip. The anterior lateral costae begin near the basal margin but become indistinct some distance up the element.

On the asymmetrical multicostate drepanodiforms, the inner anterior lateral costae and outer posterior lateral costae continue the length of the element whereas the inner posterior lateral costae and the outer anterior lateral costae disappear near the base of the cusp. The costate posterior edge of the cusp and the sharp oral edge of the base are not confluent, but are laterally displaced slightly outward and inward respectively.

The tricostate drepanodiforms each lack an inner posterior lateral costa. Outer posterior lateral costae and inner anterior lateral costae contunue the length of the element whereas the outer anterior lateral costae disappear some distance up the element. The posterior margin of the cusp is broadly carinate. The sharp oral edge of the base deflects inwards in the area of the cusp base but disappears after a short distance.

Asymmetrical bicostate drepanodiforms have a continuously sharp posterior margin and an anterior margin that is convex on the cusp but

which narrows to a rounded ridge on the base. This ridge is outwardly convex and inwardly planar. A posteriorly positioned costa on the outer lateral face begins near the basal margin and continues up the cusp to its tip. An anteriorly positioned costa on the inner lateral face runs most of the length of the element. The base of this form has near parallel outer and inner margins, unlike the triangular basal outlines of the other multicostate forms.

The inwardly bowed drepanodiforms are tapered and have sharp posterior and anterior margins that are somewhat curved inward. The outer lateral face of the element is convex. The inner cusp face carries a broad carina which narrows to become a costa on the base.

Remarks. This species shows a remarkable resemblance to the Silurian species *W. curvatus* (Branson and Branson), and is possibly an ancestral form to it. It does, however, appear to have only one form of acodiform, rather than the two described by Cooper (1975), for *W. curvatus*.

Material. 219 specimens (25 symmetrical multicostate drepanodiforms, 38 asymmetrical multicostate drepanodiforms, 67 tricostate drepanodiforms, 34 asymmetrical bicostate drepanodiforms, 55 inward bowed drepanodiforms).

Genus PSEUDOBELODINA n. gen.

Type Species. *Oepikodus copenhagenensis* Ethington and Schumacher, 1969

Diagnosis. Included in this genus are species with a type Ic apparatus comprising denticulate forms with a deep triangular basal cavity and non-denticulated oistodiforms. There may not be symmetrical forms present in the apparatus.

Discussion. The apparatus of this genus is most similar in composition to Belodina, but appears to have descended from an entirely different stock (i.e. Scalpellodus). The similarities between this genus and Belodina are probably due to evolutionary convergence.

PSEUDOBELODINA n. sp. A

Pl. 7, figs. 11a-13b; Pl. 14, 14, figs. 14,15; Fig. 29F,G

ETHINGTON and SCHUMACHER 1969, p. 465, pl. 68, figs. 5,9. Fig. 41; p. 467-68, pl. 68, figs. 1-4, Fig. 5c.

BERGSTROM, RIVA and KAY 1974, pl. 1, fig. 11.

Description. This species has belodelliform and oistodiform constituents.

The belodelliforms have a relatively short, compressed and sharp-edged cusp that is followed posteriorly by a row of 10 to 15 small, sharp, basally confluent and laterally compressed denticles that show a near constant inclination of about 20 degrees to the cusp. The anterior margin of the element is sharp and continuously curved from the basal margin to the tip of the cusp. Each lateral face carries a narrowly rounded carina which begins slightly posterior of the midline on the cusp and continues parallel to the anterior margin down to the basal margin. The inner lateral face is slightly concave with a near planar basal margin whereas the outer face is convex with a basal margin that flares outward in the region of the carina. The basal cavity is triangular in outline with its apex near the anterior margin about half way up the element. The more asymmetrical denticulated forms have a broader outer lateral flaring of the basal margin.

The oistodiforms have a short and slender sharp edged cusp that is slightly inward deflected. The anterior margin is continuously curved from the tip of the cusp to the basal margin. The posterior margin of the cusp is slightly concave and continuous with the keeled convex oral margin of the base. The outer lateral face and its basal margin are planar to slightly convex whereas the inner lateral face and its basal margin are broadly convex.

Remarks. Like Belodina, the composition of the apparatus of this genus appears to be reduced in comparison to more normal apparatuses of Panderodontidae. It appears only to have two or three asymmetrical denticulated forms and non-denticulated oistodiforms. Unlike that of Belodina, this apparatus appears to show no curvature transition and is therefore considered to be of apparatus type Ic (i.e. a variant of apparatus ~~Ib~~).

There is a very noticeable similarity between the belodelliforms of this species and the non-costate belodelliforms of Belodella n.sp.A (Fig. 29). This may indicate that the two are somehow related. There is, however, a distinct difference in the nature of the denticulation between the two species, and, in addition, the two species were not found to be associated in the Cobbs Arm Formation. Consequently the two are considered distinct.

Material. 62 specimens (33 belodelliforms, 29 oistodiforms)

Genus NEW GENUS A n. gen.

Type Species. New Genus n. sp. A n. sp.

Diagnosis. Conodonts with a denticle row posteriorly as well as

anteriorly on at least one of the constituent forms. There is a simple symmetrical asymmetrical symmetry transition only (i.e. apparatus Ib)

NEW GENUS A n. sp. A

Pl. 7, figs. 14-19b; Pl. 15, figs. 1,2; Fig. 32A-E

Description. This species has a simple symmetry transition from symmetrical and asymmetrical bicostate belodelliforms through unicostate and acostate belodelliforms to an anteriorly and posteriorly denticulated belodelliform.

The symmetrical bicostate belodelliform has a relatively long and slender erect cusp with a convex anterior margin and a sharp posterior margin. The arched oral margin of the base has about 10 compressed, sharp and basally confluent denticles that show increasing inclination away from the cusp. There are two lateral costae which begin at the tip of the cusp and continue down the anterior margin of the base where they become costa-like processes. The lateral faces of the base are planar. The basal cavity is triangular and shallow, with its apex near the anterior margin about one third the distance up the base.

The asymmetrical bicostate belodelliforms have a relatively long and slender proclined cusp with a convex anterior margin and a sharp posterior margin. The oral edge of the base is not arched as on the symmetrical forms, but is similarly denticulated. The two costae situated on the cusp continue along the anterior margin of the base as costa-like processes but are not symmetrically disposed. One costa is located more posteriorly on the cusp as well as on the base. The basal cavity is triangular and has its apex near the anterior margin about one half the

distance up the base.

The cusp of the unicostate belodelliform is about one half of the length of the base and has a sharp posterior edge and a narrowly rounded anterior edge. The denticles of the oral margin of the base decrease in size, and show an increase in inclination, away from the cusp. They are compressed, sharp and basally confluent. A single lateral costa occupies an anterior position on the cusp but near the basal margin it merges with the anterior margin. The basal cavity is triangular in outline and has its apex anterior of the midline of the element about one half of the distance up the base.

The anteriorly denticulated belodelliform has a short, compressed and sharp-edged cusp and denticulated anterior and posterior margins. The denticles are compressed, basally confluent and sharp. Those of the wing-like anterior process are near perpendicular to the basal margin, whereas those of the oral margin of the base are near parallel to the cusp. The inner surface of the element is concave whereas the outer surface is convex. In oral view, the basal margin is outward extended to a point. The basal cavity is relatively small and triangular in outline.

Remarks. This species shares many of its overall characteristics with Belodella n. sp. A. They both have a type Ib apparatus, characterized by a simple symmetrical asymmetrical symmetry transition series of forms that are posteriorly denticulated. Both species have symmetrical bicostate belodelliforms, asymmetrical bicostate belodelliforms and acostate belodelliforms, but in addition to forms with a row of denticles posteriorly, New Genus A n. sp. A has a form with a row of denticles posteriorly and anteriorly.

The latter form is similar to forms described for the genus Appalachignathus (Bergstrom, Carnes, Ethington, Votaw and Wigley, 1974), but other than this, there is very little in common between the two genera.

The anterior denticulation of one of the constituent forms is considered important to the distinction of the apparatus and it is herein assigned to a new genus. It should be noted, however, that without the presence of the anterior denticulated belodelliform, this apparatus could easily be assigned to Belodella.

Material. 28 specimens (4 symmetrical bicostate belodelliforms, 7 asymmetrical bicostate belodelliforms, 6 unicostate belodelliforms, 7 acostate belodelliforms, 4 anteriorly denticulated belodelliforms).

Family UNKNOWN

Genus ONEOTODUS Lindstrom, 1955

Type Species. Distacodus? simplex Furnish, 1938

?ONEOTODUS MITRATUS (Moskalenko, 1973)

Pl. 10, figs. 11,12; Fig. 28D,E

SERPAGLI 1967, p. 107, pl. 29, figs. 2a-c; p. 107, pl. 29, figs. 1a,b.

MOSKALENKO 1973, pl. 17, figs. 9-11; pl. 17, figs. 12-15.

DZIK 1976, Fig. 12e,f.

Description. These are irregular simple cone conodonts that have short conical cusps and squat, broadly flared bases. The oral margin of the base may be narrowly rounded. Basal cavities occupy the whole of the underside of the element.

Remarks. There does not appear to be a possible arrangement of

these forms into an apparatus; rather, they are all different and have the irregularity likely to be shown by dermal denticles.

Material. 6 specimens.

Suborder PRIONIODONTINA Dzik, 1976

Superfamily PRIONIODONTACEA (Bassler, 1925)

Discussion. Lindstrom's (1970), diagnosis of Prioniodontacea incorporates early apparatuses comprising oistodiforms, compound forms with a symmetry transition series and platform-like (prioniodiform or ozarkodiniform) elements. Younger apparatuses appear to have lost all but the platform elements during evolution.

In this diagnosis the presence of an oistodiform in the apparatus of the early forms is given precedence. However, Dzik (1976) suggests that Periodontidae, Prioniodontidae and Oistodontidae all evolved from Drepanoistodus of the D. inaequalis group. Consequently, early forms of each family would no doubt have oistodiforms within the apparatus.

Dzik (1976, Fig. 4) illustrates Drepanoistodus inaequalis as a possible ancestor to an Acodus-Oistodus-Triangulodus lineage. McTavish (1973), is convinced that Acodus deltatus and its immediate descendents are the ancestral stock to Prioniodontidae. Dzik (1976) presumes that Periodon adentatus is the oldest representative of Periodontidae, appearing somewhat earlier than Acodus deltatus in the Emmanual Formation of western Australia (McTavish, 1973).

Members of the family Prioniodontidae are characterized by forms with three processes, whereas members of the family Periodontidae

are characterized by asymmetrical forms with two branches, and so, following Dzik (1976), Periodontidae is placed within the suborder Ozarkodinina Dzik, rather than within the suborder Prioniodontina.

Genera within the superfamily Prioniodontacea have a type IV of type V apparatus. Within the family Balognathidae, Amorphognathus and Pygodus have a type IV apparatus whereas Eoplacognathus, Polyplacognathus and Rhodesognathus have a type V apparatus. Within the family Prioniodontidae, Acodus and Baltoniodus have a type IV apparatus .

Family BALOGNATHIDAE Hass, 1959

Discussion. Lindstrom (1970) suggests that this family evolved from Baltoniodus-like ancestors because members of the family Balognathidae have two kinds of platform elements: an ambalodiform, with three processes, and an amorphognathiform with four processes (i.e. Amorphognathus). Amorphognathus has a type IV apparatus.

The genus Pygodus has an apparatus that is type IV in nature, but the elements of the first symmetry transition are drastically reduced in size and the second symmetry transition appears to be represented by two rather than three forms. This kind of apparatus is most likely derrived from an Amorphognathus apparatus. The amorphognathiform of Pygodus, however, has a surface microstructure of closely spaced pits like Eoplacognathus (i.e. Plate 15, figs. 6,7). The two genera may thus be closely related but it is unlikely that one is derrived from the other; rather, the two probably diverged from an Amorphognathus apparatus separately.

The genus Polyplacognathus is clearly derrived from an Eoplacognathus apparatus.

Genus AMORPHOGNATHUS Branson and Mehl, 1933

Type Species. Amorphognathus ordovicicus Branson and Mehl, 1933

AMORPHOGNATHUS sp. cf. A. INAEQUALIS-A. KIELCENSIS trans.

Fig. 28B

Description. This species is represented by only two broken amorphognathiforms that have a long straight and narrow posterior process and a bifid postero-lateral process. The latter has a posterior lobe that carries about 6 node-like denticles and a poorly developed anterior lobe that carries a single denticle only. The basal cavity occupies the underside of all the processes.

Remarks. This description and identification was made on the basis of two isolated elements of an incomplete apparatus and thus should probably be considered tentative. However, the amorphognathiforms of this apparatus are usually considered the most diagnostic form, on the species level.

The amorphognathiform of A. kielcenses Dzik, has a postero-lateral process with a single denticle row and a swollen upper margin whereas A. inaequalis Rhodes has a bifid postero-lateral process with two denticle rows. The species of Amorphognathus represented in the Cobbs Arm Formation has a bifid postero-lateral process but the anterior lobe of this process is weakly developed and carries only a single denticle. It is consequently considered transitional between A. kielcensis and A. inaequalis.

Material. 2 specimens (2 amorphognathiforms).

Genus EOPLACOGNATHUS Hamar, 1966

Type Species. Ambalodus lindstroemi Hamar, 1964

EOPLACOGNATHUS LINDSTROEMI (Hamar, 1964)

Pl. 10, figs. 5,6,9,10; Pl. 16, figs. 1-3; Fig 37B,E,F

HAMAR 1964, p. 258-59, pl. 5, figs. 1,4,7,8,10,11, Figs. 5:1a,b,3a,b; p. 275-76, pl. 6, figs. 3,6-10, Figs. 5:7a,b,9a-c.

VIIRA 1967, Fig. 4:5a,b.

BERGSTROM 1971, p. 139, pl. 2, figs. 15-18.

VIIRA 1974, p. 74-75, pl. 8, figs. 14,15,19-22, Fig. 81; p. 106, pl. 9, figs. 19,20,28,31,32,?27, Fig. 134; p. 111, pl. 9, figs. 22-26, 29, 30, Figs. 142,143.

DZIK 1976, Figs. 33a,e.

Description. This species comprises Y-shaped ambalodiforms with usually markedly dissimilar sinistral and dextral forms and star-like polyplacognathiforms (amorphognathiforms).

The dextral ambalodiform has a long anterior process and shorter near equal length posterior and lateral processes. The cusp is short and robust, slightly posteriorly directed and inner deflected.

The posterior process is tongue-like and has a central row of low denticles that is straight to slightly curved anteriorly. The anterior process is twice the length of the posterior process, curved insignificantly outward and tapered to a point. It has a central row of denticles that is low near the cusp but becomes higher towards the anterior end of the process. Near the cusp the denticle row swings laterally about 90 degrees, into the plane of the posterior process. The lateral

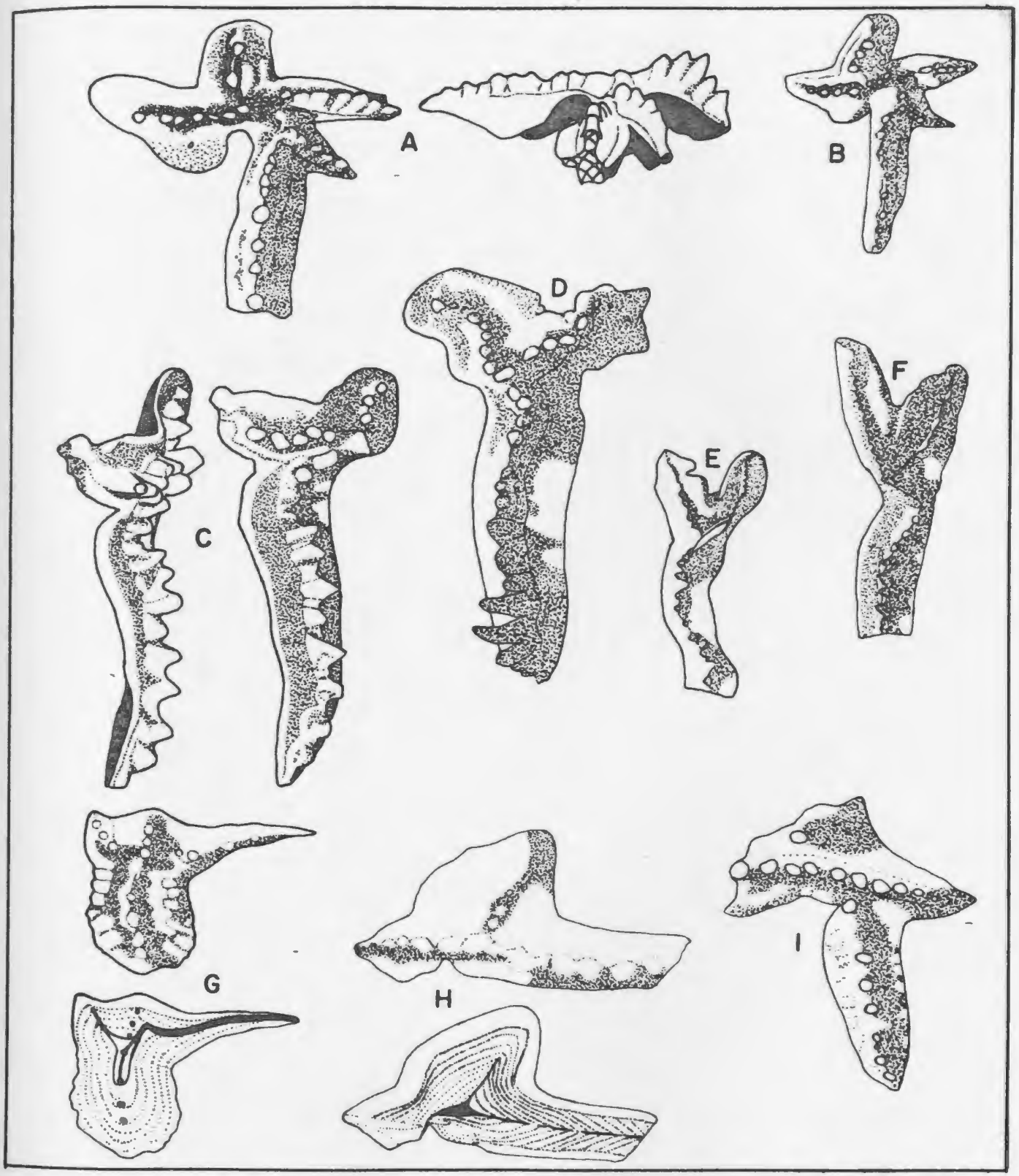

Figure 37. A,C,D, Eoplacognathus robustus Bergstrom. B,E,F, Eoplacognathus lindstroemi (Hamar). G-I, Polyplacognathus sweeti Bergstrom. D,F, dextral ambalodiforms; C,E, sinistral ambalodiforms; A,B,H,I, polyplacognathiforms; G, ambalodiform. Illustrations are all X58.

process develops from the cusp at an angle of about 60 degrees with the posterior process. It is nearly straight, nearly equal in length with the posterior process and is strongly flexed down away from the cusp.

The sinistral ambalodiform is not a mirrored image of the dextral ambalodiform. Posterior and lateral processes are nearly equal in length and set at an angle of about 90 degrees. The posterior process is curved slightly anteriorly whereas the lateral process is straight and is flexed strongly down away from the first or second denticle anterior to the cusp. The anterior process is more than twice the length of the posterior process, is tapered to a point and is denticulated in similar fashion to the dextral ambalodiform. The denticle rows of the posterior and anterior processes are set at an angle of about 110 degrees.

The basal cavities of the ambalodiforms extends down all processes as narrow slits.

The polyplacognathiforms are star-like platform conodonts with four irregular and denticulated processes. The main denticle row is slightly S-shaped and constitutes a longer posterior process with about 8 low denticles and a rather broad platform, and a shorter, pointed anterior process with about 6 higher denticles bounded by platform ridges. The platform of the posterior process is expanded more toward the outside, especially so in sinistral forms, where the outer-lateral flare may carry denticles.

The postero-lateral process is somewhat short, tongue-like and set at an angle of 60 to 70 degrees with the anterior process. It carries a central row of four or five low denticles that originate on the side of a main row denticle, one or two places posterior to the cusp. The bifid

antero-lateral process originates from the cusp and has a long, straight and tapered posterior lobe with at least 15 denticles, and a short and pointed anterior lobe with three or four denticles.

The basal cavities of the polyplacognathiforms are narrow slits that continue down all processes, but they are hidden in nearly all specimens by basal funnels which are broadly open beneath the posterior and postero-lateral processes and which are narrow beneath the anterior and antero-lateral processes.

Material. 108 specimens (15 dextral and 17 sinistral ambalodiforms, 76 polyplacognathiforms).

EOPLACOGNATHUS ROBUSTUS Bergstrom, 1971

Pl. 10, figs. 1-4,7-8b; Pl. 15, fig. 6; Pl. 16, figs. 4-6; Fig. 37A,C,D

WOLSKA 1961, p. 346, pl. 1, figs. 6a,b; ?p. 346-47, pl. 2, figs. 11a,b.

?HAMAR 1964, p. 259-60, pl. 5, figs. 5,12, Figs. 5:2a,b.

VIIRA 1967, Figs. 4:3a,b.

BERGSTROM 1971, p. 140, pl. 1, figs. 14-16.

VIIRA 1972, Fig. 8.

VIIRA 1974, p. 79-81, pl. 8, figs. 16-18, Figs. 88-91; p. 108-10, pl. 9, figs. 3-9,13-18, Figs. 137-139.

DZIK 1976, Figs. 32a-i.

Description. The dextral ambalodiform is a Y-shaped platform conodont with denticulated anterior, posterior and lateral processes. The cusp is short and stout, slightly posteriorly directed, and inner deflected. Three smooth costae diverge away and down from the tip of the cusp

to form the denticulated processes.

The posterior process is tongue-like, has about 7 low denticles and is somewhat variable in curvature such that geologically older specimens tend to have a strongly curved posterior process while the more advanced forms have a posterior process that is nearly straight. The anterior process is twice as long as the posterior process and tapered to a point. It has a central row of about 13 denticles that are low near the cusp and higher anteriorly. The denticle row is straight to slightly sinuous and distally makes a near right angle bend into the plane of the posterior process. The lateral process flexes strongly down and away from the cusp and is set at an angle of about 90 degrees with the posterior process. It is slightly shorter than the posterior process and has a central row of low denticles that are largest near the cusp and which diminish in size rapidly away from the cusp.

The sinistral ambalodiform is markedly different from the dextral ambalodiform. It is T-shaped in oral view and has very short posterior and lateral processes. The posterior process is straight to slightly bent anteriorly and short; about as long as wide. It is tongue-like, with a central row of two or three low and inconspicuous denticles. The anterior process is straight, tapered to a point, and nearly three times the length of the posterior process. A central row of about 16 denticles distally makes an angle of 100 to 110 degrees with the cusp and the posterior process. The lateral process curves posteriorly and down away from the first denticle anterior to the cusp and makes an angle of about 135 degrees with the posterior process. The process is sinuous in oral view and is nearly equal or slightly longer than the posterior process.

The basal cavities of the ambalodiforms are narrow grooves that occur beneath the three processes, but they are hidden by a basal funnel in almost all of the specimens.

Remarks. The polyplacognathiforms of E. robustus vary little from those of E. lindstroemi. The main denticle row appears to be a little more sinuous and the platform flare of the posterior process broader on polyplacognathiforms of E. robustus. The postero-lateral process and the anterior lobe of the antero-lateral process are proportionately longer on polyplacognathiforms of E. lindstroemi.

Material. 316 specimens (83 dextral and 103 sinistral ambalodiforms, 130 polyplacognathiforms).

Genus POLYPLACOGNATHUS Stauffer, 1935

Type Species. Polyplacognathus ramosus Stauffer, 1935

POLYPLACOGNATHUS SWEETI Bergstrom, 1971

Pl. 10, figs. 13-15; Pl. 16, fig. 7; Fig. 37G-I

HAMAR 1966, pl. 5, figs. 10,11.

BERGSTROM 1971, p. 143-44, pl. 1, figs. 1,2, Figs. 14c,d.

Description. The ambalodiforms have a very wide tongue-like anterior process and a narrow, pointed and spine-like posterior process that is set at an angle of about 100 degrees to the anterior process. Opposite the posterior process, there is a short lateral process that is set at an angle of about 120 degrees to the anterior process. The anterior and lateral processes each has a central row of low node-like denticles. The posterior process is similarly surmounted by rather high denticles. The

perimeter of the anterior process has low ridges arranged perpendicular to the margin.

The polyplacognathiforms (amorphognathiforms) have a relatively long platformed posterior process, with nearly parallel margins, and a short pointed anterior process which together are surmounted by a continuous central row of denticles that are high and node-like on the posterior process and equally high, compressed and confluent on the anterior process. The postero-lateral process is very broad, roughly triangular and about the same length as the anterior process. It has a central row of poorly developed node-like denticles. The antero-lateral process is about the same length as the posterior process, tapered to a point and also surmounted by a central row of denticles.

The surface of both forms is marked by a distinct pattern of minute, closely spaced pits like those on the surfaces of forms of the genus Eoplacognathus and like the surface of amorphognathiforms of the Pygodus apparatus.

The aboral surface of both forms has a shallow dish-like excavation showing conspicuous growth lines.

Material. 7 specimens (4 ambalodiforms, 3 polyplacognathiforms).

Genus PYGODUS Lamont and Lindstrom, 1957

Type species. Pygodus anserinus Lamont and Lindstrom, 1957

Discussion. Dzik (1976), considered the possibilities that Pygodus may be connected to the genera Amorphognathus and Eoplacognathus because of the occurrence of primitive ambalodiforms and amorphognathiform-like elements in its apparatus. Moreover, the surface of amorphognathiforms

from the apparatuses of Eoplacognathus and Pygodus are similarly marked by a distinct pattern of minute, closely spaced pits (Plate 15, figs. 6,7).

It is common for species of Balognathidae to have an apparatus that is reduced in composition as compared to the early Prioniodontacea stock. This is the case also for Pygodus, where oistodiforms are completely lacking and compound elements of the first symmetry transition are reduced in size and probably in their ratio of occurrence within the apparatus. Nonetheless, the genus Pygodus basically has a type IV apparatus.

PYGODUS ANSERINUS Lamont and Lindstrom, 1957

Pl. 9, figs. 5a-14b; Pl. 15, figs. 8-10,12,13; Fig. 38E-J

LAMONT and LINDSTROM 1957, p. 67-69, pl. 5, figs. 12,13, Figs. 1a-d.

SWEET and BERGSTROM 1962, p. 1241-43, pl. 171, figs. 11,12, Fig. 4; p. 1229, pl. 170, figs. 1,4; p. 1243-44, pl. 170, figs. 7-9; p. 1248-49, pl. 170, figs. 5,6.

HAMAR 1964, p. 279, pl. 4, figs. 1-4,11; p. 266-67, pl. 4, figs. 13,16, Figs. 5:6a,b; p. 280, pl. 5, figs. 15,16,20,21, Fig. 4:12; p. 285, pl. 6, figs. 4,5, Fig. 4:14.

BERGSTROM 1971, p. 149, pl. 2, figs. 20,21.

BERGSTROM, RIVA and KAY 1974, pl. 1, figs. 16,17.

DZIK 1976, p. 410, Figs. 7, 29f.

Description. P. anserinus is a multielement assemblage of compound and platform conodonts that comprise two transitions: trichonodelliform-belodiform- tetraprioniodiform and haddingodiform-pygodiform.

The trichonodelliforms are small, elongate forms with a slender

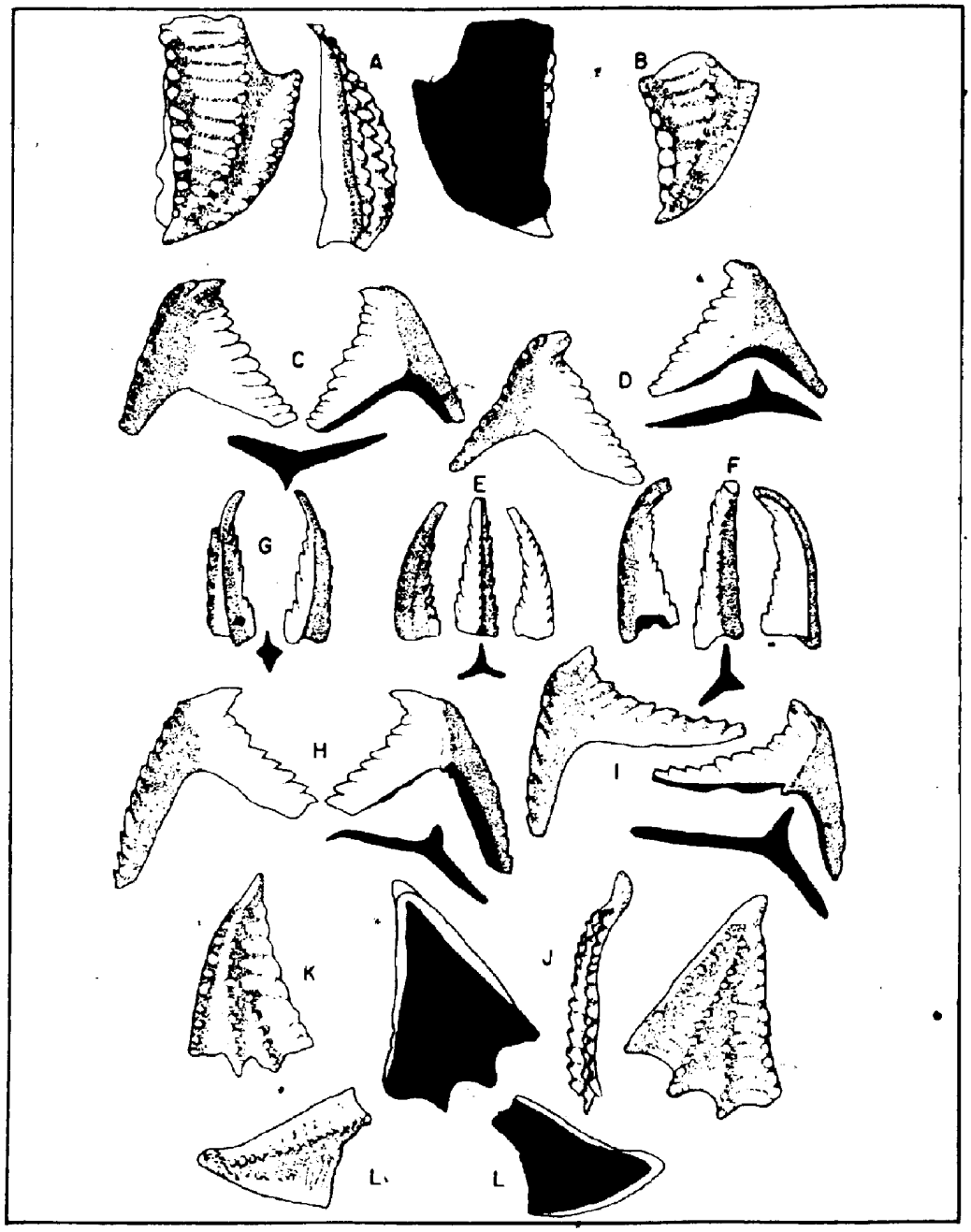

Figure 38. A-G, Pygodus serrus (Hadding). E-K, Pygodus anserinus. L, Pygodus n. sp. A. A,B,J-L, pygodiforms; C,D,H,I, haddingodiforms; E, trichonodelliform; F, belodiform; G, tetraprioniodiform. Inner lateral views to left. Illustrations are all X52.

subcircular cusp that is about one half the length of the base. A posterior process and two equally developed lateral processes each have about 8 short proclined denticles.

The belodiforms are similar to the trichonodelliforms, but have a slightly inward twisted cusp, an inward concave posterior process and unequally developed lateral processes. The outer-lateral process is wider developed than the inner-lateral process and together with the posterior process have short, basally confluent and sharp edged denticles. The inner-lateral process may or may not bear denticles.

The tetraprioniodiforms are small, elongate, slightly inward concave and have short and slender subcircular cusps. The posterior and anterior processes have 6 or 7 short and proclined inward directed denticles whereas the lateral process-like costae are undenticulated.

The haddingodiforms have short erect cusps that are sharp-edged and biconvex. The sharp edges of the cusp continue down and away from the cusp as nearly equally developed posterior and anterior processes set at an angle of 60 to 90 degrees and a mean of 75 degrees. There are 10 to 15 basally confluent and sharp denticles on each process. The outer-lateral process is about one-half the length of the other two processes and generally non-denticulated, however, there may occassionally be one or two weakly developed denticles at its distal end. A deep basal cavity extends under the entire element.

The pygodiforms are compound platform-like conodonts with a short blunt cusp situated at the anterior end of the element. Posteriorly, the platform flares widely and is surmounted by four rows of 5 to 15 blunt node-like denticles. The underside of the pygodiform is broadly

but shallowly excavated. The roof of the cavity is smooth except for the presence of circular cavities beneath the node-like denticles of the upper surface of the element.

Material. 1687 specimens (991 pygodiforms, 617 haddingodiforms, 15 trichonodelliforms, 46 belodiforms, 18 tetraprioniodiforms).

PYGODUS SERRUS (Hadding, 1913)

Pl. 9, figs. 1a-7b,10a,b; Pl. 15, figs. 7-11,14,15; Fig. 38A-G

WOLSKA 1961, p. 357, pl. 5, figs. 4,5.

HAMAR 1964, p. 280, pl. 4, figs. 5-8, Fig. 6:8.

BERGSTROM 1971, p. 149-50, pl. 2, figs. 22,23.

BERGSTROM, RIVA and KAY 1974, pl. 1, fig. 18.

DZIK 1976, Figs. 7,29a,b,c.

Discussion. The apparatus of P. serrus is the same as that of P. anserinus except for the nature of the pygodiforms and haddingodiforms. The pygodiforms of P. serrus are distinguished from the corresponding forms of P. anserinus by the presence of three, rather than four denticle rows on the upper side of the platform. The haddingodiforms are similar to those of P. anserinus but for the angular relationships between the posterior and anterior processes and the height of the basal sheath. The two processes are set at an average angle of 60 degrees in P. serrus and 75 degrees in P. anserinus. The basal sheath is longer in P. serrus.

The similarity of the denticulated edges of the haddingodiforms and the forms of the first transition series convincingly suggests that they all belong in the Pygodus apparatus, however, the pygodiforms and

haddingodiforms strongly outnumber the tiny forms of the first transition series. In only one sample did the small denticulated forms approach the frequency of the haddingodiforms and pygodiforms. It is possible that the ratios of the trichonodelliforms:belodiforms:tetraprioniodiforms:haddingodiforms:pygodiforms is as high as 1:2:2:4:4. The tiny forms of the symmetry transition may well have been sorted out or destroyed during both the sedimentological and analytical processes.

Remarks. The angular relationship between the anterior and posterior processes, of the haddingodiforms, was found to be 60 to 90 degrees with a mean of 75 degrees for P. anserinus and 55 to 80 degrees with a mean of 60 degrees to P. serrus. It is true enough that there is a strong tendency for haddingodiforms of P. anserinus to have a wider spreading, but the overlap is too great to make this a strong criterion for identification. It would appear that the evolutionary changes of the haddingodiforms and pygodiforms were somewhat staggered. The elements of the first transition series do not appear to have changed at all across the transition between the two species.

Material. 1138 specimens (581 pygodiforms, 522 haddingodiforms, 7 trichonodelliforms, 14 belodiforms, 14 tetraprioniodiforms).

PYGODUS n. sp. A

Pl. 9, fig. 15; Fig. 38L

Description. These forms have a V-shaped platform that marginally is bounded by non-denticulated ridges. A third ridge begins at the sharp posterior edge of the short compressed cusp and continues the length of the platform between the marginal ridges, in a position close to and nearly

parallel with the inner-marginal ridge. The central ridge carries 10 to 15 node-like denticles.

Remarks. These platforms have the outstanding characteristics of the platforms from the P. serrus apparatus, but in the latter case the marginal rows of the platforms bear node-like denticles. The marginal rows of Pygodus n. sp. A are non-denticulated.

It is not clear whether or not the remainder of the apparatus of Pygodus n. sp. A is the same or similar to the apparatus of P. serrus and P. anserinus. Pygodus n. sp. A was found in association with elements of P. anserinus, but only the platform elements were distinct from P. anserinus.

Material. 9 specimens.

Genus RHODESOGNATHUS Bergstrom and Sweet, 1966

Type Species. Ambalodus elegans Rhodes, 1953

RHODESOGNATHUS sp. cf. R. ELEGANS POLONICUS Dzik, 1976

Fig. 28A

Description. Only one complete specimen of this species was recovered. It has four processes, three of which diverge from the cusp. The sharp anterior and posterior edges of the short and robust cusp of this element develops into nearly equal lengthed posterior and lateral processes. In lateral view these two processes are set at an angle of about 90 degrees. The short posteriorly curved anterior process merges imperceptibly with the lateral process at the bases of the cusp. A postero-lateral process diverges from the posterior process near the cusp. Like the other

three processes, it is surmounted by sharp confluent denticles. The basal cavity continues under all four processes as a broad open cavity.

Remarks. The single complete element of this species represents an incomplete apparatus that is assigned to Rhodesognathus because of the unusual and apparently characteristic nature of the ambalodiform of the genus. The surface of the described element does not bear the distinctive pattern of minute, closely spaced pits, characteristic of some other genera within Balognathidae. It is therefore possible that this genus has closer affinity to Prioniodus or Baltoniodus, but because of the poor recovery of elements of the species in question, the genus Rhodesognathus is placed within Balognathidae following Lindstrom (1970).

Material. 3 specimens.

Family PRIONIODONTIDAE (Bassler, 1925)

Discussion. Lindstrom (1970) incorporated within this family the three genera Gothodus, Baltoniodus and Prioniodus.

Previously, Bergstrom (1968), had regarded the form species Gothodus costulatus Lindstrom s.f. as a junior synonym of Belodus gracilis Pander s.f. which he was including in a multielement assemblage along with Prioniodus carinatus s.f., Tetraprioniodus robustus s.f. and an undescribed trichonodelliform. Bergstrom was of the opinion that Belodus, Gothodus and Tetraprioniodus were synonymous with Prioniodus, the name giver to the multielement genus.

Bergstrom (1971), considered Baltoniodus and Prioniodus to be synonyms whereas Sweet and Bergstrom (1972), considered Baltoniodus to be

a subgenus of Prioniodus. Bergstrom and Cooper (1973) noted the potential for distinguishing Prioniodus evae, and forms with a similar type apparatus, as an independent subgenus. They suggested the appropriate name Oepikodus.

Serpagli (1974) reviewed the nomenclature discussions and concluded the most satisfactory solution to be to subdivide the genus Prioniodus into the three subgenera: Prioniodus (Prioniodus), Prioniodus (Baltoniodus) and Prioniodus (Oepikodus). McTavish (1973), and Serpagli (1974), recognized the prioniodiform in Lindstrom's Gothodus to be an Acodus in form taxonomy and consequently chose the genus Acodus as name bearer in preference to Gothodus. Dzik (1976) brought Acodus into the family Oistodontidae. Van Wamel (1974) raised the status of Oepikodus to the genus level.

Fahraeus and Nowlan (in press) recognized Serpagli's (1974) subgenera of Prioniodus as genera because of the major structural differences between them. They follow McTavish (1973), and Serpagli (1974), for Acodus, Lindstrom (1971), and McTavish (1973), for Prioniodus and Baltoniodus and Van Wamel (1974), for Oepikodus. Where applicable these latter genera are used herein.

McTavish (1973) is convinced that Acodus deltatus, and its immediate descendents, radiated to originate the Baltoniodus lineage, the Prioniodus elegans (Prioniodus) lineage and the Prioniodus evae (Oepikodus) lineage, during the time span of the upper part of the Emanuel Formation (lower Arenigian), of the Canning Basin, Western Australia. Lindstrom, McTavish and Ziegler (1972), observed longitudinal striations on the cusps of the most primitive prioniodids that are similar to those of the younger and more advanced species.

Genus ACODUS Pander, 1856

Type Species. Acodus erectus Pander, 1856

Discussion. This genus was placed by Dzik (1976) within the family Oistodontidae because of the undenticulated nature of the processes. Lindstrom (1970), however, diagnosed the family Oistodontidae to constitute hyaline conodont species and consequently included such differing apparatuses as those of Oistodus and Scolopodus. It has since been debated whether the hyaline nature of some species is important for classification or whether it is the result of environmental conditions (Dzik, 1976; Barnes et. al., 1973).

Serpagli (1974), and McTavish (1973), include within the genus Acodus trichonodelliforms, cordylodiforms, tetraprioniodiforms, acodiforms = prioniodiforms and oistodiforms. This is characteristic of apparatus type IV (Barnes et. al., 1977). Oistodus and Triangulodus are characterized by a type II apparatus. The genus Acodus is therefore considered more closely related to Prioniodus and Baltoniodus than to Oistodus and Triangulodus and is placed within the family Prioniodontidae.

?ACODUS n. sp. A

Pl. 11, figs. 1-6; Fig. 39A-G

Description. This multielement species is composed of simple cone conodonts with high process-like lateral costae and comprises a symmetry transition of trichonodelliforms through cordylodiforms to tetraprioniodiforms, prioniodiforms and oistodiforms.

Among the small number of elements recovered, there is only one possible trichonodelliform, which is broken. It has a suberect cusp and a

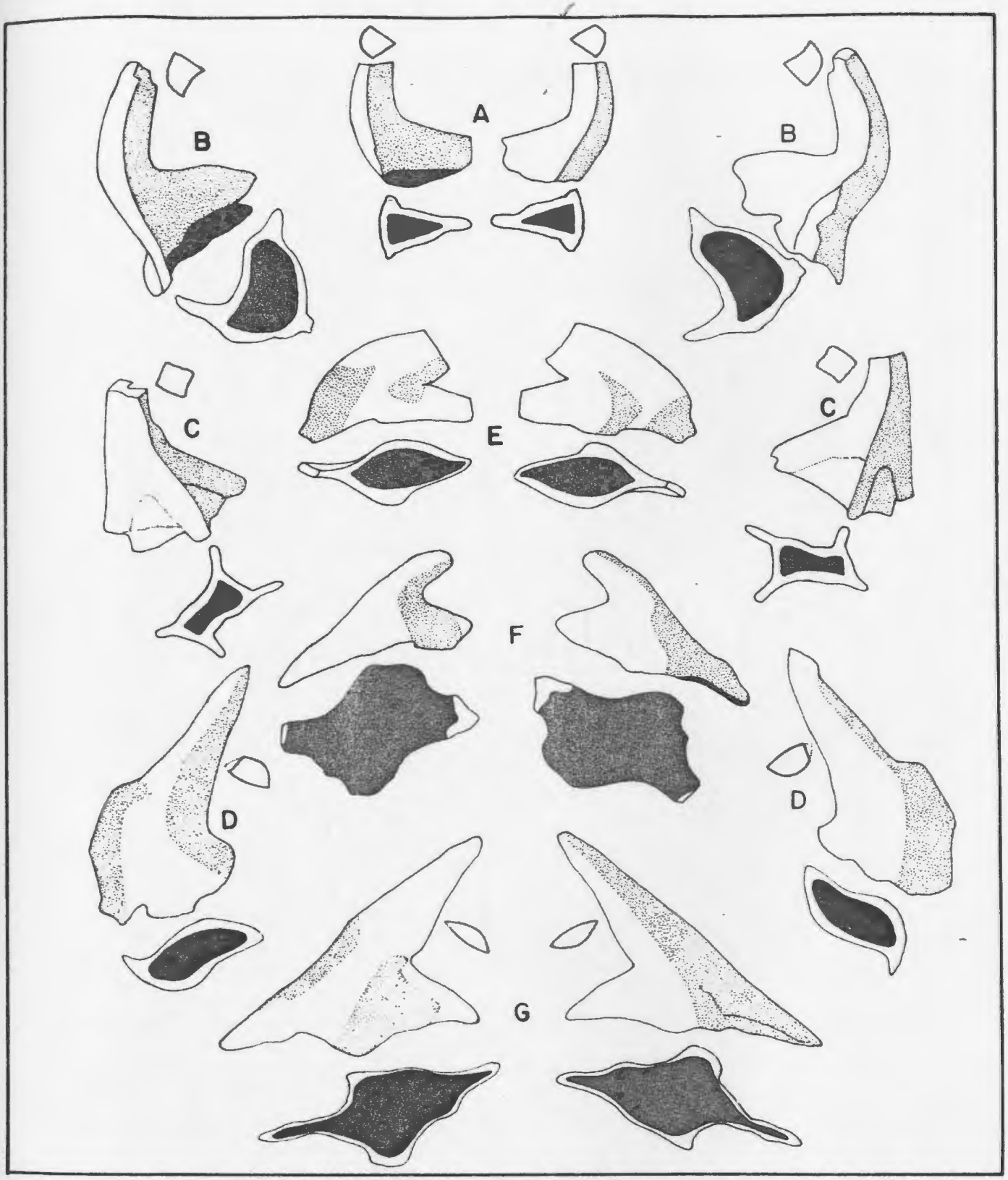

Figure 39. ?Acodus n. sp. A: A, ?trichonodelliform; B, prioniodiform; C, tetraprioniodiform; D,G,F, cordylodiforms (1, 2 and 3 respectively); E, oistodiform. Inner lateral views, left of centre; outer lateral views, right of centre. Illustrations are all X42.

sharp posterior edge that is continuous with the sharp oral margin of the base. There are two posteriorly directed costa-like processes that do not appear to be symmetrically disposed. The basal cavity is deep and triangular in cross section.

The prioniodiforms are superficially similar to the trichonodelliforms, but illustrate a more pronounced asymmetry. The basal margin is convex outward and concave inward.

The tetraprioniodiforms have a proclined cusp and sharp anterior and posterior margins that become strongly keeled on the base. Two unequally developed and asymmetrically disposed process-like costae emerge from the lateral faces in a more or less posterior direction.

The oistodiforms have a robust, biconvex and sharp-edged cusp. The oral margin of the base is sharp and about as long as the cusp. The basal cavity is lanceolate because of lateral flaring of the basal margin.

There are three forms of non-costate elements that are best regarded cordylodiforms. One form has a suberect and very robust cusp with sharp anterior and posterior edges. The outer face of the cusp is convex and the inner face is nearly planar. The base is short and not laterally expanded. A second form has a robust erect cusp with sharp edges and convex lateral faces. Unlike the first described form it is antero-posteriorly extended. The basal margin flares in both lateral directions. The third form has a short cusp, is extended antero-posteriorly and is broadly flared laterally.

Remarks. This species appears to be hyaline, but, nonetheless, is tentatively placed within Acodus because it has an apparatus more similar to Acodus than to Triangulodus or Oistodus.

Material. 48 specimens.

Genus BALTONIODUS Lindstrom, 1971

Type Species. Prioniodus navis Lindstrom, 1955

BALTONIODUS PREVARIABILIS-B. VARIABILIS transition

Pl. 8, figs. 1-8b,12a-13; Pl. 15, figs. 3,4; Fig. 40A,B,D-F,H

Description. This genus has a type IV apparatus that is characterized by two transition series: trichonodelliform-tetraprioniodiform-belodiform series and a falodiform-prioniodiform-amorphognathiform transition series.

The prioniodiform has its posterior and lateral processes set at an acute angle. The anterior process is strongly curved inward and varies from one half the length to nearly equal the length of the slightly flaring posterior process. The lateral process is straight and always longer than the other two processes. The disposition of the processes of this form is strongly asymmetrical to nearly symmetrical. In the first extreme, the anterior process is about one half the length of, and is situated 110 to 130 degrees to the posterior process. Orally, there is an angle of 70 to 90 degrees between the lateral and anterior processes, and 130 to 150 degrees between the lateral and the posterior processes. Laterally, the posterior and the lateral processes are set at about 80 degrees. In the latter extreme, the anterior process is nearly equal in length to the posterior process and oriented 130 to 150 degrees from it. Orally, there is a 70 to 90 degrees angle between the lateral and the anterior processes and a 130 to 140 degrees angle between the lateral and the posterior processes. Laterally, the posterior and the lateral processes are

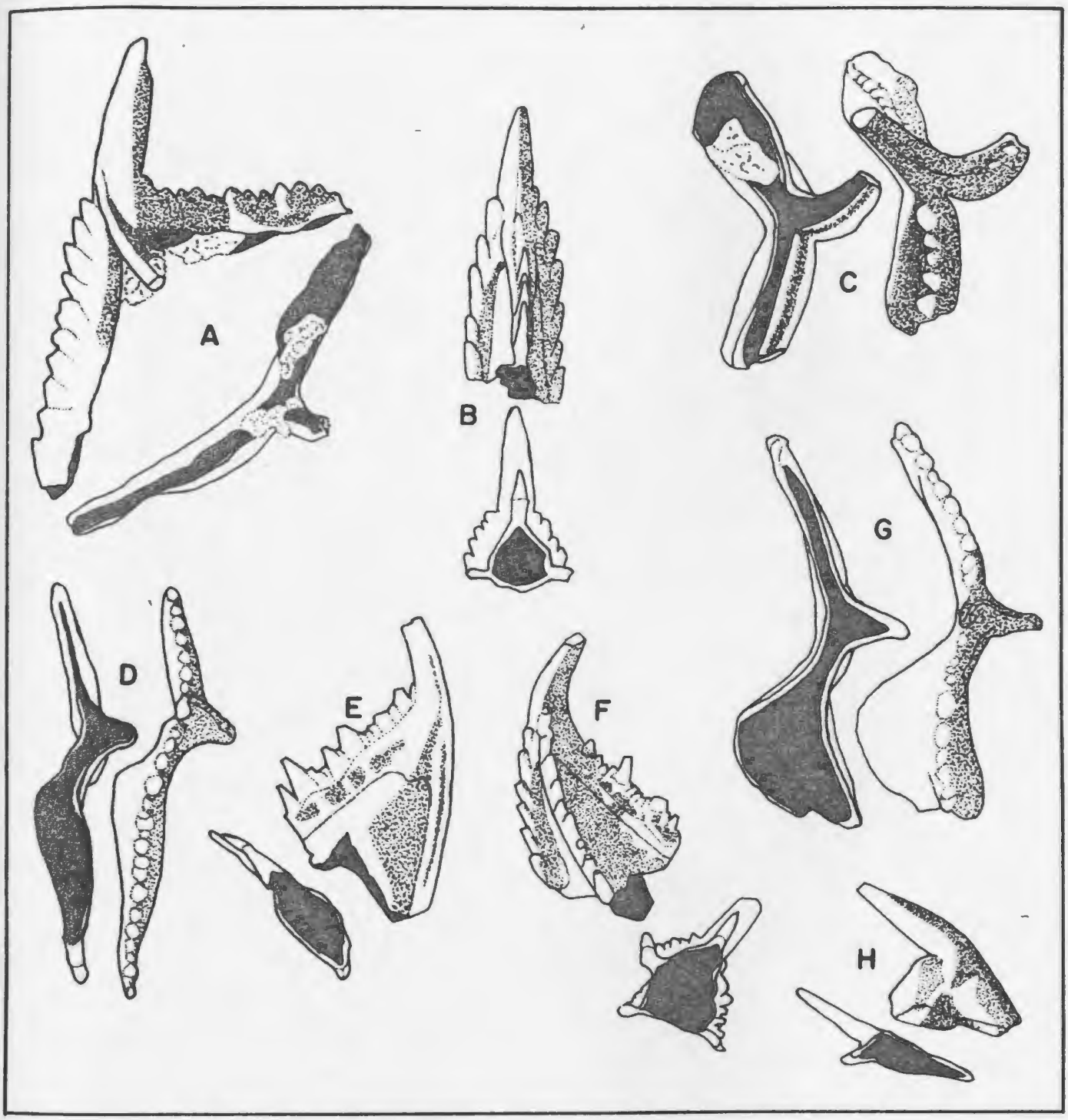

Figure 40. A,B,D,E,F,H, Baltoniodus prevariabilis-B. variabilis transition: B,C,E-H, Baltoniodus variabilis (Bergstrom). A, lateral and aboral views of prioniodiform; C, oral and aboral views of prioniodiform; D,G, oral and aboral views of amorphognathiforms; B, posterior and aboral views of trichonodelliform; E, inner lateral and aboral views of belodiform; F, inner lateral and aboral views of tetraprioniodiform; H, outer lateral and aboral views of falodiform. Illustrations are all X61.

set at an angle of 60 to 80 degrees.

The amorphognathiform has an arched posterior process and a straight lateral process set at an obtuse angle of 110 to 120 degrees. The anterior process is short and curved into a plane nearly perpendicular to the plane of the long, slightly sinuous and laterally flared posterior process. The lateral process is straight and is situated anterior (150 to 160 degrees) to the posterior process. The basal cavity continues along all three processes. It is narrow in the anterior and the lateral processes and broadly flared beneath the posterior process.

The falodiform has a robust and generally long base that exhibits a strong outer-lateral flare. The cusp is laterally compressed, outward deflected and sharp edged.

Elements of the first transition series have long and slender proclined cusps and long straight posterior processes with non-uniformly sized denticles. The trichonodelliforms have symmetrical denticulate lateral processes that orally diverge at an angle of 10 to 15 degrees and which are laterally set at an angle of 20 to 25 degrees with the posterior process. The belodiforms have a sharp-edged and undenticulated anterior process that encloses an angle of 35 to 45 degrees with the posterior process. The tetraprioniodiforms have an anterior denticulated and two lateral denticulated processes. When viewed down the cusp, the lateral processes are set at an angle of about 135 degrees. Laterally, the anterior and posterior processes make an angle of about 30 degrees and the outer-lateral and the posterior processes make an angle of about 40 degrees.

Remarks. The ambalodiforms of the B. prevariabilis apparatus are distinguished from those of the B. variabilis apparatus by having a total absence of well developed platform ledges along or near the basal margin of the processes. These ledges make their first appearance, on ambalodiforms in poorly advanced species of B. variabilis or in highly advanced species of B. prevariabilis, along the posterior side of the lateral process. More advanced forms also develop ledges along the anterior edge of the lateral process and along the anterior edge of the anterior process.

During the short time span of the evolutionary boundary between the two species it is difficult to set apart an ambalodiform which represents the B. prevariabilis apparatus from one representing a B. variabilis apparatus, consequently, forms representative of this evolutionary transition are herein called Baltoniodus prevariabilis-B. variabilis transition.

The extremely variable nature of the prioniodiforms was first noted by Bergstrom (1962), and at that time he felt it might be possible to split the species. This variability was also noted herein and was further seen to be groupable into two end member clusters, which, when counted in a few samples, were seen to be about equally represented. This may indicate that there are two different forms of prioniodiforms, which along with the numerical data below suggests a trichonodelliforms:belodiform: tetraprioniodiform:falodiform:amorphognathiform:prioniodiform ratio of 1:2:2:2:2:4.

Material. 375 specimens (104 ambalodiforms, 57 amorphognathiforms, 68 falodiforms, 32 trichonodelliforms, 58 tetraprioniodiforms, 56 belodiforms).

BALTONIODUS VARIABILIS (Bergstrom, 1962)

Pl. 8, figs. 1a-5b,9-13; Pl. 15, fig. 5; Fig. 40B,C,E-H

BERGSTROM 1962, p. 51-53, pl. 2, figs. 1-7; p. 54, pl. 5, fig. 16; p. 50-51, pl. 2, figs. 8-12, Fig. 2c; p. 55-56, pl. 2, figs. 15-17; p. 45, pl. 3, figs. 7-10, Fig. 3f.

HAMAR 1964, p. 279, pl. 5, figs. 2,3,6; p. 278, pl. 4, fig. 15, pl. 5, figs. 17,22, Fig. 6:7; p. 281, pl. 3, fig. 16, Fig. 4:11; p. 273, pl. 5, fig. 9, Fig. 6:13; p. 284, pl. 5, fig. 19; p. 269, pl. 3, figs. 1,2,7,14.

HAMAR 1966, pl. 4, fig. 6; p. 69, pl. 5, fig. 6, Fig. 6:6; pl. 7, fig. 21; pl. 7, fig. 25; p. 76, pl. 5, fig. 4; pl. 1, fig. 21.

DZIK 1976, p. 437, Figs. 24h-1.

Discussion. This species has a type IV apparatus that is characterized by two transition series: a trichonodelliform-tetraprioniodiform-belodiform series and a falodiform-prioniodiform-amorphognathiform series.

The differences between this species and B. prevariabilis lie in the nature of the prioniodiforms and amorphognathiforms. The prioniodiforms of B. variabilis are distinguished from those of B. prevariabilis by the presence of well developed platform ridges along the basal margin of the lateral and anterior processes. In the Cobbs Arm Formation, the anterior process of the prioniodiforms tend to be more conspicuously denticulated in B. variabilis than in B. prevariabilis-B. variabilis transition.

The amorphognathiforms of the B. variabilis apparatus have posterior processes with a much broader flaring basal margin than do the

corresponding elements of B. prevariabilis. Some of the amorphognathiforms of B. prevariabilis-B. variabilis transition have broadly flaring posterior processes.

Material. 1397 specimens (505 ambalodiforms, 84 amorphognathiforms, 360 falodiforms, 66 trichonodelliforms, 179 tetraprioniodiforms, 203 belodiforms).

Suborder OZARKODININA Dzik, 1976

Discussion. Dzik (1976), incorporates, into this suborder, apparatuses in which asymmetrical two branched (ozarkodiniforms and hindeodelliforms) elements predominate functionally in the apparatus.

The evidence appears to strongly suggest that the early representatives of Ozarkodinina evolved from Drepanoistodus (Dzik, 1976), and, that once developed, this lineage became more and more distinct from Prioniodontina. Early species of the lineage inherited, from Drepanoistodus, the presence of oistodiforms in their apparatuses. With further advancement, the oistodiforms transformed into neoprioniodiforms (Dzik, 1976).

Family PERIODONTIDAE Lindstrom, 1970

Genus PERIODON Hadding, 1913

Type Species. Periodon aculeatus Hadding, 1913

Discussion. Bergstrom and Sweet (1966), incorporated six different conodont forms, including the Cordylodus-Roundya symmetry transition of Lindstrom (1964), into the genus Periodon. These six forms can be regarded as two transition series referred to as: a trichonodelliform-eoligonodiniform-periodontiform (-loxognathiform) series and a falodiform-

ligonodiniform-prioniodiniform series. This is characteristic of a type IV apparatus. The forms of the first transition series have slender, recurved cusps and long, highly arched posterior processes that are distally flexed inward, outward or not at all.

Detailed examination and numerical relationships indicate that, in the Cobbs Arm Formation, there two varieties of P. aculeatus that are set apart only by the nature of the loxognathiforms and periodontiforms. These two forms constitute the third described element of the first symmetry transition series in their respective varieties and are easily distinguished. The loxognathiform has a well developed outer-lateral process, an inner postero-anterior angle of about 135 degrees and a long posterior process that is distally flexed inward.The outer-lateral surface of the periodontiform may or may not have a small costa-like process that, when present, may occassionally continue to the tip of the cusp. The inner postero-anterior angle of this form is close to 90 degrees and its long posterior process is distally flexed outward.

The frequencies of the trichonodelliforms, eoligonodiniforms, periodontiforms + loxognathiforms, ligonodiniforms, prioniodiniforms, and falodiforms suggests the respective ratios: 1:2:2:2:2:4. Within individual samples, the periodontiforms and loxognathiforms were invariably present at a ratio close to 1:1. If the two forms were to have represented two different species, then one might expect the ratio between the two forms to vary considerably from sample to sample or within differing lithologies. The ratio was consistent and consequently the two forms were taken to represent varieties of the same species; possibly a rare example of sexual dimorphism. The two varieties are referred to as

morphotype γ and morphotype β, respectively.

PERIODON ACULEATUS Hadding, 1913 morphotype γ

Pl. 11, Figs. 7-8b,10a-17; Pl. 16, figs. 8-10; Fig. 41A-E,G,H

HADDING 1913, p. 33, pl. 1, fig. 11.

LINDSTROM 1955b, p. 110, pl. 22, figs. 11,15,?14, not 10,16,35; p. 110, pl. 22, fig. 35.

LAMONT and LINDSTROM 1957, pl. 5, fig. 15.

SWEET and BERGSTROM 1962, p. 1235, pl. 171, figs. 3,9; p. 1240, pl. 171, figs. 7,8; p. 1230, pl. 170, figs. 13,14; p. 1227, pl. 170, figs. 2, 3, Fig. 2b.

HAMAR 1964, p. 274, pl. 3, figs. 17,21; p. 273, pl. 3, fig. 20; p. 278, pl. 3, fig. 28, Fig. 4:19; p. 265, pl. 4, figs. 9,10, Fig. 4:18.

SCHOPF 1966, p. 67-68, pl. 3, figs. 10,12,13,14; p. 70, pl. 4, figs. 27, 28; p. 59, pl. 4, figs. 22,26,?23; p. 56, pl. 3, fig. 11.

BRADSHAW 1969, p. 1159-60, pl. 137, figs. 1-3,5; p. 1160, pl. 137, fig. 19; p. 1152, pl. 137, fig. 18; p. 1151, pl. 135, figs. 16,17.

UYENO and BARNES 1970, p. 112, pl. 23, figs. 1,2,6,7,?4; p. 113, pl. 23, figs. 12,16; p. 108, pl. 22, figs. 8,14,15,18.

DZIK 1976, Figs. 34i,1-q.

Description. This morphotype of P. aculeatus has a type IV apparatus, which constitutes trichonodelliforms, eoligonodiniforms and periodontiforms; falodiforms, ligonodiniforms and prioniodiniforms.

The elements of the first transition series characteristically have slender and sharp edged recurved cusps and long, highly arched posterior processes. The posterior processes are surmounted by laterally

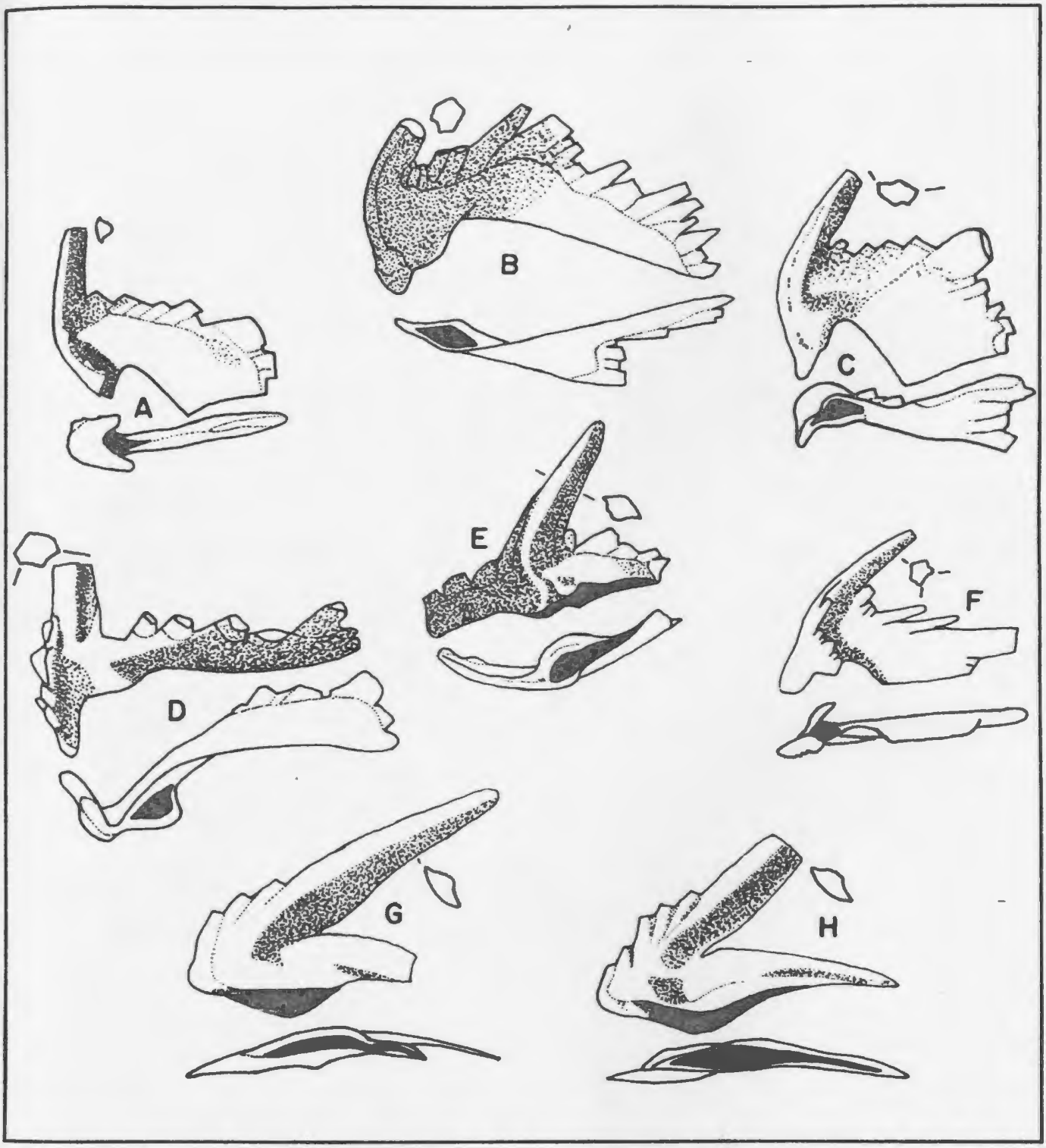

Figure 41. A-E,G,H, Periodon aculeatus Hadding, morphotype γ. A,B, D-H, Periodon aculeatus Hadding, morphotype β. A, lateral and aboral views of trichonodelliform; B, inner lateral and aboral views of eoligonodiniform; C, outer lateral and aboral view of periodontiform; D, inner lateral and aboral views of ligonodiniform; E, inner lateral and aboral views of prioniodiniform; F, outer later and aboral views of loxognathiform; G,H, outer lateral and aboral views of falodiforms. Illustrations are all X55.

compressed, basally fused and sharp-edged denticles which increase in size and in inclination towards a great denticle at the arch crest. Posterior of this the process is crowned with nearly perpendicular and smaller denticles and may be flexed inward or outward. The trichonodelliforms have posterior processes that are unflexed. The lateral costae of the cusp extend vertically, posteriorly and slightly laterally as symmetrical wing-like processes that are crowned with small peg-like denticles. A deep triangular excavation is located directly below the cusp. Posteriorly the basal cavity becomes inverted.

The eoligonodiniforms are slightly asymmetrical and have a posterior process that distally is flexed inward. The anterior edge of the cusp continues vertically and away from the cusp and the posterior process as a short blade that is undenticulated to weakly denticulated with about five fused, peg-like denticles that are upward directed, i.e. into the plane of the cusp. The anterior and posterior processes form an inner angle that is greater than 160 degrees. The basal cavity is slightly flared in both lateral directions. It generally continues anteriorly as a narrow, shallow furrow. Posteriorly the basal cavity is strongly inverted.

The periodontiforms are asymmetrical and have a posterior process that distally flexes outward. The sharp anterior edge of the cusp extends as a short denticulated blade down and posteriorly at an angle near 90 degrees with the posterior process. It carries about seven peg-like denticles that are upward directed into the plane of the cusp. There often is an outer-lateral costa on the base, that begins at a flange in the basal margin. When best developed it continues up the cusp as a ridge

along the anterior margin of a shallow furrow. The basal cavity varies in size and shape depending on the development of the outer-lateral costa, but generally is small. It is weakly triangular in outline and inverted posteriorly.

The ligonodiniforms and the prioniodiniforms have robust cusps that are inward deflected, compressed and laterally carinate. The sharp edges of the cusp continue anteriorly and posteriorly as well developed processes that are surmounted by laterally compressed, sharp and basally fused denticles. Distally the posterior processes are twisted such that the distal denticles are directed outward.

The prioniodiniforms are arched and blade-like and have nearly equally developed anterior and posterior processes that enclose an inner angle of 60 to 70 degrees. The posterior process has five or six denticles and the anterior process has four or five denticles. The basal margins flare convexly outward beneath the cusp and are separated beneath the posterior process by a narrow and shallow furrow. The basal cavity continues only a short distance along the cuneate aboral edge of the anterior process whereupon it becomes inverted.

The oral edge, of the long posterior process of the ligonodiniforms, has about 12 denticles with a posteriorly directed inclination of about 60 degrees. The generally broken anterior processes are deflected posteriorly and down to an outer-lateral position that encloses an angle of about 90 degrees with the posterior edge of the cusp. The basal cavity is gently convex outward, strongly flared inward and is inverted posteriorly.

The falodiforms have inward deflected, laterally carinate and

sharp-edged cusps and posteriorly drawn out bases which are set at an angle of about 40 degrees. The basal half of the anterior edge carries one to five fused denticles that are directed towards the tip of the cusp. The basal cavity is slightly flared laterally beneath the middle part of the base and continues posteriorly as a narrow furrow. The basal cavity often shows signs of inversion anteriorly.

Material. 274 periodontiforms, 146 trichonodelliforms, 564 eoligonodiniforms, 347 ligonodiniforms, 547 prioniodiniforms, 1099 falodiforms.

PERIODON ACULEATUS Hadding, 1913 morphotype β

Pl. 11, figs. 7-9b,11a-12b,14-17; Pl. 16, figs. 8,9,11; Fig. 41A,B,D-G

GRAVES and ELLISON 1941, p. 12, pl. 2, fig. 31, not 29,32; p. 14, pl. 2, figs. 33,35,36; p. 12, pl. 2, figs. 6,22,23,28.

HAMAR 1964, p. 267-68, pl. 3, figs. 22,24,26,27; p. 273, pl. 3, fig. 20; p. 278, pl. 3, fig. 28, Fig. 4:19; p. 265, pl. 4, figs. 9,10, Fig. 4:18.

SCHOPF 1966, p. 67-68, pl. 3, figs. 16,13,10,14; p. 70, pl. 4, figs. 27, 28; p. 59, pl. 4, figs. 22,26,?23; p. 56, pl. 3, fig. 11.

BRADSHAW 1969, p. 1159-60, pl. 137, figs. 4,6,5,1,3; p. 1160, pl. 137, fig. 19; p. 1152, pl. 137, fig. 18; p. 1151, pl. 135, figs. 16,17.

UYENO and BARNES 1970, p. 112, pl. 23, figs. 3,5,6,7,2; p. 113, pl. 23, figs. 12,16; p. 108, pl. 22, figs. 8,14,15,18.

BARNES and POPLAWSKI 1973, p. 780-81, pl. 5, figs. 16-18,18a,?15,15a.

DZIK 1976, Figs. 141-r.

Description. P. aculeatus morphotype β has a type IV apparatus that constitutes trichonodelliforms, eoligonodiniforms and loxognathiforms;

falodiforms, ligonodiniforms and prioniodiniforms.

The loxognathiforms are asymmetrical conodonts with a long and slender reclined cusp that is sharp-edged and laterally carinate. The posterior process is long, highly arched and distally flexed inward. It is surmounted by laterally compressed, basally fused and sharp-edged denticles that increase in size and in inclination towards a great denticle at the arch crest. Sequent to this the denticles are nearly perpendicular to the process and of decreasing size. The sharp anterior edge of the cusp extends down and inward as a short blade with about six peg-like denticles that are directed upward into the plane of the cusp. The anterior and posterior processes form an inner angle of about 135 degrees. An outer-lateral cusp carina continues down and posteriorly as a short process with an angle of about 40 degrees to the posterior process. This process is broken in all specimens but is denticulated similar to the anterior process. A sheath between the outer-lateral and posterior processes encloses a generally triangular basal cavity that becomes inverted posteriorly.

Remarks. The remaining elements of the apparatus are identical to corresponding elements in the *P. aculeatus* morphotype γ apparatus.

Material. 287 loxognathiforms.

?Family PERIODONTIDAE Lindstrom, 1970

Genus SPINODUS Dzik, 1976

Type Species. *Cordylodus spinatus* Hadding, 1913

Discussion. Dzik (1976) erected this genus to include species

having elements with strongly elongate posterior processes and long denticles circular in cross section. Only the type species was brought into the new genus.

S. spinatus exhibits a symmetry transition from cordylodiforms through ligonodiniforms to trichonodelliforms. Dzik (1976) associates this kind of apparatus with primitive prioniodids and consequently assigns the genus Spinodus to Prioniodontina. The morphology of the elements of Spinodus, however, suggests a closer affinity to the lower Llanvirnian species Cordylodus horridus (Barnes and Poplawski, 1973), and the older species Cordylodus angulatus. Like C. angulatus, S. spinatus has elements with slight differences in the basal part. C. horridus and S. spinatus similarly show inward and outward splaying of denticles. Nonetheless, the apparatuses of C. angulatus and C. horridus contain only two different kinds of forms and are thus distinctly different from the apparatus of S. spinatus. This point was brought out by Lindstrom (1970). Dzik (1976) points out the structural similarities between Spinodus and the hyaline Multioistodus, however, the morphological similarities of the forms is lacking.

The symmetry transition exhibited by Spinodus is most similar to the first transition series of Periodon and consequently the two may possibly be related. The observations of this study can do no more than suggest that the two belong in the family Periodontidae.

SPINODUS SPINATUS (Hadding, 1913)

Pl. 12, figs. 1a-3b; Fig. 42A-C

HADDING 1913, p. 32, pl. 1, fig. 8; ?p. 31, pl. 1, fig. 6.

LINDSTROM 1955b, p. 109, pl. 22, figs. 5,18,27; ?p. 108-109, pl. 22, figs. 12,19.

LAMONT and LINDSTROM 1957, pl. 5, fig. 10.

SWEET and BERGSTROM 1962, p. 1225-26, pl. 170, fig. 12, pl. 171, fig. 13; ?p. 1225, pl. 170, fig. 15, pl. 171, fig. 10.

LINDSTROM 1964, p. 84, Figs. 27a-c,?d.

UYENO and BARNES 1970, p. 106-107, pl. 24, figs. 7,8,10,?9,11.

DZIK 1976, p. 424, Fig. 21c.

Description. Members of this species characteristically have a long and slender cusp and denticles that are widely spaced, near circular in cross section and sharp-edged. Basal cavities are deepest beneath the cusp but continue along the posterior processes as shallow U-shaped troughs. The basal margins show the edges of individual lamellae, indicative of basal inversion.

S. spinatus exhibits a symmetry transition from cordylodiforms through ligonodiniforms to trichonodelliforms. The trichonodelliforms have long and slender recurved cusps and long slightly arched denticulated posterior processes. Equally developed short lateral processes each carry a single short and sharp-edged denticle.

Ligonodiniforms differ from trichonodelliforms in having a single lateral process, a slightly basally extended anterior margin and inward and outward splaying of denticles.

Cordylodiforms have no lateral processes and are greatly extended in the basal anterior direction.

Remarks. Some forms have a spine directed downward from in front

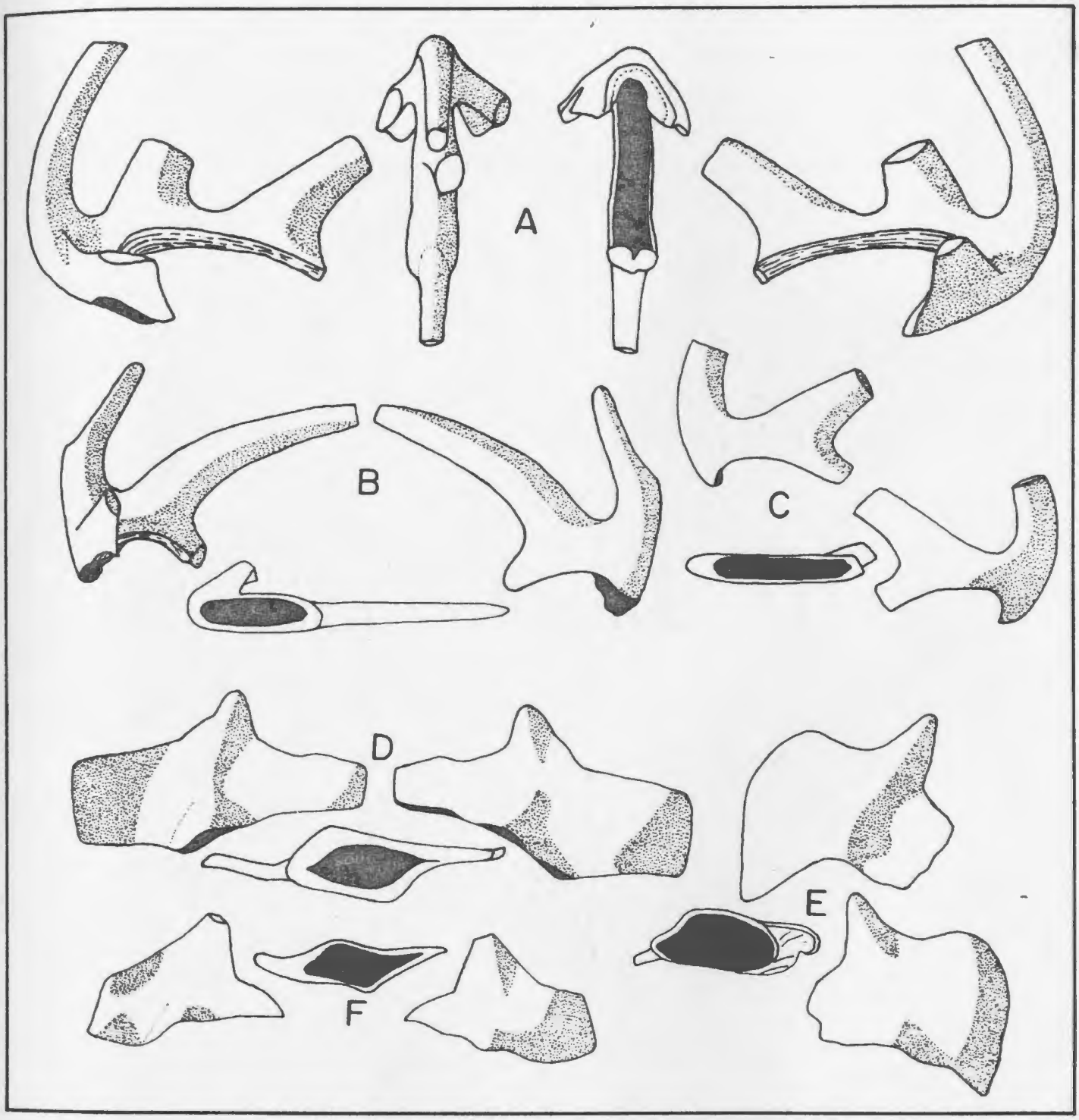

Figure 42. A-C Spinodus spinatus (Hadding): A, trichonodelliform; B, ligonodiniform; C, cordylodiform. D-F, New Genus n. sp. 1 Bergstrom, Riva and Kay. Inner lateral views, to left; outer lateral views, to right. Illustrations are all X62.

of the base, and for this reason it is assumed that C. ramosus s.f. and C. spinatus s.f. belong together in the same apparatus. The small number of recovered elements of the genus Spinodus, from the Cobbs Arm Formation, do not give strong support to this idea.

Material. 20 specimens.

Suborder UNKNOWN

NEW GENUS Bergstrom, Riva and Kay, 1974

Type Species. New Genus n. sp. 1 Bergstrom, Riva and Kay, 1974

NEW GENUS n. sp. 1 Bergstrom, Riva and Kay, 1974

Pl. 12, figs. 6a-8; Fig. 42D-F

BERGSTROM, RIVA and KAY 1974, pl. 1, fig. 8.

Description. This apparatus consists of undenticulated blade-like forms with short, robust and sharp-edged cusps. The sharp edges of the cusp continue anteriorly and posteriorly as processes. The basal cavities are shallow, laterally flared and extend beneath the posterior process only. All of the recovered forms are asymmetrical.

Remarks. This species shows some similarity to previously described forms of Polycaulodus (Branson and Mehl, 1933), but the nature of the apparatus of either genus is presently unknown.

Material. 4 specimens.

Order WESTERGAARDODINIDA Lindstrom, 1970

Family WESTERGAARDODINIDAE Muller, 1959

Genus WESTERGAARDODINA Muller, 1959

Type Species. Westergaardodina bicuspida Muller, 1959

WESTERGAARDODINA sp. cf. W. BICUSPIDA Muller, 1959

Pl. 12, figs. 14a,b; Fig. 28C

Description. A U-shaped element that is entirely excavated on the aboral side. The two subparallel "points" are tapered and slightly more than half the length of the element. Each is strongly convex on the oral surface and broadly excavated beneath.

Material. 1 specimen.

8.3 Residuals.

distacodiform

Pl. 12, fig. 9; Fig. 35F

HAMAR 1964, p. 263, pl. 1, figs. 19,20, Fig. 6:3a.

Description. This is a simple cone conodont with a robust and relatively long and reclined anteriorly and posteriorly sharp cusp. The short oral margin is convex similarly to the upward flexed posterior part of the basal margin. There is a costa on each lateral face of the base that continues up the cusp. The costa on the outer face is stronger and in a more posterior position; it is bounded posteriorly by a furrow. The inner costa is bounded by a furrow on the base, but further up the cusp it weakens to a more centrally developed carina.

Material. 1 specimen.

oistodiform 1

Pl. 12, figs. 10,11; Fig. 35G,H

Description. This is a simple cone conodont with a compressed, biconvex and sharp-edged robust cusp and a relatively short base. The oral margin of the base is sharp. The basal margin is biconvex and more broadly flared inward on the form with the smaller postero-oral angle.

Material. 2 specimens.

oistodiform 2

Pl. 12, figs. 12a,b; Fig. 36F

Description. Oistodiform with long, slender, compressed and sharp-edged cusp that is inward deflected, has a convex outer surface and a broadly carinate inner surface. The base is relatively long and high and is triangular in outline. The basal cavity is fairly deep and has a bi-convex margin that flares slightly more inward.

Material. 2 specimens.

panderodiform

Pl. 4, figs. 13a,b; Fig. 31K

Description. Simple cone conodont with long and slender erect cusp and a short base. The anterior margin of the element is narrowly rounded whereas the posterior margin is sharp. A narrow furrow runs from the basal margin to the tip of the cusp on the outer postero-lateral part of the element. The basal margin is pear-shaped and the surface around the basal margin bears longitudinal striations.

Material. 2 specimens.

strachanognathiform

Pl. 12, figs. 5a,b; Fig. 36G

Description. A simple cone conodont with a fairly deep triangular basal cavity, a denticulated anterior margin and a sharp posterior margin. The outer surface of the cusp is convex whereas the inner surface of the cusp is near planar. The basal margin is biconvex; flaring slightly

more outward.

Material. 1 specimen.

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PLATES

The meaning of the section abbreviations is as follows:

CAm = Cobbs Arm section (middle quarry face).

CAw = Cobbs Arm section (west quarry face).

CAR = Cobbs Arm road section.

CI = Cottles Island section.

Hill = Hillgrade section.

QC = Quarry Cove section.

SC = Squid Cove section.

PLATE 1

All specimens X45. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-5b Distacodus venustus (Stauffer)

1a, outer lateral; and b, inner lateral view of drepanodiform (SC4).

2a,b, lateral views of symmetrical drepanodiform (QC19).

3a, inner; and b, outer lateral views of drepanodiform (SC4).

4a, inner; and b, outer lateral views of oistodiform (CI19).

5a, outer; and b, inner lateral views of oistodiform (QC19).

Figures 6-15b Drepanoistodus n. sp. A

6, symmetrical drepanodiform (CAm12).

7, symmetrical oistodiform (QC3).

8a,9b,10b,11a,12b,13b, outer lateral; and 8b,9a,10a,11b,12a,13a, inner lateral views of drepanodiforms (QC3).

14a,15b, outer lateral; and 14b,15a, inner lateral views of oistodiforms (QC3).

Figures 16-21b Paltodus semisymmetricus (Hamar)

16, symmetrical drepanodiform (CAm7).

17a,18b, outer; and 17b,18a, inner lateral views of asymmetrical drepanodiforms (QC3).

19a, outer; and 19b, inner lateral views of asymmetrical drepanodiform (CI15).

20a, inner; and 20b, outer lateral views of oistodiform (QC9).

21a, inner; and 21b, outer lateral views of oistodiform (QC3).

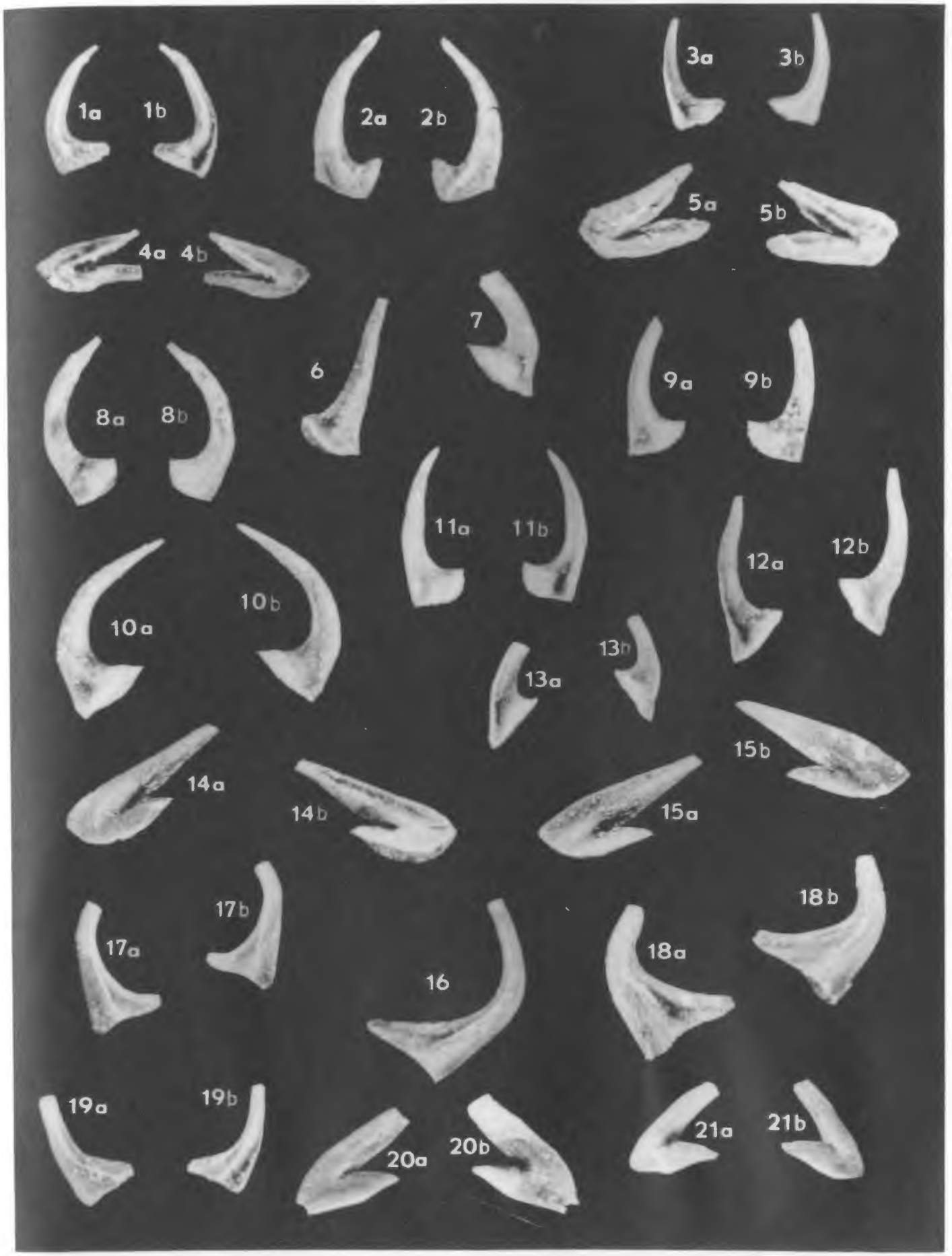
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PLATE I

PLATE 2

All specimens X50. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-4b Strachanognathus parva Rhodes.

1a,3,4a, inner lateral; and 1b,4b, outer lateral views of asymmetrical forms (CI2).

2a,b, lateral views of near symmetrical form (CI2).

Figures 5-12 Drepanodus robustus (Hadding)

5, near symmetrical bicostate drepanodiform (QC13).

6, outer lateral view of weakly bicostate drepanodiform (QC13).

7a, outer; and b, inner lateral view of weakly bicostate drepanodiform (CI13).

8a, inner; and b, outer lateral views of asymmetrical bicostate drepanodiform (QC7).

9, inner lateral view of oistodiform (CI6).

10, lateral view of multicostate drepanodiform (CI8).

11, inner lateral view of weakly bicostate drepanodiform (QC8).

12, inner lateral view of weakly bicostate drepanodiform (QC7).

PLATE 2

PLATE 3

All specimens X52. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-7 Drepanodus sp. cf. D. arcuatus Pander

1a, outer; and b, inner lateral views of acostate drepanodiform (QC2).

2, lateral view of symmetrical bicostate drepanodiform (CI14).

3a, outer; and b, inner lateral views of unicostate drepanodiform (CI17).

4a, inner; and b, outer lateral views of acostate drepanodiform (QC3).

5a, outer; and b, inner lateral view of ?oistodiform (QC2).

6, outer lateral view of acostate drepanodiform (QC2).

7, outer lateral view of oistodiform (CAm7).

Figures 8-11b Protopanderodus peselephantis (Lindstrom)

8, symmetrical form (SC4)

9a, outer; and b, inner lateral views of asymmetrical form (CI19).

10a, inner; and b, outer lateral views of asymmetrical form (CI1).

11a, outer; and b, inner lateral views of asymmetrical form (SC4).

Figures 12-16b Protopanderodus rectus (Lindstrom)

12, symmetrical costate drepanodiform (SC4)

13a, outer; and b, inner lateral views of asymmetrical costate drepanodiform (CI8).

14a, outer; and b, inner lateral views of asymmetrical costate drepanodiform (CI9).

15 outer lateral view of asymmetrical costate drepanodiform (SC4).

16a, inner; and b, outer lateral views of scandodiform (SC4).

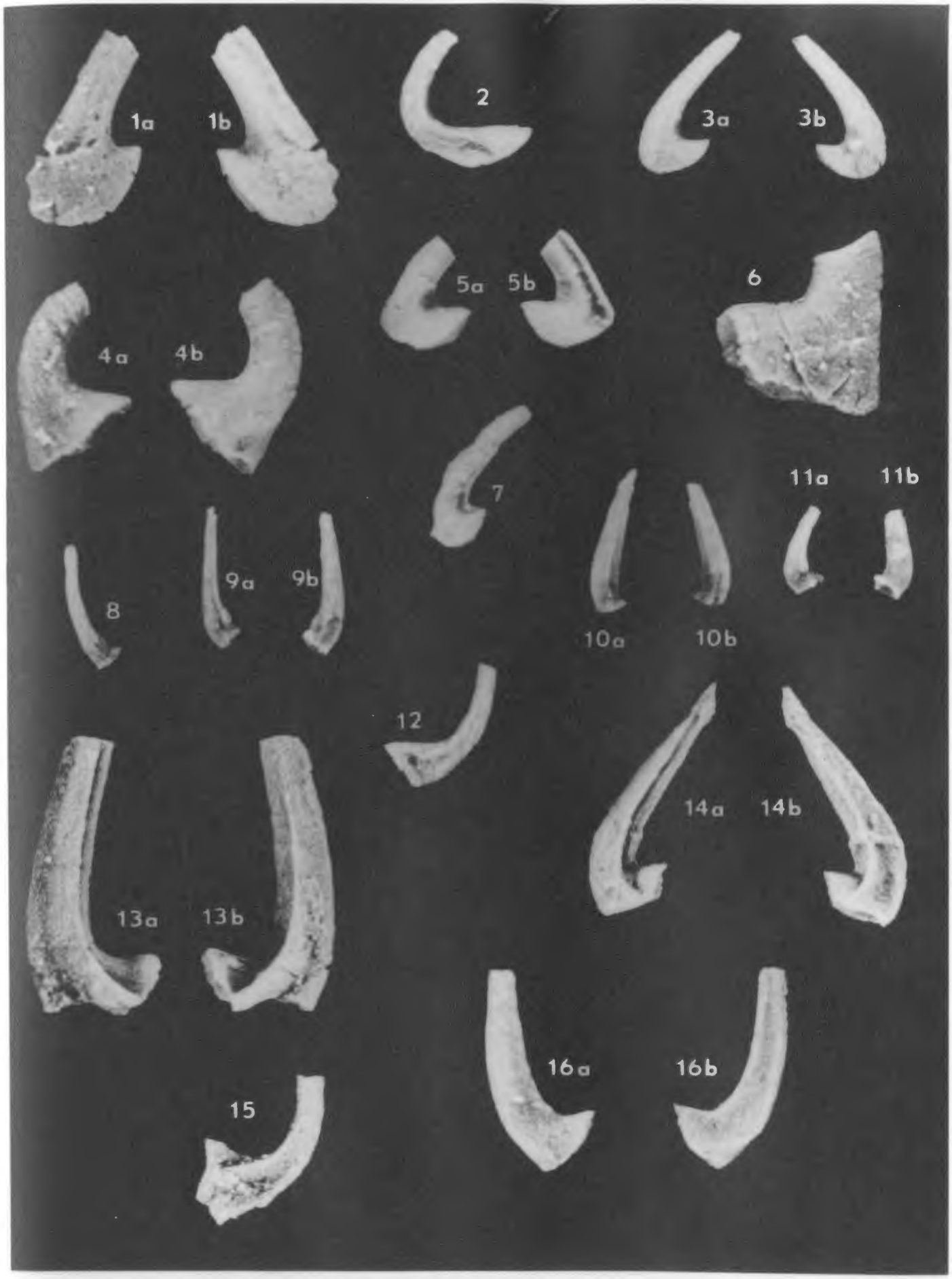
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PLATE 3

PLATE 4

All specimens X52. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-7b Protopanderodus varicostatus (Sweet and Bergstrom)

1a, outer; and b, inner lateral views of asymmetrical multicostate drepanodiform (CI4).

2, lateral view of symmetrical multicostate drepanodiform (CI8).

3, inner lateral view of scandodiform (CI9).

4a, inner; and b, outer lateral views of asymmetrical multicostate drepanodiform (CI5).

5a, outer; and b, inner lateral views of asymmetrical multicostate drepanodiform (CI14).

6a, outer; and b, inner lateral views of scandodiform (CI14).

7a, outer; and b, inner lateral views of tricostate drepanodiform (CI8).

Figures 8a,b Belodina serrata (Dzik)

8a, outer; and b, inner lateral view of belodiniform (CAR1).

Figures 9a,b,11a,b Belodina n. sp. A

9a, inner; and b, outer lateral views of eobelodiniform (CI5).

11a, inner; and b, outer lateral views of belodiniform (QC4).

Figures 10a-c,12a,b ?Panderodus n. sp. A

10a, posterior; and b,c, lateral views of symmetrical form (QC9).

12a, outer; and b, inner lateral view of asymmetrical form (QC9).

Figures 13a,b panderodiform

13a, inner lateral; and b, outer lateral views (QC9).

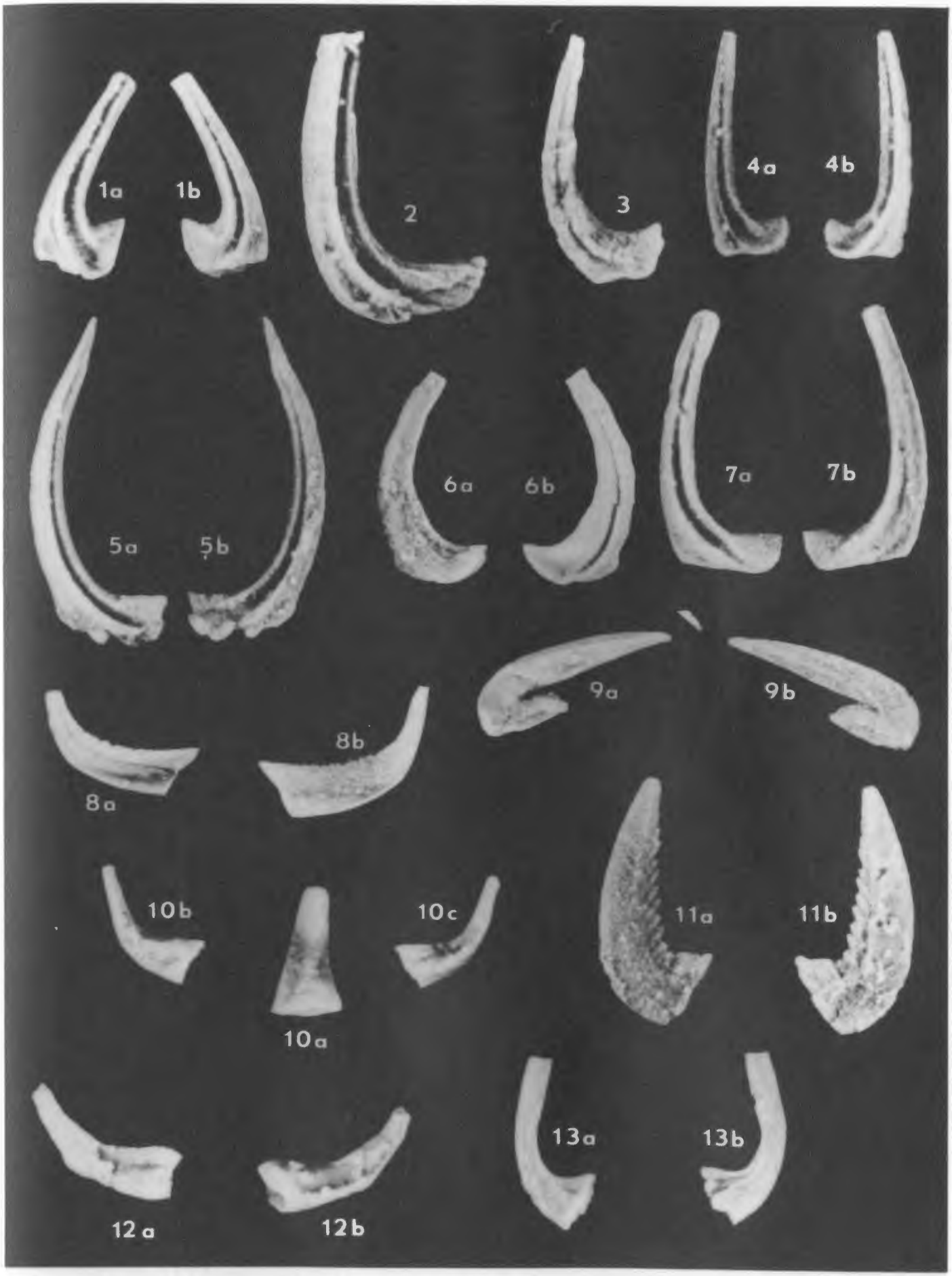
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PLATE 4

PLATE 5

All specimens X53. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-7 Panderodus gracilis (Branson and Mehl)

1a,b, lateral views of symmetrical gracilid panderodiform (QC3).

2a,3a,5a, inner lateral; and 2b,3b,5b, outer lateral views of asymmetrical gracilid panderodiforms (QC3).

4a,6b, inner lateral; and 4b,6a, outer lateral views of compressid panderodiform (QC3).

7, outer lateral view of ?gracilid panderodiform (QC3).

Figures 8a-12b Panderodus mutatus (Branson and Mehl)

8a,9a,10,11a, outer lateral; and 8b,9b,11b, inner lateral views of inner costate panderodiform (SC4).

12a, inner lateral; and 12b, outer lateral views of outward costate panderodiform (CI7).

Figures 13a-16b Belodella n. sp. A

13a, inner lateral; and 13b, outer lateral view of asymmetrical bicostate belodelliform (CI15).

14a, lateral; and 14b, posterior views of symmetrical bicostate belodelliform (CI15).

15a, inner lateral; and 15b, outer lateral views of acostate belodelliform (CI15).

16a, inner lateral; and 16b, outer lateral view of non-costate belodelliform (CI15).

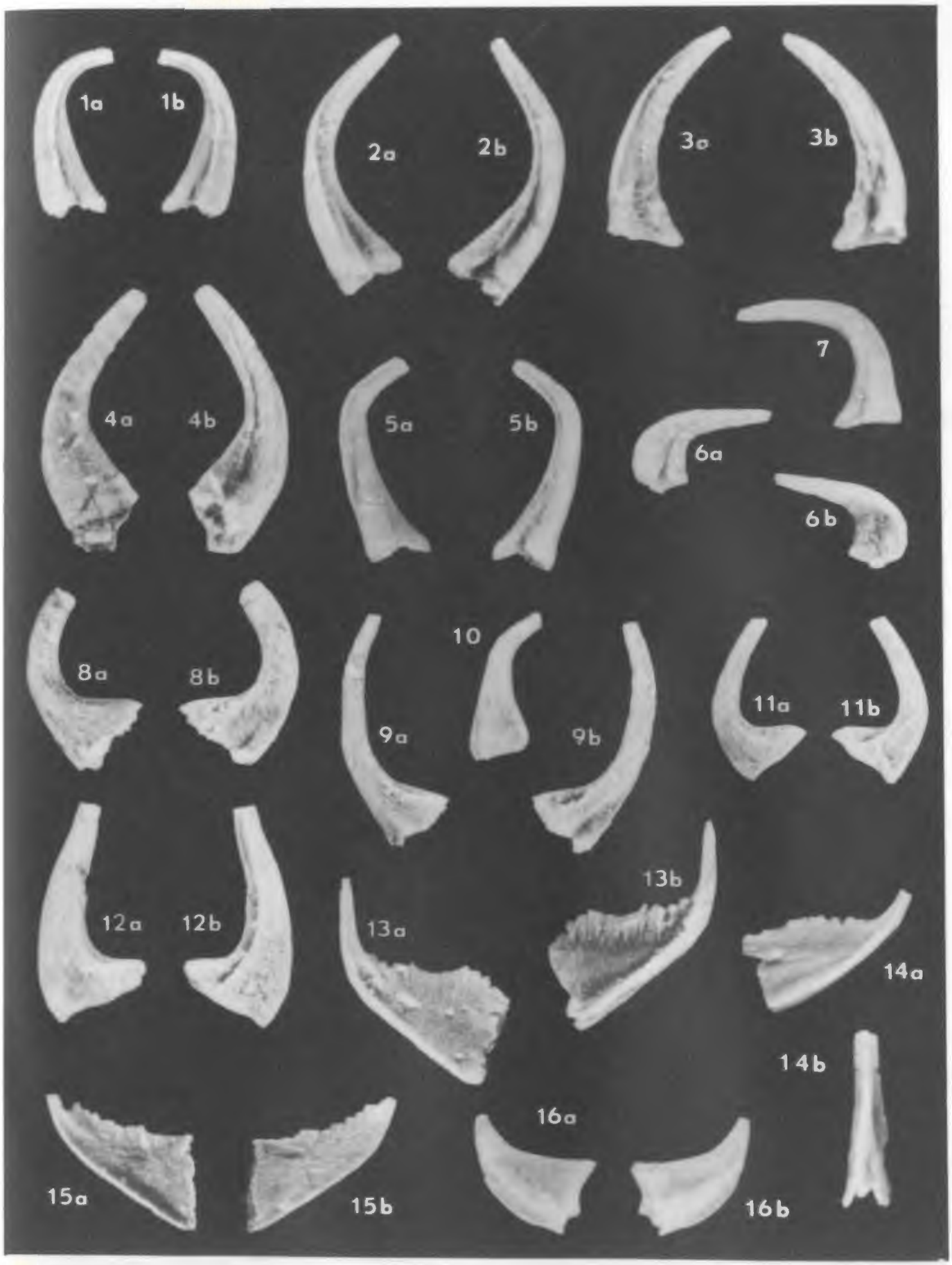
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PLATE 5

PLATE 6

All specimens X52. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-7b Scalpellodus cavus (Webers)

1a, b, lateral views of near symmetrical bicarinate drepanodiform (CI1).

2a,5a, outer lateral; and 2b,5b, inner lateral views of non-carinate drepanodiforms (QC3).

3a, outer; and 3b, inner lateral views of strongly bowed drepanodiform (CI15).

4a, inner; and 4b, outer lateral views of unicarinate drepanodiform (QC3).

6a, outer; and 6b, inner lateral view of non-carinate drepanodiform (CI8).

7a, inner lateral; and 7b, outer lateral views of unicarinate drepanodiform (CI13).

Figures 8a-10b Scalpellodus n. sp. A

8a,b, lateral views of near symmetrical drepanodiform (CAR4).

9a,10a, outer lateral; and 9b,10b, inner lateral views of asymmetrical drepanodiforms (QC2).

Figures 11a-16b Walliserodus ethingtoni (Fahraeus)

11a, posterior; and 11b, lateral views of symmetrical multicostate drepanodiform (CI16).

12a, inner lateral; and 12b, outer lateral views of asymmetrical multicostate drepanodiform (CI15).

13a, inner lateral; and 13b, outer lateral views of asymmetrical multicostate drepanodiform (CI17).

14a, outer lateral; and 14b, inner lateral views of acostate drepanodiform (CI8).

15a, outer lateral; and 15b, inner lateral views of asymmetrical multicostate drepanodiform (CI9).

16a, inner lateral; and 16b, outer lateral views of inward bowed drepanodiform (CI15).

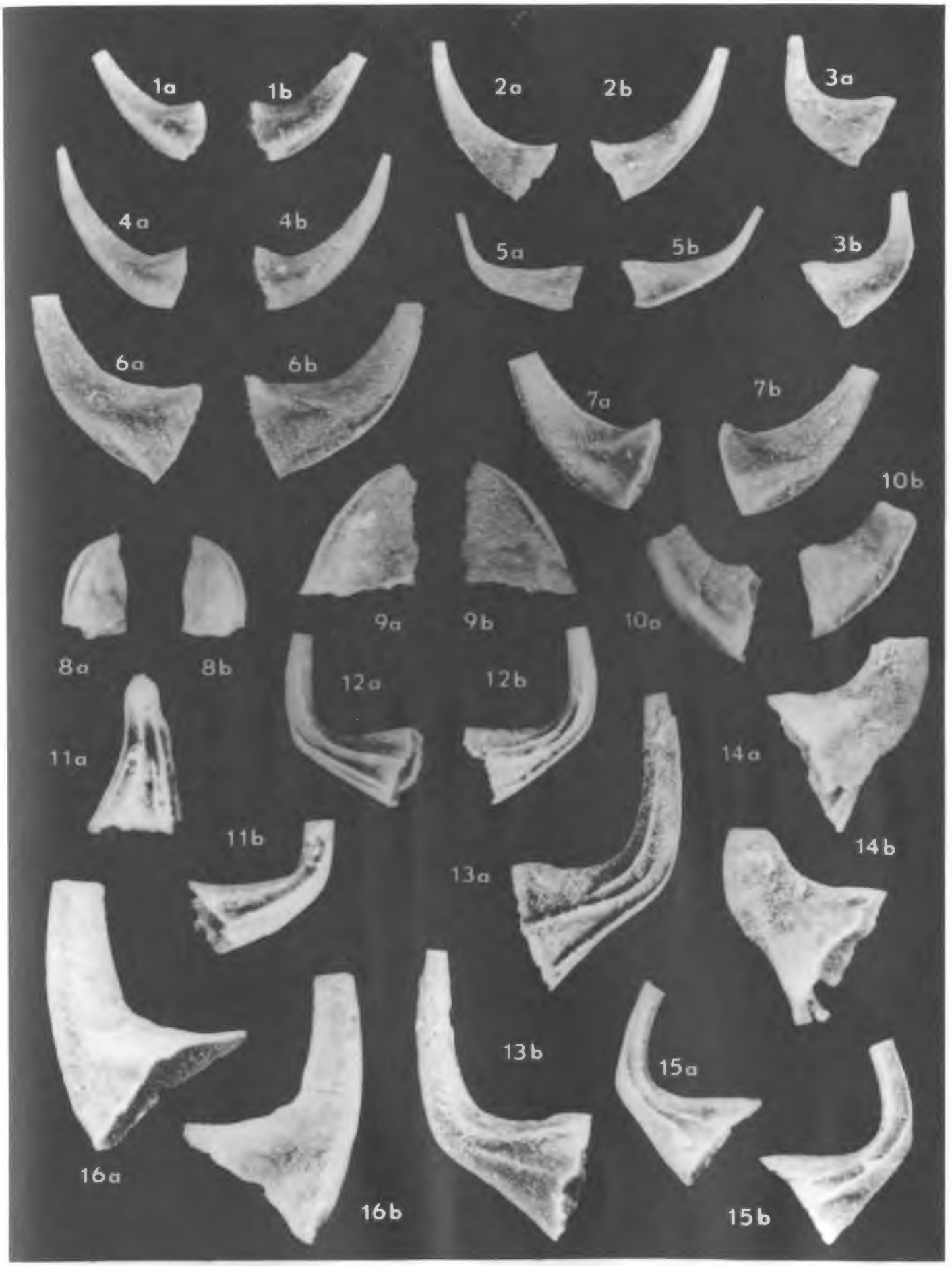
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PLATE 6

PLATE 7

Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1-5b *Walliserodus nakholmensis* (Hamar) X50

1, lateral view of symmetrical multicostate drepanodiform (CI3).

2, lateral view of symmetrical multicostate drepanodiform (CAw1).

3a, outer; and 3b, inner lateral views of tricostate drepanodiform (CI5).

4a, inner lateral; and 4b, outer lateral views of asymmetrical bicostate drepanodiform (CI3).

5a, outer lateral; and 5b, inner lateral views of inward bowed drepanodiform (CI3).

Figures 6a-10b *Walliserodus* n. sp. A X50

6a,b, lateral views of symmetrical multicostate drepanodiform (CII5).

7a, inner lateral; and 7b, outer lateral views of asymmetrical multicostate drepanodiform (CII5).

8a, outer lateral; and 8b, inner lateral views of asymmetrical bicostate drepanodiform (CII5).

9a, outer lateral; and 9b, inner lateral views of inward bowed drepanodiform (CII5).

10a, outer lateral; and 10b, inner lateral views of tricostate drepanodiform (CII5).

Figures 11a-13b, *Pseudobelodina* n. sp. a X50

11a, outer; and 11b, inner lateral views of belodelliform (CAR1).

12a,13a, outer; and 12b,13b, inner lateral views of oistodiform (CAR1).

Figures 14-19b New Genus A n. sp. A X65

14, lateral view of symmetrical belodelliform (CAR1).

15a, inner lateral; and 15b, outer lateral views of asymmetrical bicostate belodelliform (CAR1).

16a, inner lateral; and 16b,17, outer lateral views of acostate belodelliform (CAR1).

18a, outer lateral; and 18b, inner lateral views of unicostate belodelliform (CAR1).

19a, inner lateral; and 19b, outer lateral views of anteriorly denticulated belodelliform (CAR1).

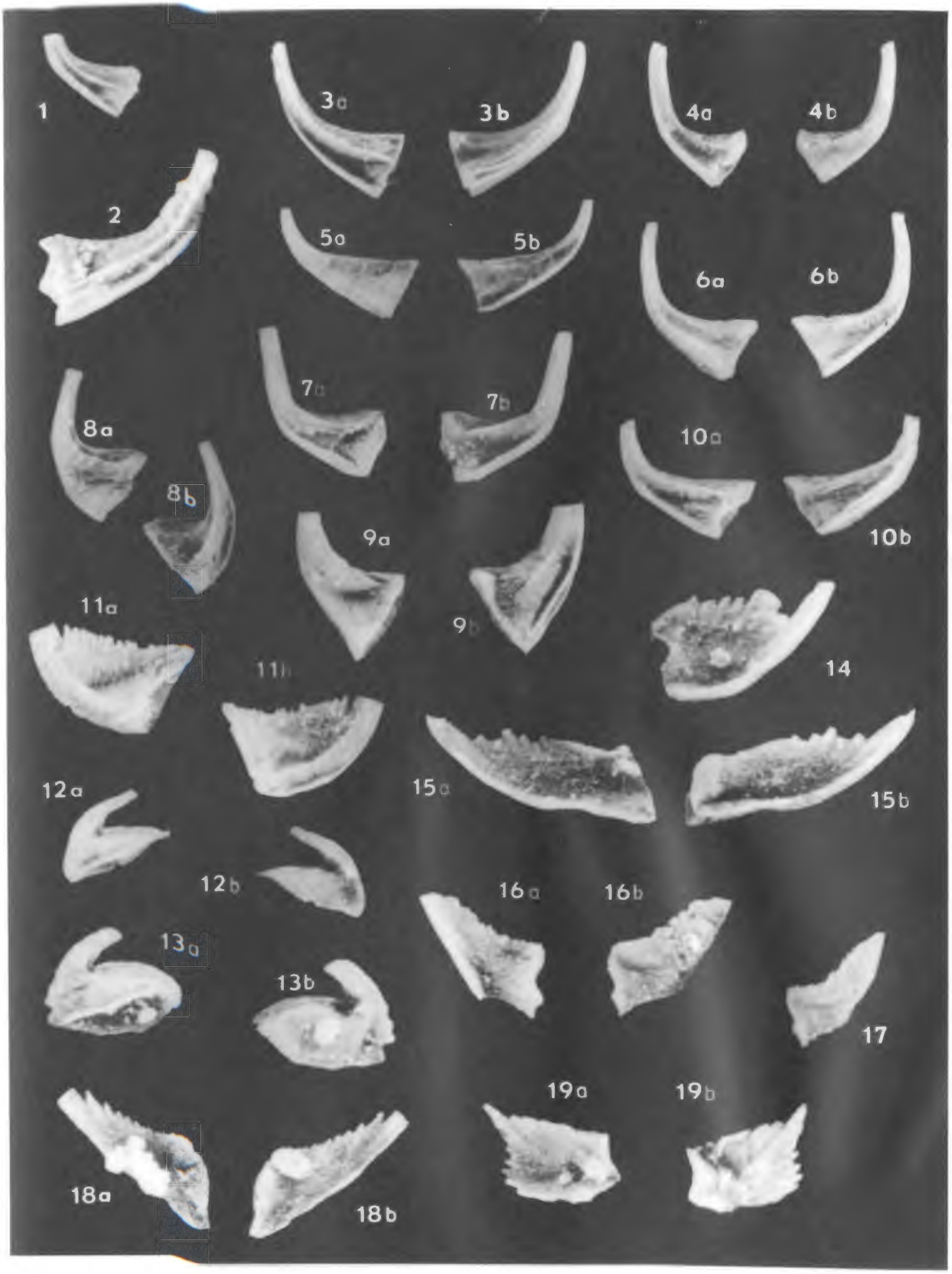
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PLATE 7

PLATE 8

All specimens X49. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-8b,12a-13 Baltoniodus prevariabilis-B. variabilis transition

1a, lateral; and 1b, posterior views of trichonodelliform (QC3).

2a, outer; and 2b,3, inner lateral views of belodiform (QC3).

4a,5b, outer; and 4b,5a, inner lateral views of tetraprioniodiform (4a,b-QC3; 5a,b-QC8).

6a,7, antero-lateral; and 6b, inner lateral views of prioniodiform (6a,b-QC7; 7-QC3).

8a, outer; and 8b, inner lateral views of amorphognathiform (QC3).

12a,13, inner; and 12b, outer lateral views of falodiforms (QC3).

Figures 1a-5b,9-13 Baltoniodus variabilis (Bergstrom)

9, oral view of prioniodiform (retouched) (QC8).

10a,11 outer; and 10b, inner lateral view of amorphognathiform (QC3).

PLATE 8

PLATE 9

All specimens X50. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-7b,10a,b *Pygodus serrus* (Hadding)

1a,2, oral; and 1b, aboral views of pygodiform (QC3).

3,4, outer lateral views of haddingodiforms (QC3).

5a, posterior; and 5b, lateral views of trichonodelliform (CI14).

6a, posterior; 6b, inner lateral; and 6c outer lateral views of belodiform (CI17).

7a,10a inner lateral and 7b,10b, outer lateral views of tetraprioniodiform (7a,b-SC4; 10a,b-CAm12).

Figures 5a-14b *Pygodus anserinus* Lamont and Lindstrom

8,12,13b, oral; and 13a, aboral views of pygodiform (8-CI17; 12,13-CI18).

9,11b,14a, outer lateral; and 11a,14b, inner lateral views of haddingodiforms (9-CI17; 11a,b-CI17; 14a,b-CI18).

Figure 15 *Pygodus* n. sp. A

15, oral view of pygodiform (CI17).

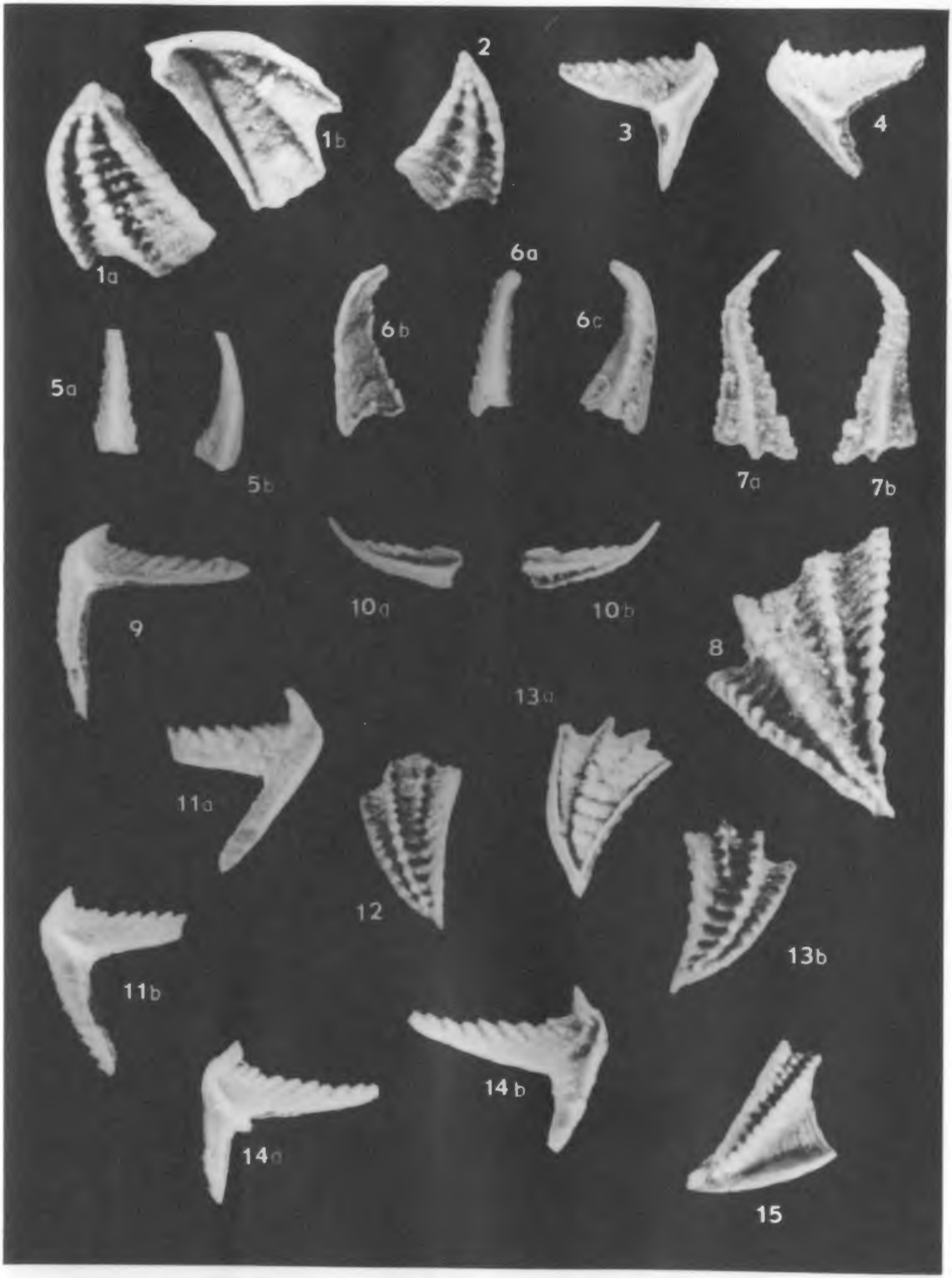
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PLATE 9

PLATE 10

Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1a-4,7-8b *Eoplacognathus robustus* Bergstrom X48

1a, aboral; and 1b, oral view of sinistral ambalodiform (CI13).

2-4, oral views of dextral ambalodiform (2,3-CAm12; 4-Hill 2).

7, oral view of sinistral polyplacognathiform (CI8).

8a, oral; and 8b, aboral view of dextral polyplacognathiform (CI8).

Figures 5,6,9,10 *Eoplacognathus lindstroemi* (Hamar). X48

5, oral view of sinistral ambalodiform (CI17).

6, oral view of dextral ambalodiform (CI15).

9,10, oral views of sinistral polyplacognathiforms (CI17).

Figures 11,12 ?*Oneotodus mitratus* (Moskalenko) X52

11,12, oral views (CAm12).

Figures 13-15 *Polyplacognathus sweeti* Bergstrom X52

13,14, oral views of polyplacognathiform (QC8).

15, oral view of ambalodiform (QC8).

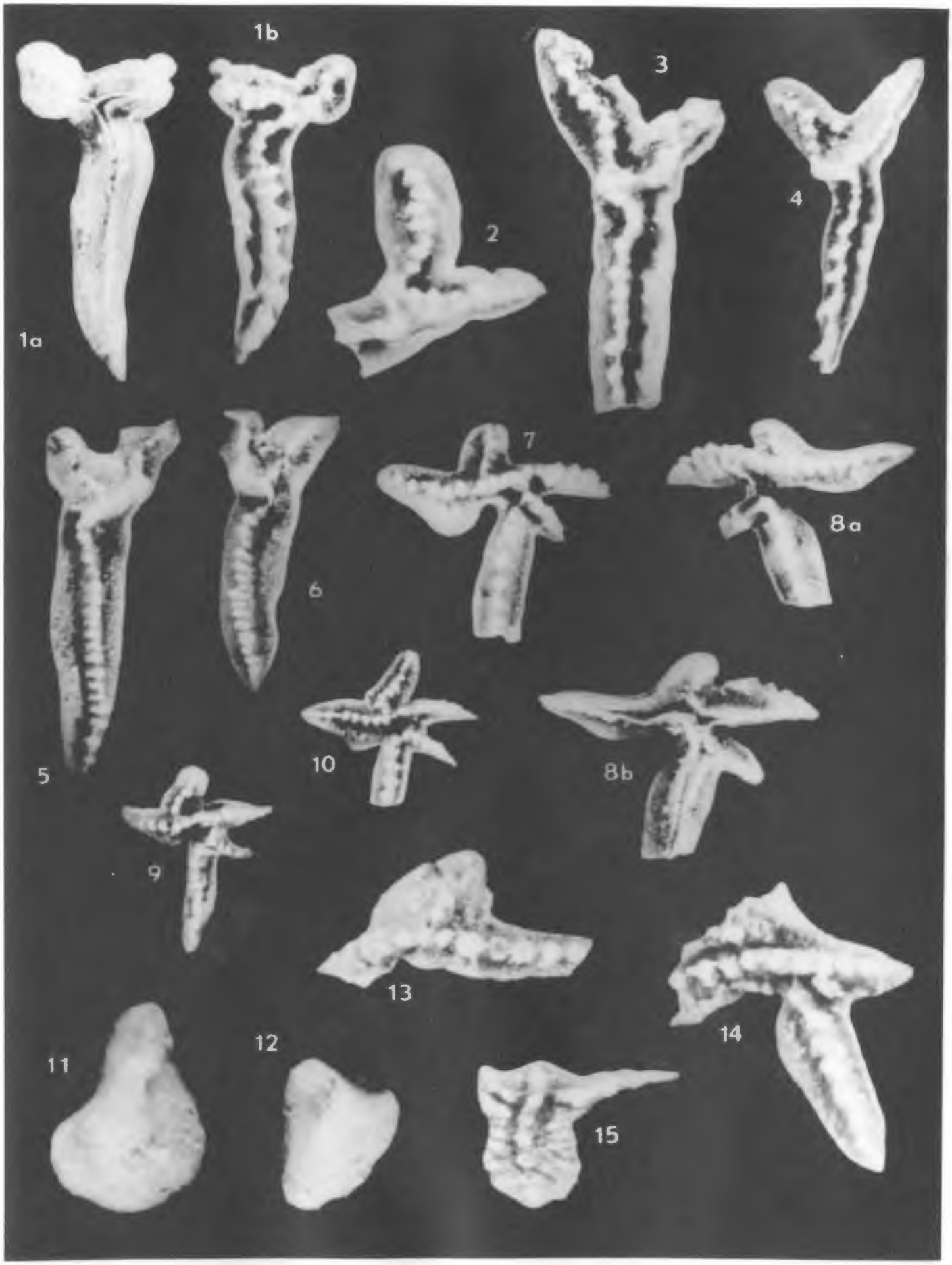


PLATE 10

PLATE 11

All specimens X55. Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1-6 ?*Acodus* n. sp. A

1, posterior view of prioniodiform (isolate sample D).

2, lateral view of ?trichonodelliform (CAm1).

3, lateral view of tetraprioniodiform (QC2).

4,5, lateral views of cordylodiforms (QC2).

6, lateral view of oistodiform (QC2).

Figures 7-8b,10a-17 *Periodon aculeatus* Hadding morphotype γ

7, lateral view of trichonodelliform (CI14).

8a, inner; and 8b, outer lateral views of eoligonodiniform (CI14).

10a,13a, outer; and 10b,13b, inner lateral views of periodontiforms (CAm2).

11a, outer; and 11b, inner lateral views of ligonodiniform (CI15).

12a, inner; and 12b, outer lateral views of prioniodiniform (CI17).

14, inner; and 15-17, outer lateral views of falodiforms (14-CI17; 15-17-CI15).

Figures 7-9b,11a-12b,14-17 *Periodon aculeatus* Hadding morphotype β.

9a, inner; and 9b, outer lateral views of loxognathiform (QC3).

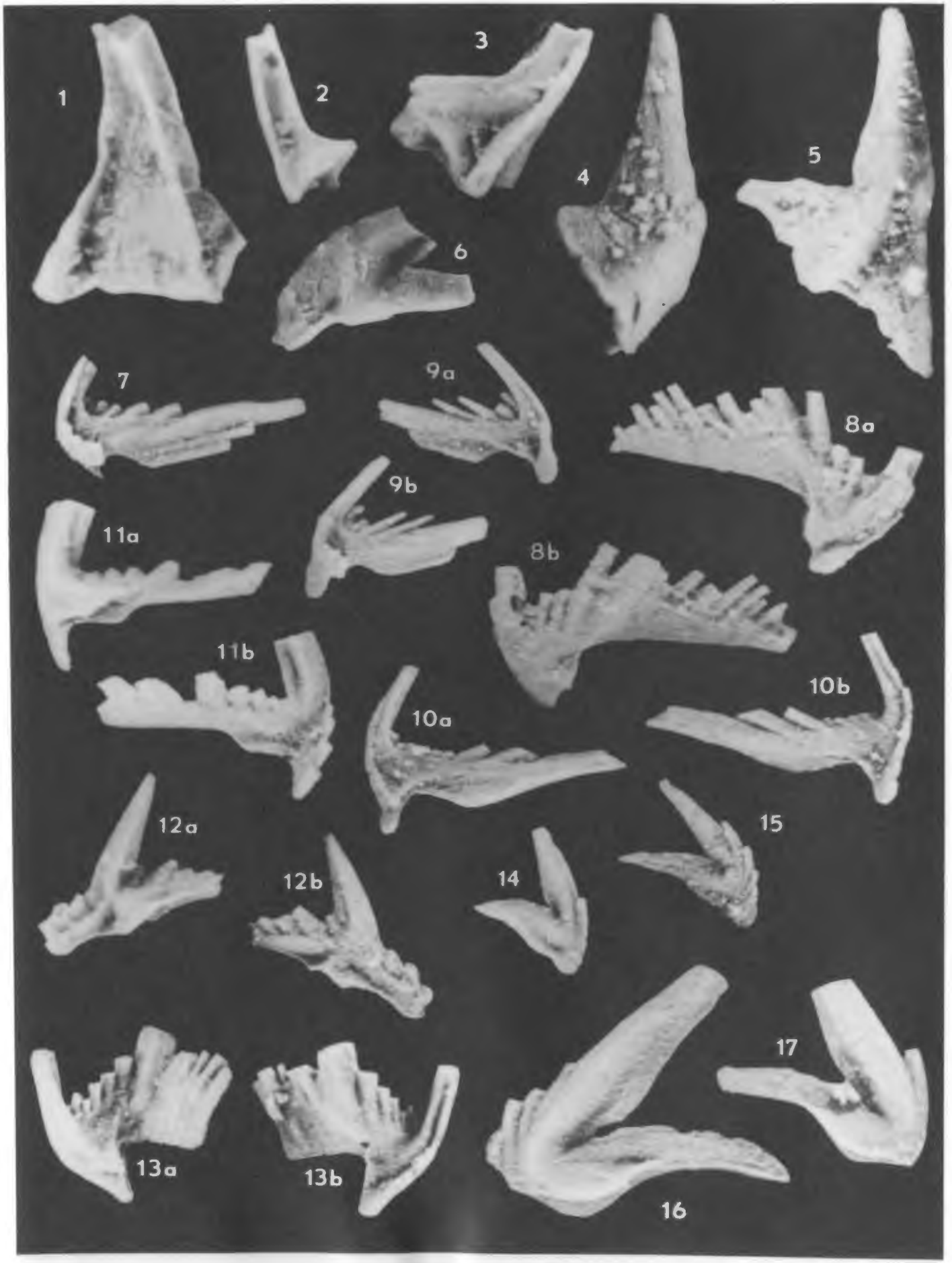


PLATE 11

PLATE 12

All specimens X55. Samples numbers from which the specimens were obtained are given in parentheses.

Figures 1a-3b *Spinodus spinatus* (Hadding)

1a,b, lateral views of trichonodelliform (CI11).

2a,b, lateral views of cordylodiform (QC13).

3a,b, lateral views of ligonodiniform (QC7).

Figures 4a,b *Westergaardodina* sp. cf. *W. bicuspida* Muller

4a, oral; and 4b, aboral view (Hill 8).

Figures 5a,b strachanognathiform

5a, outer lateral; and 5b, inner lateral view (CAm1).

Figures 6a-8 New Genus n. sp. 1 Bergstrom, Riva and Kay

6a,7a, inner lateral; and 6b,7b,8, outer lateral views (6a,b,7a,b,-CAm1; 8-CAR1).

Figure 9 distacodiform; inner lateral view (CI5).

Figures 10,11 oistodiform 1; outer lateral views (CI14).

Figures 12a,b oistodiform 2

12a, inner lateral; and 12b, outer lateral view (CI15).

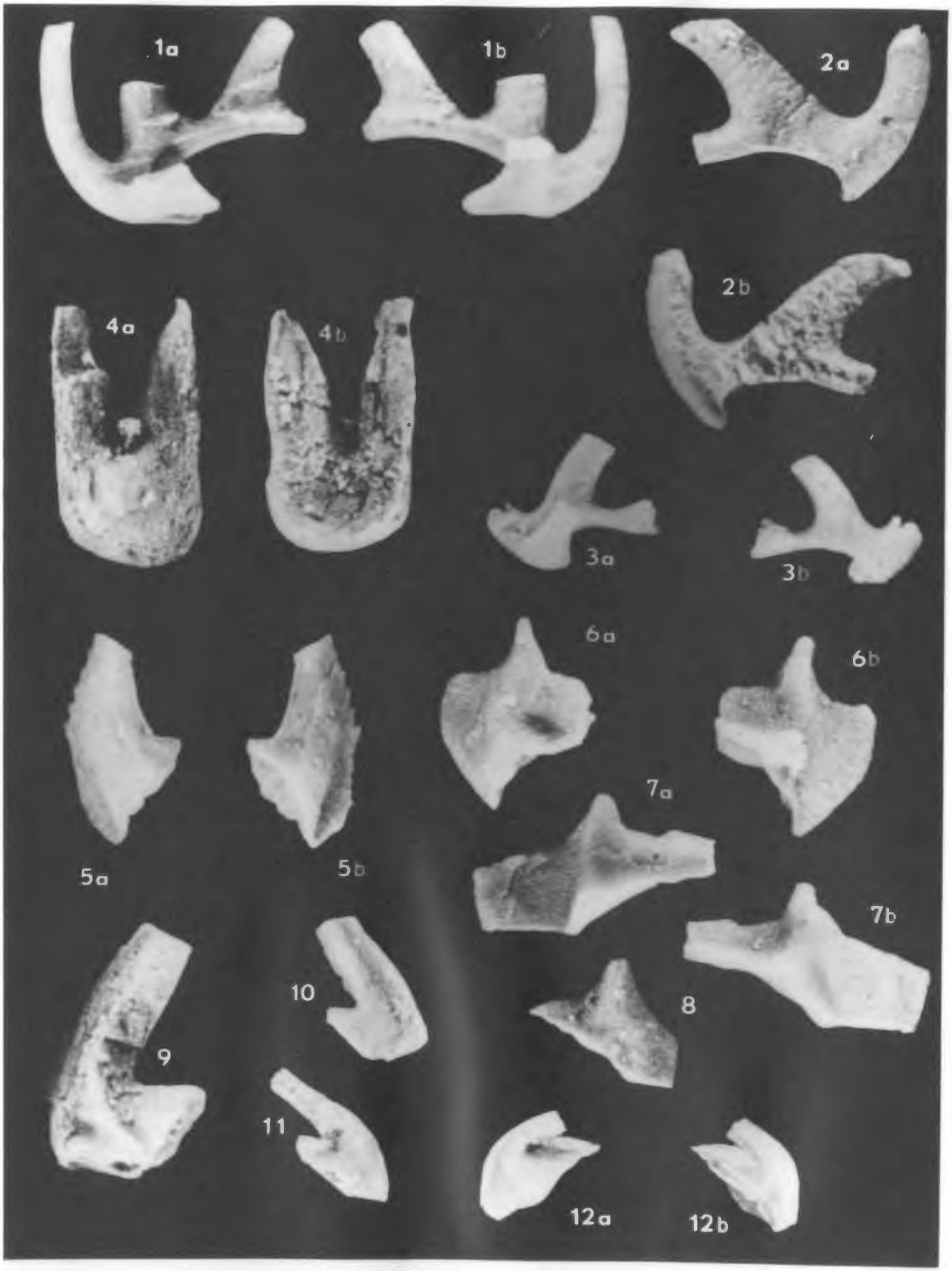


PLATE 12

PLATE 13

Sample numbers from which the specimens were obtained are given in parentheses.

Figure 1 Strachanognathus parva Rhodes; inner lateral view X124 (CI2).

Figures 2,3 Distacodus venustus (Stauffer)

2, outer lateral view of drepanodiform X102 (QC19).

3, outer lateral view of oistodiform X106 (CI19).

Figures 4,5 Paltodus semisymmetricus (Hamar)

4, lateral view of symmetrical drepanodiform X91 (CAm7).

5, outer lateral view of oistodiform X140 (QC9).

Figures 6-8 Drepanoistodus n. sp. A

6, inner lateral view of asymmetrical drepanodiform X89 (QC3).

7, outer lateral view of oistodiform X78 (CI17).

8, lateral view of symmetrical drepanodiform X84 (QC3).

Figures 9,10 Drepanodus robustus (Hadding)

9, lateral view of weakly bicostate drepanodiform X64 (CI13).

10, lateral view of symmetrical multicostate drepanodiform X71 (CI8).

Figures 11-13 Drepanodus sp. cf. D. arcuatus Pander

11, lateral view of symmetrical bicostate drepanodiform X81 (CI14).

12, inner lateral view of acostate drepanodiform X84 (QC3).

13, outer lateral view of unicostate drepanodiform X76 (CI17).

Figures 14-16 Protopanderodus rectus (Lindstrom)

14, lateral view of symmetrical costate drepanodiform X126 (SC4).

15, outer lateral view of asymmetrical costate drepanodiform X80 (CI9).

16, inner lateral view of scandodiform X80 (SC4).

Figure 17 Protopanderodus peselephantis (Lindstrom)

17 lateral view of asymmetrical costate form X100 (CI1).

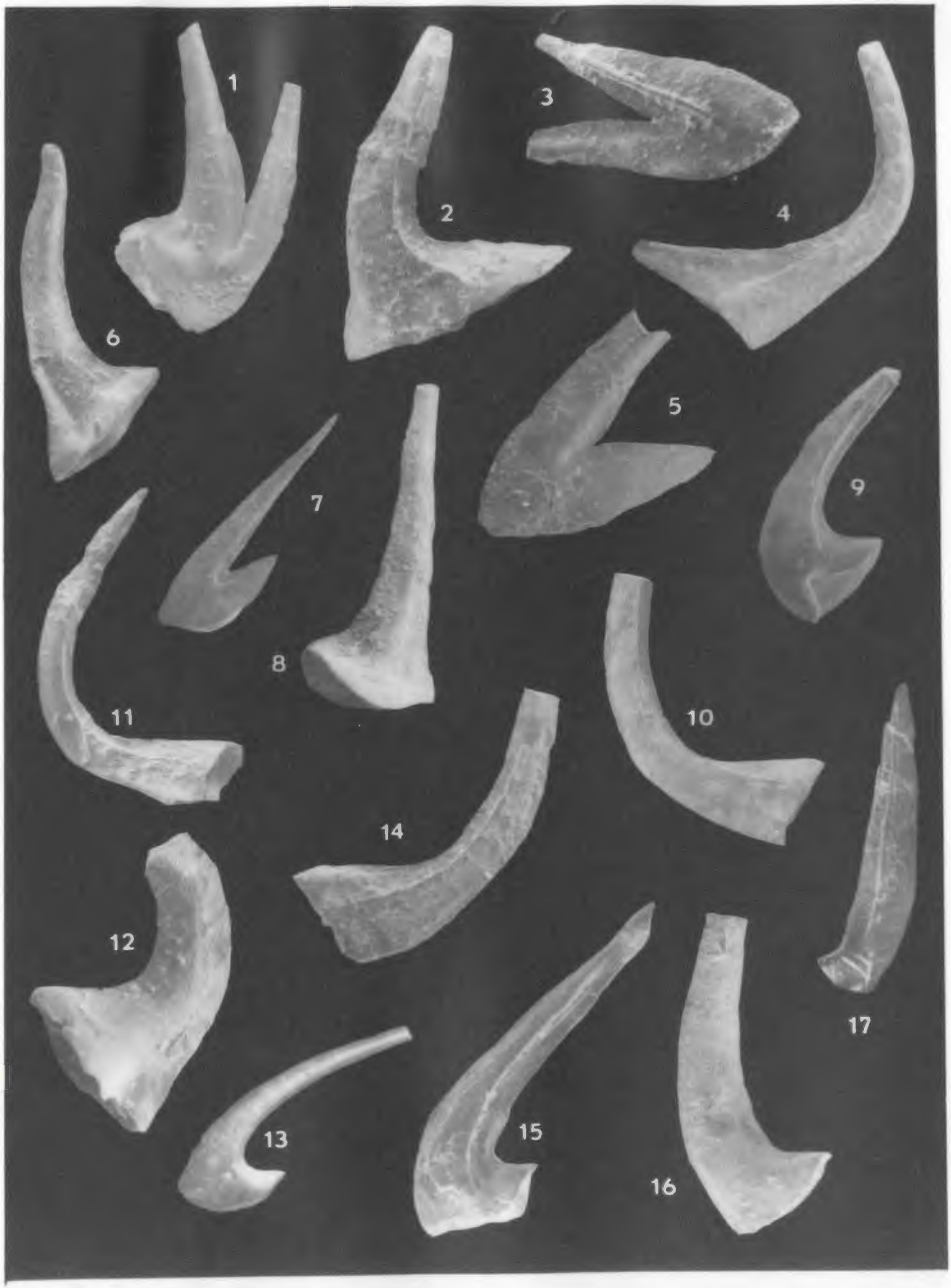


PLATE 13

PLATE 14

Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1,1a *Protopanderodus varicostatus* (Sweet and Bergstrom)

1, outer lateral view of asymmetrical multicostate drepanodiform X78 (CI8).

1a, same X750.

Figures 2,2a *Scalpellodus cavus* (Webers)

2, inner lateral view of non-carinate drepanodiform X81 (QC3).

2a, same X250.

Figure 3, *Panderodus gracilis* (Branson and Mehl)

3, lateral view of symmetrical gracilid panderodiform X160 (QC3).

Figure 4 *Belodina serrata* (Dzik); inner lateral view of belodiniform X109 (CAR1).

Figures 5,6 *Panderodus mutatus* (Branson and Mehl)

5, outer lateral view of outer costate panderodiform X84 (CI16).

6, inner lateral view of inner costate panderodiform X78 (CI7).

Figure 7 *Belodina* n. sp. A

7, outer lateral view of belodiniform X98 (CI3).

Figures 8,9 *Belodella* n. sp. A

8, inner lateral view of acostate belodelliform X120 (CI15).

9, lateral view of symmetrical bicostate belodelliform X96 (CI15).

Figure 10 Scalpellodus n. sp. A

10, lateral view of near symmetrical drepanodiform X150 (CAR1).

Figure 11 Walliserodus n. sp. A

11, inner lateral view of inward bowed drepanodiform X100 (CI15).

Figure 12 Walliserodus nakholmensis (Hamar)

12, inner lateral view of asymmetrical bicostate drepanodiform X89 (CI3).

Figure 13 Walliserodus ethingtoni (Fahraeus)

13, postero-lateral view of symmetrical multicostate drepanodiform X90 (CI16).

Figures 14,15 Pseudobelodina n. sp. A

14, inner lateral view of oistodiform X98 (QC1).

15, outer lateral view of belodelliform X101 (CAR1).

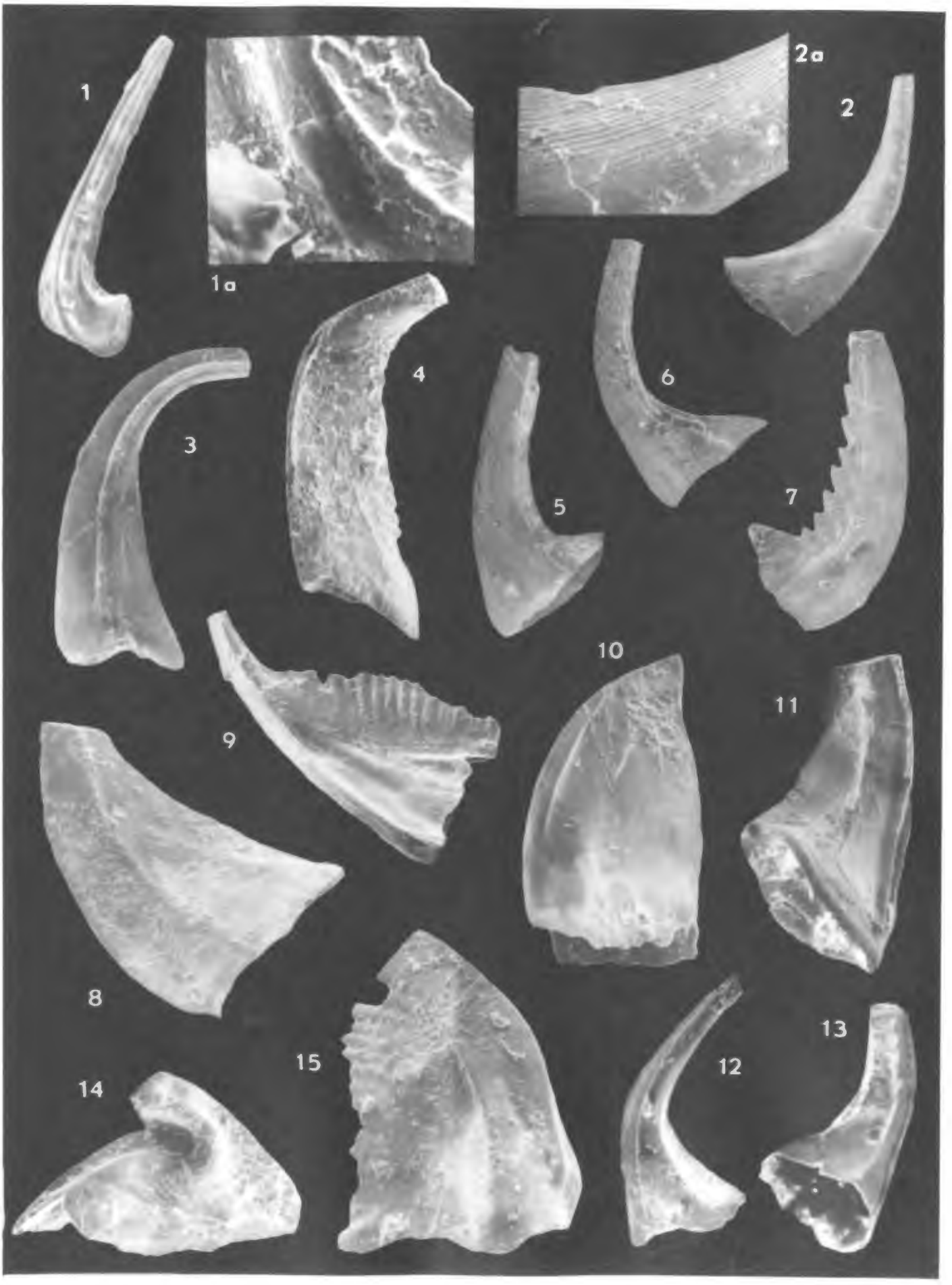


PLATE 14

PLATE 15

Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1,2 New Genus A n. sp. A

1, inner lateral view of acostate belodelliform X119 (CAR1).

2, inner lateral view of anteriorly denticulated belodelliform X141 (CAR1).

Figures 3,4 Baltoniodus prevariabilis-B. variabilis transition

3, outer lateral view of prioniodiform X58 (CAm2).

4, antero-lateral view of prioniodiform with incipial ledge development X55 (QC7).

Figure 5 Baltoniodus variabilis (Bergstrom)

5, oral view of prioniodiform with well developed ledge X58 (QC8).

Figure 6 Eoplacognathus robustus Bergstrom; close up of lateral process of a dextral ambalodiform, illustrating characteristic surface microstructure. X275.

Figure 7 Pygodus serrus (Hadding); close up of pygodiform illustrating characteristic surface microstructure X170.

Figures 8-11,14,15 Pygodus serrus (Hadding)

8, posterior view of trichonodelliform X106 (CI14).

9, posterior view of belodiform X94 (CI14).

10, inner lateral view of tetraprioniodiform X98 (CAm12).

11, oral view of pygodiform X69 (QC3).

14, outer lateral view of haddingodiform X88 (QC3).

15 aboral view of pygodiform X78 (CI14).

Figures 8-10,12,13 Pygodus anserinus Lamont and Lindstrom

12, oral view of pygodiform X49 (CI17).

13, outer lateral view of haddingodiform X70 (CI18).

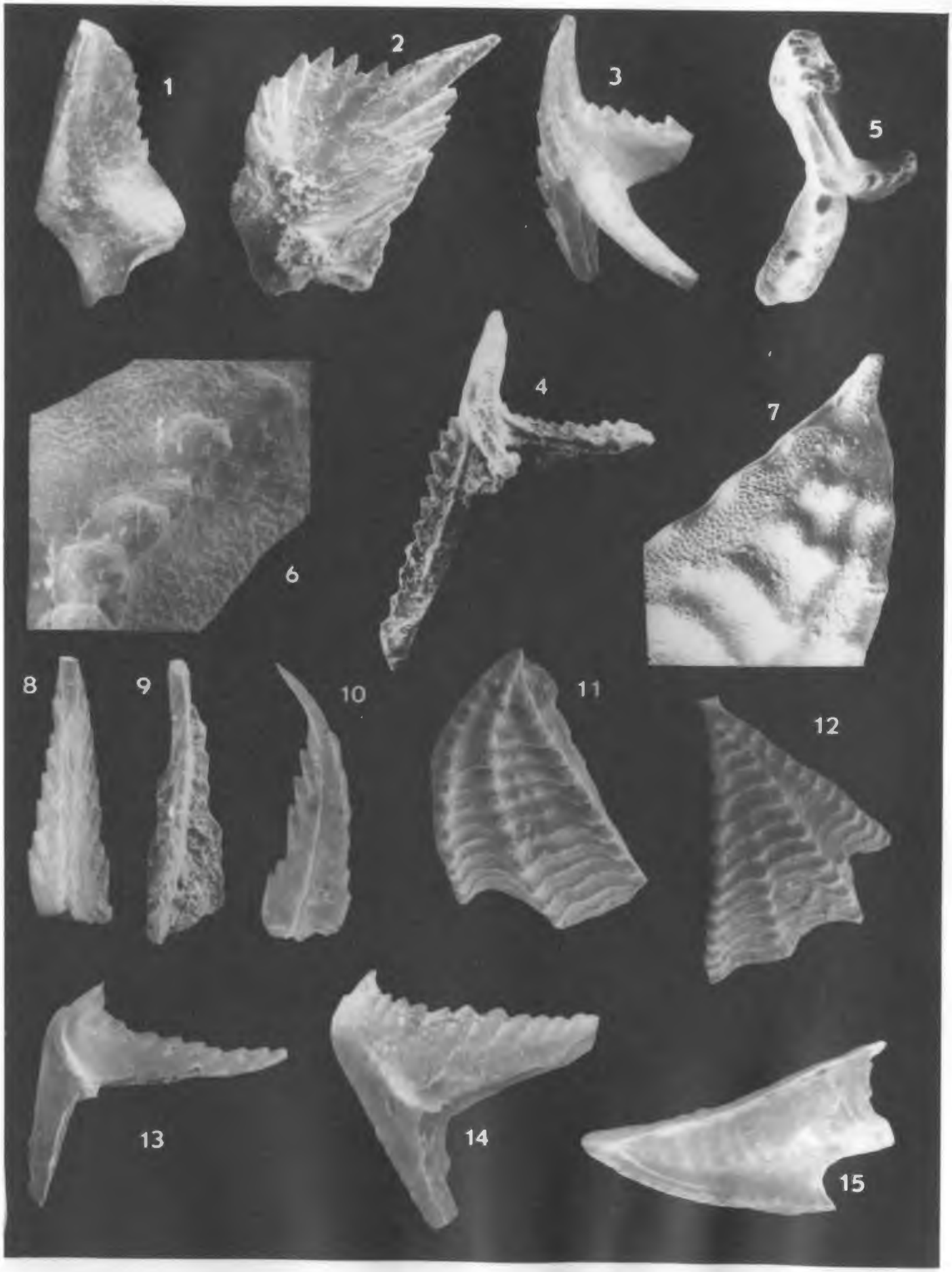


PLATE 15

PLATE 16

Sample numbers from which the specimens were obtained are given in parentheses.

Figures 1-3 Eoplacognathus lindstroemi (Hamar)

1, oral view of polyplacognathiform X77 (CI17).

2, oral view of dextral ambalodiform X55 (CI15).

3, oral view of sinistral ambalodiform X42 (CI17).

Figures 4-6 Eoplacognathus robustus Bergstrom

4, oral view of sinistral ambalodiform X52 (CI13).

5, oral view of dextral ambalodiform X50 (Hill 2).

6, oral view of polyplacognathiform X60 (CI8).

Figure 7 Polyplacognathus sweeti Bergstrom

7, oral view of ambalodiform X75 (QC8).

Figures 8-10 Periodon aculeatus Hadding morphotype γ

8, lateral view or trichonodelliform X67 (CI14).

9, inner lateral view of eoligonodiniform X59 (CI14).

10, outer lateral view of periodontiform X61 (CAm2).

Figures 8,9,11 Periodon aculeatus Hadding morphotype β

11, outer lateral view of loxognathiform X72 (CI17).

Figures 12-15 Illex illecebrosis (Lesueur)

12, posterior view of rachidian (trichonodelliform) tooth X54.

13, posterior view of bicuspid lateral tooth X52.

14, posterior view of inner marginal tooth X63

15, postero-lateral view of outer marginal tooth X57.

16, oral view of part of a row of bicuspid lateral teeth X40.

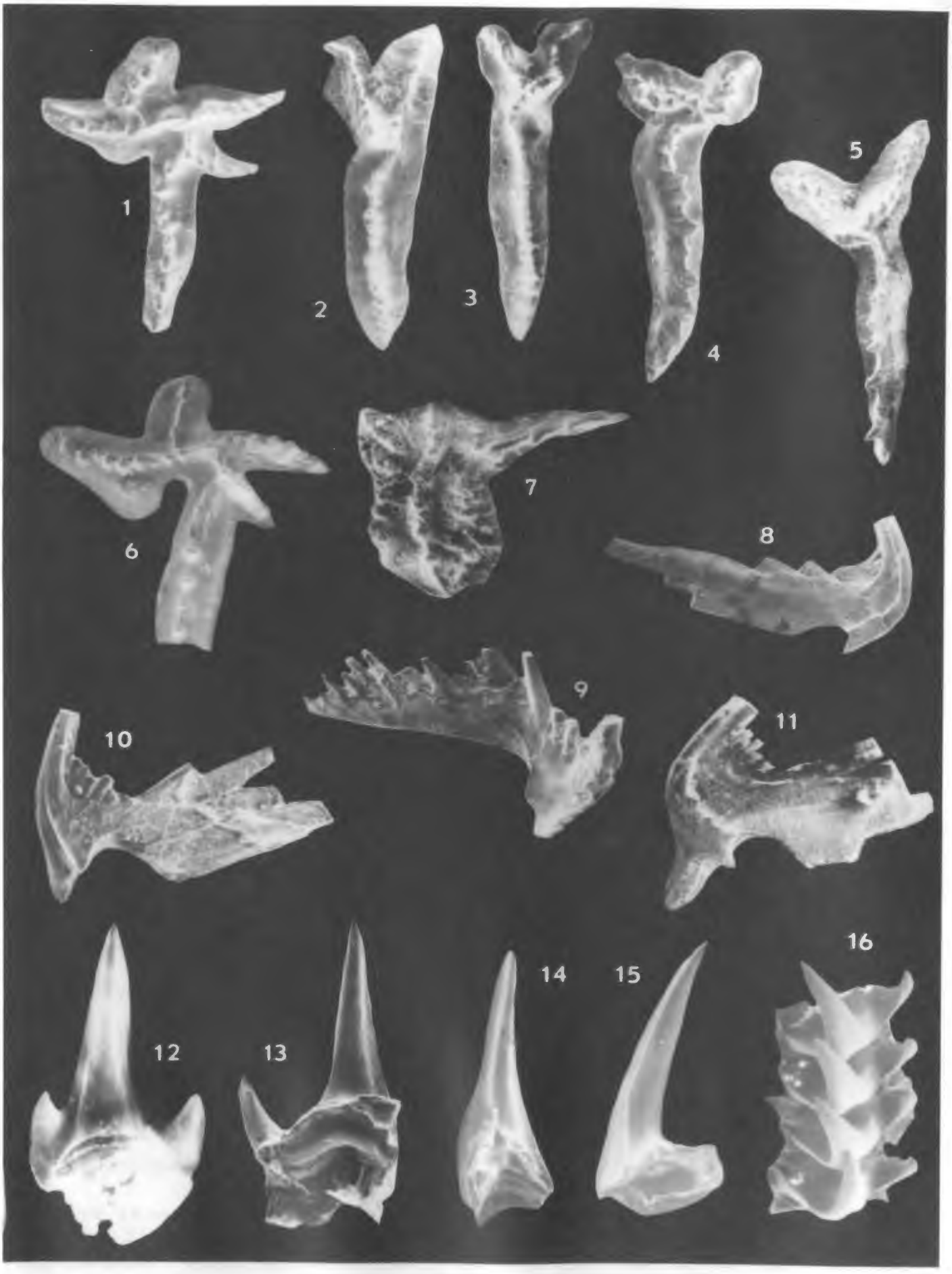


PLATE 16

APPENDIX A

In addition to the seven measured sections of the Cobbs Arm Formation, 13 isolated samples were collected on New World Island, in the Bay of Exploits, Seal Bay and on Long Island. This appendix is designed to give information about the locations and conodont yields of each of these samples. They are ordered 1 to 13, as in Figure 2.

(1) A small limestone lense or boulder within the lowermost unit of the Roberts Arm Group (Sops Head Complex), on Duck Island, Seal Bay. The Sops Head Complex is a sedimentary-volcanic slump melange. The sample contains abundant and good preserved black conodonts that are identical to those found in the Cobbs Arm Formation. The boulder must have originated from strata of equivalent age to the Cobbs Arm Formation (see Tables 1a,b; isolate sample A).

(2) Several samples of a coarse limestone breccia unit were collected from the village of Lusches Bight, Long Island. The conodont yield was relatively low and showed close affinity to conodonts from the middle Table Head Formation (S. Stouge, pers. comm.), and the lower Llanvirnian Mystic Conglomerate of Quebec (Barnes and Poplawski, 1973).

(3) A large limestone lense or block within the lowermost unit of the Cottrels Cove Group (Boones Point Complex) on south west Hummocky Island, Bay of Exploits. This unit is considered a correlative of the Sops Head Complex from which sample 1 was collected (Dean and Strong, 1976f). The conodont yield was relatively low and included a few specimens of Periodon aculeatus, Protopanderodus varicostatus and Belodella n. sp. A,

and several elements of a species of Eoplacognathus transitional between E. pseudoplanus (Viira) and E. suecus Bergstrom. This suggests an upper-lower Llanvirnian age for the sample.

(4) A limestone lense in the volcanics of Horne's (1970) Unit D, near the tip of the penninsula illustrated in Figure 2. The sample was barren.

(5) A large limestone lense in the volcanics of Horne's (1970) Unit Z, near Cottles Island. The sample yielded a few fragments of Panderodus gracilis only.

(6) A limestone lense within the volcanics of Horne's (1970) Unit D, on the Cottles Island road about 1.6 km north west of Village Cove. The sample was barren.

(7) This sample was collected from a limestone outcropping in the hill-side above the head of the cove illustrated in Figure 2, on the south west coast of New World Island. The sample was barren.

(8) A small limestone lense in the volcanics of Horne's (1970) Unit Z, about 1.7 km south west from the head of Village Cove. The sample was barren.

(9) A thick limestone lense in the volcanics of Horne's (1970) Unit Z, about 1.4 km southwest from the head of Village Cove. The sample contained only a few indeterminable fragments.

(10) A sample of limy tuff in the volcanics of Horne's (1970) Unit B, near the mouth of Virgin Arm. The sample was barren.

(11) A limestone lense in the Summerford Group volcanics on the road to Tilt Cove. The sample produced a low conodont yield (see Tables 1a,b (isolate sample B); and Figure 16 of text).

(12) A limy lense within green tuffs along the shore beneath the Anglican church south west of Herring Neck. The sample produced a relatively low conodont yield (see Tables 1a,b (isolate sample C); and Figure A1).

(13) A limestone lense in the Summerford Group volcanics along the roadside near Newville. The sample produced a relatively low conodont yield (see Tables 1a,b (isolate sample D); and Figure A2).

Figure A1. A limestone lense (outlined) in the volcanics of the Sumford Group near Newville.

Figure A2. A limy lense in tuffs near the shore beneath the Anglican church south west of Herring Neck.

APPENDIX B

Photomicrographs of some of the characteristic components and textures of the Cobbs Arm Formation sediments.

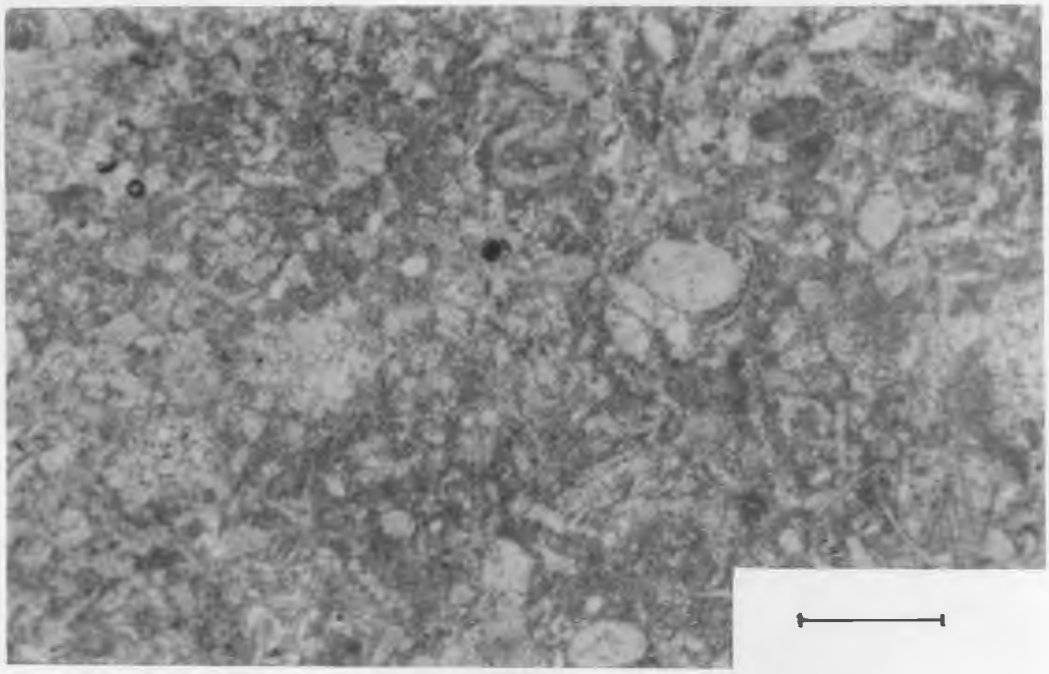


Figure B1. Characteristic texture of a sediment deposited in an environment with a low wave kinetic energy release. (QC3). Bar equals 1.0 mm.

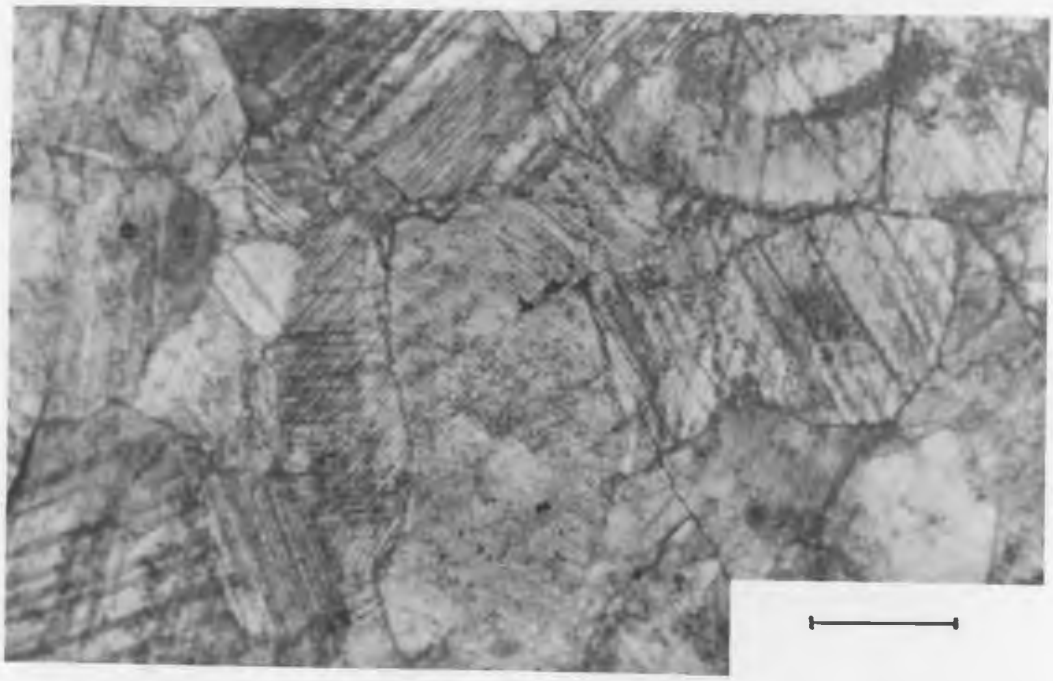


Figure B2. Characteristic texture of a sediment deposited in an environment with a high wave kinetic energy release. (CI4). Bar equals 1.0 mm.

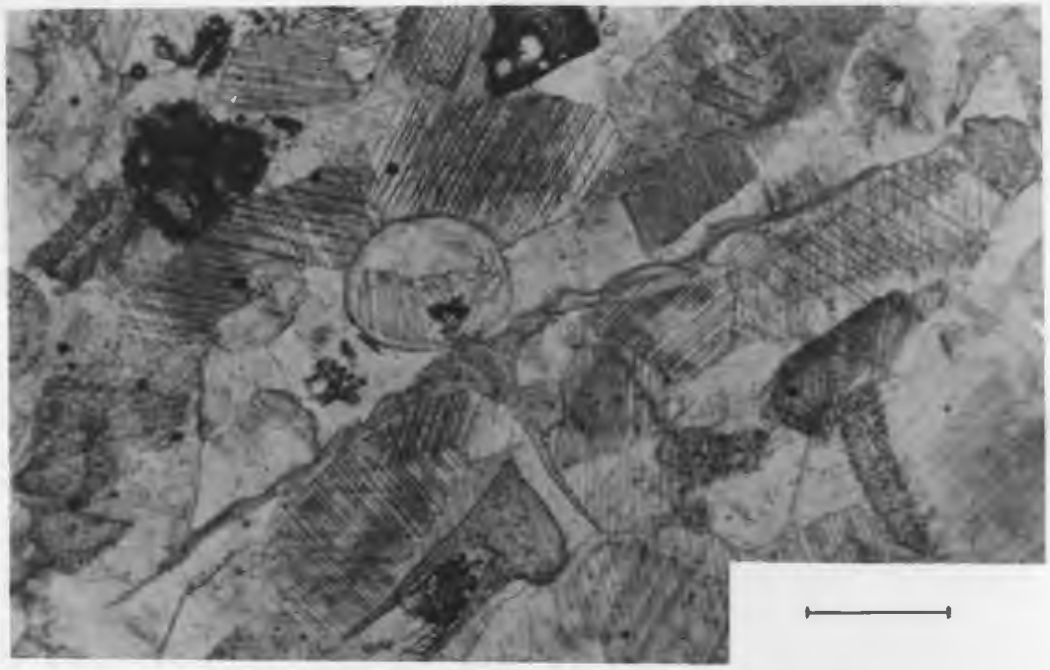


Figure B3. Sediment deposited in an environment with a high wave kinetic energy release. (Hill 3). Bar equals 1.0 mm.

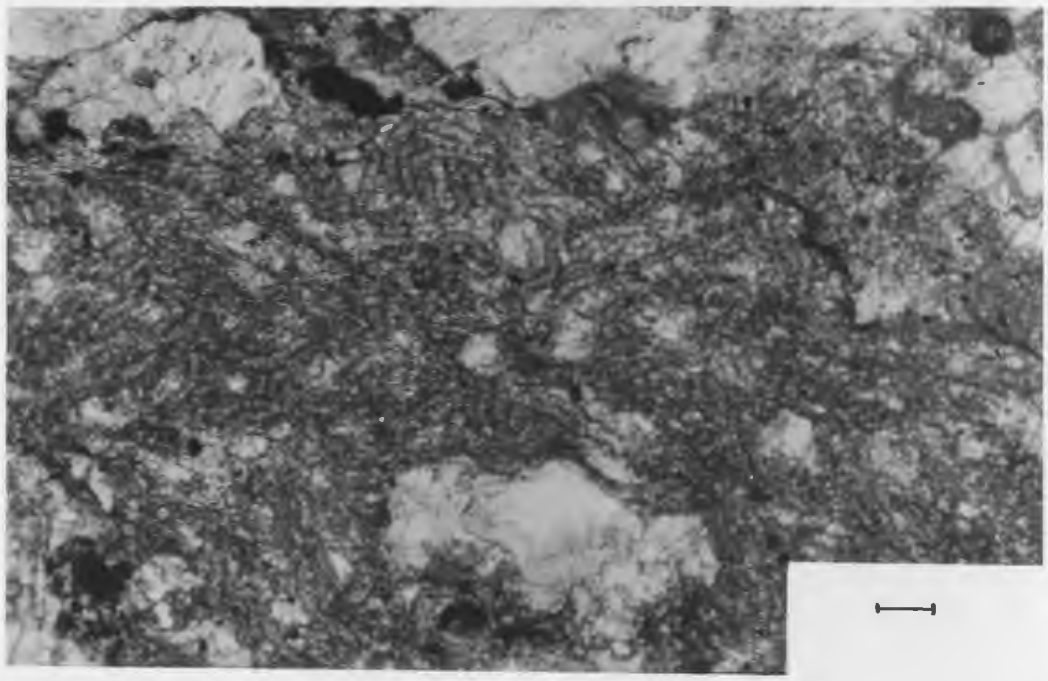


Figure B4. An example of matrix Girvanella. (from a lithological sample collected in the eastern quarry of the Cobbs Arm quarry). Bar equals 0.1 mm.

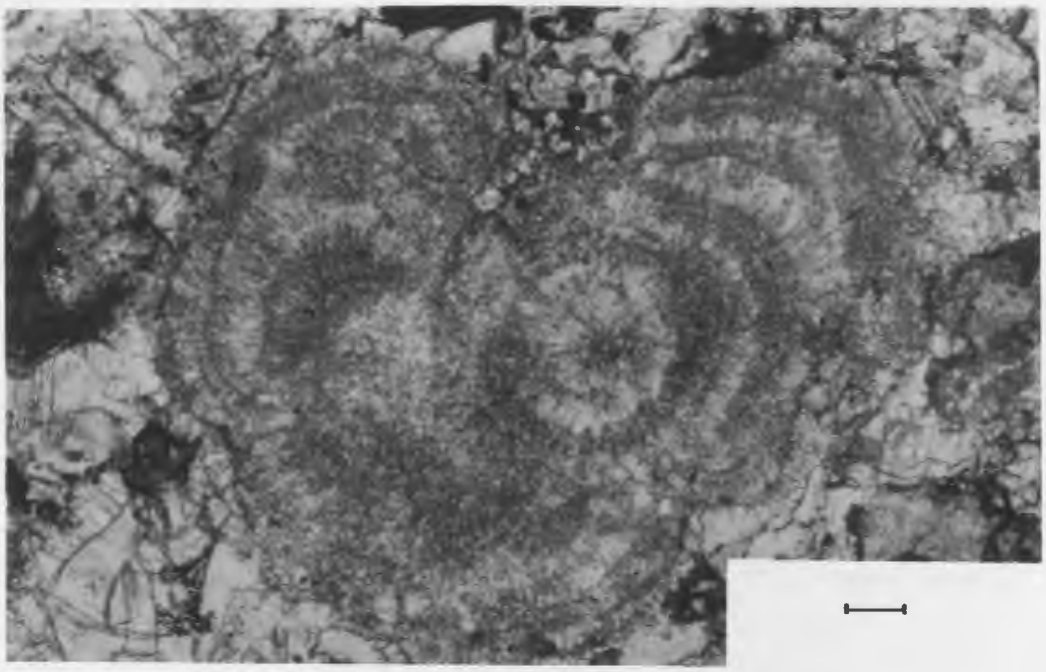


Figure B5. A fragment of the calcareous algae Nuia.(from a lithological sample collected in the eastern quarry of the Cobbs Arm quarry). Bar equals 0.1 mm.

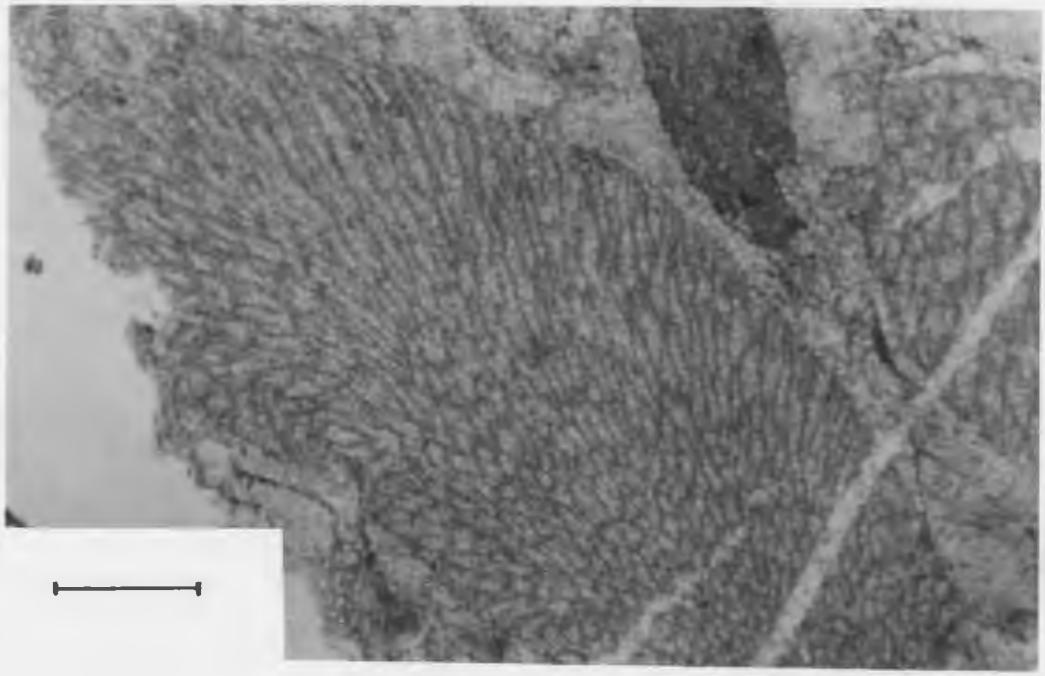
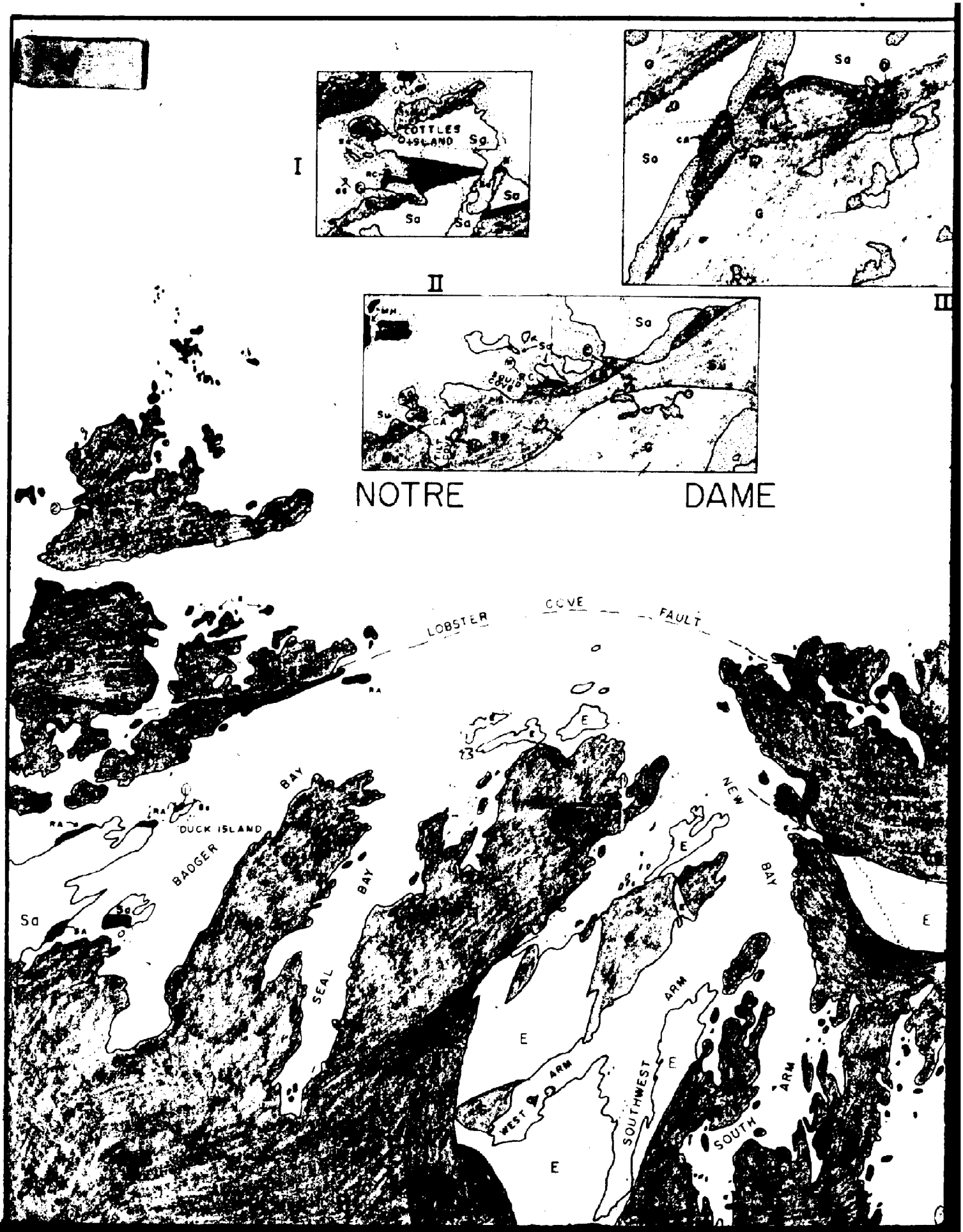
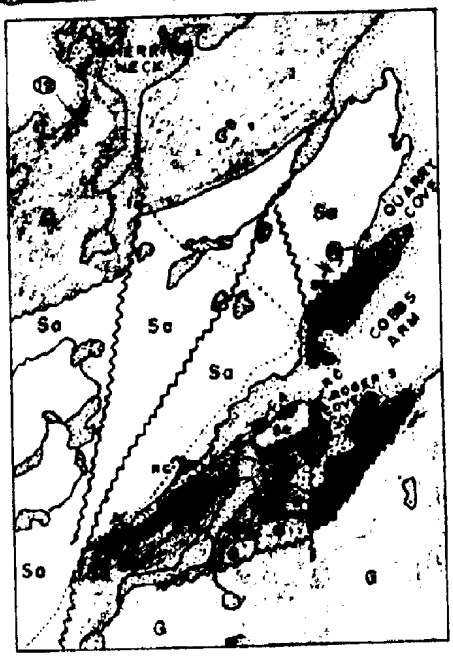


Figure B6. A fragment of the calcareous algae Hedstroemia. (QC20). Bar equals 1.0 mm.


I
COTTLES ISLAND
Sa
II
III
NOTRE DAME
LOBSTER COVE FAULT
DUCK ISLAND
BADGER BAY
SEAL BAY
NEW BAY
WEST ARM
SOUTHWEST ARM
SOUTH ARM
E



BAY

TWILLINGATE ISLAND

NEW WORLD ISLAND

CHANCEPORT FAULT

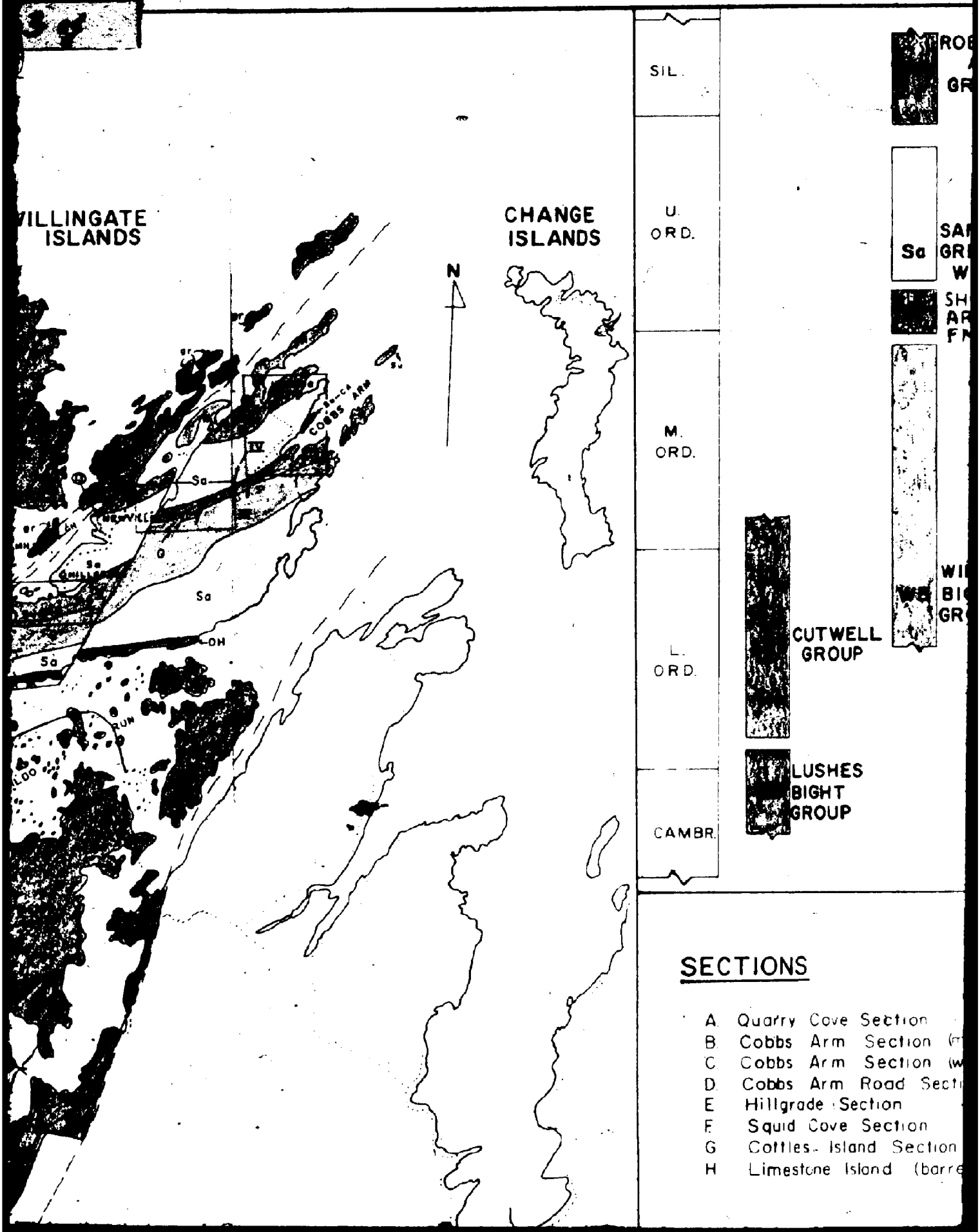
LUKES ARM FAULT

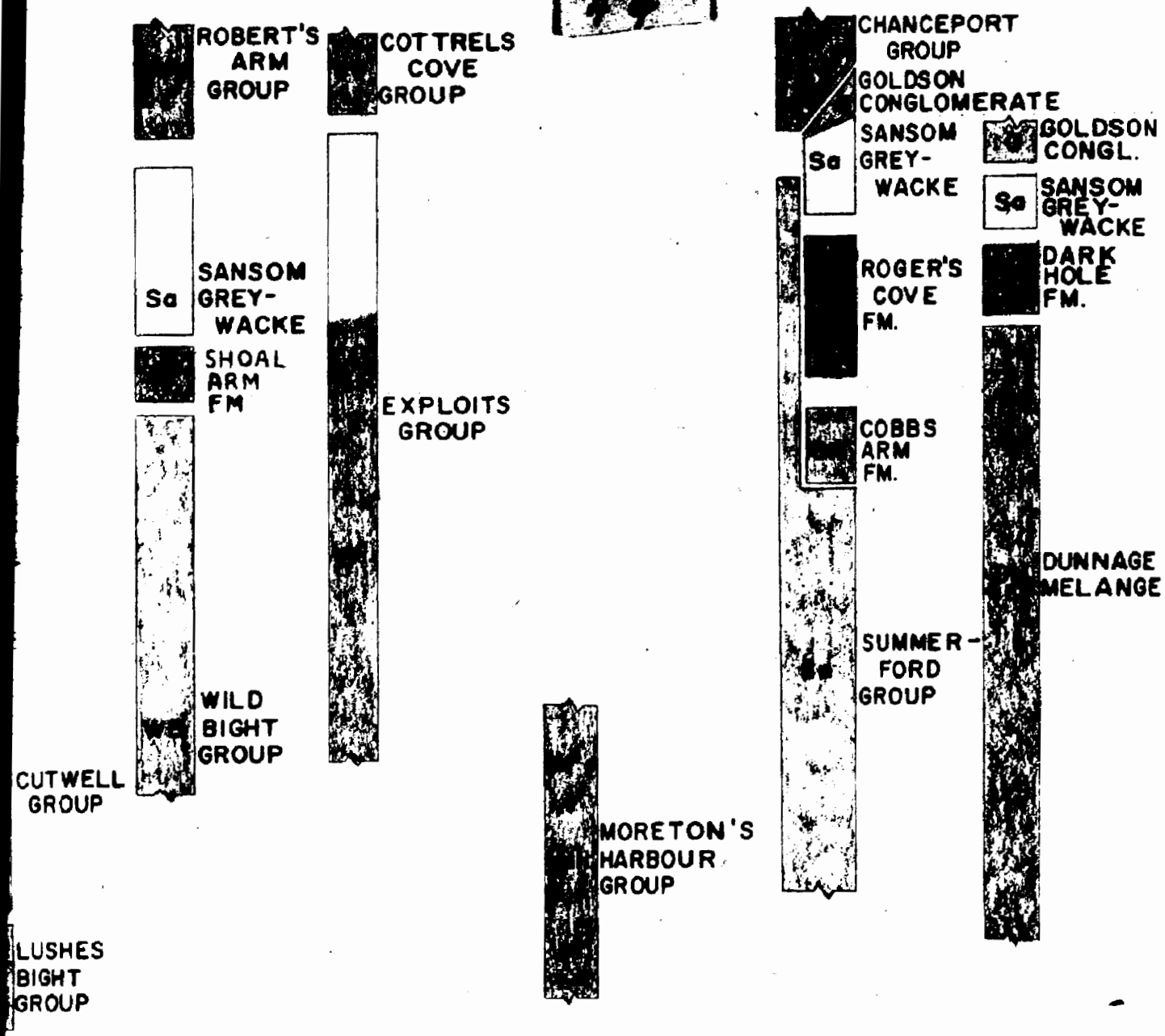
FARMERS ISLAND

VILLAGE COVE

DILDO

BAY OF EXPLOITS


WILLINGATE ISLANDS
CHANGE ISLANDS
N
COBBS ARM
Sa
Q
LOH
SIL.
U. ORD.
M. ORD.
L. ORD.
CAMBR.
CUTWELL GROUP
LUSHES BIGHT GROUP
SECTIONS
A Quarry Cove Section
B Cobbs Arm Section
C Cobbs Arm Section
D Cobbs Arm Road Sect
E Hillgrade Section
F Squid Cove Section
G Cottles Island Section
H Limestone Island (barre



NS

rv Cove Section
bs Arm Section (middle quarry face)
bs Arm Section (west quarry face)
bs Arm Road Section
grade Section
id Cove Section
tles Island Section
nestone Island (barren)

ISOLATED SAMPLES

1 - 13 (see appendix A)

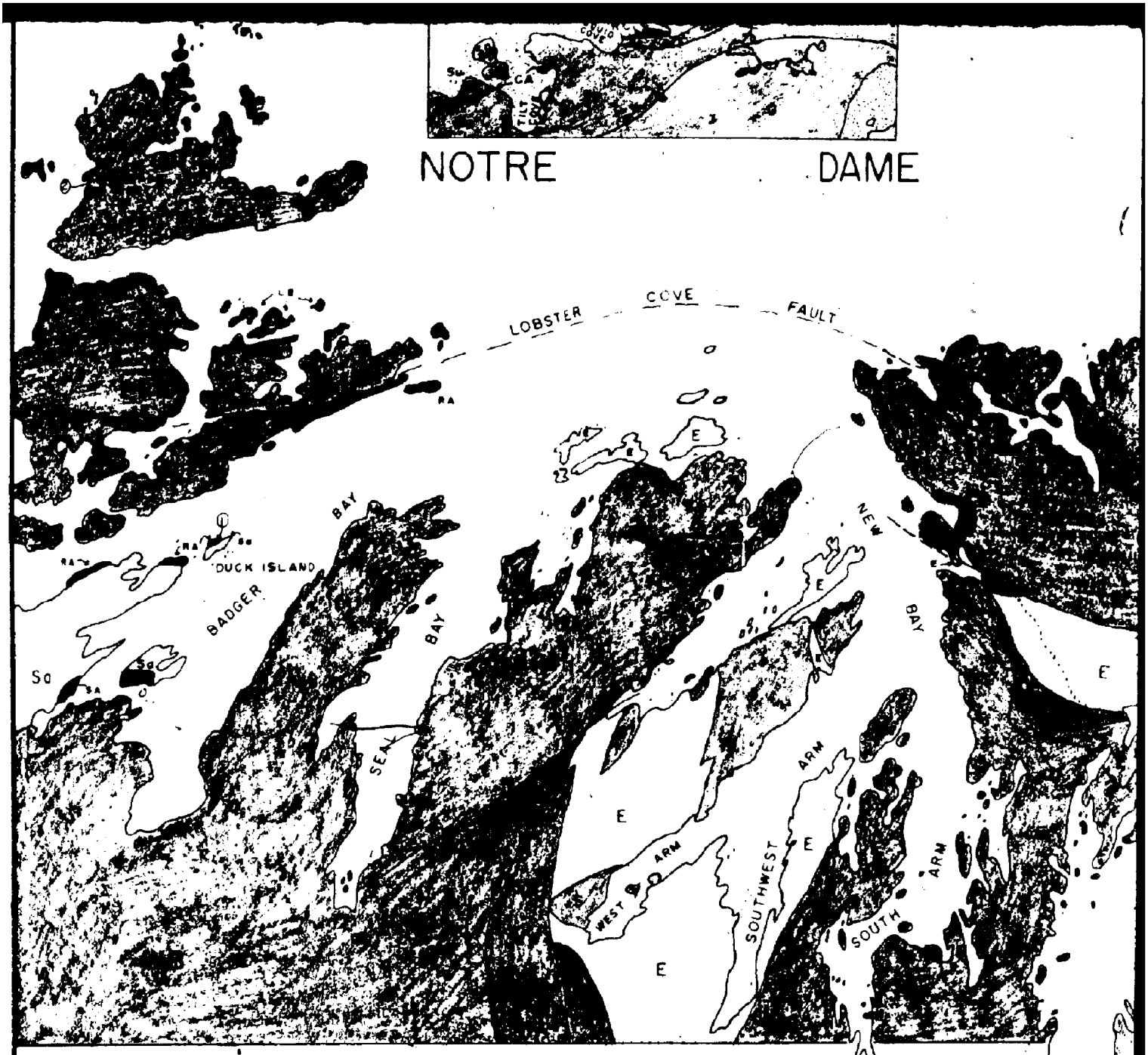


FIGURE 2

CONODONT SAMPLE LOCALITIES and the GEOLOGY of NOTRE DAME BAY

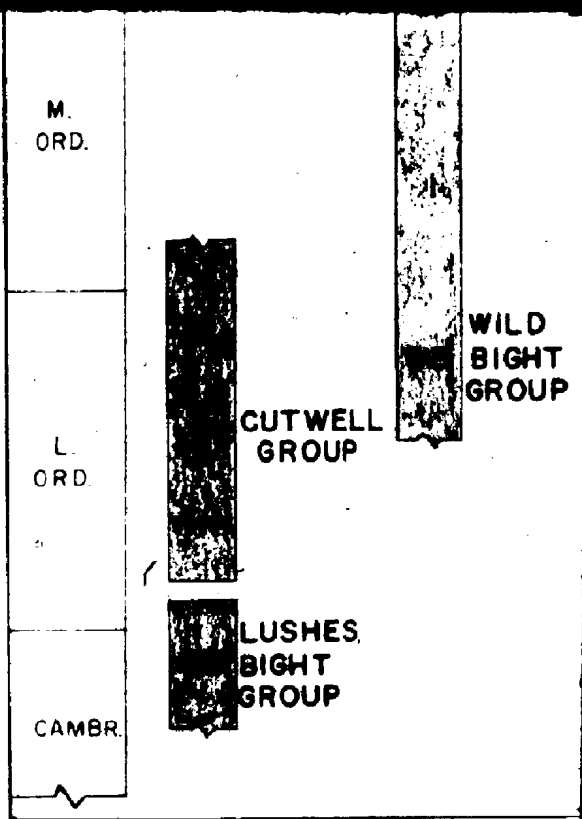
0 5 10 15 KILOMETRES

SCALE

Geology after Dean and Strong, 1976


IV
BAY
NEW
WORLD
ISLAND
CHANCEPORT
FAULT
LUKES
ARM
FAULT
FARMERS
ISLAND
VILLAGE
COVE
OLDO
RUN
BAY
OF
EXPLOITS
LEWISPORTE
Sa
DM
MH
I
E

6 of



SECTIONS

A Quarry Cove Section
B Cobbs Arm Section (middle
C Cobbs Arm Section (west c
D Cobbs Arm Road Section
E Hillgrade Section
F Squid Cove Section
G Cottles Island Section
H Limestone Island (barren)

..... ROADS

GEOLOGICAL BOUNDARY

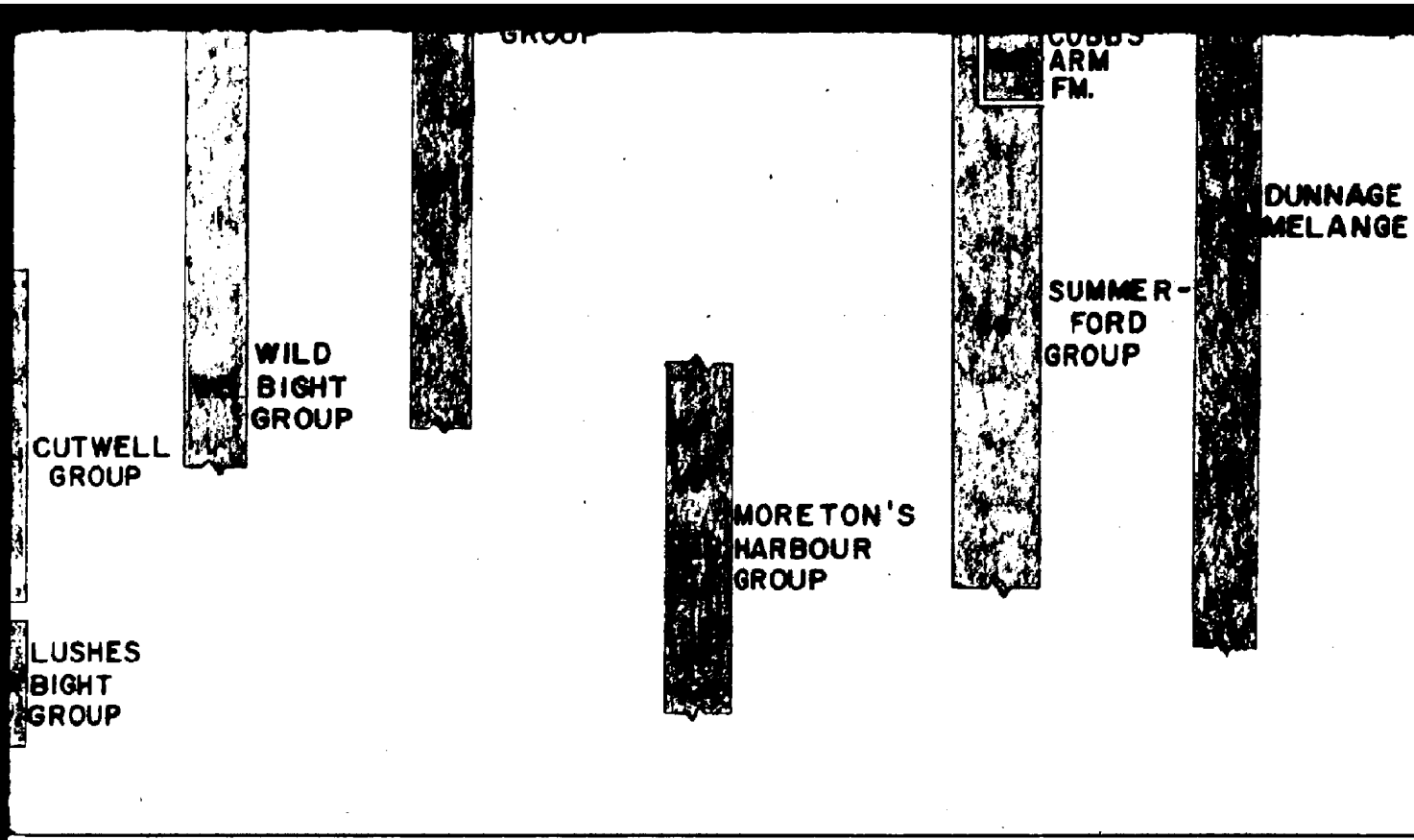
O SAMPLE LOCALITY

BEDDING (overturned)

gr GRANITE

gb GABBRO

74



NS

ry Cove Section
os Arm Section (middle quarry face)
os Arm Section (west quarry face)
os Arm Road Section
grade Section
id Cove Section
tles Island Section
estone Island (barren)

ROADS

GEOLOGICAL BOUNDARY

SAMPLE LOCALITY

BEDDING (overturned)

GRANITE
GABBRO

ISOLATED SAMPLES

1 - 13 (see appendix A)

TABLE Ib Conodont Species from the Cobbs Arm

MULTIELEMENT SPECIES / LOCALITY	COTTLES ISL								
	1	2	3	4	5	6	7	8	
Protopanderodus peselephantis	2	2	3						
Protopanderodus rectus									
costate drepanodiforms		7	2	1				2	
scandodiform			1						
Protopanderodus varicostatus									
symmetrical multicostate drepanodiform	3	5	7	7	9	2		13	
tricostate drepanodiform	2	14	14	29	17	4	3	27	1
asymmetrical multicostate drepanodiforms	5	18	33	41	34	7	8	40	2
scandodiform	4	15	15	16	13	3	2	19	
Pseudobelodina n. sp. A									
belodelliform									
cistodiform									
Pygodus anserinus									
pygodiform									
haddingodiform									
trichodelliform			1						
belodiform				2				1	
tetraprioniodiform			1					1	
Pygodus serrus									
pygodiform	17	29	26	3	8	2	5	14	
haddingodiform	22	38	26	1	4	3	4	12	
Pygodus n. sp. A									
pygodiform									
Rhodesognathus sp. cf. R. elegans polonicus									
ambalodiform									
Scalpellodus cavus									
symmetrical bicarinate drepanodiform	14	4	11	1			1	5	
unicarinate drepanodiform	22	7	21	3	3	1	2	9	
non-carinate drepanodiform	45	9	19	4	2		4	16	
strongly bowed drepanodiform	18		4		1			6	
Scalpellodus n. sp. A									
Spinodus spinatus									
Strachanognathus parvus	42	374	127	12	33	2	1	81	
Walliserodus ethingtoni									
symmetrical multicostate drepanodiform									
asymmetrical multicostate drepanodiform		1	2						
acostate drepanodiform			1					1	
strongly bowed drepanodiform									
Walliserodus nakholmensis									
symmetrical multicostate drepanodiform	3	6	3		1				
tricostate drepanodiform	6	12	5	1	3				
asymmetrical bicostate drepanodiform	3	15	10	2	2	1		1	
inward bowed drepanodiform			10	5					
Walliserodus n. sp. A									
symmetrical multicostate drepanodiform	3		3					1	
asymmetrical multicostate drepanodiform	5		2	1					
tricostate drepanodiform	11	1	12	1			1	6	
asymmetrical bicostate drepanodiform	4		3						
inward bowed drepanodiform	5		4					2	
Westergaardodina sp. cf. W. bicuspida									
New Genus n. sp. 1									
New Genus A n. sp. A									

Cobbs Arm Formation Measured Sections

OTTLES ISLAND SECTION [redacted]

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
															1	2
2	1				2	1		1					1	1		
2	7	9	2		13	6	7	4	1	3	10	8	8	7	10	1
4	29	17	4	3	27	16	12	5	2	5	38	24	14	27	5	
3	41	34	7	8	40	21	17	5	4	12	51	31	32	22	17	3
5	16	13	3	2	19	11	6	7	2	6	26	14	6	10	5	
												80	22	266	179	42
												57	23	174	135	14
											3	1		2		1
	2				1				1		3	4		8	2	
					1						2	3		5		
6	3	8	2	5	14	6	5	4	5	1	134	10	3			
6	1	4	3	4	12	1	3	4	4	4	108					
														2	7	
1	1			1	5	2				4	5	9				1
1	3	3	1	2	9	4				6	15	16				6
9	4	2		4	16	5				10	13	19		4	1	10
4		1			6	2						20		1		4
								2				1				
27	12	33	2	1	81	8		1								
									1			1	1	1	1	
2							4	1			2	5	1	5	1	1
1					1	1	1				3	4	2	1	2	1
											1	2	1	1		
3		1												1		
5	1	3														
0	2	2	1		1						3					
0	5										1				1	
3					1							14				1
2	1									1		26				3
2	1			1	6					1	3	22				4
3						1						22				3
4					2					4		37				3

QUARRY COVE SECTION

1	2	3	4	5	6	7	8	9	12	13	14	15
		4					1		1			
		1	3	1	1	15	2	2	1		2	
		5	1			20	3	4	1		2	
		7	7			46	6	7	3	6	4	
		1	2	1		18	1	1				
6												
8												
						12	50	6	53	22	13	
						1	10		23	7	2	
		3										
			4								1	
		5						1				
2	3	98	16	2	4			44				3
	8	94	14		4			56				1
		4					1	2	2			
	3	13	4				4	6	2	3		1
	4	5	3				5	6	1	2		
		1					1	1	1	1	1	
	6											
						3				2	1	
		1					1		1	1		
							1					

VE SECTION								COBBS ARM SECTION (MIDDLE)											COBBS ARM (WEST)					HILLGRADE S					
9	12	13	14	15	16	18	19	1	2	3	5	6	7	8	9	10	11	12	1	2	3	4	5	1	2	3	4	5	6
	1						1																						
																						3	3			1			
2	1		2			4	1			1					2				1	1		1		1		1			
4	1		2			5	2								6		1			2		1	2			1			
7	3	6	4			14	9				4			2	9	3	2			4		4	4	1		1			
1						8					2				3					1			4			2			
6	53	22	13			4	88				11					1				3		18	16						
	23	7	2			1	22				6									2	1	6	2						
			1						1			1						1				2							
1					1				1									2											
44				3	7				54			2						26						10	2	1		1	
56				1	1				42			1						34						9				1	
																		3											
2	2										1											1	1						
6	2	3		1			2	1															1					1	
6	1	2					2									1						1	1						
1	1	1	1								1					1													
								1																					
		2	1			1	2				3				3	1													
1	1	1													2	1													
1																													
	1	1	1						1										1			1							
	4	5	1						1											1		2							
	3	3		1			1															1							
			1				1															1							
1																													
2							1																						
								2																					

HILLGRADE SECTION										SQUID COVE SECTION					COBBS ARM ROAD S.					ISOLATE SAMPLES				SUB TOTAL	TOTAL
1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5	A	B	C	D		
													9												26
																									66
		1								1		2	22	2					1				4	54	
													11											12	
																									1291
1		1					3		1											1				157	
		1					4	2	4			2							1					327	
1		1					3	4	7		4	8						1	2	7			1	581	
		2							1											1				226	
																									62
															27									33	
															21									29	
																									1676
												38	59	3							3			988	
												22	99	2							1			609	
													11											22	
											1		28											60	
												1	9											32	
																									1149
10	2	1		1				10	2		2							1	2	19				584	
9				1			4	13										5	3	5				530	
																									9
																								9	
																									3
																								3	
																									521
													5		1					1				76	
				1					1			2	11		1					1				172	
													12							1				205	
													4											68	
																		3	2						12
																									20
													5	1											687
																									81
																								5	
												3	11											45	
													2	1										21	
												2	1	1										10	
																									149
												1												22	
																								48	
											1	1	3											56	
													3											23	
																									219
													1											25	
																								38	
													2											67	
													1											34	
																								55	
							1																		1
															2										4

scandodiform									
Pseudobelodina n. sp. A									
belodelliform									
oistodiform									
Pygodus anserinus									
pygodiform									
haddingodiform									
trichodelliform			1						
belodiform				2				1	
tetraprioniodiform			1					1	
Pygodus serrus									
pygodiform	17	29	26	3	8	2	5	14	6
haddingodiform	22	38	26	1	4	3	4	12	1
Pygodus n. sp. A									
pygodiform									
Rhodesognathus sp. cf. R. elegans polonicus									
ambalodiform									
Scalpellodus cavus									
symmetrical bicarinate drepanodiform	14	4	11	1			1	5	2
unicarinate drepanodiform	22	7	21	3	3	1	2	9	4
non-carinate drepanodiform	45	9	19	4	2		4	16	5
strongly bowed drepanodiform	18		4		1			6	2
Scalpellodus n. sp. A									
Spinodus spinatus									
Strachanognathus parvus	42	374	127	12	33	2	1	81	8
Walliserodus ethingtoni									
symmetrical multicostate drepanodiform									
asymmetrical multicostate drepanodiform		1	2						
acostate drepanodiform			1					1	1
strongly bowed drepanodiform									
Walliserodus nakholmensis									
symmetrical multicostate drepanodiform	3	6	3		1				
tricostate drepanodiform	6	12	5	1	3				
asymmetrical bicostate drepanodiform	3	15	10	2	2	1		1	
inward bowed drepanodiform			10	5					
Walliserodus n. sp. A									
symmetrical multicostate drepanodiform	3		3					1	
asymmetrical multicostate drepanodiform	5		2	1					
tricostate drepanodiform	11	1	12	1			1	6	
asymmetrical bicostate drepanodiform	4		3						
inward bowed drepanodiform	5		4					2	
Westergaardodina sp. cf. W. bicuspida									
New Genus n. sp. 1									
New Genus A n. sp. A									
symmetrical bicostate belodelliform									
asymmetrical bicostate belodelliform									
unicostate belodelliform									
acostate belodelliform									
anteriorly denticulated belodelliform									
distacodiform					1				
oistodiform 1									
oistodiform 2									
panderodiform									
strachanognathiform									
SAMPLE TOTALS	292	712	528	172	161	34	55	313	11

Isolated Sample Localities: A. Duck Island; B. Tilt Cove Road; C. Newville; D. Back Cove.

16	13	3	2	19	11	6	7	2	6	26	14	6	10	5				1	2	1		18	1	1					
																6													
																8													
											80	22	266	179	42							12	50	6	53	22	13		
											57	23	174	135	14							1	10		23	7	2		
										3	1		2		1			3											
2				1				1		3	4		8	2					4								1		
				1						2	3		5					5						1					1
3	8	2	5	14	6	5	4	5	1	134	10	3				2	3	98	16	2	4			44				3	7
1	4	3	4	12	1	3	4	4	4	108							8	94	14		4			56				1	1
													2	7															
1			1	5	2				4	5	9				1			4					1	2	2				
3	3	1	2	9	4				6	15	16				6		3	13	4				4	6	2	3		1	
4	2		4	16	5				10	13	19		4	1	10		4	5	3				5	6	1	2			
	1			6	2						20		1		4			1					1	1	1	1	1		
																	6												
							2				1											3				2	1		
12	33	2	1	81	8		1																						
								1			1	1	1	1															
						4	1			2	5	1	5	1	1			1					1	1	1	1			
				1	1	1				3	4	2	1	2	1									1					
										1	2	1	1					1											
	1												1										2		1	1	1		
1	3																	1					6		4	5	1		
2	2	1		1						3								1	1				3		3	3		1	
5										1				1													1		
				1							14				1							1		1					
1									1		26				3														
1			1	6					1	3	22				4							1		2					
					1						22				3														
				2					4		37				3														
																1													
																1													
																2													
	1																												
										2																			
											2																		
																								2					
172	161	34	55	313	116	67	70	45	115	908	959	264	092	643	189	125	237	1714	269	5	13	480	937	985	499	248	47	50	19

ack Cove.

1						8					2				3					1			4			2			
6	53	22	13			4	88				11					1				3		18	16						
	23	7	2			1	22				6									2	1	6	2						
			1						1			1						1				2							
1					1				1									2											
44				3	7				54			2						26						10	2	1		1	
56				1	1				42			1						34						9				1	
																		3											
2	2										1											1	1						
6	2	3		1			2	1															1					1	
6	1	2					2									1						1	1						
1	1	1	1								1					1													
								1																					
		2	1			1	2				3				3	1													
1	1	1													2	1													
1																													
	1	1	1																1			1							
	4	5	1				1													1		2							
	3	3		1			1															1							
			1				1															1							
1																													
2							1																						
								2																					
2																													
								1																					
985	499	248	47	50	19	193	662	92	1145	2	176	57	342	11	66	84	3	1139	6	68	11	107	85	65	44	56	8	95	3

1

		2							1											1				226	
																									62
															27									33	
															21									29	
																									1676
												38	59	3							3			988	
												22	99	2							1			609	
													11											22	
											1		28											60	
												1	9											32	
																									1149
10	2	1		1				10	2		2							1	2	19				584	
9				1			4	13										5	3	5				530	
																									9
																								9	
																									3
																								3	
																									521
													5		1					1				76	
				1					1			2	11		1					1				172	
													12							1				205	
													4											68	
																		3	2						12
																									20
													5	1											687
																									81
																								5	
												3	11											45	
													2	1										21	
												2	1	1										10	
																									149
												1												22	
																								48	
											1	1	3											56	
													3											23	
																									219
													1											25	
																								38	
													2											67	
													1											34	
																								55	
							1																		1
															2										4
																									28
															3									4	
															7									7	
															5									6	
															5									7	
															4									4	
																									1
																									2
																									2
																									2
																									1
65	44	56	8	95	3	5	48	75	35	14	18	176	590	33	210	0	0	24	69	178	4	20	74	#	18456

TABLE Ia Conodont Species from the Cobbs Arm

MULTIELEMENT SPECIES / LOCALITY	COTTLES ISL							
	1	2	3	4	5	6	7	8
†Acodus n. sp. A								
Amorphognathus sp. cf. A. inaequalis-A. kielcensis transition								
amorphognathiform								
Baltoniodus prevariabilis-B. variabilis transition								
ambalodiform							1	
amorphognathiform								
trichonodelliform								
belodiform								
tetraprioniodiform								
falodiform								
Baltoniodus variabilis								
ambalodiform								
Belodella n. sp. A								
symmetrical bicostate belodelliform								
asymmetrical bicostate belodelliform								
acostate belodelliform								
non-denticulated belodelliform		1						
Belodina n. sp. A								
belodiniform			1					2
eobelodiniform		1			1			1
Belodina serrata								
Distacodus venustus								
distacodiform								
oistodiform								
Drepanodus sp. cf. D. arcuatus								
symmetrical bicostate drepanodiform	2	1	1					
unicostate drepanodiform		2	1					
acostate drepanodiforms								
oistodiform			1					
Drepanodus robustus								
symmetrical multicostate drepanodiform			4					2
symmetrical bicostate drepanodiform				1				
asymmetrical bicostate drepanodiform			2	1				2
weakly bicostate asymmetrical drepanodiform			1					
oistodiform				2		2	1	1
Drepanoistodus n. sp. A								
homocurvatid drepanodiform	3	1	3				1	
suberectid drepanodiform		1						
oistodiform			3					
Eoplacognathus lindstroemi								
dextral ambalodiform								
sinistral ambalodiform								
polyplacognathiform								
Eoplacognathus robustus								
dextral ambalodiform	2			4	2			5
sinistral ambalodiform	2		1	5	6	1	1	4
polyplacognathiform	4	3	2	5	5	3	2	5
†Oneotodus mitratus								
Paltodus semmisymmetricus								
paltodiform			2					1
oistodiform		2	1				2	
Panderodus gracilis								

obbs Arm Formation Measured Sections

TTLES ISLAND SECTION [redacted] QUARRY COVE SECTION

4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	1	2	3	4	5	6	7	8	9	12	13	14	15	16
																4	21												
			1											5				38					16						
														2				32				5	35		12	6			
																		14				3	23		23	3			
																		31				9	66		43	8			
																		32				6	56		41	14			
														1				35				13	145		49	13			
																						49	186		67	39			
											4								1										
					1						1																		
											3		1	1					2										
											6		1	1					1										
				2														1	3	1				3					
	1			1															4		1			1					
																1													
															3								10	2	5				
															9								34	1	10				
										2																			
											1							2											
																	6	2											
				2		1							2													1			
1									1				1									4	2			1			
1				2		1			2	2			6									11	1		4	4	1		
										2			2									14	6		5	3	1		
2		2	1	1						1			1									6	4		3	2			
			1							9		1		7		3	22	140	2					36	5				
														2		1	1	20						10					
										1				5		1	2	46	3					12	5				
											1		7	3								2							
											1		7	4								1							
											1	1	33	20								10		2					
4	2			5		1	3	6	7							1		1	1					13					
5	6	1	1	4			2	3	8	4						1	1		2					16	1				
5	5	3	2	5	1	2	3	5	10							1	3	2					1	10	1			2	
				1							6	2				2	1	7	1					3					
			2								2							2	4					6					

[redacted]

OVE SECTION									COBBS ARM SECTION (MIDDLE)											COBBS ARM (WEST)					HILLGRADE				
8	9	12	13	14	15	16	18	19	1	2	3	5	6	7	8	9	10	11	12	1	2	3	4	5	1	2	3	4	5
									10																				
										1																			
6										9							1		19							3	2		4
35		12	6				2	10		8		4					2		7					1		3			3
23		23	3					13		5		1							9						1				
56		43	8				1	55		6		8				1	1		9							1			
56		41	14				4	44		5		6				1	3		8							1			3
45		49	13				9	98		3		13				8	14		4				1	1	1	3	1		1
86		67	39				16	81				12				2	4							4					
									2																				
	3																		1						1				
	1																		4										
10	2	5						25											1		1		4		1				
34	1	10						28				2							8			2	3	1	2				
									1								1												
								1	1					2											1				
								4	1																				
								2						2															
			1					2				1				1							1						
2			1				2			1						1													
1		4	4	1			2	1				1				3							1						
6		5	3	1			8	4				2				1	1												
4		3	2				4	3				1				2	1												
	36	5						4		17				6					51										
	10							4	1	4				2					12			1							
	12	5						1	2	9				1					15			3							
							1																						
							1								3														
	2						5								1														
	13									4	1								11							3		1	7
	16	1							1	4									12							4			8
1	10	1			2					4				3					17							5	1		13
									1										4										
	3								1					5		1			2										
	6								2					1					1										

	HILLGRADE SECTION										SQUID COVE SECTION					COBBS ARM ROAD S.					ISOLATE SAMPLES						
5	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	1	2	3	4	5	A	B	C	D		
																10								3		48
																										2
																							1		2	
																										375
		3	2		4			2						4											104	
1		3			3								2								10				141	
	1																				3				98	
		1											1	4		1			1		13				259	
		1			3															3	10				237	
1	1	3	1		1				2					1					1		11				428	
																										1397
4																					45				505	
																										26
																									5	
																									2	
																									7	
																									12	
																										30
	1															2			1						16	
																1									14	
																2										3
																										218
	1													25											77	
1	2													41											141	
																										41
									1					1						1					11	
	1													2											13	
																									13	
																									4	
																										161
																									12	
										2															16	
										2															47	
										2															52	
																									34	
																										530
											5		4	4		4				3				13	344	
											1	1				1								1	63	
											2		3	2		2							1	5	123	
																										108
																					1				15	
																									17	
																					5				76	
																										280
		3		1	7			1				1							1				1	3	79	
		4			8			1																1	89	
		5	1		13					3		1											4	4	122	
																			1							6
																										62
														1	1	1									37	
																2									25	
																										5786

ambalodiform								
Belodella n. sp. A								
symmetrical bicostate belodelliform								
asymmetrical bicostate belodelliform								
acostate belodelliform								
non-denticulated belodelliform		1						
Belodina n. sp. A								
belodiniform			1					2
eobelodiniform		1			1			1
Belodina serrata								
Distacodus venustus								
distacodiform								
oistodiform								
Drepanodus sp. cf. D. arcuatus								
symmetrical bicostate drepanodiform	2	1	1					
unicostate drepanodiform		2	1					
acostate drepanodiforms								
oistodiform								
Drepanodus robustus								
symmetrical multicostate drepanodiform			1					2
symmetrical bicostate drepanodiform				1				
asymmetrical bicostate drepanodiform			2	1				2
weakly bicostate asymmetrical drepanodiform			1					
oistodiform				2		2	1	1
Drepanoistodus n. sp. A								
homocurvatid drepanodiform	3	1	3				1	
suberectid drepanodiform		1						
oistodiform			3					
Eoplacognathus lindstroemi								
dextral ambalodiform								
sinistral ambalodiform								
polyplacognathiform								
Eoplacognathus robustus								
dextral ambalodiform	2			4	2			5
sinistral ambalodiform	2		1	5	6	1	1	4
polyplacognathiform	4	3	2	5	5	3	2	5
?Oneotodus mitratus								
Paltodus semmisymmetricus								
paltodiform			2					1
oistodiform		2	1				2	
Panderodus gracilis								
gracilid panderodiform	11	87	75	14	6		6	
compressid panderodiform	6	32	35	2	7		2	1
Panderodus mutatus					2		5	2
?Panderodus n. sp. A								
Periodon aculeatus, morphotype I								
periodontiform	2	1						4
trichonodelliform	1							1
eoligonodiniform	3	5	4	2				3
ligonodiniform	2	3	4	2				1
prioniodiniform	9	5	7	1	1	1	1	4
falodiform	9	10	15	2		2	3	13
Periodon aculeatus, morphotype II								
loxognathiform			3	1	1			2
Polyplacognathus sweeti								
ambalodiform								
polyplacognathiform								

Isolated Sample Localities: A. Duck Island; B. Tilt Cove Road; C. Newville; D. Sock Cove.

																								49	186		67	39							
												4										1													
						1						1																							
												3		1	1							2													
												6		1	1							1													
				2																1	3	1				3								
	1			1																	4		1			1								
																		1																	
																3									10	2	5								
																9									34	1	10								
										2																									
												1								2															
																		6		2															
				2		1								2																1					
1									1					1										4	2					1					
1				2		1			2	2				6										11	1			4		4	1				
										2				2										14	6			5		3	1				
2		2	1	1						1				1										6	4			3		2					
			1							9			1			7		3		22	140	2					36	5							
																2		1		1	20						10								
										1						5		1		2	46	3					12	5							
												1		7		3								2											
												1		7		4								1											
												1	1	33		20								10			2								
4	2			5		1	3	6	7									1			1	1					13								
5	6	1	1	4			2	3	8	4								1		1		2					16	1							
5	5	3	2	5	1	2	3	5	10									1		3	2					1	10	1				2			
				1								6	2					2		1	7	1					3								
			2									2									2	4					6								
5	14	6		6		1					5	15	10	6	8	5		71	124	741	142			147	156	614	82	63		4	34				
5	2	7		2	1			2			12	6	10	3	4			17	17	228	42			43	34	81	29	18		2	8				
		2		5	2		1	1				3	4		3							1		2						2					
																											3								
					4	1	1	3		4	35	37	12	46	22	8				7	1		1		1	1	2	5	1					
					1			4	1		21	23	4	14	11	1			1	9				1	1	1	1							
	2				3	5	1	3	1	1	75	55	14	81	48	11			1	21	2		1	6	4	6	2	1	2					
	2				1	3	1	4	1	3	48	41	26	74	20	6			1	10				1	9	1	1	1	1		2			
	1	1	1	1	4	4	1	7	4	7	66	113	10	53	43	19			5	13	1			9	6	1	2	1			1			
5	2		2	3	13	14	2	3	3	14	161	167	48	176	47	18	2		7	25	1		1	20	36	15	9	10	4		1			
	1	1			2	1		1	1	1	41	41	8	40	19	10				10				1	6	4		2						
																									1									
																									2									

6		67	39				16	81				12				2	4							4											
									2																										
	3																			1							1								
	1																			4															
0	2	5						25												1		1		4			1								
4	1	10						28				2								8			2	3	1		2								
									1								1																		
								1	1					2													1								
								4	1																										
								2						2																					
			1					2				1				1								1											
2			1				2			1						1																			
1		4	4	1			2	1				1				3								1											
6		5	3	1			8	4				2				1	1																		
4		3	2				4	3				1				2	1																		
	36	5						4		17				6						51															
	10							4	1	4				2						12			1												
	12	5						1	2	9				1						15			3												
																															1				
							1																												
							1								3																				
	2						5								1																				
	13									4	1									11									3			1	7		
	16	1							1	4										12									4				8		
1	10	1			2					4				3						17									5	1			13		
									1											4															
	3								1					5		1				2															
	6								2					1						1															
66	614	82	63	4	34	3	62	98	55	532		71	33	246	3	12	44		617	2	40	3	25	11	20	11	5	6	37					
34	81	29	18	2	8	3	22	26	9	101		7	4	49		1	4		94	1	5	1	3	1	3	3	2	1	5					
				2				12				1				1					1				3									
	3																																		
1	1	2	5	1			2	2		27		1		4					13				1	2	1		4								
1	1	1								25			1	1					7				1	1	1		2		1						
4	6	2	1	2			2	1		85		4	6	2					41	1	2		4	6		1	9		3						
9	1	1	1	1		2	4	1		32		2	1	1		1			15		1						1		1						
6	1	2	1			1	5	2		32		5	3	3	1	2			34		1		7	4	5	1	12		3						
36	15	9	10	4		1	4	7		106		6	1	16	1	3			37		2		9	15	2	3	5		3						
6	4		2							30			4						20			1	3	4	2		5								
1																					1		1												
2																							1												

																										26
																								8		
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																								7		
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	1														2			1						16		
															1									14		
															2											3
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	1											25												77		
1	2											41												141		
																										61
								1				1							1					11		
	1											2												13		
																								13		
																								4		
																										161
																								12		
										2														16		
										2														47		
										2														52		
																								34		
																										530
											5		4	4		4				3				13	344	
											1	1				1								1	63	
											2		3	2		2							1	5	123	
																										108
																					1				15	
																									17	
																					3				76	
																										280
		3		1	7			1				1						1					1	3	79	
		4			8			1																1	89	
		5	1		13					3		1											4	4	122	
																		1								6
																										62
														1	1	1				1					37	
																2									25	
																										5756
1	20	11	5	6	37		1	19	16	3	3	5	43	37	9	92			9	42	33		3	24	4701	
1	3	3	2	1	5			3	2		1	1	17	6		13				6	13		1	6	1053	
	3												1	65		2										112
																										3
																										1565
2	1		4						3				2	12	1								3	1	274	
1	1		2		1				3	1				7											146	
6		1	9		3	1	1		4	2			7	20	1								1	1	564	
			1		1	1			1					14	2					1			2		347	
4	5	1	12		3	1	1	2	3	1	1		3	11	4					1				4	547	
5	2	3	5		3		2	4	5	2			8	12	13	1				1			1	2	1099	
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4	2		5					1	5	1		1	2	9	2					1			2	1	287	
																										7
													1													4
																										[illegible]