RADIOLARIA FROM THE LOWER SILURIAN OF THE CAPE PHILLIPS FORMATION, CORNWALLIS ISLAND, NUNAVUT, CANADA

by

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Submitted in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

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ABSTRACT

Well-preserved Radiolaria were recovered from a nearly continuous succession of Llandovery to lower Wenlock strata from the Cape Phillips Formation, Nunavut, Canada. Age control is well-constrained by graptolite biostratigraphy. Only one previous radiolarian study had a comparable degree of stratigraphic continuity in the Llandovery. The present study thus provides a baseline of data on radiolarian taxonomy and stratigraphic distribution in the Llandovery for future comparitive studies.

The Secuicollactidae include *Secuicollacta* (nine species described), *Diparvapila* (four species), and *Rotasphaera* (three species). The Palaeoscenidiidae include *Goodbodium* (2 species), *Insolitignum* (three species), *Palaeodecaradium* (three species), *Palaeoephippium* (three species) *Palaeopyramidium* (one species), and *Protoentactinia* (one species). The Haplotaeniatumidae include *Haplotaeniatum* (seven species described) and Orbiculopylorum (three species described). The Inaniguttidae are not assigned to genera. Five taxa are described. The genus *Labyrinthosphaera* of uncertain family is represented by three species.

The radiolarian fauna changed at three stratigraphic levels. At the Rhuddanian-Aeronian boundary abundance shifts from *Haplotaeniatum* to *Secuicollacta*, and *Orbiculopylorum* appears. In a poorly constrained interval (upper *turriculatus* to *crispus* zones) *Orbiculopylorum* and some species of *Haplotaeniatum* disappear, and the Inaniguttidae first appear in the formation. Also poorly constrained, across the Llandovery-Wenlock boundary species abundances are rearranged, and *Ceratoikiscum* and *Helenifore* appear. The Rhuddanian-Aeronian change may be associated with a global shift in graptoloid dominance. The upper *turriculatus* to *crispus* zones change is dubiously associated with the *Stimulograptus utilis* graptolid event. The Llandovery-Wenlock change apparently coincides with one or both of the *Cyrtograptus lapworthi* and *C. murchisoni* graptoloid events and the Ireviken oceanic event.

Changes in the radiolarian fauna allow the distinction of four biostratigraphically successive zones. The *Haplotaeniatum* Zone extends from basal Llandovery to topmost *cyphus* graptolite Zone. Boundaries of the next three zones are only approximate due to nonrecovery of radiolaria. The *Orbiculopylorum* Zone ranges from the top of the *Haplotaeniatum* Zone to presumably the *crispus* Zone. The Inaniguttid Zone presumably extends from the *crispus* Zone to the Llandovery-Wenlock boundary. The *Ceratoikiscum* Zone follows the Inaniguttid Zone; the top of the interval is not established.

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CHAPTER 1 - INTRODUCTION

Radiolaria are marine protists distinguished by the presence of a membrane, the central capsule, which segregate the cytoplasm into internal and external parts. Commonly, they produce an internal, siliceous skeleton. They are planktonic and occur at all latitudes and depths. In the modern oceans, their abundance and distribution are influenced by factors such as temperature and salinity (Anderson, 1983). They first appear in the fossil record in the Cambrian (Dong et al., 1997).

The great majority of works on Silurian Radiolaria have been published only since 1986. Only one significant work (Nazarov, 1975) was published prior to this time; other works were only brief faunal descriptions (Stürmer, 1952, 1966; Holdsworth, 1977; Goodbody, 1982) and the thin-section descriptions of Rüst (1892). Few papers consider the taxonomy of Llandovery Radiolaria (Nazarov, 1975; Goodbody, 1986; Noble et al., 1998; MacDonald, 1998, 1999; Kurihara and Sashida, 2000a; Noble and Maletz, 2000; Won et al., 2002); most of these consider only small portion a fauna or are stratigraphically limited. The present study is the first description of Llandovery radiolarians from a continuous succession since Nazarov (1975, 1988). Indeed, it is somewhat more complete than that of Nazarov (1975, 1988), which did not include the Rhuddanian, the lowest stage of the Llandovery.

Just as the taxonomy of Silurian radiolarians is only now becoming clear, so is the stratigraphic distribution of species. Several local radiolarian biostratigraphic schemes have been presented for Wenlock and higher strata (Furutani, 1990;

Wakamatsu et al., 1990; Noble, 1994; Kurihara and Sashida, 2000b). However, other than Nazarov's (1988) Llandovery through Wenlock *Haplotaeniatum tegimentum* Assemblage, the early Palaeozoic biozonation of Noble and Aitchison (2000) is the only attempt to characterize the Llandovery based on contained Radiolaria.

The presence of well-preserved Silurian Radiolaria in the Cape Phillips Formation of Nunavut was first reported by Thorsteinsson (1958). The Cape Phillips Formation is one of the finest laboratories for the study of early Palaeozoic Radiolaria. In addition to the fine preservation, graptolitic age control is well established and the radiolarians are contained in readily-digested carbonates rather than cherts. In spite of these benefits, study of the Cape Phillips radiolarians has been sporadic. Other than brief surveys of the fauna (Holdsworth, 1977; Goodbody, 1982) and the unpublished thesis of Goodbody (1981), no research on the Cape Phillips radiolarians was published until Goodbody's (1986) paper on the Palaeoscenidiidae from the uppermost Llandovery through lower Ludlow of the formation. As with Goodbody (1986), subsequent publications were of limited taxonomic extent (Renz,1988, Wenlock *Ceratoikiscum*; MacDonald, 1998, 1999, Archaeospicularia and the palaeoscenidiid *Insolitignum* from a single Llandovery graptolite zone).

The present study reports the Radiolaria from the Llandovery and lower Wenlock of the Cape Phillips Formation. It is the most stratigraphically complete study of Llandovery radiolarians since Nazarov (1975, 1988). With the graptolitic age control, the present study provides baseline data on radiolarian taxonomy and stratigraphic distribution for future comparitive studies. There are three objectives.

1) Systematically describe the radiolarians. Taxa are the basic data for practical applications of fossils, such as biostratigraphy, and must be well constrained. Owing to time constraints, this work remains incomplete. The entactinids (sensu lato) are not described here and the treatment of *Secuicollacta* remains a work in progress.

2) Biostratigraphy is an important application of fossils. Early Palaeozoic radiolarian biostratigraphy is becoming better defined, as best demonstrated in the recent zonation of Noble and Aitchison (2000). The present work records the stratigraphic ranges of species and characterizes intervals of strata based on the contained Radiolaria. Three intervals are recognized in the Llandovery and one in the Wenlock.

3) This study makes a preliminary attempt at determining if changes in the Llandovery radiolarian fauna coincide with globally recognized changes in other faunal groups. Five graptoloid and two conodont bioevents occur within the interval studied herein. Three of the graptoloid events and both conodont events are associated with eustatic drops in sea level. Three changes in the radiolarian fauna were observed. Changes at the Rhuddanian-Aeronian boundary and Llandovery-Wenlock boundary apparently coincide with graptolite and conodont faunal changes. Associating a change in the radiolarian fauna within the upper *turriculatus-crispus* zones with a small graptoloid event is equivocal.

CHAPTER 2 - STRATIGRAPHY AND LOCALITY

The Cape Phillips Formation

The Cape Phillips Formation was first described by Thorsteinsson (1958). It occurs at the surface and subsurface in an arcuate belt from Ellesmere Island in the northeast to Melville Island in the west. It is the lateral equivalent of the shallower water, autochthonous carbonates of the Allen Bay Formation and Read Bay Group. The formation is a thermally mature hydrocarbon source horizon which, except for its most basal portion, was deposited in mostly anoxic conditions (de Freitas et al., 1999). Thorsteinsson (1958) recognized three informal members with gradational contacts. Member A ranges from Ashgill to earliest late Llandovery. It predominantly consists of interbedded argillaceous limestone, dolostone, and calcareous or dolomitic shale. Shales are commonly petroliferous. Also found are lesser amounts of limestone, cherty limestone, cherty calcareous shale, and dolomitic limestone (Thorsteinsson, 1958; Melchin, 1989). Member B (late Llandovery) includes cherty argillaceous limestone, argillaceous limestone, cherty calcareous shale, cherty limestone, limestone, and calcareous shale. Unlike member A, the chert content is higher in member B, the amount of shale is reduced, and the shales are not petroliferous. Member B may be absent in some areas (Thorsteinsson, 1958; Melchin, 1989). Member C extends from the latest Llandovery to Early Devonian. The member is composed chiefly of calcareous shale and shale, with some limestone or argillaceous limestone (Thorsteinsson, 1958;

Melchin, 1989; Lenz and Melchin, 1990).

The Cape Phillips Formation is part of the Franklinian Basin which extends from Ellesmere Island in the northeast to Melville Island in the southwest. To the south and east of the basin lies the stable Arctic Platform. The Franklinian Basin is divided into the deeper-water Hazen Trough to the north and west, and an unstable shelf in the south and east. The boundary between the unstable shelf and deep-water basin moved cratonward from late Early Cambrian to Early Devonian; the Cape Phillips Formation occupied most of this unstable shelf from latest Ordovician to Early Devonian (Trettin et al, 1991; Melchin, 1989). Melchin (1989) noted that the Cape Phillips Formation was separated from the Hazen Trough by carbonate build-ups and apparently formed a distinct and continuous subbasin on the unstable shelf. This subbasin was referred to as the Cape Phillips Basin by Melchin (1989) and as the Cape Phillips Embayment by de Freitas et al. (1999).

The Cape Phillips Embayment resulted from a rapid transgression at the end of the Ordovician coupled with subsidence of the part of the unstable shelf (Trettin et al., 1991). By the end of this rearrangement, the carbonate platform had migrated ten to hundreds of kilometres east and south of its Ordovician position, and the shelf-to-basin transition was more ramplike (de Freitas et al., 1999). The transition from members A to B (lower upper Llandovery) marks the transition from open shelf conditions to a deeper, slope and basinal setting with a retreat of the platform. Coarser, resedimented sediments become more common in member B, and more so in member C (Melchin, 1989). Melchin (1987, 1989) suggested that this change in sedimentation marks a change from a more ramplike setting to one with greater slope-to-basin relief. A carbonate unit of resedimented limestone in the *sedgwickii* Zone might mark the beginning of this change in morphology (Melchin, 1989).

Study Sections

Material for this study was collected from three sections of the Cape Phillips Formation on Cornwallis Island, Nunavut (Figure 2.1). Graptolitic age control for the sections was provided by M. J. Melchin (personal commun., 2000).

Cape Manning 2 and Cape Manning 3 are located inland of Cape Manning, Cornwallis Island (75°26'42"N, 94°20'15"W, UTM Zone 15 463200 8373850 and 75°26'49"N, 94°18'40"W, UTM Zone 15 462475 8373500 respectively). Cape Manning 2 is a 114 m section with its base in the uppermost Ordovician *persculptus* Zone and top in the lower Telychian *turriculatus* Zone. The section consists of calcareous shale with intercalated sparse limestone beds, dolomitic shales, and some dolostone beds (Figure 2.2). Cape Manning 3 is separated from Cape Manning 2 by an interval of colluvium and is regarded as stratigraphically continuous with Cape Manning 2. The section is 170 m thick and composed of calcareous shale with intercalated calcarenitic debris flows and sparse limestone beds (Figure 2.2). The section is dated as Telychian (*crispus* to *sakmaricus* zones). More detailed lithologic descriptions are given in Appendix H. Sections described by MacDonald (1998, 1999) are approximately 1 km east of Cape Manning 3.

The Cape Phillips type section is located on the northeast shore of Cornwallis Island (75°37'18"N, 94°31'00"W, UTM Zone 15 457875 8393225). The measured 284 m of the section is composed of calcareous shales, argillaceous limestone, and limestone (Figure 2.2). The base is dated as Telychian (possibly *crispus* Zone) and the top is in the upper Sheinwoodian (*opimus-perneri* Zone). The Llandovery-Wenlock boundary is at 171 m. Radiolarian sampling in the Wenlock extended only to the top of the *instrenuus-kolobus* Zone. Detailed lithologic description of the sections is given in Appendix H.

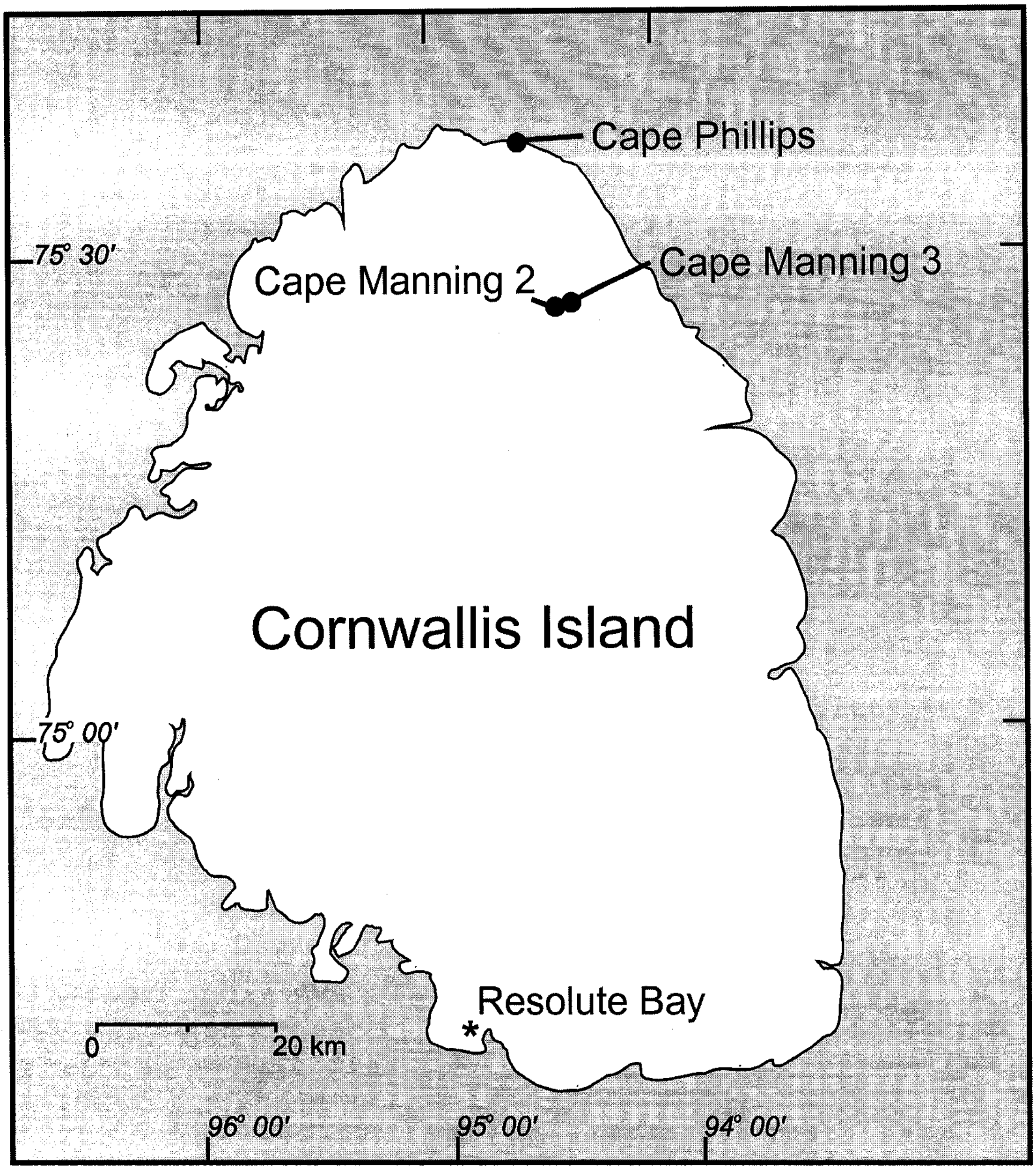
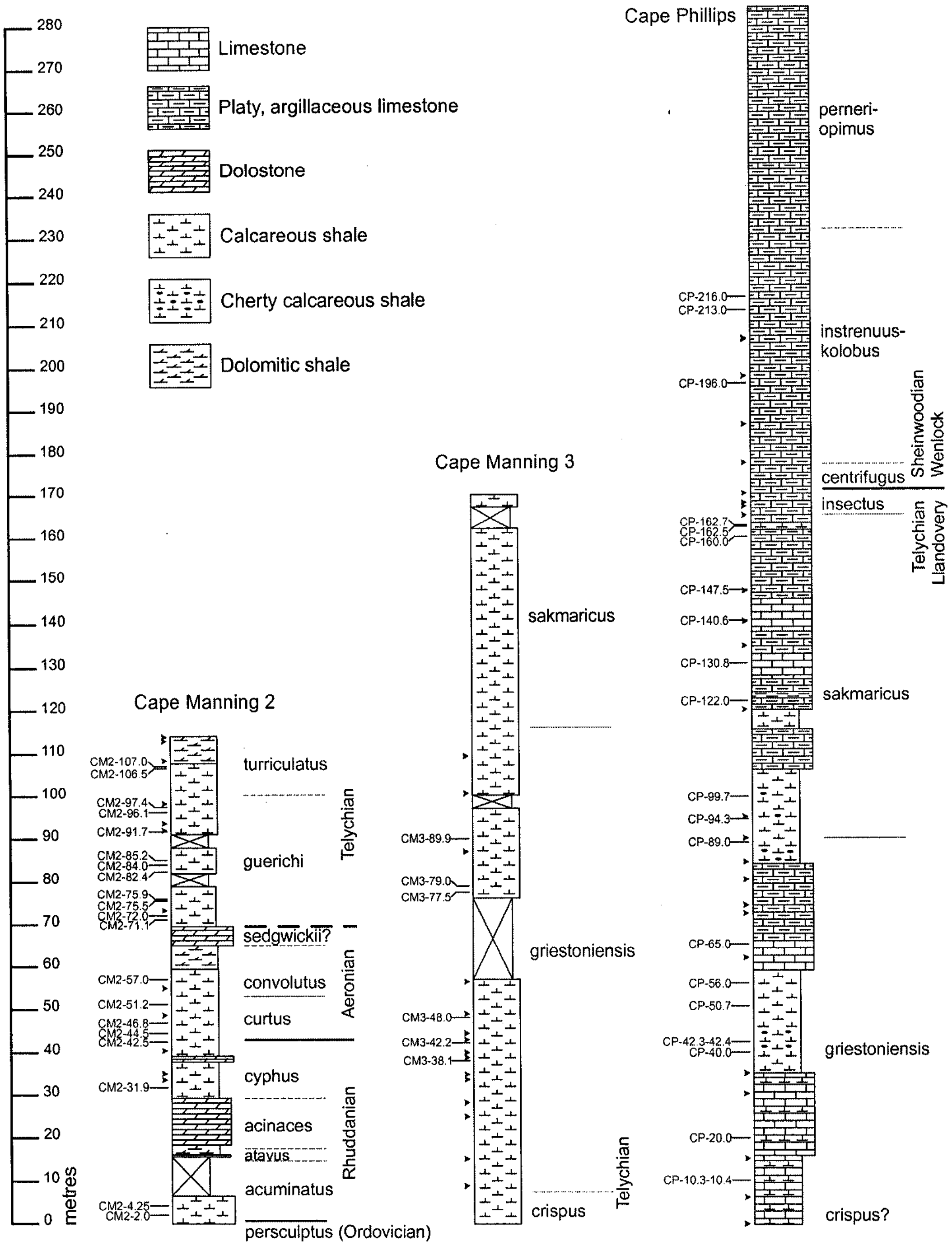


Figure 2.1

Map of Cornwallis Island, Nunavut, showing location of study sections.



Text-figure 2.2

Lithology of the two sections from Cape Manning and the Cape Phillips type section. Graptolite zones and Silurian stages are given. Labelled horizons yielded Radiolaria. Horizons marked by arrow heads are barren.

CHAPTER 3 - MATERIAL AND METHODOLOGY

Limestone concretions and bedded limestones were collected from the sections at Cape Manning and Cape Phillips, Cornwallis Island. Platy limestone samples were taken from the *insectus* through lower *instrenuus-kolobus* zones of the Cape Phillips section (165 to 186 m) due to an absence of concretions or thicker beds. Samples were collected as available in the sections with an attempt to obtain as even a distribution as possible. For Cape Manning 2, sampling was as close to 2 m intervals as possible, and as close to 3 m as possible for Cape Manning 3. For Cape Phillips, the sampling target was 5 m intervals. Samples were also collected for graptolites, conodonts, and Chitinozoa (research projects of M. Melchin, D. Jowett, and A. Soufiane, respectively). The sections were measured with a Jacob's staff. Graptolitic age control was determined by M. J. Melchin (personal commun., 2000).

Samples were etched in the laboratory using 10 percent HCl in order to determine the presence of radiolarians. Fifty to 100 g of each productive sample were digested in dilute HCl. Additional material was digested for some samples to increase the recovery of Radiolaria. The insoluble residue was collected on 0.177 mm and 63 μm sieves. A 1 mm top sieve removed larger debris. Capturing the residue on two sieves helped concentrate the radiolarians for study. This was particularly useful for obtaining an adequate abundance for preparation of strewn-mounted slides. The use of two sieves, however, does complicate the determination relative abundances.

Strewn-mounted slides were prepared for residue fractions with abundant radiolarians. These slides were prepared using the procedure given by Roeloph and Pisias (1986). Epofix Resin was used for the mounting medium of the majority of slides. Although previously used with success (MacDonald, 1998, 1999), this medium proved undesirable in this study. The epoxy often failed to set properly, and for many slides it became unstable after several months. Refrigeration controlled the degradation. Samples CP-160, CP-162.5, and CP-162.7 were mounted using Norland Optical No. 61. This medium appears quite stable and is very clear. The chief disadvantage with Norland Optical No. 61 is its viscosity, which hindered the penetration of the radiolarian skeletons.

The residue from the coarse and fine fractions or complete samples with inadequate yield for strewn slides were picked with a fine brush. These were examined under a dissecting microscope. Isolated individuals from either picked or strewn samples were examined under a JEOL JSM-5300 scanning electron microscope. Appendix A indicates which samples were strewn-mounted or picked.

For strewn-mounted fractions, as close to 400 radiolarians were counted per slide as was possible. These counts are given in Appendix B. Total number of radiolarians per fraction were calculated using the equations given by Roeloph and Pisias (1986). The data required for these calculations is given in Appendix A. Proportions of taxa in the fraction were determined from the slide count. Picked fractions or complete samples were simply counted. For samples with both fractions picked, about 40 percent achieved a total yield of less than 300. Data for the picked samples is given in Appendix C. For samples with the fine fraction strewn, but not the coarse fraction, the number of individuals recovered from coarse fraction was quite variable. These data are given in Appendix D.

This study is not intended to be a rigorous statistical study of the Cape Phillips radiolarians. It is desirable, however, to have an understanding of the proportions of taxa and total abundance of radiolarians for the samples. This required combining data for coarse and fine fractions. To obtain the total number of radiolarians per sample, the totals per fraction were added together. As indicated above, these values for the two size fractions may both be estimated from strewn-mount data, or one fraction is a strewn-mount estimate while the other fraction is an absolute, picked count. To obtain the relative abundances of taxa per sample, the relative abundance for a fraction was determined from the slide count. The number of individuals of a taxon per fraction was estimated by this percentage. The total of a taxon per sample was the addition of the number of individuals of the taxon in each fraction. This sample taxon total and the sample total number of individuals was then used to determine the relative abundance per sample. Again, for some samples, one fraction may be based on strewn-mount data, the other fraction an absolute, picked count. For samples for which both fractions were picked, total individuals and relative abundances were a matter of simple counting.

For all samples, the total number of individuals per sample was normalized against the mass of rock sample digested. These weights are given in Appendix E. All results -- relative abundances and individuals per gram -- were rounded to the nearest unit value. Samples were counted only once; a second preparation and count of each sample was not possible due to time constraints, but would determined reproducibility.

The sand fraction for CM3-89.9 was a picked fraction. Unfortunately, individuals of *Secuicollacta* from this fraction were lost. Consequently, relative abundances for this taxon and a final count of total radiolarians for this fraction could not be obtained. A preliminary total count had been made, and is included with the data for this sample. This allowed calculation of relative abundance for the other contained taxa and total radiolarians per gram sample. It is not known how accurate this preliminary, rather impromptu, count of the fraction actually is. This fraction, however, was also strewn mounted. This slide had a low count, however, calculations based on the strewn mount are in reasonable accord with the preliminary picked count results with the exception of *Labyrinthosphaera*. Results based on both the preliminary picked count and the strewn count are included herein. Unless otherwise stated in the text of the thesis, results are derived from the strewn-mount data.

CHAPTER 4 - THE CAPE PHILLIPS FORMATION RADIOLARIA

The three sections of the Cape Phillips Formation of this study provide a near continuous record of the Llandovery. The only major stratigraphic gap separates the Cape Manning 2 and Cape Manning 3 sections and encompasses the upper part of the *turriculatus* Zone and most of the *crispus* Zone. Forty-six of the 98 samples collected were productive (Figure 2.2). In terms of recovery of Radiolaria from the samples, the most significant gap is across the Llandovery-Wenlock boundary (*insectus* through lower *instrenuus-kolobus* zones). The upper *acuminatus* Zone to *acinaces* Zone also is not represented, largely due to the presence of dolostones rather than limestones in that interval. In spite of the three gaps noted here, the three study sections provided a fairly complete record of the Radiolaria from the base of the Llandovery into the lower Wenlock.

Overall, preservation in the Cape Phillips Formation is excellent. The preservation is variable, however, and can be poor enough to hinder identification of taxa. Particularly in the lower Llandovery the radiolarians are less well preserved. Radiolarians skeletons may be etched, recrystalized, overcoated with secondary silica or cemented detritus, or pyritized.

Radiolaria in the Cape Phillips Formation include the Palaeoscenidiidae (*Goodbodium, Insolitignum, Palaeodecaradium, Palaeoephippium, Palaeopyramidium,* and *Protoentactinia*), Haplotaeniatumidae (*Haplotaeniatum, Orbiculopylorum*), Inaniguttidae (genus indet.), Secuicollactidae (*Secuicollacta, Diparvapila, Rotasphaera*), the incertae sedis *Labyrinthosphaera*, entactinids (sensu lato), the albaillellarian genera *Ceratoikiscum* and *Helenifore*, and unassigned spongiose Spumellaria (see Systematic Palaeontology below). Of these taxa, the entactinids, Albaillellaria, and the spongiose Spumellaria are not treated taxonomically herein. This was due purely to time constraints on the thesis. These taxa are included in "unassigned" in taxa counts. The entactinids are ubiquitous in the three study sections. Because this group is not described herein, it is not referred to in the synopses below. The Albaillellaria and spongiose Spumellaria are restricted to the Wenlock samples from the Cape Phillips section.

Other taxa that occasionally occurred in the processed samples included graptolites, sponge spicules, bivalves, Chitinozoa, gastropods, ostracodes, mazuelloids, tasmanitids, scolecodonts, and very rare foraminifera.

In an unpublished work, Goodbody (1981) described Radiolaria from the uppermost Llandovery and Wenlock of the Cape Phillips Formation. His 1986 classification of the Palaeoscenidiidae was derived from that work. Goodbody (1981) followed the classification of Haeckel (1887). This hampers detailed comparison with the present study; however, the two works appear to be in accord taxonomically in the interval in which they overlap. The main focus of Goodbody (1981) was the Wenlock, and the taxa appear consistent with other reported Wenlock-Ludlow radiolarians. The present thesis extends the Palaeoscenidiidae lower into the Llandovery than indicated by Goodbody (1981, 1986). Goodbody's (1981) data indicate that some taxa not observed in the three Wenlock samples of the present study likely are present in the Wenlock.

These are the inaniguttids described herein, *Labyrinthosphaera*, *Secuicollacta malevola*, *S. sceptri*, and *S. resodiosae*. Goodbody (1981, 1986) noted that entactinids (sensu lato) are very rare in the Cape Phillips Formation and described two species which he assigned to *Polyentactinia*. The present study finds that the entactinids are not uncommon and are moderately diverse. A proper systematic treatment is yet to be done on this group from the formation. Goodbody's study relied primarily on reflected light microscopy which generally cannot resolve the internal features that identify the entactinids.

Four papers other than Goodbody (1986) have been published on the Cape Phillips radiolarians. Holdsworth (1977) presented a brief survey of the radiolarians and Renz (1988) presented the systematics of *Ceratoikiscum* from the Wenlock. Both used grab samples collected by R. Thorsteinsson in the 1950's. MacDonald (1998) described Archaeospicularia from four Llandovery samples (*sakmaricus* Zone) collected in 1994. MacDonald (1999) described the genus *Insolitignum* from the same four samples.

Synopses of Radiolaria from the Cape Manning and Cape Phillips sections

Cape Manning 2.–The species present in Cape Manning 2 are summarized in Tables 4.1 and 4.2. The relative abundance of genera and the Palaeoscenidiidae is given in Appendix F and Figure 4.1. Relative abundances of species are in Appendix G and Figure 4.2a and 4.2b.

The Cape Manning 2 section can be considered in two parts. In the lower third

CM2-42.5 and lower), *Haplotaeniatum* dominates the fauna (in excess of 60 percent) in three of four samples. *Haplotaeniatum ?cathenatum* and *H. ?labyrintheum* are the chief component of the lowest two samples; however, the relative abundances of the two were not determined owing to preservation. *Haplotaeniatum ?labyrintheum* exceeds 40 percent in the top sample dominated by *Haplotaeniatum* (CM2-42.5). *Secuicolacta* forms a lesser component of the fauna (approximately 10 percent), represented chiefly by *S. multispinosa*. *Secuicollacta parvitesta* and *S. resodiosae* appear at 31.9 and 42.5 m respectively. Because of the weaker preservation in this lower portion of Cape Manning 2, it is difficult to positively confirm other species of the genus. For example, either or both of *S. malevola* or *S. resodiosae* may be present in the lowest samples. *Diparvapila* is represented only as rare *D. fleischerorum*.

In the upper two-thirds of the Cape Manning 2 section, there is an increase in diversity and *Secuicollacta* becomes the dominant genus. Starting at 44.5 m, *Secuicollacta* becomes the dominant genus of the Cape Manning 2 section, ranging from approximately 34 to 100 percent of the fauna. All Llandovery species of the genus described in this thesis are present -- *S. bipola*, *S. glaebosa*, *S. malevola*, *S. multispinosa*, *S. parvitesta*, *S. resodiosae*, and *S. sceptri*. *Secuicollacta resodiosae* is numerically the more important species from mid *convolutus* Zone (CM2-57) to mid *guerichi* Zone (CM2-85.2), comprising approximately seven to nearly 80 percent of the fauna. Below this *S. resodiosae* optimum, *S. multispinosum* varies 15 to 24 percent in the *curtus* Zone. There is a second peak in *S. multispinosum* in the upper two samples of the section (*turriculatus* Zone, 10 and 49 percent). *Secuicollacta glaebosa* increases in abundance approximately (15 to 49 percent) coincident with the drop in *S. resodiosae* abundance.

Orbiculopylorum (not including species assigned to ?*Orbiculopylorum*) appears at the 42.5 m level of Cape Manning 2 and is initially represented by *Orbiculopylorum* species A and *Orbiculopylorum* species B. *Orbiculopylorum* cf. *O. marginatum* appears slightly higher. *Orbiculopylorum* peaks in abundance first in the uppermost *cyphus* Zone and base of the *curtus* Zone (11-13 percent), and again in the *guerichi* Zone (18-30 percent). There is no pattern to one species of the genus dominating over the other; indeed the upper peak is built largely upon poorly preserved specimens not assigned to species. The genus is rare above the *guerichi* Zone peak.

Haplotaeniatum adobensis appears in the upper two thirds of the Cape Manning section. The abundance of the genus is diminished in this part of the section, with two peaks of less than 20 percent in samples CM2-46.8 and CM2-84. The former is composed of *H.* ?*labyrintheum* whereas the second is of poorly preserved, unassigned specimens.

Also appearing in the upper portion of Cape Manning 2 are *Diparvapila hicocki*, *D. larseni*, *Rotasphaera severa*, *Rotasphaera* species A, *Rotasphaera* species B, *Labyrinthosphaera macdonaldi*, and *Labyrinthosphaera* species B. For the most part these form a small, but noticeable part of the fauna. Of these taxa, *Diparvapila* is the more important numerically in the uppermost part of the section, forming approximately 20 percent of the fauna in sample CM2-106.5. Most belong to *D. fleischerorum*; however, the caveat must be noted that distinguishing *D. fleischerorum* from *D. larseni* can be difficult in picked material. The importance of *D. fleischerorum* may in part be an artefact.

The Palaeoscenidiidae are uncommon throughout the whole of the Cape Manning 2 section. The family is largely represented by unassigned specimens. Maximum abundance is approximately 16 percent in CM2-96.1. Five identified species are *Insolitignum dissimile*, *Palaeoephippium bifurcum*, *P. radices*, *Palaeoephippium spinosum*, and *Palaeopyramidium spinosum*. All of these are rare.

The number of radiolarians per gram sample varies from less than 1 to 113. The minimal values are concentrated in the *guerichi* Zone (CM2-7.5 to CM2-84). These data are presented in Appendix E and Figure 4.7.

Cape Manning 3.–The species present in Cape Manning 3 are summarized in Tables 4.1 and 4.3. The relative abundance of genera and the Palaeoscenidiidae is given in Appendix F and Figure 4.3. Relative abundances of species are in Appendix G and Figure 4.4.

As with the upper portion of the Cape Manning 2 section, *Secuicollacta* is more abundant than other genera in the Cape Manning 3 section. However, the abundance is lower than in the upper part of Cape Manning 2, with values between approximately 24 and 62 percent. The species of the genus are the same as those in the Cape Manning 2 section. *Secuicollacta glaebosa* and *S. malevola* are numerically the two more important species with *S. glaebosa* forming approximately 20 percent of the fauna in one sample.

The Palaeoscenidiidae become an important part of the fauna, exceeding 30 percent of the fauna in two samples. More species are present than in the Cape Manning

2 section. *Goodbodium flammatum*, *G. rarispinosum*, *Insolitignum cancellatum*, *Palaeodecaradium apertum*, *P. umbelliforme*, and *Palaeopyramidium spinosum* occur in addition to the five species noted in Cape Manning 2. Almost all of the Palaeoscenidiidae present in the section are assigned to *Insolitignum*. *Insolitignum dissimile* dominates the genus in all but sample CM2-38.1, in which *I. cancellatum* is slightly more abundant (17 versus 13 percent for *I. dissimile*).

Overall, *Diparvapila* is only slightly less abundant than the Palaeoscenidiidae. Of the three species also found in Cape Manning 2, only *D. hicocki* exceeds approximately 6 percent of the fauna in two sample. *Diparvapila* species A and *Diparvapila* species B are also found, but are rare.

Rotasphaera is slightly more abundant than in Cape Manning 2, and varies between approximately two to six percent of the fauna. The species are the same as at Cape Manning 2. None of the species exceeds approximately two precent of the fauna.

Haplotaeniatum, which was so prevalent in the Cape Manning 2 section, is quite rare in Cape Manning 3. It is noted in only two samples and does not exceed two percent of the fauna. The genus is represented only by *Haplotaeniatum* species A. *Orbiculopylorum* is completely absent from the section.

Labyrinthosphaera is more abundant than in Cape Manning 2, and forms three percent or more of the fauna. It is represented chiefly by *L. macdonaldi*. *Labyrinthosphaera* species A and *Labyrinthosphaera* species B are both rare.

The Inaniguttidae are present in the Cape Manning 3 section, and are represented by rare specimens of Inaniguttid species A, Inaniguttid species B, and Inaniguttid species C.

The number of radiolarians per gram sample varies from 26 to 1781. The 1781 radiolarians per gram sample (CM3-77.5) is an anomaly with the next largest value being 458 radiolarians per gram in CM3-79. Data are presented in Appendix E and Figure 4.7.

Cape Phillips.–The species present in Cape Phillips are summarized in Table 4.4. The relative abundance of genera and the Palaeoscenidiidae is given in Appendix F and Figure 4.5a and 4.5b. Relative abundances of species are in Appendix G and Figure 4.6a and 4.6b.

For most of the Llandovery of the Cape Phillips section, *Secuicollacta* is the more important group numerically, with maxima of over 90 percent in samples CP-89 and CP-99.7. However, in the upper *sakmaricus* Zone and Wenlock the abundance is diminished. A minimum of three percent of the fauna occurs in sample CP-160. The species of *Secuicollacta* found in the Cape Phillips section are the same as in the previous two sections, with the addition on *Secuicollacta* species A and *Secuicollacta* cf. *S. resodiosae* in the Wenlock. *Secuicollacta malevola*, *S. parvitesta*, *S. resodiosae*, and *S. sceptri* were not observed in the three Wenlock samples. Overall, *Secuicollacta malevola* is the more numerically important species forming a maximum of nearly 80 percent of the fauna in CP-89. However, the abundance of the species diminishes above sample CP-122.

The decline in the abundance of *Secuicollacta* in the *sakmaricus* Zone coincides with an increase in the abundance of Palaeoscenidiidae. The relative abundance of the palaeoscenidiids approaches 60 percent in the upper Llandovery and has a maximum abundance of approximately 75 percent in the Wenlock. In two samples from the *griestoniensis* Zone (CP-40 and CP-56), it exceeds 65 percent of the fauna. Most of the Llandovery samples with high abundances of palaeoscenidiids are dominated by *Insolitignum*. In the Wenlock, *Insolitignum* and *Palaeoephippium* form roughly the same proportion of the fauna, approximately 13 to 30 percent. In the Llandovery, *I. dissimile* is the dominant species of the genus in most samples. Higher in the Llandovery and Wenlock, *I. cancellatum* either roughly equals the abundance of *I. dissimile* or forms the major portion of the genus. *Goodbodium* ranks third in numerical importance in the Wenlock after *Inslotignum* and *Palaeoephippium*, but does not exceed 10 percent of the fauna. *Goodbodium flammatum* dominates the genus. The species of Palaeoscenidiidae in the Cape Phillips section are the same as in Cape Manning 2 and 3, with the addition of *Insolitignum vivanima*, which is restricted to the uppermost Llandovery, and *Palaeodecaradium gordoni*, which appears in the Wenlock.

Below the mid-*sakmaricus* Zone, *Diparvapila* forms approximately three to nearly 30 percent of the radiolarian fauna. It declines to persistently low abundances roughly coincident with abundance decline of *Secuicollacta*. All species observed in the two Cape Manning sections are present in the Cape Phillips section; however, only *D. fleischerorum* was observed in the three Wenlock samples.

As with the Cape Manning 3 section, *Haplotaeniatum* is a minor component of the fauna, generally absent or not exceeding one percent. Three species are recognized -

- *Haplotaeniatum* cf. *H. raneatela* and *Haplotaeniatum* species A, and *Haplotaeniatum* species B (in one sample). *Orbiculopylorum* (excluding ?*Orbiculopylorum* species C) is absent from the section.

The Inaniguttidae vary in abundance through the Llandovery of the Cape Phillips section, ranging from absent to approximately 14 percent of the fauna. Identification of taxa up-section becomes problematic owing to incomplete preservation. In addition to the species observed in the Cape Manning 3 section, Inaniguttid cf. species A and Inaniguttid species D were observed. The inaniguttids were not noted in the Wenlock samples.

As with the Inaniguttidae, *Labyrinthosphaera* varies in abundance, with a maximum of approximately 13 percent. It is rare in the Wenlock. *Labyrinthosphaera macdonaldi* generally dominates the genus; however, in the uppermost Llandovery samples, *Labyrinthosphaera* species A is either more abundant than *L. macdonaldi* or essentially equal. *Labyrinthosphaera macdonaldi* was not observed in the Wenlock samples.

Rotasphaera is a fairly minor part of the Cape Phillip section fauna, and does not exceed approximately four percent. This is the only section in which *Rotasphaera* species B is observed. Other species are the same as the two Cape Manning sections.

Ceratoikiscum, *Helenifore*, and spongiose Spumellaria of unestablished affinity were observed only in the three Wenlock samples from the Cape Phillips section. These are not treated taxonomically herein. However, the presence of these distinguishes the three Wenlock samples from the Llandovery of the Cape Phillips Formation.

In the Llandovery of the Cape Phillips section, the number of radiolarians per gram sample varies from 1 to 731. In the three Wenlock samples, recovery increases markedly with yields of 3100 to 5885 radiolarians per gram. These data are presented in Appendix E and Figure 4.7.

TABLE 4.1–Occurrence of spicular radiolarians in samples from Cape Manning. Samples not indicated here contained no spicular taxa presented in this study. 'X' indicates present, '-' indicates absent, '?' indicates a provisional identification.

	CM2-44.5	CM2-96.1	CM2-106.5	CM3-38.1	CM3-42.2	CM3-48	CM3-77.5	CM3-79	CM3-89.9
Goodbodium flammatum	-	-	-	-	-	-	X	?	-
Goodbodium rarispinosum	-	-	-	-	?	X	X	-	-
Insolitignum cancellatum	-	-	-	X	X	X	X	X	X
Insolitignum dissimile	-	-	X	X	X	X	X	X	X
Palaeodecaradium apertum	-	-	-	-	X	-	-	-	-
Palaeodecaradium umbelliforme	-	-	-	-	-	X	X	X	-
Palaeoephippium bifurcum	-	X	-	X	-	-	X	-	-
Palaeoephippium radices	-	-	X	-	X	X	-	-	-
Palaeoephippium spinosum	-	-	X	-	X	-	X	-	-
Palaeopyramidium spinosum	-	-	-	-	-	-	X	-	X
Protoentactinia tricorne	X	-	-	-	-	-	-	-	-

TABLE 4.2–Occurrence of spherical radiolarians in samples from the Cape Manning 2. Symbols as for Table 4.1.

	CM2-2.0	CM2-4.25	CM2-31.9	CM2-42.5	CM2-44.5	CM2-46.8	CM2-51.2	CM2-57	CM2-71.1	CM2-72	CM2-75.5
Diparvapila fleischerorum	X	X	-	X	X	X	-	-	-	-	-
Diparvapila hicocki	-	-	-	-	-	?	X	-	-	-	-
Diparvapila larseni	-	-	-	-	-	X	X	-	-	X	-
Diparvapila n. sp. B	-	-	-	-	-	-	-	-	-	-	-
Secuicollacta bipola	-	-	-	-	-	-	-	-	-	-	X
Secuicollacta glaebosa	-	-	-	-	-	?	-	-	-	X	-
Secuicollacta malevola	?	-	?	?	?	X	X	X	X	X	X
Secuicollacta multispinosa	X	X	X	X	X	X	-	-	X	X	-
Secuicollacta parvitesta	-	-	X	X	X	X	X	X	X	X	X
Secuicollacta resodiosae	-	-	-	X	X	?	X	X	X	X	X
Secuicollacta sceptri	-	-	?	-	-	X	X	-	X	X	X
Rotasphaera severa	-	-	-	-	-	X	-	-	-	-	?
Rotasphaera sp. A	-	-	-	-	-	?	-	-	?	-	-
Rotasphaera sp. C	-	-	-	-	-	-	-	-	-	-	-

Continues next page.

TABLE 4.2–Continued.

	CM2-75.9	CM2-82.4	CM2-84	CM2-85.2	CM2-91.7	CM2-96.1	CM2-97.4	CM2-106.5	CM2-107
Diparvapila fleischerorum	-	-	-	-	X	?	?	X	?
Diparvapila hicocki	-	-	-	-	X	-	-	X	-
Diparvapila larseni	-	-	-	-	X	-	-	X	-
Diparvapila n. sp. B	-	-	-	-	-	-	-	?	-
Secuicollacta bipola	X	-	-	?	-	-	-	-	-
Secuicollacta glaebosa	-	-	-	-	X	-	-	X	-
Secuicollacta malevola	X	X	-	X	X	?	-	X	-
Secuicollacta multispinosa	-	X	-	X	X	?	X	X	X
Secuicollacta parvitesta	?	X	-	X	X	-	-	X	-
Secuicollacta resodiosae	X	?	X	X	X	-	-	X	-
Secuicollacta sceptri	?	-	-	X	X	-	-	X	-
Rotasphaera severa	-	-	-	?	X	-	-	?	-
Rotasphaera sp. A	-	-	-	-	X	-	-	X	-

Continues next page.

TABLE 4.2–continued.

	CM2-2.0	CM2-4.25	CM2-31.9	CM2-42.5	CM2-44.5	CM2-46.8	CM2-51.2	CM2-57	CM2-71.1	CM2-72	CM2-75.5
Haplotaeniatum adobensis	-	-	-	X	-	-	?	-	X	X	X
Haplotaeniatum ?cathenatum	X	X	-	?	X	-	X	-	-	-	-
Haplotaeniatum ?labyrintheum	X	X	X	X	X	X	X	-	-	-	-
Haplotaeniatum cf. H. raneatela	-	-	-	-	-	-	?	-	-	-	-
Haplotaeniatum sp. C	X	-	-	-	X	X	X	-	-	-	-
Orbiculopylorum cf. O. marginatum	-	-	-	-	-	-	-	-	X	X	X
Orbiculopylorum sp. A	-	-	-	X	X	?	-	-	-	-	-
Orbiculopylorum sp. B	-	-	-	X	X	X	X	-	?	?	?
?Orbiculopylorum sp C	-	-	-	X	X	X	?	-	-	?	-
?Orbiculopylorum sp. D	-	-	X	-	-	-	X	-	-	-	-
inaniguttid sp. B	-	-	-	-	-	-	-	-	-	-	-
Labyrinthosphaera macdonaldi	-	-	-	-	-	-	-	-	-	-	-
Labyrinthosphaera sp. B	-	-	-	-	-	-	-	-	-	-	-

Continues next page.

TABLE 4.2–continued.

	CM2-75.9	CM2-82.4	CM2-84	CM2-85.2	CM2-91.7	CM2-96.1	CM2-97.4	CM2-106.5	CM 2-107
Haplotaeniatum adobensis	X	-	-	X	X	-	-	?	-
Haplotaeniatum ?cathenatum	-	-	-	X	-	-	-	-	-
Haplotaeniatum ?labyrintheum	-	-	-	-	-	-	-	?	-
Haplotaeniatum cf. H. raneatela	-	-	-	-	-	-	?	-	-
Haplotaeniatum sp. C	-	-	-	-	-	-	-	-	-
Orbiculopylorum cf. O. marginatum	-	-	-	-	?	-	-	-	-
Orbiculopylorum sp. A	-	-	-	-	-	-	-	-	-
Orbiculopylorum sp. B	-	?	-	-	?	-	?	X	-
?Orbiculopylorum sp C	-	-	-	-	-	-	-	-	-
?Orbiculopylorum sp. D	-	-	-	-	-	-	-	-	-
inaniguttid sp. B	-	-	-	-	-	-	-	?	-
Labyrinthosphaera macdonaldi	-	-	-	-	X	-	-	X	-
Labyrinthosphaera sp. B	-	-	-	-	X	-	-	X	-

TABLE 4.3–Occurrence of spherical radiolarians in samples from the Cape Manning 3. Symbols as for Table 4.1.

	CM3-38.1	CM3-42.2	CM3-48	CM3-77.5	CM3-79	CM3-89.9
Diparvapila fleischerorum	X	X	X	X	X	X
Diparvapila hicocki	X	X	X	X	X	X
Diparvapila larseni	X	X	X	X	X	X
Diparvapila n. sp. A	-	-	-	X	X	-
Diparvapila n. sp. B	X	X	-	-	-	-
Secuicollacta bipola	X	X	X	X	X	X
Secuicollacta glaebosa	X	X	X	X	X	X
Secuicollacta malevola	X	X	X	X	X	X
Secuicollacta multispinosa	X	X	X	?	X	?
Secuicollacta parvitesta	X	-	-	-	-	-
Secuicollacta resodisae	X	?	X	X	X	X
Secuicollacta sceptri	X	X	X	X	X	X
Rotasphaera severa	-	X	X	X	X	-
Rotasphaera sp. A	X	X	X	X	X	X
Rotasphaera sp. C	X	X	X	X	X	X
Haplotaeniatum sp. A	-	-	-	X	-	X
inaniguttid sp. A	-	X	X	-	-	-
inaniguttid sp. B	-	-	-	X	-	X
inaniguttid sp. C	-	-	-	-	-	X
Labyrinthosphaera macdonaldi	X	X	X	X	X	X
Labyrinthosphaera sp. A	X	-	-	X	?	?
Labyrinthosphaera sp. B	X	X	-	X	?	X

TABLE 4.4–Occurrence of radiolarians in samples from Cape Phillips. Symbols as for Table 4.1.

	CP-10.3-10.4	CP-20	CP-40	CP-42.3-42.4	CP-50.7	CP-56	CP-65	CP-89	CP-94.3	CP-99.7
Diparvapila fleischerorum	?	X	X	X	?	-	?	-	X	X
Diparvapila hicocki	X	X	X	X	X	-	X	-	X	X
Diparvapila larseni	?	X	X	X	?	-	?	X	X	X
Diparvapila n. sp. A	-	-	X	-	X	-	-	-	?	-
Diparvapila n. sp. B	-	X	-	-	-	-	-	-	-	-
Secuicollacta bipola	X	X	X	X	-	X	-	-	X	-
Secuicollacta glaebosa	?	X	X	X	X	-	X	?	X	X
Secuicollacta malevola	X	X	X	X	X	X	X	-	X	X
Secuicollacta multispinosa	X	X	X	X	X	-	-	X	X	X
Secuicollacta parvitesta	-	-	-	-	-	-	-	-	X-	-
Secuicollacta resodiosae	-	X	X	X	X	?	X	-	X	X
Secuicollacta cf. S. resodiosae	-	-	-	-	-	-	-	-	-	-
Secuicollacta sceptri	-	X	X	X	X	-	-	X	X	X
Secuicollacta n. sp. A	-	-	-	-	-	-	-	-	-	-

Continues next page.

TABLE 4.4–continued.

	CP-122	CP-130.8	CP-140.6	CP-147.5	CP-160	CP-162.5	CP-162.7	CP-196	CP-213	CP-216
Diparvapila fleischerorum	?	X	-	-	-	-	X	X	X	X
Diparvapila hicocki	X	X	-	-	-	-	-	-	-	-
Diparvapila larseni	?	X	-	?	-	-	-	-	-	-
Diparvapila n. sp. A	-	-	-	-	-	-	-	-	-	-
Diparvapila n. sp. B	-	-	-	-	-	-	-	-	-	-
Secuicollacta bipola	-	-	-	-	-	-	-	-	-	-
Secuicollacta glaebosa	X	X	-	X	?	X	?	X	X	X
Secuicollacta malevola	X	X	-	X	-	X	X	-	-	-
Secuicollacta multispinosa	-	X	?	?	-	-	-	X	X	X
Secuicollacta parvitesta	-	-	-	-	-	-	-	-	-	-
Secuicollacta resodiosae	X	X	X	X	-	-	-	-	-	-
Secuicollacta cf. S. resodiosae	-	-	-	-	-	-	-	X	X	-
Secuicollacta sceptri	X	X	?	X	-	?	-	-	-	-
Secuicollacta n. sp. A	-	-	-	-	-	-	-	X	X	X

Continues next page.

TABLE 4.4–continued.

	CP-10.3-10.4	CP-20	CP-40	CP-42.3-42.4	CP-50.7	CP-56	CP-65	CP-89	CP-94.3	CP-99.7
Rotasphaera severa	-	X	X	X	?	-	-	-	X	-
Rotasphaera sp. A	-	X	X	X	X	-	-	-	X	-
Rotasphaera sp. B	-	X	-	-	-	-	-	-	?	-
Rotasphaera sp. C	-	X	X	X	-	-	-	-	X	X
Haplotaemiatum cf. H. ranealtela	-	X	-	-	-	-	X	-	X	-
Haplotaeniatum sp. A	X	?	-	X	-	X	X	-	X	-
Haplotaeniatum sp. B	-	X	-	-	-	-	-	-	-	-
?Orbiculopylorum sp. C	X	-	-	-	-	-	-	-	-	-
inaniguttid sp. A	-	-	-	-	X	X	-	-	-	-
inaniguttid cf. sp. A	-	X	-	X	-	-	-	-	-	-
inaniguttid sp. B	X	X	-	X	X	-	X	-	-	-
inaniguttid sp. C	X	X	-	X	X	-	-	X	-	-
inaniguttid sp. D	X	X	-	-	-	-	-	-	-	-
Labyrinthosphaera macdonaldi	-	X	X	X	X	X	X	-	X	-
Labyrinthosphaera sp. A	-	?	-	X	?	-	?	-	X	-
Labyrinthosphaera sp. B	-	-	-	X	X	-	X	-	X	-

Continues next page.

TABLE 4.4–continued.

	CP-122	CP-130.8	CP-140.6	CP-147.5	CP-160	CP-162.5	CP-162.7	CP-196	CP-213	CP-216
Rotasphaera severa	-	X	X	-	X	X	X	X	X	X
Rotasphaera sp. A	-	X	-	-	-	-	-	X	X	-
Rotasphaera sp. B	-	-	-	-	-	-	-	-	-	-
Rotasphaera sp. C	-	X	-	-	-	-	-	-	-	-
Haplotaemiatum cf. H. ranealtela	X	-	X	X	?	-	-	-	X	-
Haplotaeniatum sp. A	?	-	?	?	-	-	-	-	-	-
Haplotaeniatum sp. B	-	-	-	-	-	-	-	-	-	-
?Orbiculopylorum sp. C	-	-	-	-	-	-	-	-	-	-
inaniguttid sp. A	-	-	X	X	-	X	X	X	X	X
inaniguttid cf. sp. A	-	-	-	-	-	-	-	-	-	-
inaniguttid sp. B	?	-	-	-	X	-	-	-	-	-
inaniguttid sp. C	-	-	-	-	-	-	-	-	-	-
inaniguttid sp. D	-	-	-	-	-	-	-	-	-	-
Labyrinthosphaera macdonaldi	?	X	X	X	-	X	X	-	-	-
Labyrinthosphaera sp. A	X	X	?	X	X	X	X	-	X	-

Continues next page.

TABLE 4.4–continued.

	CP-10.3-10.4	CP-20	CP-40	CP-42.3-42.4	CP-50.7	CP-56	CP-65	CP-89	CP-94.3	CP-99.7	CP-122
Goodbodium flammatum	-	-	?	-	-	-	-	-	-	-	-
Goodbodium rarispinosum	-	-	-	X	-	-	-	-	-	-	-
Insolitignum cancellatum	X	X	X	X	X	X	X	-	X	-	X
Insolitignum dissimile	X	X	X	X	X	X	X	-	X	X	X
Insolitignum vivanima	-	-	-	-	-	-	-	-	-	-	-
Palaeodecaradium apertum	-	-	-	-	X	-	-	-	-	-	-
Palaeodecaradium gordoni	-	-	-	-	-	-	-	-	-	-	-
Palaeodecaradium umbelliforme	-	X	X	X	X	X	X	X	X	-	X
Palaeoephippium bifurcum	-	-	-	-	X	X	-	-	-	-	-
Palaeoephippium radices	-	-	-	-	-	-	-	-	-	-	-
Palaeoephippium spinosum	-	-	-	-	-	-	-	X	-	-	-
Palaeopyramidium spinosum	-	-	-	X	-	X	X	-	-	-	X
Protoentactinia tricorne	-	-	-	-	-	-	-	-	-	-	-

Continues next page.

TABLE 4.4—continued.

	CP-130.8	CP-140.6	CP-147.5	CP-160	CP-162.5	CP-162.7	CP-196	CP-213	CP-216
Goodbodium flammatum	X	-	X	X	-	-	X	X	X
Goodbodium rarispinosum	-	-	-	-	-	X	X	X	X
Insolitignum cancellatum	X	X	X	X	X	X	X	X	X
Insolitignum dissimile	X	X	X	X	X	X	X	X	X
Insolitignum vivanima	-	-	X	X	-	X	-	-	-
Palaeodecaradium apertum	-	-	-	-	-	-	X	X	X
Palaeodecaradium gordoni	-	-	-	-	-	-	X	X	X
Palaeodecaradium umbelliforme	X	X	X	X	X	X	X	X	X
Palaeoephippium bifurcum	-	X	X	-	X	X	X	X	X
Palaeoephippium radices	X	-	-	-	X	X	X	X	X
Palaeoephippium spinosum	-	-	-	-	X	X	X	X	X
Palaeopyramidium spinosum	X	X	X	-	X	X	-	X	X

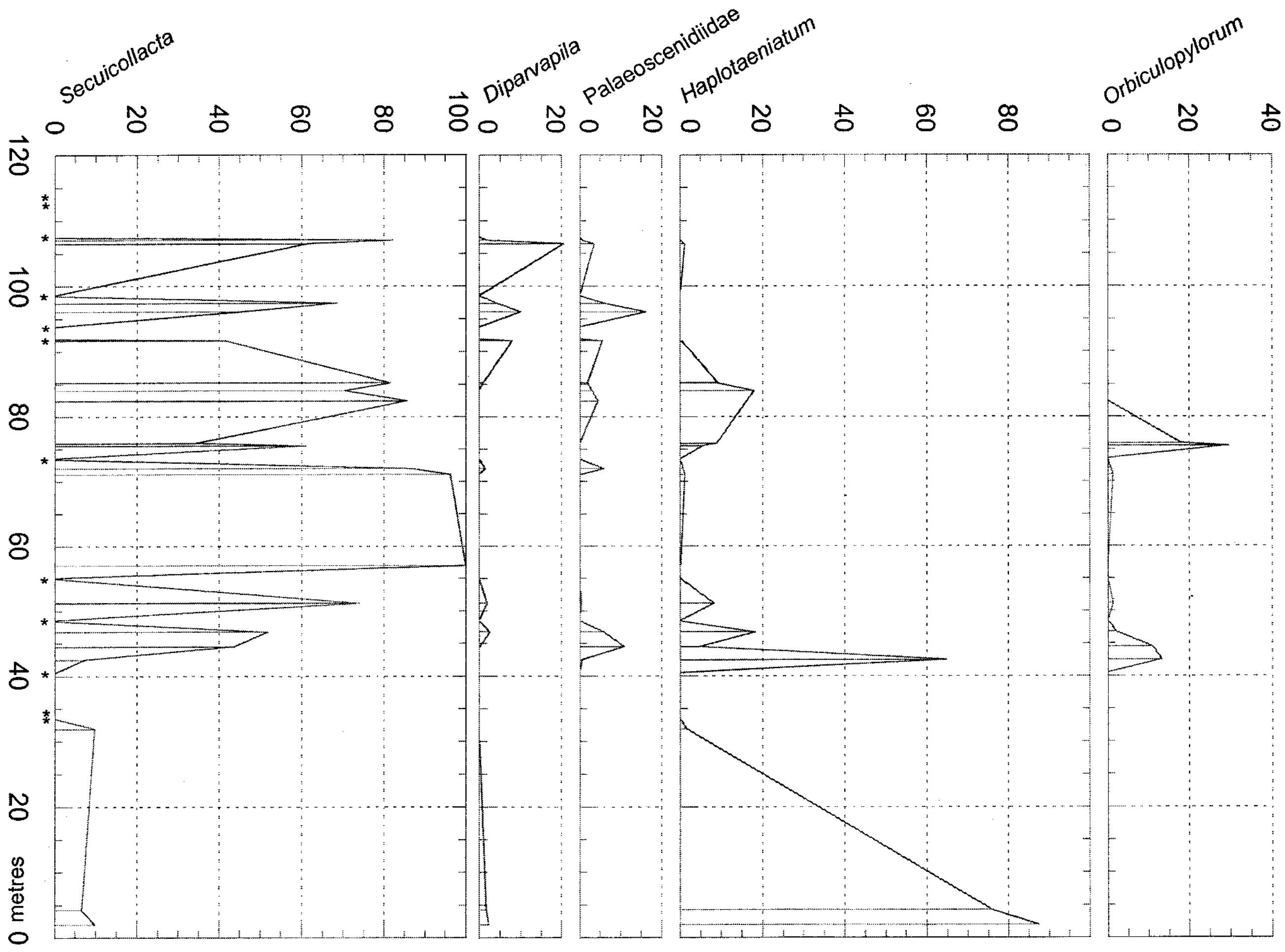


Figure 4.1

Relative abundance (%) of genera and Palaeoscenidiidae from the Cape Manning 2 section. Asterisks indicate barren horizons.

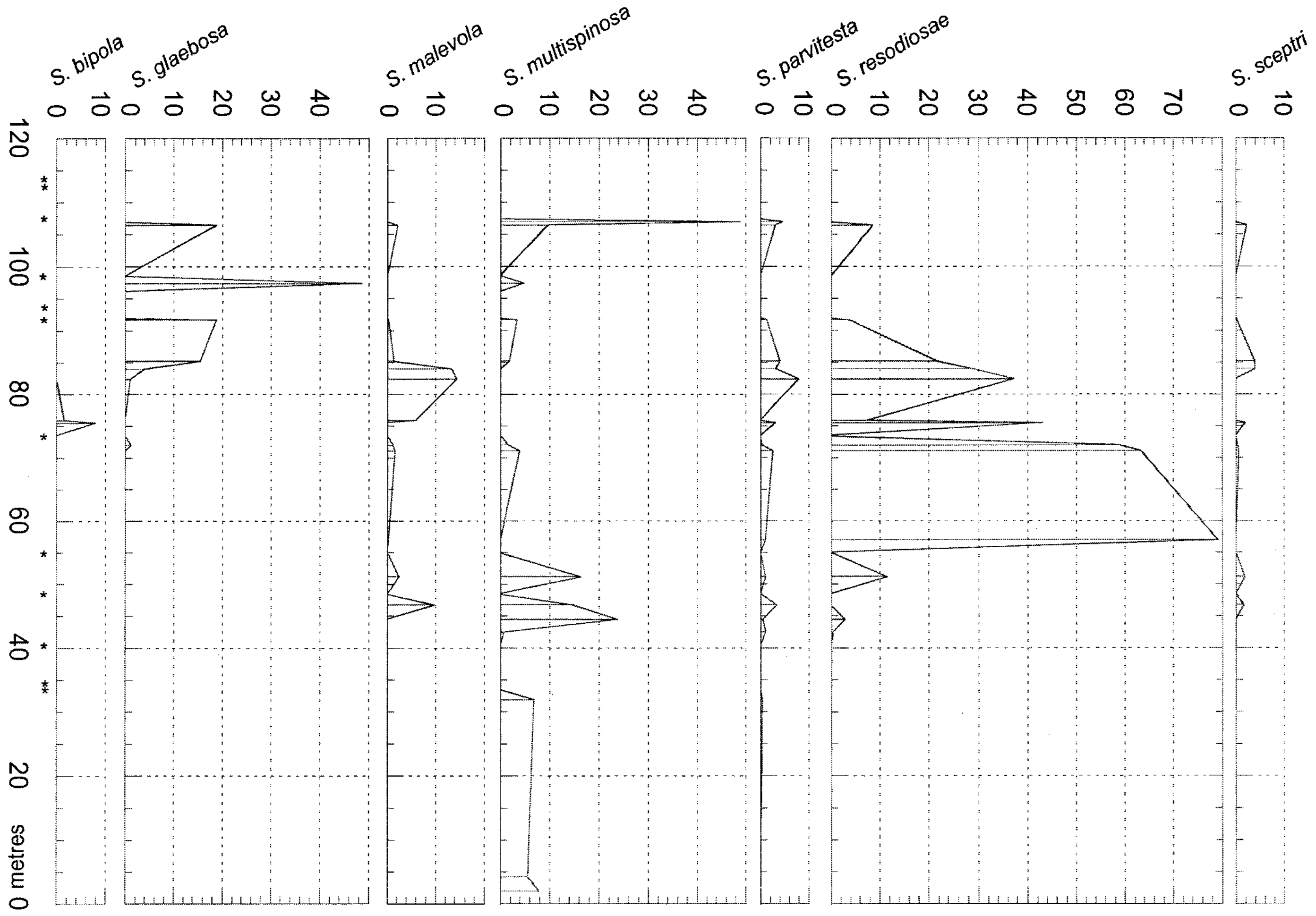


Figure 4.2a

Relative abundances (%) of selected species from the Cape Manning 2 section. Asterisks indicate barren horizons.

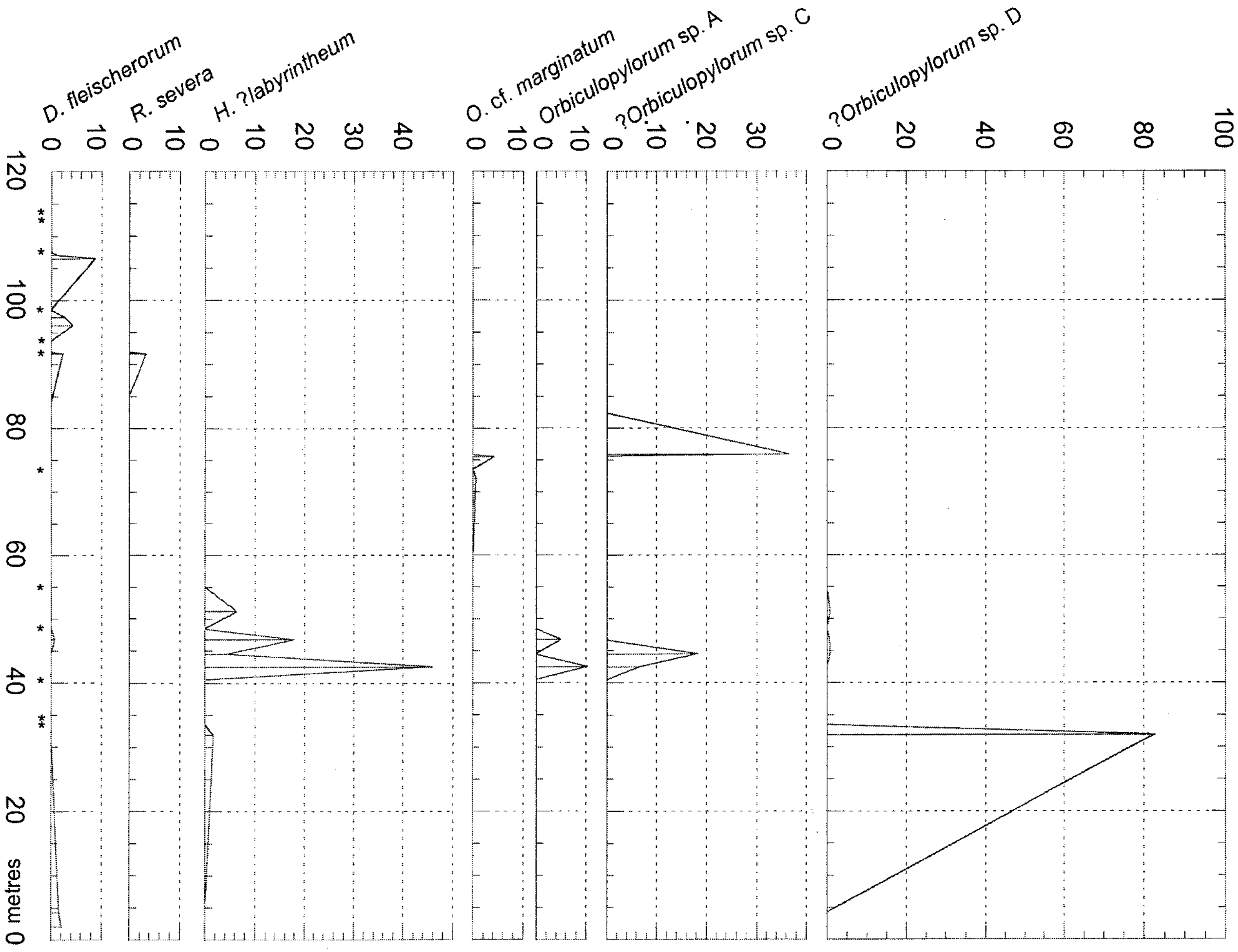


Figure 4.2b

Relative abundances (%) of selected species from the Cape Manning 2 section. Asterisks indicate barren horizons.

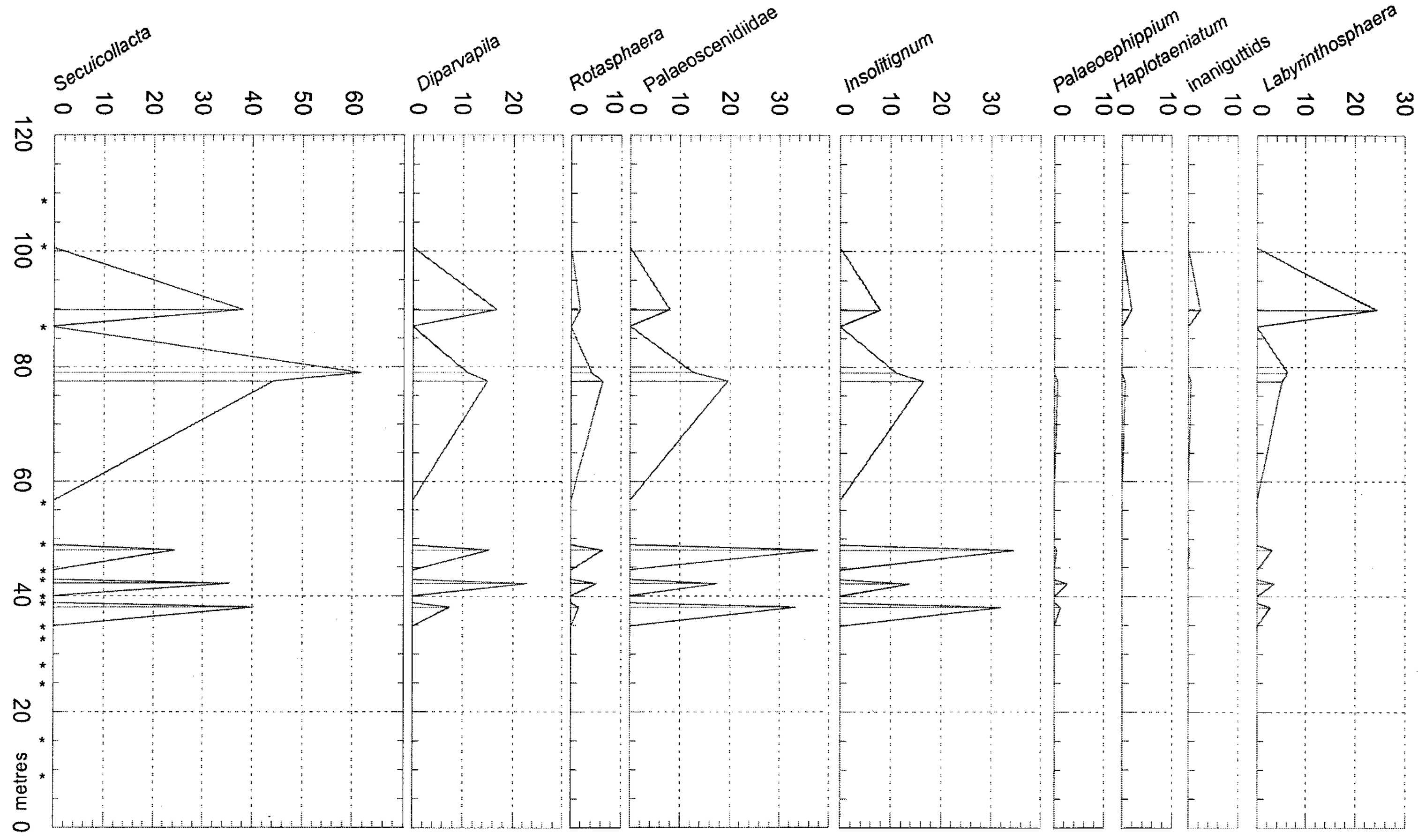


Figure 4.3

Relative abundances (%) of genera, Palaeoscenidiidae and Inaniguttidae from the Cape Manning 3 section. Asterisks indicate barren horizons.

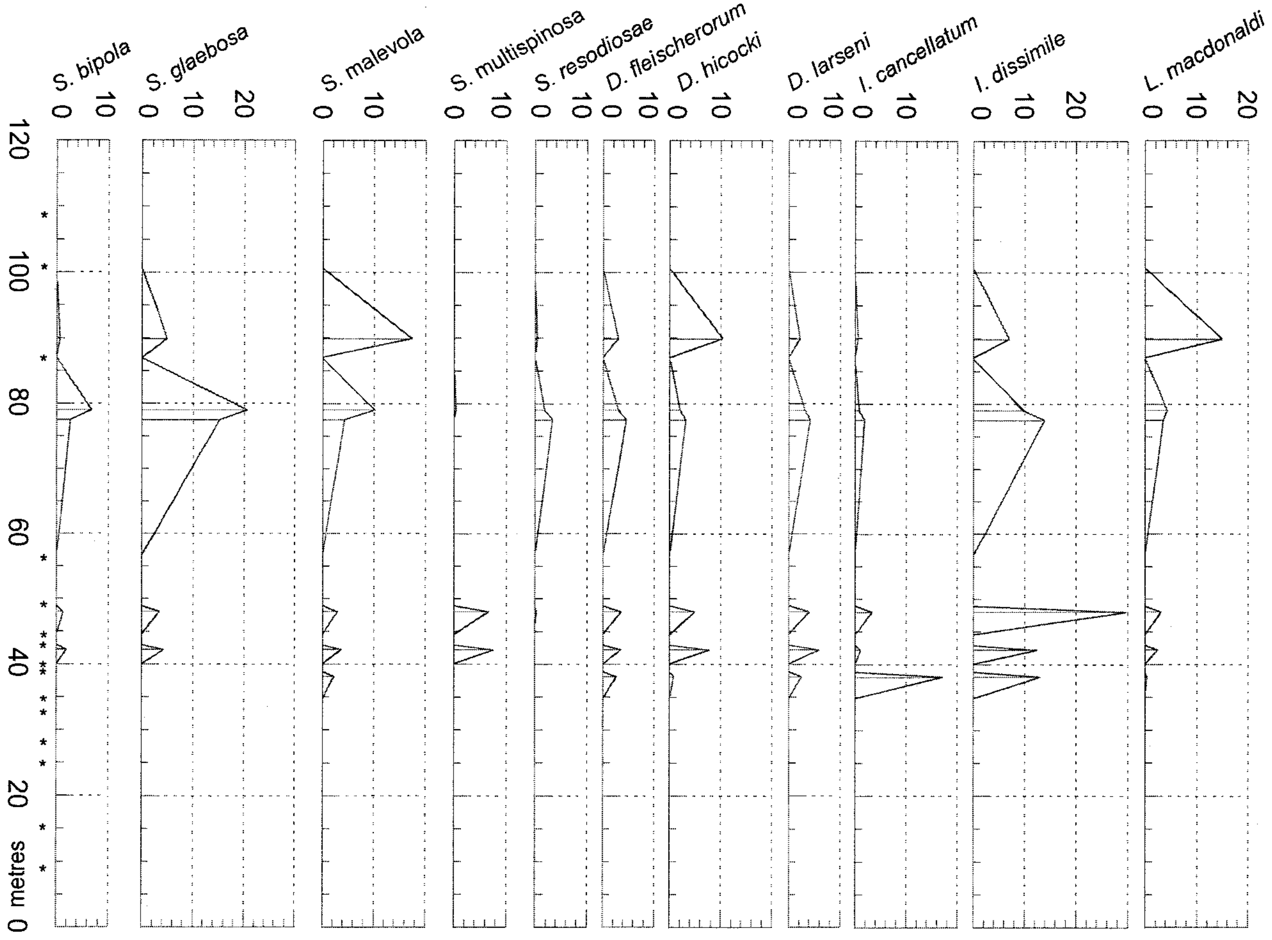


Figure 4.4

Relative abundances (%) of selected species from the Cape Manning 3 section. Asterisks indicate barren horizons.

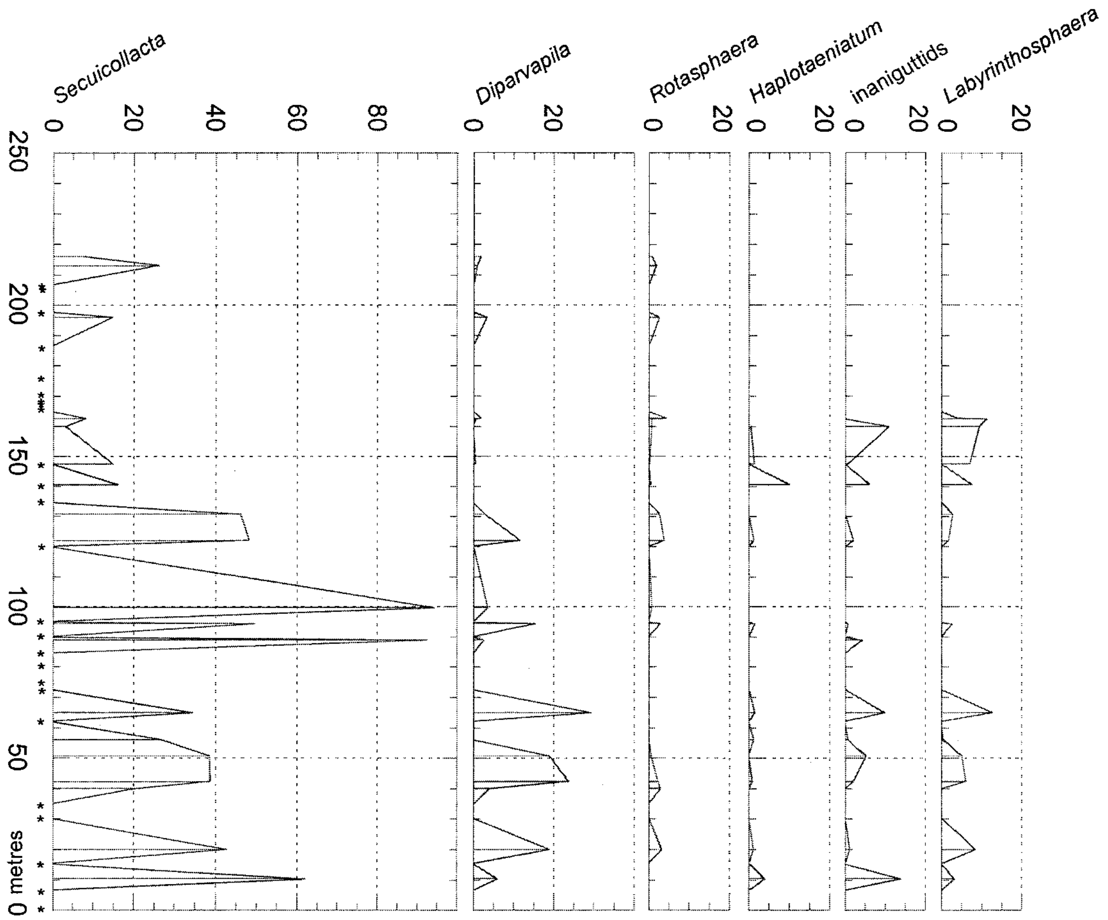


Figure 4.5a

Relative abundances (%) of genera, Palaeoscenidiidae, and Inaniguttidae from the Cape Phillips section. Asterisks indicate barren horizons.

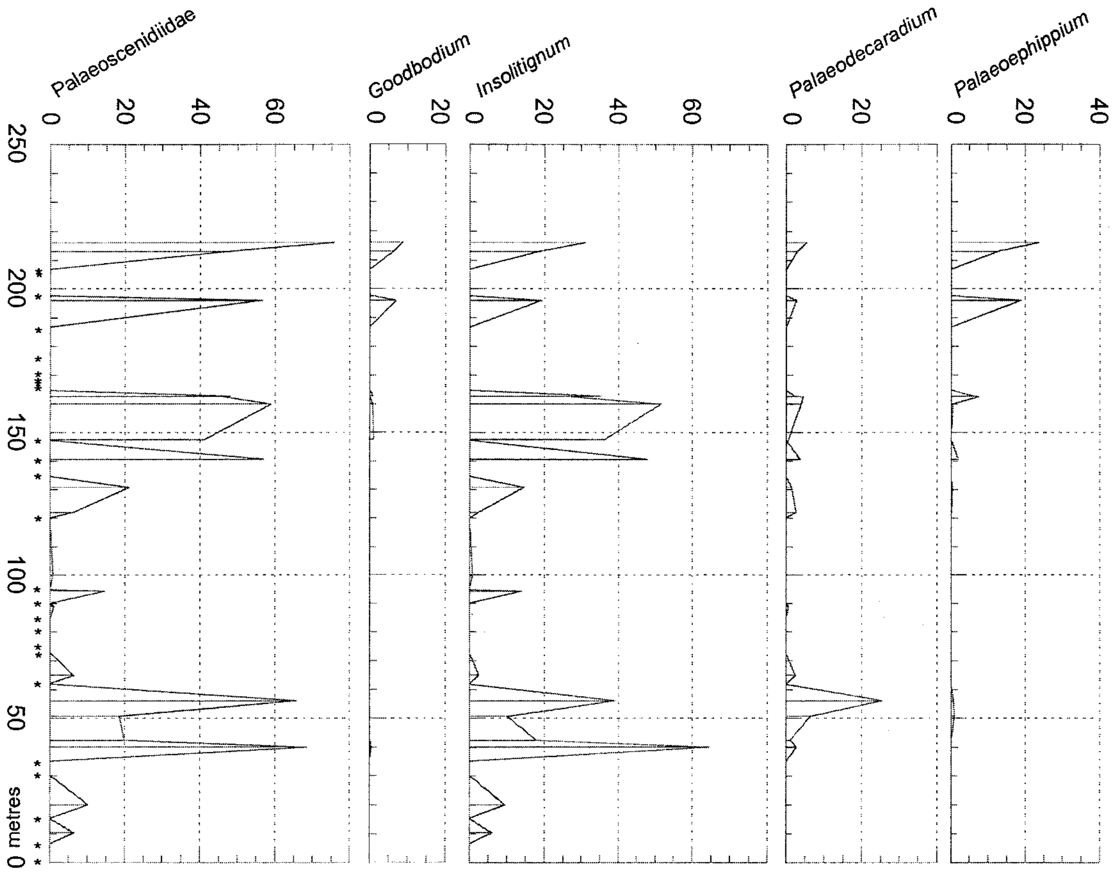


Figure 4.5b

Relative abundances (%) of genera, Palaeoscenidiidae, and Inaniguttidae from the Cape Phillips section. Asterisks indicate barren horizons.

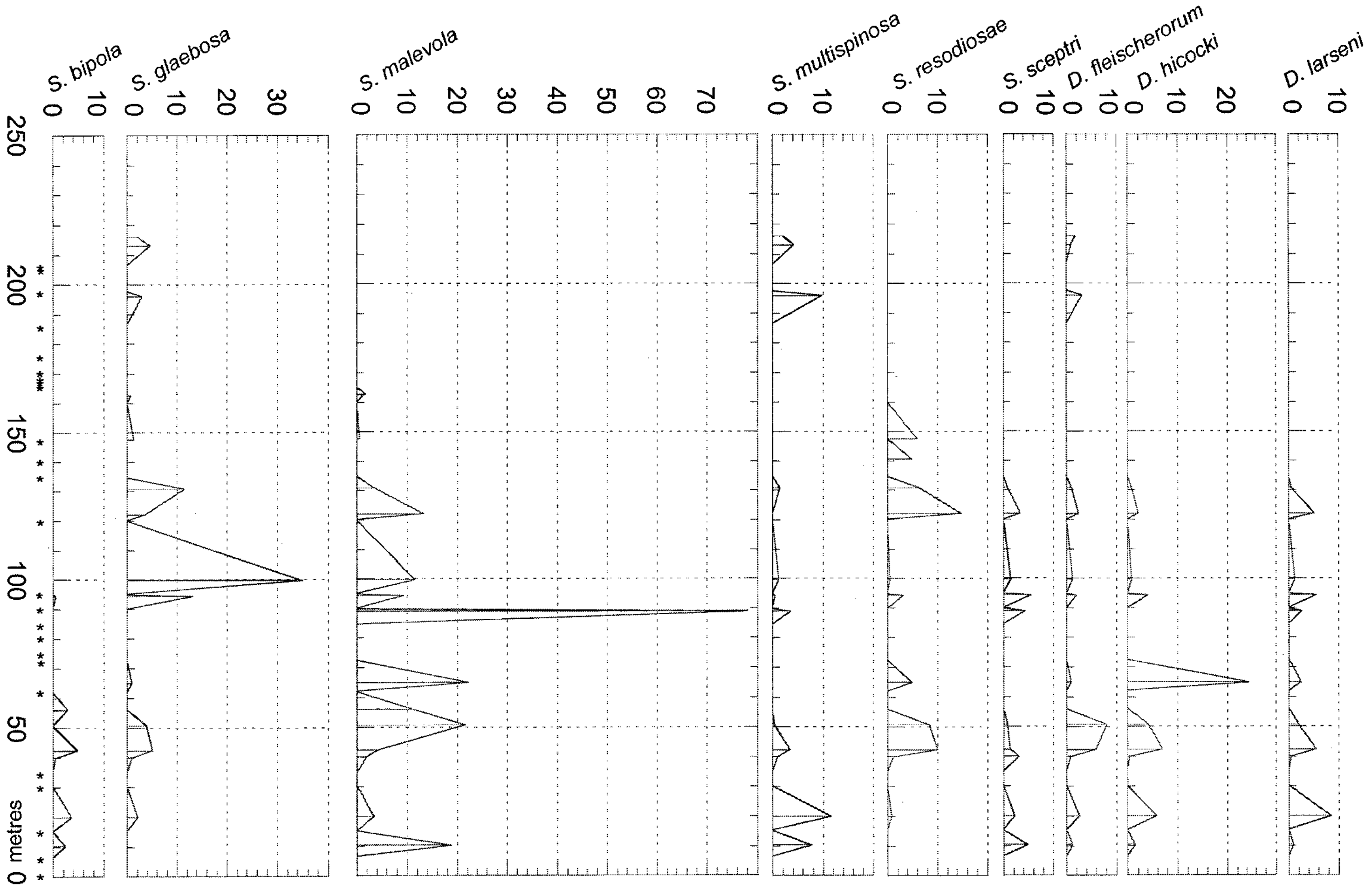


Figure 4.6a

Relative abundances (%) of selected species from the Cape Phillips section. Asterisks indicate barren horizons.

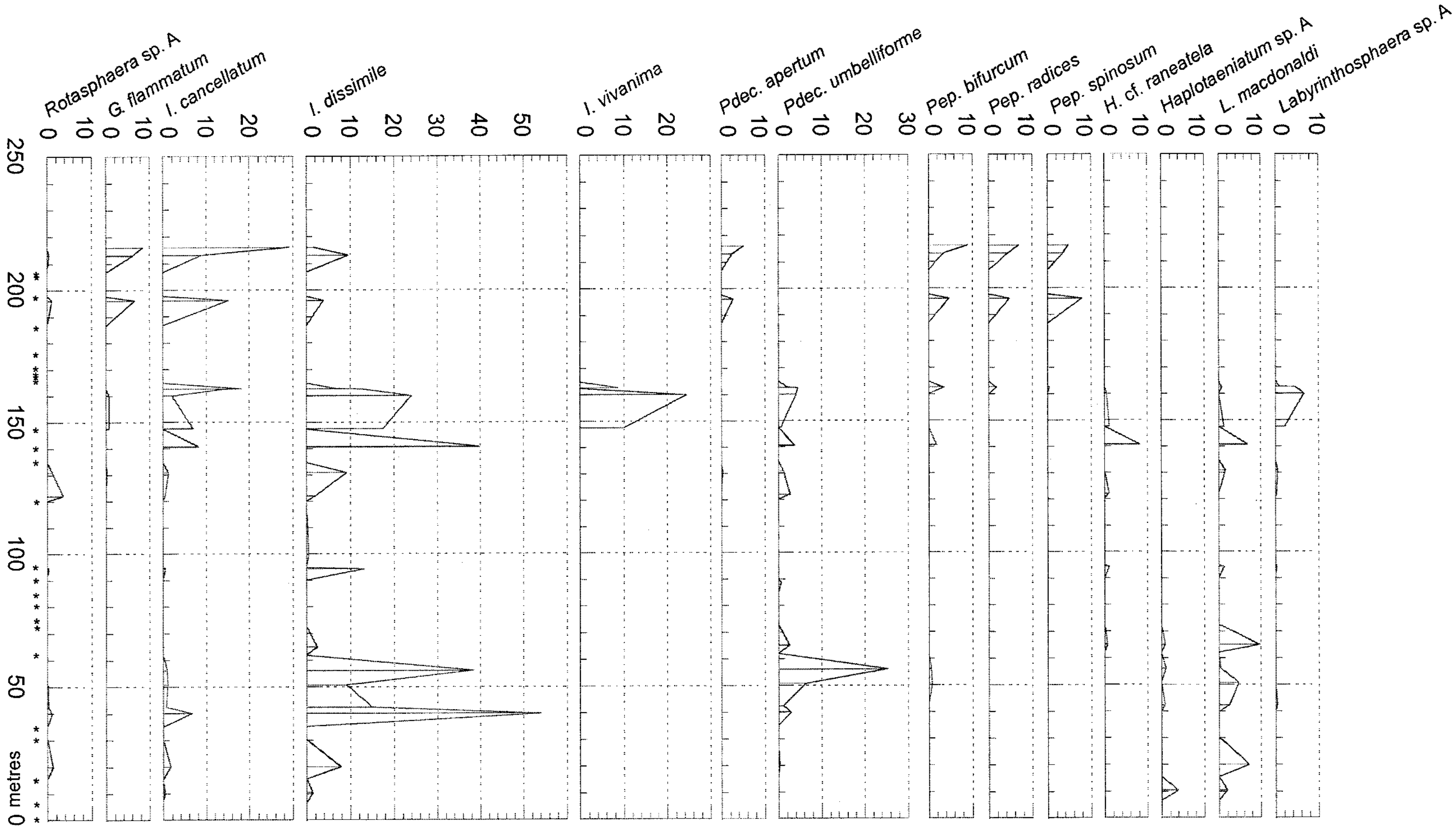


Figure 4.6b

Relative abundances (%) of selected species from the Cape Phillips section. Asterisks indicate barren horizons.

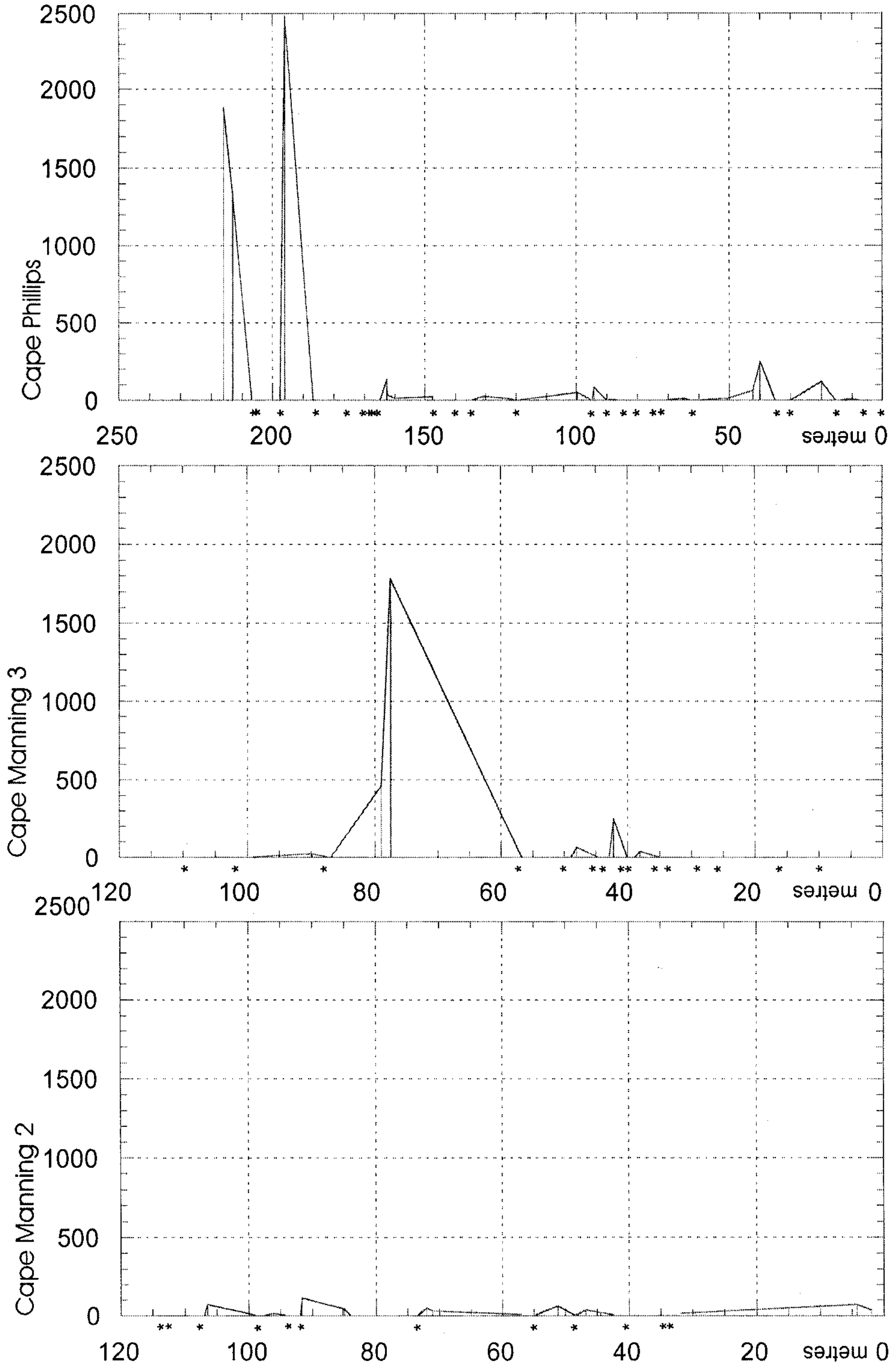


Figure 4.7

Number of radiolarians per gram sample. Asterisks indicate barren horizons.

CHAPTER 5 - COMPARISON TO OTHER LOWER SILURIAN FAUNAS

Papers dealing with the Silurian Radiolaria are still few. The most significant effort of the past century was that of B. B. Nazarov (1975, 1988; Nazarov and Ormiston, 1993), who was able to categorize Silurian strata based upon the contained Radiolaria. Prior to Nazarov (1975), Silurian radiolarians were know from a thin-section study by Rüst (1892) and brief faunal descriptions by Stürmer (1952, 1966).

Building on taxonomic work on Cambrian to Devonian Radiolaria from Kazakhstan (Nazarov, 1975), Nazarov (1988; in English in Nazarov and Ormiston, 1993) recognized two assemblages of Radiolaria in the Silurian. The lower, *Haplotaeniatum tegimentum* Assemblage (middle Llandovery to Wenlock) coincides overall with the Llandovery of the Cape Phillips Formation. The assemblage is most characterized by species of *Haplotaeniatum* and *Syntagentactinia*, plus *Haplentactinia silurica* and at least one species of Inaniguttidae (*Inanihella crubellata*). However, while *Haplotaeniatum* is noticeable in the Cape Phillips Llandovery, identifying Nazarov's species with certainty proved difficult. The Cape Phillips inanigutiids are also less certain taxonomically than indicated by Nazarov. *Syntagentactina* and *Haplentactina silurica* were not observed in the Cape Phillips Formation. Additionally, the three Wenlock samples of the present study do not coincide with the *Haplotaeniatum tegimentum* Assemblage, nor with Nazarov's overlying *Inanihella tarangulica-Secuicollacta cassa* Assemblage, except for the presence of *Helenifore.*

Noble et al. (1997) reported a fauna from the lower Llandovery of the Cherry

Spring Chert of Nevada. More abundant and better preserved specimens from the formation were reported by Noble et al. (1998), who included a taxonomic treatment and comparison to samples collected from Germany. Noble et al. (1998) assigned the Nevada material to the *cyphus* Zone; however, Won et al. (2002) cited a personal communication from W. Berry indicating that the age is less precisely defined.

The Nevada fauna consists of *Orbiculopylorum marginatum*, *O. splendens*, *Haplotaeniatum adobensis*, ?*Haplotaeniatum aperturatum*, *Haplotaeniatum* aff. *H. cathenatum*, *Syntagentactinia afflicta*, *Syntagentactinia* sp. A, Genus novum A, and Genus novum B (Noble et al., 1998). *Secuicollacta*, ?*Oriundogutta*, and ?palaeoactinosphaerids were also noted (Noble et al., 1997, 1998). The German material was similarly composed of *Haplotaeniatum*, *Orbiculopylorum*, *Syntagentactinia*, and *Secuicollacta* (Noble et al., 1998). Noble et al. (1998) noted that the Nevada and German faunas were in accord with radiolarians figured by Stürmer (1952, 1966).

The faunas described by Noble et al. (1997, 1998) are largely consistent with the Radiolaria observed in the Cape Phillips Formation from the *curtus* to *guerichi* zones. *Haplotaeniatum adobensis* is observed in this interval. While ?*Haplotaeniatum aperturatum* was not noted in the Cape Phillips Formation, many specimens assigned to *H. adobensis* possessed the large openings seen in the former species. It was not possible to make a definite distinction between *H. adobensis* with or without these openings. It is possible that differences between different faunas in part represent the developing understanding of Lower Palaeozoic radiolarian morphology and taxonomy.

In a similar vein, *Orbiculopylorum marginatum* was not noted in the Cape Phillips Formation; however, *Orbiculopylorum* cf. *O. marginatum* differs primarily by the presence of a labyrinthine layer that might not have been preserved in the Nevada fauna. Genus novum B from Nevada is very similar to *Orbiculopylorum* species A from the Cape Phillips Formation.

The specimens of *Secuicollacta* figured by Noble et al. (1997, pl. 1, figs. 1-3) appear to be *S. sceptri*. Two of the Nevadan *Secuicollacta* figured by Noble et al. (1998, pl. 5, figs. 7, 8) are *S. resodiosae*, whereas the German *Secuicollacta* (Noble et al., 1998, pl. 6, figs. 7-12) could either be poorly preserved *S. resodiosae* or *S. multispinosa*. All of these species are found in the Cape Phillips Formation.

The only major difference between the Nevada and German samples (Noble et al., 1997, 1998) and the Cape Phillips Formation is the absence of *Syntagentactinia* in the Cape Phillips fauna. A second difference is the absence of *Diparvapila* in the Nevada and German material.

Kurihara and Sashida (2000a) described radiolarians from the Ise area of the Hida "Gaien" Belt of central Japan. The material is not precisely dated, but Kurihara and Sashida (2000a) assigned it to the early to middle Llandovery based on comparison with Nazarov's (1988) *Haplotaeniatum tegimentum* Assemblage and the Nevada faunas of Noble et al. (1997, 1998).

As with the Nevada and German faunas outlined above, the Japanese fauna includes *Syntagentactinia*, which was not found in the Cape Phillips Formation. The species described by Kurihara and Sashida (2000a) are *S. afflicta*, *S. excelsa*, and

?*Syntagentactinia* sp.

The material recovered by Kurihara and Sashida (2000a) is generally poorly preserved. Consequently, some of the taxonomic assignments might be debated. Kurihara and Sashida (2000a) assigned five species to the Inaniguttidae -- *Oriundogutta* sp., ?*Oriundugutta* sp., *Inanihella* sp., ?*Inanihella* sp., and Inaniguttidae gen. et sp. indet. sp. A. It is possible that some of these are *Orbiculopylorum*. For example, ?*Oriundogutta* sp. could be interpreted as related to *Orbiculopylorum* sp. A of the present study. *Inanihella* sp. bears some similarity to *Orbiculopylorum* sp. B from the Cape Phillips Formation. ?*Inanihella* sp. appears to be the same as ?*Orbiculopylorum* species D from the Cape Phillips Formation; however, the latter could be misassigned to *Orbiculopylorum*.

Other taxa described by Kurihara and Sashida (2000a) include *Haplotaeniatum tegimentum*, *Haplotaeniatum* sp. A, *Auliella* sp., an incompletely preserved palaeoscenidiid, a species of Sponguridae, ?*Cessipylorum*, *Orbiculopylorum* sp., and indeterminate Spumellaria. No secuicollactines nor *Labyrinthosphaera* were recovered from the Japanese samples.

As indicated above, preservation does hamper a comparison to the Cape Phillips radiolarians. Kurihara and Sashida (2000a) noted that *Haplotaeniatum* and *Syntagentactinia* were the major component of the fauna, with the inaniguttids being the next most common. The presence of *Haplotaeniatum* and *Syntagentactinia* is in common with the lower Llandovery fauna of Nevada. If the Japanese inaniguttids are *Orbiculopylorum*, then the fauna is consistent with the *curtus* Zone to *guerichi* Zone interval of the Cape Phillips Formation, as is the Nevada fauna. The absence of *Labyrinthosphaera* is also consistent with Cape Phillips Formation below the upper *guerichi* Zone. The absence of secuicollactines, however, is not consistent with any level of the Cape Phillips Formation, nor the Nevadan faunas. Kurihara and Sashida (2000a) suggested that the secuicollactines may not have been preserved. If Kurihara and Sashida's (2000a) inaniguttids are accepted, the Japanese fauna would coincide with *griestoniensis* Zone and higher in the Cape Phillips Llandovery. In this interval, *Haplotaeniatum* is rare and *Labyrinthosphaera* is a fairly noticeable component of the fauna. The Nevada fauna (Noble et al., 1997, 1998) also has little in common with stratigraphically higher material from the Cape Phillips Formation.

Won et al. (2002) reported radiolarians extracted from siliceous rock fragments collected from a boulder in the Road River Formation, Alaska. The material was dated as late Aeronian to early Telychian. The fauna is mainly secuicollactines with lesser haplotaeniatumids. Won et al. (2002) ascribed the rarity of the latter to selective preservation. They noted the general similarity of the material to the Nevada radiolarians of Noble et al. (1997, 1998) and to several samples from Arctic Canada.

The species-level taxonomy of *Secuicollacta* is being reconsidered by the present author. Consequently, some of Won et al.'s (2002) taxa are synonymized herein (see Systematic Palaeontology below). In common with the Cape Phillips Formation, the Road River fauna contains *Secuicollacta bipola*, *S. glaebosa*, *S. malevola*, *S. multispinosum*, *S. parvitesta*, *S. resodiosae*, and *Haplotaeniatum adobensis*. Won et al.'s (2002) *S. magnaspina* and *Diparvapila pygmaea* are potentially synonymous with

S. sceptri and *D. fleischerorum*, respectively. Won et al. (2002) also noted *H. aperturatum*, *Orbiculopylorum marginatum*, ?*Diparvapila* sp. A, and four incertae sedis. ?*Diparvapila* sp. A could be the same as *Rotasphaera* species B of the present study. One of the incertae sedis, Genus and species indet. D is very similar to *Orbiculopylorum* species A from the Cape Phillips Formation. It could possibly also be interpreted as an inaniguttid.

The presence of *Haplotaeniatum* and *Orbiculopylorum* are in common with studies of Noble et al. (1997, 1998), Kurihara and Sashida (2000a), and the present study in the interval from the *curtus* to *turriculatus* zones. The species of *Secuicollacta* described by Won et al. (2002) are generally present through the Llandovery of the Cape Phillips Formation. *Secuicollacta bipola*, however, is more limited stratigraphically and was not noted below the *guerichi* Zone. This would further restrict the Road River Formation fauna to the *guerichi* to *turriculatus* zones (lowest Telychian).

Radiolaria from a calcareous concretion from the *turriculatus* Zone of Dalarna, Sweden were briefly described by Maletz and Reich (1997) and treated in more detail by Noble and Maletz (2000). Noble and Maletz (2000) noted the presence of *Haplotaeniatum cathenatum*, *Gyrosphaera raneatela*, *G. siljanensis*, *Labyrinthosphaera macdonaldi*, *Secuicollacta malevola*, *S. resodiosae*, *S. glaebosa*, *Diparvapila larseni*, *Diparvapila* sp. A, ?*Parvalanapila* sp., *Paleoephippium echinatum*, and *Insolitignum dissimile*. In this thesis, *Gyrosphaera* is regarded as a junior synonym of *Haplotaeniatum*, and *Parvalanapila* is synonymized with *Diparvapila*. *Palaeoephippium echinatum* is not treated systematically in the present study, although it is present in the Cape Phillips Formation. It will require reassigment at the genus level owing to the taxonomic revisions herein.

The Dalarna fauna is largely consistent with the Cape Phillips Formation Radiolaria from the *turriculatus* Zone. The absence of inaniguttids and diverse palaeoscenidiids differentiate the Swedish fauna from the *crispus* Zone and higher in the Cape Phillips Formation. *Haplotaeniatum* presents the chief difference between the Swedish fauna and the *turriculatus* Zone of the Cape Phillips Formation. *Haplotaeniatum ?cathenatum* described herein is not observed above the *guerichi* Zone. "*Gyrosphaera*" (*Haplotaeniatum* herein) is dubiously present below the *griestoniensis* Zone; specimens consistent with "*Gyrosphaera*" are very rare in the *turriculatus* Zone and their appearance could be the result of poor preservation. However, *Haplotaeniatum* cf. *H. raneatela* is present slightly higher and could simply be poorly represented lower in the formation. The species may prove conspecific with Noble and Maletz's (2000) *H. raneatela* from Sweden.

Noble and Maletz (2000) also noted that *Haplotaeniatum* was abundant in the Dalarna material (approximately 40 percent for *H. cathenatum*); however, the genus becomes a minor part of the Cape Phillips Formation fauna by approximately the middle of the *guerichi* Zone.

Other published accounts of Silurian Radiolaria are stratigraphically higher than the present study (Aitchison et al., 1996; Amon et al., 1995; Furutani, 1990; Górka, 1994; Kurihara and Sashida, 1998, 2000b; Li, 1994; Nazarov, 1988; Nazarov and Ormiston, 1993; Noble, 1994; Suzuki et al., 1996; Umeda, 1997, 1998a, 1998b;

Wakamatsu et al., 1990). Few species reported herein are found in these later Wenlock to Pridoli studies. The genus *Secuicollacta* persists into the Devonian (Nazarov and Ormiston, 1993). As indicated earlier, Goodbody's (1981) data indicate that some of the Llandovery species of the genus continue into the Wenlock; however, the known Llandovery species are not described from published Wenlock and later studies. Goodbody (1981) also indicated the presence of inaniguttids similar to those described herein and *Labyrinthosphaera* in the Wenlock. Bladed radiolarians from the Ludlow described briefly by Amon et al. (1995) may belong to *Labyrinthosphaera*; Amon et al. (1995) commented that Holdsworth (1977) had noted bladed forms in the Cape Phillips Formation.

Goodbody (1986) noted that some of the palaeoscenidiid species from the Cape Phillips Formation persist to the Ludlow. *Goodbodium flammatum*, *Palaeoephippium bifurcum*, *Palaeoephippium radices*, and *"Palaeoephippium" echinatum* are known in the Ludlow of the southern Urals (Amon et al., 1995). *Palaeoephippum radices* (i.e., *Holdsworthum*) and *Goodbodium* are also known from the Ludlow of Nevada (Noble, 1994) and latest Silurian or early Devonian of Japan (Furutani, 1990). Li (1994) dated as mid-Wenlock a radiolarian-bearing sample from Xinjiang based on the contained palaeoscenidiids. These included *Goodbodium flammatum*, *Insolitignum cancellatum*, *Palaeoephippium radices*, and *Palaeodecaradium apertum*. *Ceratoikiscum leonoides*, first described from the Wenlock of the Cape Phillips Formation (Renz, 1988), was also in the sample. While these are in common with the three Wenlock samples of the present study, other taxa described by Li (1994) are not. The presence of *Inanihella* *macracantha* suggest a younger fauna than the material considered herein.

CHAPTER 6 - BIOSTRATIGRAPHY

A chief goal in radiolarian palaeontology is the establishment of useful biostratigraphic zonations. The portion of the Cape Phillips Formation considered in this study can be divided into four biostratigraphically successive radiolarian biozones (Figure 6.1, 6.2). The boundaries at two levels are imprecise owing to nonrecovery of radiolarians -- there is a stratigraphic gap in the upper *turriculatus-crispus* graptolite zones, whereas the *insectus* to lower *instrenuus-kolobus* grapolite zones is an interzone barren of Radiolaria. All the zones reported here are interval zones as defined by the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983).

Haplotaeniatum Zone.–This is the lowest of the four zones. The base is conditionally taken as the first appearance of *Haplotaeniatum ?labyrintheum*, *H. ?cathenatum*, *Haplotaeniatum* species C, and *Diparvapila fleischerorum*. These first appear in sample CM2-2.0, immediately above the Ordovician-Silurian boundary. The top of the interval is marked by the first appearance of *Orbiculopylorum* in sample CM2-42.5 immediately below the boundary between the *cyphus* and *curtus* graptolite zones. It should be noted that Radiolaria were not collected from below the *acuminatus* graptolite Zone, thus the first appearance of the species defining the base could an artefact. Goto et al. (1992) reported two species of *Haplotaeniatum* from the Upper Ordovician of Australia; synonymy between these species and those reported herein in could not be established owing to the preservation of the Australian specimens. *Secuicollacta multispinosa* and *S. parvitesta* are present in this assemblage. Other species of *Secuicollacta* can only be conditionally acknowledged owing to poor preservation.

Orbiculopylorum Zone.–The base is defined by the first appearance of *Orbiculopylorum* -- specifically *Orbiculopylorum* species A and *Orbiculopylorum* species B -- immediately below the base of the *curtus* graptolite Zone (sample CM2-42.5). *Haplotaeniatum adobensis* also first appears at the base of the interval. The top of the zone is defined by the last appearance of *Orbiculopylorum*. The precise position of the boundary between the *Orbiculopylorum* Zone and the subsequent Inaniguttid Zone is not established. There is a stratigraphic gap between the two zones within which the true last appearance of the genus may occur. *Orbiculopylorum* is last observed in sample CM2-106.5 (*turriculatus* graptolite Zone). Conditionally, the boundary is placed in the *crispus* graptolite Zone.

The full diversity of Llandovery species of *Secuicollacta* appear in the *Orbiculopylorum* Zone; *S. bipola* appears near the middle of the interval. *Diparvapila hicocki* and *D. larseni* appear slightly above the base, as do *Rotasphaera severa* and *Rotasphaera* species A. *Rotasphaera* species C appears in the upper part of the interval. *Labyrinthosphaera* appears near the middle of the zone, but the level of its first appearance is not yet confirmed. Once established, the first appearance of *Labyrinthosphaera* may prove biostratigraphically useful and result in the division of the present zone. Rare Palaeoscenidiidae first appear near the top of the zone, and are represented by *Insolitignum dissimile, Palaeoephippium bifurcum*, *P. radices, Palaeoephippium spinosum*, and *Protoentactinia tricorne*. This family is known from the Ordovician (e.g., Renz, 1990), but not the species reported here. *Haplotaeniatum* species C disappears low in the zone.

Inaniguttid Zone.–The base of the Inaniguttid Zone is defined by the first appearance of inaniguttid species B, inaniguttid species C, inaniguttid species D, and *Haplotaeniatum* species A. They are first noted in sample CP10.3-10.4 (*griestoniensis* or possibly uppermost *crispus* graptolite Zone). A stratigraphic gap separates this zone from the underlying *Orbiculopylorum* Zone. Consequently, the true first appearance of these taxa may lower than recorded here. The Inaniguttidae are known from the Ordovician (cf. Nazarov, 1988), but are not observed in the Cape Phillips Formation below the Inaniguttid Zone. The last appearance of *Orbiculopylorum* might also be used to define the base of the Inaniguttid Zone; however, as noted above, the last appearance datum of this genus is not firmly established. The top of the Inaniguttid Zone is not firmly established; a barren interzone separates the Inaniguttid Zone from the subsequent *Ceratoikisum* Zone. The uppermost sample from the zone is CP-162.7 (uppermost *sakmaricus* graptolite Zone). Conditionally, the top is defined by the first appearance of *Ceratoikiscum*. Owing to preservation, the precise ranges of the inaniguttid species are not known; Goodbody's (1981) unpublished data suggest that they extend into the Wenlock.

Inaniguttid species A and *Haplotaeniatum* species B appear near the base of the zone. *Diparvapila* species A, *Diparvapila* species B, and *Rotasphaera* species B are found in this zone, but they are very rare. The Palaeoscenidiidae become more diverse with the appearance of *Goodbodium flammatum*, *G. rarispinosum*, *Insolitignum cancellatum*, *I. vivanima*, *Palaeodecaradium apertum*, *Palaeodecaradium umbelliforme*, *Palaeopyramidium spinosum*, in addition to species that appeared in the previous zone. *Insolitignum vivanima* is restricted to the upper portion of the zone. *Diparvapila hicocki* and *D. larseni* last appear in the upper reaches of the zone. *Secuicollacta bipola* and *S. parvitesta* last appear near the middle of the zone.

Ceratoikiscum Zone.–The highest zone recognized in this study is known from three sample in the mid-*instrenuus-kolobus* Zone. *Ceratoikiscum* first appears in these samples and is taken as indicating the base of the interval. The precise position of the first appearance of *Ceratoikiscum* is not established due to the barren interzone between this zone and the underlying Inaniguttid Zone. The base is conditionally set at the Llandovery-Wenlock boundary. No productive samples were recovered from above the mid-*instrenuus-kolobus* graptolite Zone, and thus the top of the *Ceratoikiscum* Zone is not established.

In addition to *Ceratoikiscum*, *Helenifore* is also observed for the first time in this zone. The abundance of Palaeoscenidiidae is greater than lower in the Cape Phillips Formation; however, only one species is new to the interval -- *Palaeodecaradium gordoni*. *Secuicollacta* species A and *Secuicollacta* cf. *S. resodiosae* first appear in this interval. The taxonomic treatment of this zone is not as complete as the Llandovery of the Cape Phillips Formation.

Previous Silurian Biostratigraphies

Seven papers have endeavoured to categorize Silurian strata an the basis of contained Radiolaria. The first such attempt was that of Nazarov (1988, presented in English in Nazarov and Ormiston, 1993) who described two assemblages in the Silurian based largely on material from the Urals. Most recently, Noble and Aitchison (2000) presented the first global radiolarian biozonation for the early Palaeozoic which described four zones in the Silurian. It is these two schemes which are relevant to the present study and will be discussed below.

The five remaining biozonations are for strata higher in the Silurian than the present study and thus are not discussed here. Briefly, Furutani (1990) described five assemblages of Wenlock or early Ludlow age though Middle Devonian from the Fukuji Area of Japan. Noble (1994) described six zones for the Caballos Novaculite of west Texas. The lowest zone is dated as Wenlock-Ludlow; contained taxa are not observed in the present study and this is evidently higher in the Wenlock than the present study. Umeda (1998b) recognized four zones ranging from Ludlow-Pridoli to Middle Devonian. Kurihara and Sashida (2000b) recognized four assemblages from the Hida Gaien Belt of Japan. These range from Ludlow-Prioli to Emsian-Eifelian. Wakamatsu et al. (1990) presented six assemblages. Although the lowest two were initially dated as late Llandovery-Wenlock, Noble (1994) suggested that the assemblages are actually younger, and considered the lower assemblage as Wenlock-Ludlow. Specimens from Wakamatsu et al.'s (1990) assemblages are poorly preserved and there are no taxa which might clearly assign them to lower in the Silurian.

Nazarov (1988, in English in Nazarov and Ormiston, 1993) assigned two radiolarian assemblages to the Silurian. The stratigraphic boundaries of both are imprecise. The *Haplotaeniatum tegimentum* Assemblage was dated as mid Llandovery (*triangularis* graptolite Zone) to Wenlock (*testis* graptolite Zone). *Haplotaeniatum* predominates in the assemblage. Presumably, the genus first appears in this assemblage. Characteristic taxa are *Haplotaeniatum tegimentum*, *H. labyrintheum*, *H. cathenatum*, *Syntagentactinia excelsa*, *S. afflicta*, and *Haplentactinia silurica*.

Nazarov (1988) assigned the Ludlow to the *Inanihella tarangulica - Secuicollacta cassa* Assemblage. *Inanihella* predominates. Characteristic taxa are *Inanihella tarangulica*, *I. perarmata*, *I. legincula*, ?*Helenifore fasciola*, *Aciferpylorom admirandum*, *Oriundogutta litterula*, and *O.* ?*roemeri*. Radiolaria with spicule-based skeletons are also common, including ?*Helenifore*. Nazarov (1988) noted that *Secuicollacta* first appears in this assemblage.

Recently, Noble and Aitchison (2000) published the first global radiolarian biozonation for the early Palaeozoic. In this scheme, the Silurian is represented by four zones, two, possibly three, of which are within the stratigraphic range of the present study. The Pylomate-large concentric sphaerellarian Zone 2 tentatively has its base at the base of the Llandovery. The oldest dated samples are from the *cyphus* graptolite Zone, and the youngest from the *turriculatus* graptolite Zone. It is not clear from Noble and Aitchison (2000) if the top of the zone is taken as *turriculatus* Zone in age or is higher, coincident with the youngest dated level of the subsequent Long-spined inaniguttid Zone 2 (i.e., *sakmaricus* graptolite Zone). *Orbiculopylorum* and *Labyrinthosphaera* are present in the lower part of the zone. Noble and Aitchison (2000) noted that *Diparvapila* occurs in the upper part of the zone. The chief characteristic of the zone is an abundance of *Haplotaeniatum*. Noble and Aitchison (2000) stated that the zone could be regarded as an acme zone.

Noble and Aitchison (2000) place the base of the next zone, the Long-spined inaniguttid Zone 2, at the last appearance of *Haplotaeniatum*. The top of the zone coincides with the first appearance of *Ceratoikiscum* and the *Inanihella tarangulica* Group. The oldest dated material is assigned to the *sakmaricus* graptolite Zone and the youngest is middle Wenlock (*rigidus* graptolite Zone). The lower part of the zone includes *Gyrosphaera* (synonymized herein with *Haplotaeniatum*), *Inanihella penrosei* Group, and *Labyrinthosphaera*. They suggested that the zone is best recognized by the co-occurrence of inaniguttids and *Secuicollacta*.

Noble and Aitchison's (2000) third Silurian zone is the Long-spined inaniguttid Zone 3. The base is marked by the first appearance of *Ceratoikiscum* and the top the last appearance of rotasphaerids (sensu Holdsworth, 1977). The *Inanihella tarangulica* Group has its first appearance near the base of the zone. Distinctive taxa are *I. tarangulica* Group, *Ceratoikiscum*, rotasphaerids, *Cenosphaera hexagonalis*, palaeoscenidiidae, and *Zadrappolus*. The upper portion of this zone includes the lowest assemblages of Furutani (1990), Wakamatsu et al. (1990), and Noble (1994).

A fourth zone for the Silurian, the Postrotasphaerid Zone, is beyond the range of this study (Noble and Aitchison, 2000). It is marked by the last appearance of rotasphaerids at the base and the last abundance of inaniguttids at the top.

Comparison to Nazarov (1988) and Noble and Aitchison (2000)

Nazarov's (1988) *Haplotaeniatum tegimentum* Assemblage encompasses the stratigraphic interval of the present study (Figure 6.1). One problem with Nazarov's (1988) assemblage is that Nazarov indicated that the defining species do not extend into the Wenlock, although the assemblage includes the Wenlock. Additionally, Noble et al. (1998) noted that late Llandovery faunas differ from *Haplotaeniatum*-dominated faunas, and suggested that the assemblage, and possibly *Haplotaeniatum* itself, has a more limited stratigraphic range. The present study found that differentiating Nazarov's species of *Haplotaeniatum* (cf. Nazarov and Ormiston, 1993) can be problematic; thus the actual species ranges may be suspect. The zonation of Noble and Aitchison (2000) and the intervals described herein do demonstrate that the Llandovery can be more finely divided than the pioneering work of Nazarov.

Noble and Aitchison (2000) defined their Pylomate-large concentric sphaerellarian Zone 2 by abundance of *Haplotaeniatum* and suggested that the zone could be considered an acme zone. The top of the zone is the last appearance of this genus. The *Haplotaeniatum* and *Orbiculopylorum* zones of the present study are largely modifications of this zone (Figure 6.1). Chiefly, abundance is not regarded herein as a reliable datum. While the genus is dominant, or at least very common, in the two intervals described herein, the abundance is variable and the genus may be rare or absent in a given sample. Furthermore, the genus does appear to extend into the Wenlock, but is exceedingly rare. Considering the rarity of the genus above the *Orbiculopylorum* Interval, Noble and Aitchison's (2000) last appearance datum is understandable. In differentiating the *Orbiculopylorum* Zone from the Pylomate-large concentric sphaerellarian Zone 2, the base of the interval is placed slightly higher than the age of *Orbiculopylorum* reported by Noble et al. (1998). Noble et al. (1998) assigned *Orbiculopylorum* from Nevada to the *cyphus* Zone; however, Won et al. (2002, p. 943) cited a personal communication from W. Berry indicating that the graptolite used to date the Nevada material was not age diagnostic.

The Inaniguttid interval apparently is identical to the Long-spined inaniguttid Zone 2 of Noble and Aitchison (2000; Text-figure 6.1). The two share in common the appearance of long-spined inaniguttids and the absence of *Orbiculopylorum*. As noted above, the disappearance of *Haplotaeniatum* is not a valid datum. Noble and Aitchison (2000) were only able to note that the oldest dated occurrence of the Long-spined inaniguttid Zone 2 was in the *sakmaricus* Zone. The base of the Inaniguttid Zone described herein is provisionally placed in the *crispus* Zone. Both the Inaniguttid Zone and the Long-spined inaniguttid Zone 2 mark their upper limits by the appearance of *Ceratoikiscum*; however, Noble and Aitchison (2000) extend their zone much higher than the Inaniguttid Zone. Noble and Aitchison (2000) placed the appearance of this genus (and the start of their next zone) either late in the *rigidus* Zone (*instrenuus*-

kolobus Zone of Arctic Canada) or post-*rigidus*. Both the present author's observations and those of Goodbody (1981) place the appearance of *Ceratoikiscum* as somewhat lower. Goodbody noted the genus in the bottom of the *riccartonensis* Zone (*instrenuus-kolobus* Zone).

The *Ceratoikiscum* Zone described herein differs from Noble and Aitchison's (2000) Long-spined inaniguttid zone 2 and Long-spined inaniguttid zone 3 (Text-figure 6.1). The latter zone commences slightly above the stratigraphic interval considered in this thesis and includes *Inanihella tarangulica* Group inaniguttids. Noble and Aitchison (2000) noted that it is essentially the same as Nazarov's (1988) *Inanihella tarangulica-Secuicollacta cassa* Assemblage. Such inaniguttids were not observed in the present study. Indeed, no inaniguttids were recovered from the three Wenlock samples of this study. Goodbody's (1981) unpublished data suggested that the inaniguttids observed in the Inaniguttid Interval could extend to the *lundgreni-testis* Zone. His data also indicated that *Inanihella tarangulica*-type inaniguttids appear within the *riccartonensis* Zone (lower part of *instrenuus-kolobus* Zone). Very possibly, the three Wenlock samples of the present study are not entirely representative of the early Wenlock radiolarian fauna. It remains to be demonstrated if the *Ceratoikiscum* Assemblage is the same as the Long-spined inaniguttid zone 3, which is also marked by the appearance of *Ceratoikiscum*, or if this is an interval between the two zones of Noble and Aitchison (2000).

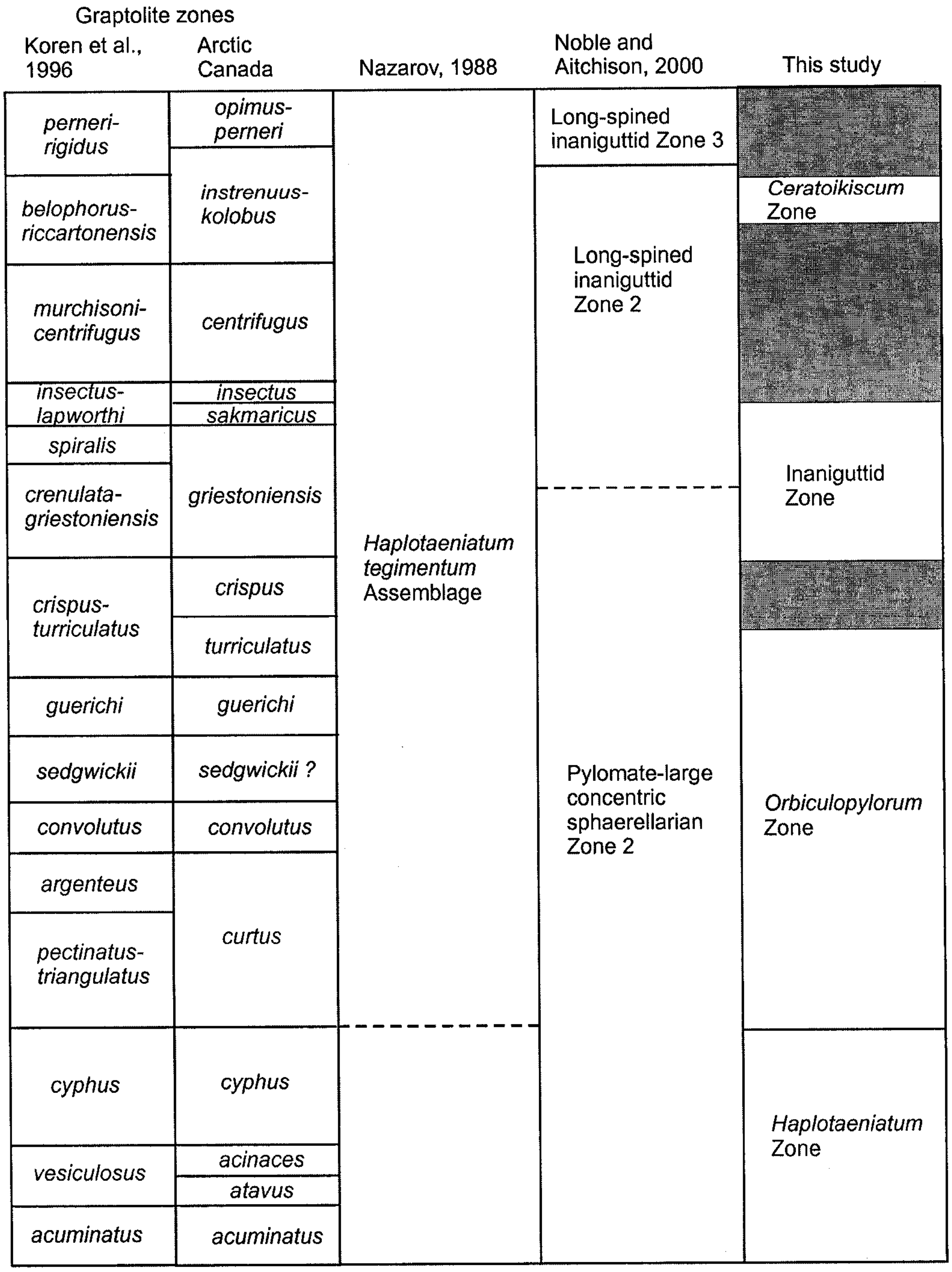


Figure 6.1

Radiolarian biostratigraphic intervals from the Lower Silurian of the Cape Phillips Formation with comparison to Nazarov (1988) and Noble and Aitchison (2000). Shaded intervals represent no recovery of Radiolaria. Arctic graptolite zones from Melchin (pers. commun., 2002).

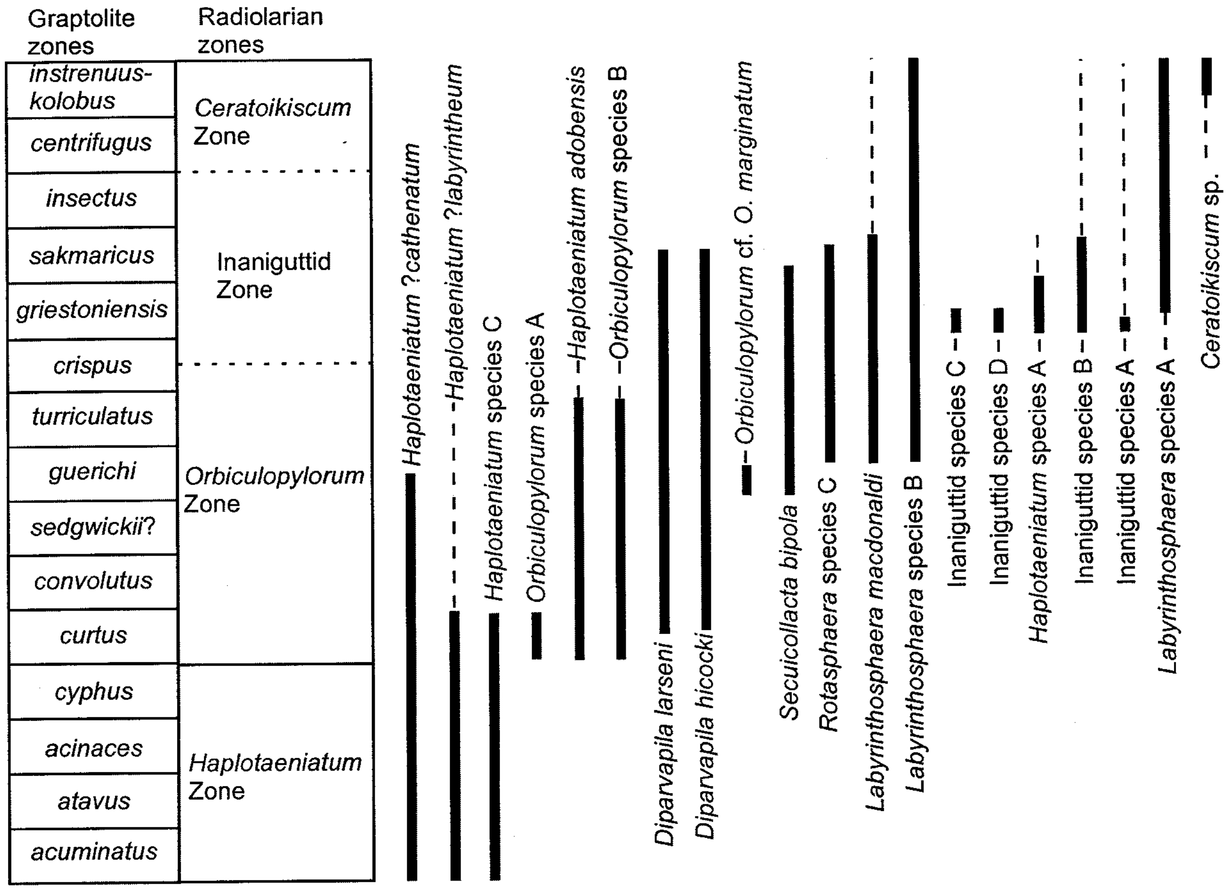


Figure 6.2

Stratigraphic ranges of selected species plotted against Arctic graptolite zones and the radiolarian biostratigraphic intervals defined herein.

CHAPTER 7 - CORRELATION OF CAPE PHILLIPS RADIOLARIAN FAUNAL CHANGES TO GRAPTOLOID AND CONODONT BIOEVENTS

Melchin et al. (1998) recognized ten graptoloid bioevents in the Silurian, all but two of which are of global significance. Five of these bioevents occurred within the interval encompassed by the present study of Cape Phillips Formation radiolarians. These are the late *Parakidograptus acuminatus*, *Stimulograptus sedgwickii*, *Stimulograptus utilis*, *Cyrtograptus lapworthi*, and *Cyrtograptus murchisoni* events. Graptoloid bioevents generally are linked to eustatic sea-level fall, with the exceptions of the *P. acuminatus*, *C. murchisoni*, and late Ludlow *Monograptus spineus* events (Melchin et al., 1998). Two conodont bioevents also occurred during the interval considered herein. The Sandvika Event coincides with the *S. sedgwickii* graptoloid Event (Aldridge et al., 1993) and the Ireviken Event which is associated with the *C. lapworthi* and *C. murchisoni* grapoloid events (Aldridge et al., 1993; Jeppsson, 1997a).

There are three stratigraphic levels in the Cape Phillips Formation at which the radiolarian fauna undergoes a reorganization (Figure 7.1). The lowest occurs at the Rhuddanian-Aeronian boundary and is not associated with a graptoloid or conodont bioevent. At two other levels, the upper *turriculatus-crispus* zones and the Llandovery-Wenlock boundary, no radiolarians were recovered; however, the radiolarian fauna changes across these intervals. These faunal changes occur near, but not necessarily in conjunction with graptoloid and conodont bioevents.

Rhuddanian-Aeronian Boundary

A noticeable change in the radiolarian fauna is at the boundary between the Rhuddanian and Aeronian (*cyphus* and *curtus* zones) where *Secuicollacta* replaces *Haplotaeniatum* as the dominating component of the fauna. *Orbiculopylorum* appears at this level. This abundance shift does not coincide with a graptoloid or conodont bioevent. There was no global drop in sea level at this time, although sea level does fall higher in the *curtus* Zone (Johnson, 1996; Loydell, 1998).

While there is no graptoloid bioevent in the sense of increased extinction, the transition from the *cyphus* to *curtus* zones is a time of increasing monograptid diversity and dominance (Rickards et al., 1977). There is some preliminary evidence of this from the Cape Manning 2 section; however, the increase in monograptid diversity apparently occurred in mid *curtus* Zone (Russel-Houston, 2001).

In the *turriculatus* Zone of Dalarna, Sweden, *Haplotaeniatum* comprises about 60 percent of the fauna (*H. cathenatum* [~40 percent] plus "*Gyrosphaera*" [~20 percent]; Noble and Maletz, 2000) whereas *Secuicollacta* forms about 20 percent. This is essentially the opposite of what is observed in the *guerichi* to *turriculatus* zones of the Cape Phillips Formation; that is, above the *cyphus-curtus* zone boundary shift to the predominance of *Secuicollacta*. This suggests that the abundance shift at the Cape Phillips Formation *cyphus-curtus* zone boundary represents a local environmental change.

Upper *turriculatus* - *crispus* zones

Radiolaria were not recovered from the upper portion of the *turriculatus* Zone and essentially all of the *crispus* Zone. This is due to the stratigraphic break separating the Cape Manning 2 and Cape Manning 3 sections coupled with the absence of radiolarians in the lower portion of Cape Manning 3. Consequently, the change in the radiolarian fauna above and below this interval cannot be more precisely dated. Additionally, some specimens from the *turriculatus* Zone are too poorly preserved to identify with certainty. As noted below, a positive identification of these specimens could aid in establishing the time of faunal change.

Across the upper *turriculatus* Zone - *crispus* Zone gap, the genus *Orbiculopylorum* disappears. This does not include species conditionally assigned to the genus. Inaniguttidae are noted with certainty starting at the base of the *griestoniensis* Zone, but are absent below the sampling gap. For convenience sake, one might take the change in these two groups as within the *crispus* Zone; however, it is possible that the change occurs within the *turriculatus* Zone. Two poorly preserved individuals that could belong to Inaniguttid species B were recovered from the *turriculatus* Zone of the Cape Manning 2 section. Also, only *Orbiculopylorum* species B is known with certainty from the same level in the *turriculatus* Zone. *Orbiculopylorum* cf. *O. marginatum* is last noted with certainty in the *guerichi* Zone. A poorly preserved specimen which may belong to this species is noted higher in the *guerichi* Zone (CM2-91.7). Clearly, better sampling is needed to better date the faunal change.

Also across the sampling gap, *Haplotaeniatum ?cathenatum*, *H. adobensis*, and *H. ?labyrintheum* disappear. Individuals similar to these species are found in the *griestoniensis* Zone and higher in the Cape Phillips Formation; however, they are quite rare and are not classified. The species of *Haplotaeniatum* as described by Nazarov and Ormiston (1993; *H. cathenatum*, *H. labyrintheum*) presumably occur throughout the Llandovery. Consequently, it is possible that the disappearance of the three *Haplotaeniatum* species in the Cape Phillips Formation is an artefact of sampling.

This change in the Cape Phillips radiolarian fauna is near to, but apparently not coincident with, the *Stimulograptus utilis* graptolite event. This event is noted in Britain, Spain, and the Barrandian region of the Czech Republic (Loydell, 1994; Štorch, 1995) and occurs at the transition between the *guerichi* and *turriculatus* zones (*utilis* Subzone of Loydell, 1994). Jeppsson (1997b) considered this bioevent as marking a change in oceanic conditions; that is, a secundo-primo event marking the transition between the Malmøykalven Secundo Episode and the Snipklint Primo Episode. Melchin et al. (1998) indicated that it was a fairly minor event globally, and is not significant in the Cape Phillips Formation or Bornholm. The *utilis* Event is coincident with a eustatic drop in sea-level (Loydell, 1994, 1998). A sea-level fall also occurred within the *crispus* Zone (Johnson, 1996; Loydell, 1998).

Llandovery-Wenlock Boundary

No radiolarians were recovered across the Llandovery-Wenlock boundary from the uppermost *sakmaricus* Zone to mid *instrenuus-kolobus* Zone. Within this interval there is an apparent disappearance of some taxa and a change in total and relative abundances.

The disappearance of some species across the Llandovery-Wenlock boundary in the Cape Phillips Formation is somewhat problematic. Most of the species not observed in the three Wenlock samples of this study likely are present in the Wenlock judging by the unpublished data of Goodbody (1981). Goodbody (1981) noted in the Wenlock the presence of inaniguttids similar to, if not the same, as those observed in the Llandovery of the present study. Similarly, Llandovery species of *Secuicollacta* that are absent in the Wenlock samples are likely present in the Wenlock (Goodbody, 1981). *Insolitignum vivanima*, which appears in the upper *sakmaricus* Zone is not seen in the Wenlock. Goodbody (1981, 1986) does not report this species, and its disappearance appears to be genuine. *Diparvapila hicocki* and *D. larseni* are not observed with certainty above approximately the mid *sakmaricus* Zone. It should be noted that the topmost *sakmaricus* Zone samples (CP-160, CP-162.5, CP-162.7) are smaller than most ($n \leq 100$ for each size fraction) and the two species may statistically not be represented. It is not clear from Goodbody's (1981) data if these species are present in the Wenlock. Considering the contradiction between Goodbody (1981) and the present study with respect to the inaniguttids and *Secuicollacta*, the disappearance of *D. hicocki* and *D. larseni* is only conditionally accepted.

More noticeable across the Cape Phillips Formation Llandovery-Wenlock boundary is the change in radiolarian abundances. These were detailed in chapter 4. Briefly, total number of radiolarians per gram sample increases dramatically in the Wenlock samples. In the upper *sakmaricus* Zone, the Palaeoscenidiidae became more abundant than *Secuicollacta*. However, while *Insolitignum dissimile* was the more abundant species of palaeoscenidiid in the Llandovery, its abundance is reduced in the Wenlock and several palaeoscenidiid species are better represented, in particular *I. cancellatum*, *Palaeoephippium bifurcum*, *P. radices*, *P. spinosum*, and *Goodbodium flammatum*.

Two graptoloid bioevents occurred within the upper Llandovery-lower Wenlock interval of the Cape Phillips Formation that did not yield Radiolaria. The *Cyrtograptus lapworthi* Event is known from Arctic Canada, the British Islands, Lithuania, and the Czech Republic (Melchin, 1994; Štorch, 1995). According to Melchin et al. (1998), 38 percent of graptoid taxa survived this event. The event occurred during a major sea-level fall. In the Cape Phillips Formation, the event is recorded immediately above the radiolarian-bearing samples from the top of the *sakmaricus* Zone (Melchin, pers. commun., 2003).

Štorch (1995) noted that the *Cyrtograptus murchisoni* Event is well-known geographically. In the Barrandian area of the Czech Republic, graptoloid species diversity drops from 21 to four (Štorch, 1995). Melchin et al. (1998) stated that 36 percent of taxa survived the event. As with the prior *C. lapworthi* Event, this event is recorded the upper Llandovery-lower Wenlock interval of strata from the Cape Phillips section that did not yield radiolarians; as with the prior event, no direct comaprison to radiolarian responses can be made. The *Cyrtograptus murchisoni* Event occurred at a time of rising sea level, unlike most Silurian graptoloid bioevents (Melchin et al., 1998).

The Ireviken Event (Aldridge et al., 1993; Jeppsson et al., 1995; Jeppsson, 1997a) straddles the Llandovery-Wenlock boundary. It is marked by the step-wise extinction of conodonts. Jeppsson (1997a) noted ten levels (datums) of conodont faunal change, and commented that trilobites and brachiopods were also affected during the event. According to Jeppsson (1997a), 60 conodont taxa were reduced to 12 during the course of the Ireviken Event. He commented that these numbers do not include the reappearance of taxa during and after the event. The *Cyrtograptus lapworthi* grapotlite event coincides with the lowest datums of the Ireviken Event, while the *Cyrtograptus murchonsoni* graptolite event is near or at the final datum (Jeppsson, 1997a).

As noted above, there is a reorganization of radiolarian relative and total abundances across the Llandovery-Wenlock boundary. The precise timing of this change (or changes) and its relationship, if any, to the *Cyrtograptid lapworthi* and *C. murchisoni* events are yet to be determined. Clearly, however, the environmental parameters affecting the northern margin of Laurentia changed during the time interval represented by the strata between the 162.7 and 196 metre levels of the Cape Phillips section. Possibly, the same changes that altered the radiolarian abundances had a role in one or both of the graptoloid events, and in conodont extinction datums. Significantly, much of the changes in the conodont fauna through the Ireviken Event were changes in relative and absolute abundances (Aldridge et al., 1993; Jeppsson, 1997a). However, the possibility that the radiolarian abundance changes could represent a local phenomenon, such as a change in upwelling or circulation, ought not be rejected prematurely. Better radiolarian data across the Llandovery-Wenlock boundary would be most elucidating.

Other Bioevents

Two other graptoloid bioevents occurred during the time interval considered in this thesis. The *Parakidograptus acuminatus* Event occurred at a time of rising sea level and had a 35 percent survivorship (Melchin et al., 1998). The *Stimulograptus sedgwickii* Event, with a survivorship of 41 percent, occurred during a fall in global sea level (Melchin et al., 1998). This event coincides with the Sandvika Event discussed by Aldridge et al. (1993). Aldridge et al. (1993) noted that conodonts, trilobites, brachiopods, and acritarchs were affected. In Estonia, more than 50 percent of conodont species and 25 percent of conodont genera disappeared during the Sandvika Event (Mănnik and Viira, 1993). There are no definitive changes in the Cape Phillips radiolarian fauna that could be associated with *S. sedgwickii*/Sandvika event. There is a large gap in sampling at the base of the Llandovery (Cape Manning 2). The similarities between CM2-4.25 and CM2-42.5 suggest there is no major effect on the radiolarian fauna at the *P. acuminatus* Event; however, the proportions from CM2-31.9 are noticeably different from CM2-4.25 and CM2-42.5. It remains to be demonstrated if this sample represents a transient local effect on the radiolarians.

Discussion

A detailed attempt at elucidating the causes for the radiolarian faunal variations in the Cape Phillips Formation is beyond the scope of this thesis. However, a few preliminary thoughts on this topic are offered here.

Rhuddanian-Aeronian Boundary.–The radiolarian faunal changes at this level do not coincide with graptoloid or conodont bioevents. Faunas from Nevada of similar age (Noble et al., 1997, 1998) are in accord with Cape Phillips Rhuddanian fauna. The percentages of *Haplotaeniatum* from a single sample from the *turriculatus* Zone of Sweden, on the other hand, are more in accord with the Cape Phillips Rhuddanian than Aeronian. This suggests that whatever parameter that influences the abundance of *Haplotaeniatum* may operate on a local scale. A global event at this level remains to be demonstrated.

A convenient explanation for the Rhuddanian-Aeronian shift in radiolarian relative abundances is variation in sea level. Radiolarian faunas in shallower water settings are low in abundance and diversity, and certain taxa tend to dominate (e.g., Blueford, 1983; Swanberg and Bjørklund, 1987). The shift in relative abundance and general increase in diversity up-section after the *cyphus* Zone could relate to greater open ocean influence. The presence of mottled dolostones in the lower and middle Llandovery of the Cape Phillips Formation indicates periods of low sea level. The atypical abundance in sample CM2-31.9 may similarly be related. The global sea-level curves of Johnson (1996) and Lloydell (1998) place this change in the Cape Phillips radiolarian fauna at or near a time of oceanic high stand.

As noted by Holdsworth (1977), while sea level is involved in changes such as noted above, it is the influence of more oceanic water that is the cause, rather than specific depth or distance from shore. Blueford (1983) attributed radiolarian faunal changes in the Bering Sea slope somewhat vaguely to circulation changes associated with the opening of the Bering Sea and/or climatic changes.

Future studies of the Rhuddanian-Aeronian boundary globally may benefit from comparison of sedimentology to recovered radiolarians. Palmer (1986) suggested that changes in the radiolarian fauna from the Miocene Calvert Formation of Maryland were due to changes from an upwelling setting through neritic to delta-influenced settings. These settings were determined from the sedimentology of the formation. As indicated by Blueford (1983) above, the evolution of basinal geometry ought also be considered.

Upper *turriculatus - crispus* Zone.–As noted above, there is no recovery of Radiolaria in this interval. Within this interval, Loydell (1998) described a sea-level rise in the upper *turriculatus* Zone followed by sea-level fall in the *crispus* Zone. Because of lithologic gap in the Cape Phillips Formation sections, coincidence with either sea-level change cannot be established.

The last appearance of some species of *Haplotaeniatum* across this interval may be an artefact. The first appearance of the inaniguttids may represent the return of a Lazarus taxon, or these large, spherical forms may be derived from *Orbiculopylorum*, as suggested by Won et al. (2002). The last appearance of *Orbiculopylorum* either slightly before or within this stratigraphic gap is the only reasonably confident observation.

If the individuals described herein as Inaniguttidae truly belong to the family, then some alteration in the oceanic environment is implied. The slightly rarer occurrence of *Haplotaeniatum* above this interval may be related to this. As noted by Melchin (1987), Cape Phillips Embayment did deepen over time. The changes across the upper *turriculatus* - *crispus* zones could reflect further oceanic influence, similar to that suggested above. There may have been some change in circulation bringing forms from another area. There are no obvious indications of increased productivity across this interval that could suggest increased upwelling (e.g., increased radiolarian abundances) that could have introduced deeper water forms into the area.

Alternatively, if the forms described here as inaniguttids evolved from *Orbiculopylorum* (Won et al., 2002), then one might question if this interval has any palaeoenvironmental significance. Other than the last appearance of *Orbiculopylorum* and the first appearance of the inaniguttids, little occurs in the radiolarian fauna. There are no corresponding changes of significance amongst the graptoloids or conodonts, two important groups that shared the planktonic environment with the Radiolaria.

Llandovery-Wenlock boundary.–Radiolarians were not recovered across this boundary. It is unknown if the changes in the fauna coincide with the *Cyrtograptus lapworthi* graptolite Event (sea-level fall) or with the *Cyrtograptus murchisoni* graptolite Event (sea-level rise). The Ireviken conodont Event occurred stepwise across this interval, which suggest that changes in the oceanic environment were more complex than simply changes in sea level. The sea-level fall in this interval coincides with the last glacial advance in South America reported by Grahn and Capto (1992). The glacial advance may have invoked changes in circulation, upwelling, or nutrient and oxygen levels.

The absolute abundance of radiolarians in the Cape Phillips Formation increases markedly in the Wenlock. There are no obvious lithological changes that might indicate a reduction in sedimentary dilution of the radiolarians. The increased abundances could indicate more eutrophic condition possibly a result of upwelling; radiolarian abundance in modern sediments is higher under upwelling systems and other fertile areas (De Wever et al., 2001). The differences in relative abundances across the Llandovery-Wenlock boundary might also reflect greater vertical movement of the water.

The radiolarian faunal changes in this interval could represent circulation changes (with or without upwelling) independent of the glaciation in South America. As noted by Wilde et al. (1991), the northward drift of Siberia through the Silurian would have resulted in the deflection of colder water south and down the western coast of Laurentia. Their palaeoceanographic maps (Wilde et al., 1991, text-fig. 4, text-fig.5) place the subtropical convergence near to, but apparently north of, Cornwallis Island in the Llandovery, whereas the entire northern margin of Laurentia is in contact with waters north of the convergence in the Wenlock. It is possible that the Wenlock radiolarian fauna reflects a change in water mass influence.

A carbon isotope study of the Cape Phillips Formation which may elucidate more details of the environmental changes across the Llandovery-Wenlock boundary is in progress (cf. Melchin and Holmden, 2000). Additionally, there is a change in the abundance and character of the poriferan fauna across this boundary in the Cape Phillips Formation. Murchey and Jones (1994) used the association of sponges and radiolarians to infer different depositional environments in terranes in Oregon. A similar study might be done in the Cape Phillips Formation.

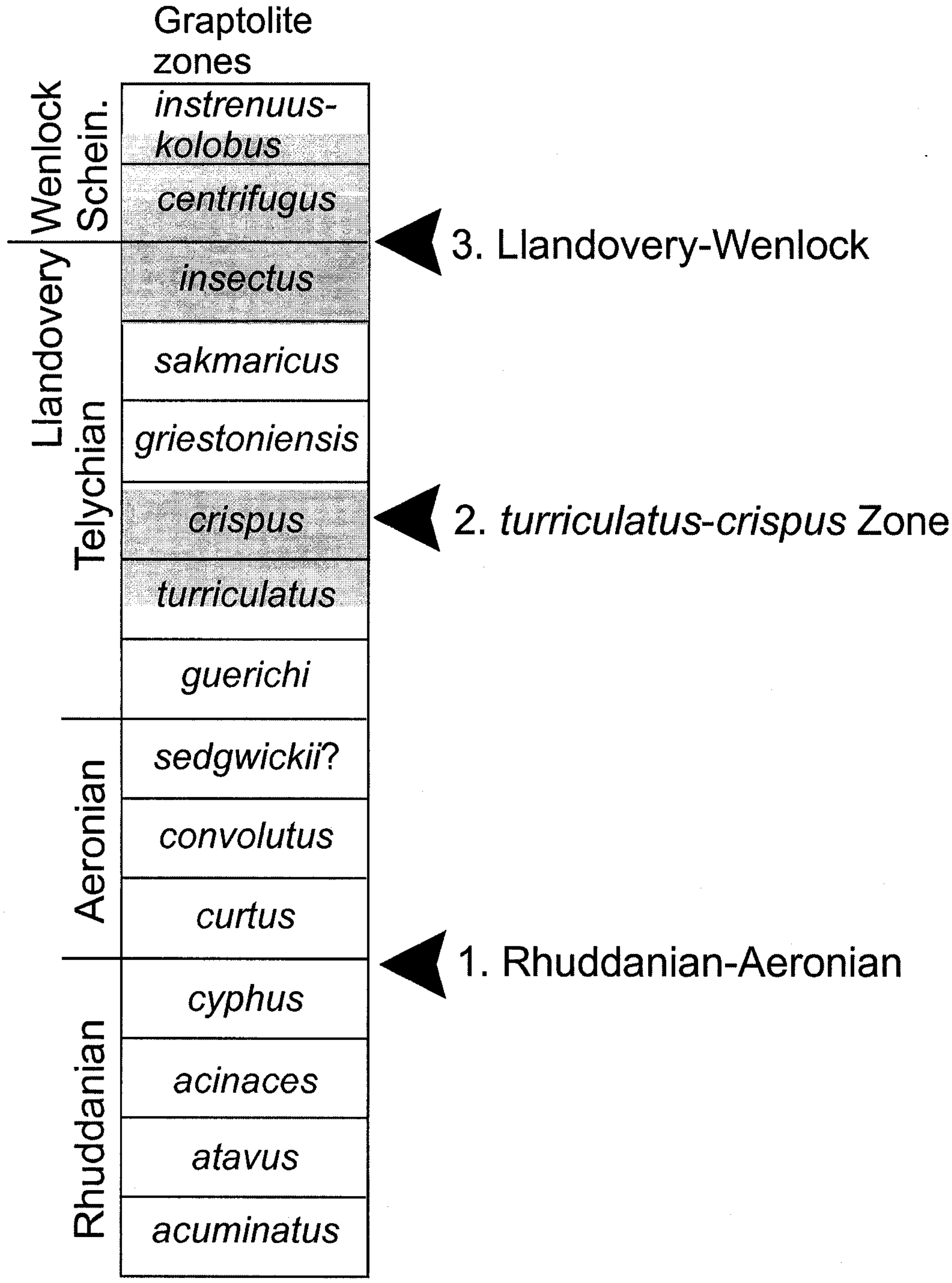


Figure 7.1

Stratigraphic position of radiolarian faunal changes observed in the Lower Silurian of the Cape Phillips Formation. No radiolarians recovered in shaded intervals.

CHAPTER 8 - SYSTEMATIC PALAEONTOLOGY

Repository.–Figured and type specimens will be deposited at the National Type Collection of Invertebrate and Plant Fossils, Geological Survey of Canada. GSC numbers are already assigned to the Palaeoscenidiidae.

Terminology.–The terminology for the Secuicollactidae is that of Noble (1994) and MacDonald (1998, adopted from Dumitrica, 1978). The apical spine is the spine of the spicule that is perpendicular to the radially arranged basal rays (Figure 8.1). Basal spines are continuations of the basal rays. The antapical spine is positioned at or near the pole opposite the apical ray. The term "primary unit" refers to the components of the skeleton formed from lattice bars radiating from a common point; a spine may arise at the centre of a primary unit.

The terminology used for the Palaeoscenidiidae is that of Holdsworth (1977) and Goodbody (1986). The "apical hemisphere" consists of weaker, less ornate "apical rays," whereas the rays of "basal hemisphere" are large and commonly more ornate that the apical rays (Figure 8.2). MacDonald (1999) used the term "principal ray" to denote the ray in *Insolitignum* that occupies neither an apical nor basal position. This term is avoided in the present paper. This ray may develop as an apical or basal ray in some specimens; consequently, the application of the term "principal ray" is problematic is these specimens. Additionally, *Palaeoephippium* shows a similar, variably developed ray; however, the homology of the variable ray in *Insolitignum* and *Palaeoephippium* is not known. The more neutral term "intermediate ray" is used herein to denote any ray that occupies a position anywhere between the apical or basal rays of an individual regardless of its taxonomic significance. Goodbody (1986) used the term "spinules" refers to smaller rays emanating from the apical or basal rays, and "microspinules" to small extensions off rays or spinules. A "verticil" is a group of spinules arranged radially about an axis (Goodbody, 1986).

The term "medullary shells" refers to the inner shells of concentrically arranged spherical skeletons; the "cortical shell" is the outermost shell or the shell of a single shelled form (Campbell, 1954). These terms are not applied to the Inaniguttidae described herein because there remains some uncertainty about the total number of shells within a given species. Instead, the different shells are numbered outwards starting at the shell adjacent to the centre-most structure.

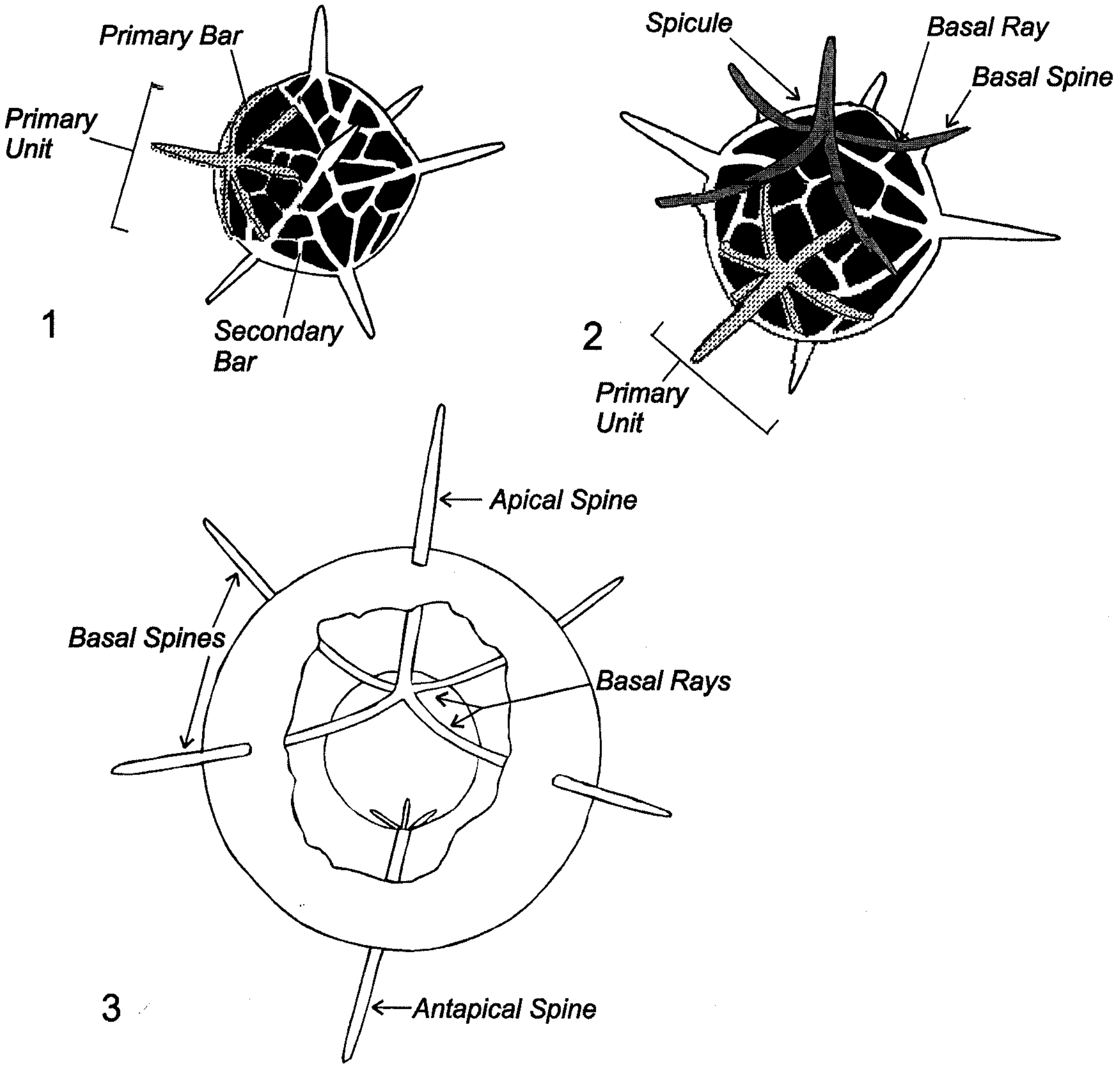


Figure 8.1

Morphologic features of the Secuicollactidae. 1) *Rotasphaera*; 2) *Secuicollacta*; 3) *Diparvapila* (modified after MacDonald, 1998).

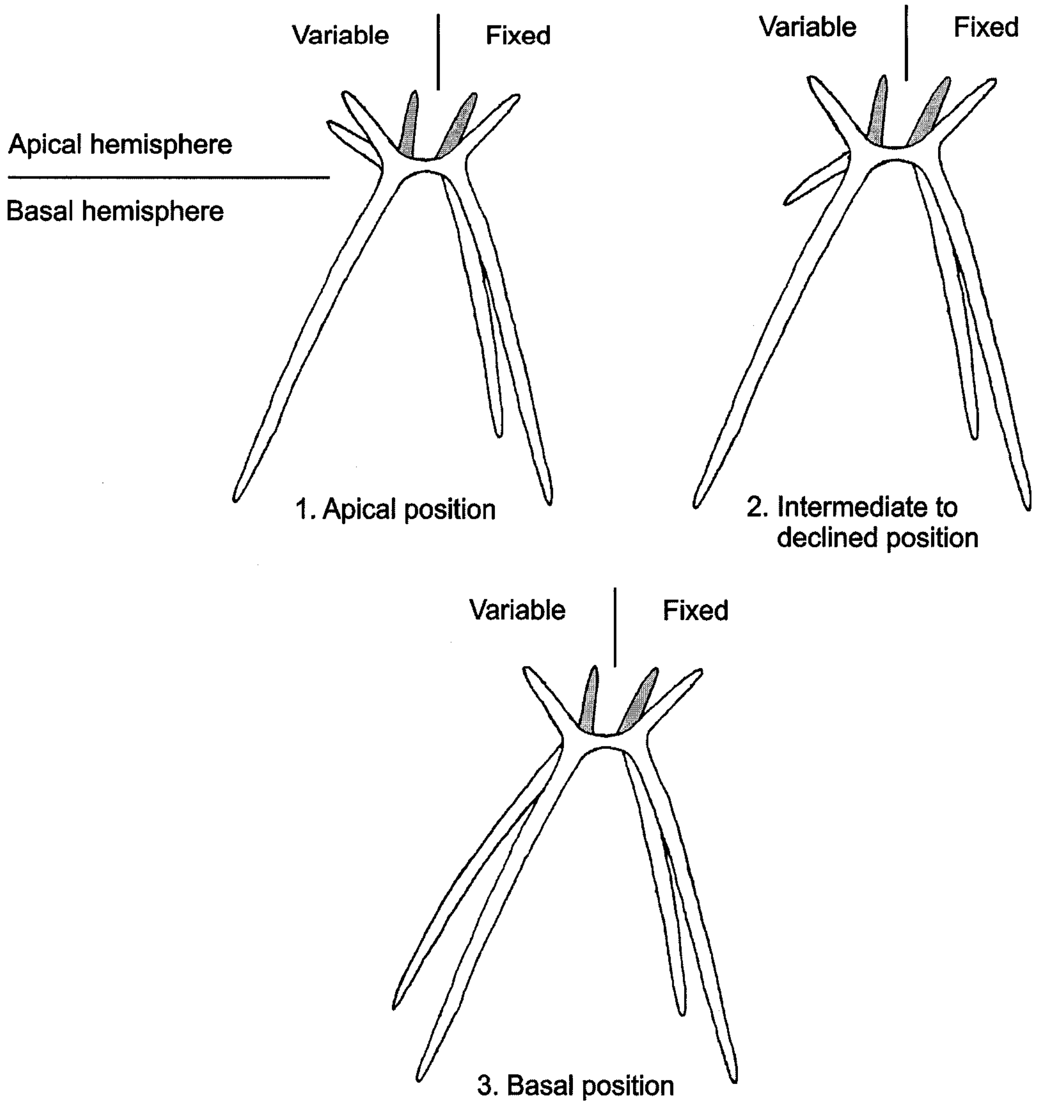


Figure 8.2

Principal within species variations seen in *Insolitignum* and *Palaeoephippium*. Shaded apical rays may be absent. Orientation of rays is fixed on one side of the median bar (at right). On other side of the median bar, one ray may take an apical to declined position (1, 2) or develop fully as a basal ray (3).

Class ACTINOPODA, Calkins, 1909

Subclass RADIOLARIA, Müller, 1858

Superorder POLYCYSTINA Ehrenberg, 1838

Order ARCHAEOSPICULARIA Dumitrica, Caridroit, and De Wever, 2000

Superfamily SECUICOLLACTACEA Nazarov and Ormiston, 1984

Rotasphaeracea NOBLE, 1994, p. 19; NOBLE AND MALETZ, 2000, p. 268.

Emended diagnosis.–One or more spherical or subspherical shells; shell or innermost shell of multishelled species with single or multiple primary units.

Discussion.–Noble, 1994, diagnosed the Rotasphaeracea as having one or two shells, with primary units on the outer shell. Dumitrica et al. (2000) gave priority of name to Secuicollactacea. The principal difference between the diagnoses given by Noble (1994) and Dumitrica et al. (2000) is that Noble (1994) place the primary units on the cortical shell of multiple-shelled forms, whereas, Dumitrica et al. (2000) placed the primary units on the innermost shell of multiple-shelled forms. Dumitrica et al.'s (2000) diagnosis is consistent with the present author's observations and is used here. The emended diagnosis given here is essentially that of Dumitrica et al. (2000), except that the shell need not form from the coalescing or interweaving of primary units; this is not observed in *Diparvapila*. Also, the reference to the variable presence of an ectopic spicule is removed because this is not diagnostic at the superfamily level.

Both Noble (1994) and Dumitrica et al. (2000) divided the Secuicollactacea into two families -- those with a single shell (Secuicollactidae) and those with two shells (Pseudorotasphaeridae). MacDonald (1998), in contrast, followed Nazarov and Ormiston (1984) and assigned taxa bearing an ectopically-placed spicule to the Haplentactinidae; taxa lacking a spicule were assigned to Noble's (1994) Rotasphaeridae (Secuicollactidae of Dumitrica et al, 2000). Noble and Maletz (2000) believed that *Secuicollacta*, *Diparvapila* and the nonspicular genus *Rotasphaera* are sufficiently similar to warrant placing in the same family, the Rotasphaeridae. They assigned the genera with a spicule to the subfamily Secuicollactinae, but expressed concern that *Secuicollacta* and *Rotasphaera* may be congeneric. Won et al. (2002) placed all genera of the superfamily Secuicollactacea into a single family without subdivision into subfamilies.

A classification based on the presence or absence of a spicule appears more natural than one based on the number of shells, such as Dumitrica et al. (2000). The ectopic spicule is a consistent feature. *Diparvapila* is not observed without a spicule. *Secuicollacta*, within limits of observation possesses a spicule (see discussion on Secuicollactinae). *Rotasphaera* is not observed with a spicule. Dumitrica et al. (2000) suggested that the internal spicule of the Entactinaria may be a modified archaeospicularian skeletal element. It would seem reasonable to hypothesize that the ectopic spicule in *Secuicollacta* and *Diparvapila* is, likewise, a modified primary unit. When this distinct and, evidently, stable modified primary unit appeared in the evolution of the Archaeospicularia (or perhaps lost in *Rotasphaera*) is not established; however, two clades appear to be the result.

The suprageneric classification herein follows Noble and Maletz (2000). The similarity of the primary units in *Secuicollacta*, *Rotasphaera* and *Diparvapila* unite these taxa at the family level (Secuicollactidae). Two subfamilies of Secuicollactidae are considered herein -- Secuicollactinae, which bears an ectopic spicule, and Rotasphaerinae, which lacks this structure. As such, *Diparvapila* is in the Secuicollactinae along with *Secuicollacta*, rather than in the Pseudorotasphaeridae along with *Pseudorotasphaera* and *Stylactinosphaera* as proposed by Dumitrica et al. (2000).

The two-shelled genera *Pseudorotasphaera* and *Stylactinosphaera* were not observed in this study. Both Noble (1994) and Dumitrica et al. (2000) placed these genera in the family Pseudorotasphaeridae. Won et al. (2002) argued that the family should be disregarded because shell number is generally a genus-level character. The available information of the pseudorotasphaerid genera (Noble, 1994) gives little information about the inner shell. Dumitrica et al. (2000) made the hopeful statement that a spicule "seems to exist" with the inner shell; however, Noble's (1994) description and figures neither support nor refute this. *Pseudorotasphaera* and *Stylactinosphaera* differs markedly from *Secuicollacta*, *Diparvapila*, and *Rotasphaera* in that primary units are present on the outer shell. The presence of primary units on the inner shell of *Pseudorotasphaera* and *Stylactinosphaera* is not established. In contrast, in the two-shelled forms described herein, primary units are exclusively on the inner shell. De Wever et al. (2001) regarded the Palaeoactinosphaeridae Noble, 1994, as synonymous with the Pseudorotasphaeridae. De Wever et al. (2001) do not discuss their synonymy; however, one assumes it is based on the similarity of the spines. The palaeoactinosphaerids possess strongly bladed or grooved spines that are quite similar to the spines of *Pseudorotasphaera*. In such case, one must question if *Pseudorotasphaera* and *Stylactinosphaera* are secuicollactaceans. The supposed primary bars of these genera may be extensions of the spine blades rather than true primary bars of primary units. De Wever et al. (2001) also conditionally assigned *Intracorpus* to the Pseudorotasphaeridae. Similar to the Palaeoactinosphaeridae, this monospecific genus has strongly bladed spines. The interior of *I. octahedron* is a polygonal meshwork not unlike *Rotasphaera*. It remains to be demonstrated if this structure is the same as *Pseudorotasphaera* and the Palaeoactinosphaeridae. Until details of the inner shell can be clarified, the relation of *Pseudorotasphaera* and the Palaeoactinosphaeridae to the Secuicollactidae is ambiguous.

Family SECUICOLLCTIDAE Nazarov and Ormiston, 1984

Rotasphaeridae NOBLE, 1994, p. 19; MACDONALD, 1998, p. 599; NOBLE AND MALETZ, 2000, p. 268; WON, BLODGETT, AND NESTOR, 2002, p. 945.

Secuicollactinae NAZAROV AND ORMISTON, 1984, p. 74; MACDONALD, 1998, p. 587.

Emended diagnosis.–One or two lattice shells, or one lattice shell with labyrinthine overlayer. Inner shell or shell of single-shelled forms possess one or more primary units. Spicule, when present, ectopically placed on shell of single-shelled forms, with inner shell of multi-shelled forms. Primary units consist of primary bars radiating from a common junction, straight or curved outwardly convex; often a spine perpendicular to primary bars at the common junction.

Discussion.–The diagnosis given here is a slight modification of Noble and Maletz's (2000). Noble and Maletz (2000) regarded the ectopic spicule and primary units as equivalent and use the term "rotasphaerid structure" to encompass both features. However, as discussed below with the Secuicollactinae, the spicule is morphologically distinct from primary units, and acknowledgement of its uniqueness is required for distinction of the two subfamilies. The emended diagnosis here removes the term "rotasphaerid structure." According to the earlier diagnosis, the lattice shell is formed by the coalescing of primary units. This is not observed in *Diparvapila* and is removed from the diagnosis.

Subfamily SECUICOLLACTINAE Nazarov and Ormiston, 1984

Secuicollactinae NAZAROV AND ORMISTON, 1984, p. 74; MACDONALD, 1998, p. 587; NOBLE AND MALETZ, 2000, p. 270.

Emended diagnosis.–One or more spherical or subspherical shells; shell of single-shelled forms and innermost shell of multi-shelled forms possess one or more primary units plus an ectopically placed spicule; spicule possesses one apical spine, two or more, generally four, basal rays; basal rays curved apically concave, continue as spines.

Discussion.–Nazarov and Ormiston (1984) regarded the Secuicollactinae as a subfamily for the Haplentactinidae and simply diagnosed the subfamily as Haplentactinidae with an ectopically placed spicule. The emended diagnosis given here is more expansive. The detail of the spicule is stated and the presence of one or more primary units included. It also clarifies that the spicule and primary unit occur on the inner shell of multiple-shelled forms.

Dumitrica et al. (2000) dismissed the ectopically placed spicule as an unusual primary unit. More recently, Won et al. (2002) in an examination of Radiolaria from the Road River Formation, Alaska, proposed that the spicule (their prominent primary unit) was an amalgamation of primary units. The present examination of the Cape Phillips Formation radiolarians supports MacDonald's (1998) argument that the spicule is a unique and consistent feature. *Diparvapila* (which here includes *Parvalanapila* MacDonald, 1998) was not observed without a spicule. Won et al.'s (2002) treatment would require some specimens of this genus to possess six distinct primary units, which was not observed. The spicule in *Diparvapila* is in all ways identical to that seen in *Secuicollacta*. What must be kept in consideration is that the spicule is positioned at the lattice sphere; inevitably, the lattice bars of the sphere will interact with the spicule. Won et al. (2002) present their figure 6.5a, 6.5b as a demonstration of primary unit amalgamation; however, the configuration is more readily explained, and consistent with numerous observations by the present author, as a unique structure in association with the rest of the skeleton.

Won et al. (2002) also state that the basal spines of the spicule are the spines emanating from a modified primary unit. These modified primary units may or may not show remnants of their original spokelike arrangement. Such an interpretation must be approached with caution. By simple geometry, the basal spines leave the shell at a point. The number and configuration of lattice bars attached at this point will depend on the individual specimen with the influence of shell size and density of lattice construction. In the author's own observations, no clear pattern emerges at the base of the basal spines. The author has observed only two specimens of *Diparvapila hicocki* with quite noticeable bars radiating from the basal spine. While Won et al.'s (2002) interpretation does not appear to explain a (presumably) random appearance of the spicule in a population, it does present a valid hypothesis for the evolutionary origin of the spicule.

Another important consideration is that the spicule is not morphologically identical to the primary unit. The primary bars of primary units are curved such that the convex surface is directed outwards, thus forming the curvature of the lattice sphere. The basal rays of the spicule are curved in the opposite manner; that is, the concave suface is directed outwards (described by MacDonald, 1998, as apically concave). Quite commonly, the basal rays will form a bell-like shape -- convex immediate to the apical spine, then curving to concave. Convex spicules are seen only in species where the shell becomes radially thickened (e.g. *Secuicollacta glaebosa*, occasionally *S. multispinosa*). This appears related to the overall ontogeny of the species. As stated above, the spicule is positioned such that it is associated with the lattice sphere; growth that would thicken the lattice presumably also influences the spicule. Only in very rare cases do the bars of primary units extend slightly beyond the shell surface. The basal rays of the spicule invariably continue as spines; they can be diminutive or long depending on the species or preservation.

As noted by Noble and Maletz (2000), the ectopic spicule can be very difficult to differentiate from primary units, particularly in less well-preserved material. Won et al. (2002) appear to have overlooked the spicule in many specimens. Although the specimen of *Secuicollacta magnitesta* figured in their figure 1.1-1.5 is stated to lack a spicule, a close examination of figure 1.5 does show two apically concave basal rays extending from the spine marked "12?"; these rays can also be seen continuing as short spines. The specimen figured in Won et al.'s (2002) figure 6.4 has a spicule with the apical spine at the nine o'clock position, although this specimen is supposed to lack a spicule. In figure 6.1, Won et al. (2002) present a specimen of *Diparvapila* from the Canadian Arctic which supposedly possesses only one primary unit and no spicule. Such a configuration has never been seen by the present author in the Cape Phillips Formation radiolarians. Won et al.'s (2002) figure is consistent with an antapical view of a specimen with a spicule whose basal rays pass just under the medullary shell surface, a not uncommon configuration in the author's experience. This specimen warrants re-examination. The internal ridges figured by Won et al. (2002) figures 2.21 and 4.1 can clearly be seen as the basal rays of the spicule.

A key point of Won et al. (2002) is that the spicule is a random feature. In an attempt to isolate specimens of *Secuicollacta* which genuinely lack a spicule rather than an obscured spicule, the author examined 1217 individuals from the Cape Phillips Formation. Of these, 145 could provide no useful information, either due to the dense occurrence of spines or preservation obscuring a clear examination. Of the remaining 1072 individuals, the spicule was clearly present in 971 specimens (90.6 %); 19 individuals presented a deformed spicule (1.8 %); and 70 individuals (6.5 %) presented structures suggestive of a spicule, but a spicule could not be definitely confirmed. Only 12 specimens (1.1 %) apparently lacked a spicule. The author also examined 189 specimens of *Secuicollacta* from the Road River Formation (provided by M.-Z. Won); this did not include fragments of individuals or individuals that were coated with secondary silica deposits. Of the 189, the spicule was confirmed in 182 individuals (96.3 %). Six specimens (3.2 %) were ambiguous due to preservation. A spicule could not be confirmed in one specimen (0.5 %).

Given the rarity of specimens in which a spicule could not be confirmed, the presence of the spicule does not appear to be random. The question does remain as to why it should be absent in these few individuals. These specimens could be oddities within the population that genuinely did not develop the structure. Alternatively, the spicule may simply not have been observed in spite of the overall good condition of the specimens. Also, the current study revealed a small number of specimens in which the spicule was deformed. This included the spicule being oriented at odd angle, deflection of the basal rays from a normal path, and the apparent incorporation of basal rays into the lattice. Possibly the absence is misidentification due to similar deviation. One specimen was observed with two spicules. Noble and Maletz (2000) also noted specimens of *Secuicollacta* from the Telychian of Sweden in which no spicule could be found. In addition to preservation and being obscured by later growth, they suggested that the absence may be the result of resorption of skeletal elements.

SECUICOLLACTA Nazarov and Ormiston, 1984

Parasecuicollacta WON, BLODGETT, AND NESTOR, 2002, p. 953, figs. 3.1-3.11, 3.13-3.17, 4.1-4.17.

Type species.–*Secuicollacta cassa* Nazarov and Ormiston, 1984, from the Wenlock-Ludlow, Tarangul River, southern Urals.

Diagnosis.–Single spherical shell, formed mainly of primary units; spicule ectopically placed, one apical ray perpendicular to two to five basal rays.

Discussion.–The diagnosis used here is that of MacDonald (1998). The diagnosis as given by Nazarov and Ormiston (1984) is too general and encompasses *Diparvapila*. Diagnoses given by Noble (1994) and Won et al. (2002) exclude the spicule from the genus. Noble and Maletz (2000) did not alter the diagnosis of MacDonald (1998) but did question the reliability of the spicule as a defining character. As noted above with the discussion on the Secuicollactidae, the spicule is consistent in *Secuicollacta* and distinguishes it from *Rotasphaera*.

Parasecuicollacta Won et al. , 2002, is regarded here as a junior synonym of *Secuicollacta*. Won et al. (2002) separated *Parasecuicollacta* from *Secuicollacta* based on the thicker shell, and lumpy or ragged appearance of the outer surface. However, the basic structure of *Parasecuicollacta* does not differ from that of *Secuicollacta*. Both are formed of several primary units and a spicule. The lumpy or ragged appearance plus the real, and in some cases only apparent, shell thickening seems a variation on the development of the lesser spines. The secondary spines of *Secuicollacta resodiosae* MacDonald, 1998, range from fine rods or needles to an almost labyrinthine layer similar to that in *S. multispinosa* (Won et al., 2002). At the fine rod end of this species variation, it is quite similar to *S. malevola* MacDonald, 1998. *Secuicollacta bipola* (Won et al., 2002) shows a similar range in lesser spine morphology. *Secuicollacta multispinosa* also may develop fine, rodlike by-spines. The species assigned to *Parasecuicollacta* by Won et al. (2002) are indeed, at least superficially, very similar to one another. However, considering that the basic shell construction is the same as other species of *Secuicollacta*, and that the apparent raggedness can be explained by a variation in the spine development, the present author prefers a more conservative classification.

As indicated in the above paragraph, there can be considerable within species variation in *Secuicollacta*. It appears that some of the species-level distinctions made by MacDonald (1998) and Won et al. (2002) represent over-splitting of taxa. Determining the full spectrum of within-species variation of the genus remains a work in progress; however, the author is reasonably comfortable with the species treated herein.

SECUICOLLACTA BIPOLA (Won, Blodgett, and Nestor, 2002)

Plate 1, Figures 1, 2

Plate 4, Figures 1-6

Parasecuicollacta bipola WON, BLODGETT, AND NESTOR, 2002, p. 953, figs. 3.1-3.6, 3.14-3.17.

Emended diagnosis.–Large, conical apical and antapical spines; equatorial primary units without spines; secondary spines numerous, vary from cones or knobs to long rods.

Description.–Shell spherical or slightly ellipsoidal. One primary unit at antapical end, four(?) at or near shell equator; five to six, rarely seven primary bars per primary unit; edges of primary bars may be uneven; secondary bars variably developed; lattice irregular, level of development variable; pores subangular to rounded, framed by three to five lattice bars. Spicule ectopic, pentactine; basal rays curved apically concave, continue directly as basal spines; basal spines usually diminutive, not larger than by-spines, small rods or cones, occasionally larger; basal rays and basal spines usually obscured by seconday spines. Apical and antapical spines subequal, antapical may be slightly finer, large cones, length one-half to over one shell diameter, antapical spine may be parallel or inclined to line defined by apical spine. No spines with equatorial primary units. Secondary spines numerous, development variable; small knobs to long, tapered rods or cones, when larger may be clublike; longer secondary spines usually with apophyses distally or terminally, link adjacent secondary spines; secondary spines may be linked by weblike membrane; proximal joining of secondary spines gives shell thickened aspect.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 83-105; pore diameter 5-24; primary bar width 5-6; secondary bar width to 4; apical spine length 50-113; apical spine base width 15-20; antapical spine length 38-100; antapical spine base width 13-18; by-spine length 13-28.

Material and occurrence.–Over 100 specimens examined. Upper Llandovery (*guerichi* to lower *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut. Also in Llandovery, Road River Formation, Alaska (Won et al., 2002).

Discussion.–The diagnosis is emended here simply to clarify that the large polar spines are the apical and antapical spines.

The secondary spines are quite similar to those of *Secuicollacta resodiosae*. As with *S. resodiosae* the typical appearance is long, tapered rods or cones. These may bear lateral thorns or apophyses as with *S. resodiosae*. The secondary spine morphology also shows the same range of variability as *S. resodiose*. As with *S. resodiosae*, it is not clearly established whether smaller secondary spines represent an earlier level of growth, preservation, or some combination thereof.

No spines were noted with the equatorial primary units. A fews showed knoblike protuberances. Won et al. (2002) noted that these primary units may have very short primary spines or nodes. The basal spines usually are very short and difficult to observe. In a few specimens they are enlarged, albeit shorter than apical and antapical spines (Plate 4, Figures 5, 6).

SECUICOLLACTA GLAEBOSA MacDonald, 1998

Plate 1, Figures 3-5

Plate 5, Figures 1-6

Secuicollacta glaebosa MacDONALD, 1998, p. 592, figs. 3.6-3.10, 7.1, 7.2.

Description.–Shell spherical, radially thick. Five primary units, four in equatorial position, one near or at antapical pole; four to seven primary bars per primary unit; primary bars wide, edges uneven; secondary bars usually sparse to absent, occasionally better developed, width uneven; lattice crudely developed; pores generally without definite pattern. Spicule pentactine, rarely tetractine or hexactine; basal ray thickness variable, usually equal to shell thickness, basal ray outer edge commonly parallel to shell surface, inner edge may curve concave or convex towards shell centre. Spines from spicule and antapical primary unit, conelike, size variable, basal spines usually smaller than apical and antapical spines. Rarely spines from equatorial primary units, small cones when present. Outer surface of skeleton uneven, varies slightly bumpy to ragged with conical or webbed projections.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 63-93; shell thickness 12-23; pore diameter 5-12; primary bar width 5; secondary bar with 2-3; apical spine length 10-30; apical spine base width 5-12; basal spine length 3-28; basal spine base width 3-12; antapical spine length 15-30; antapical spine base width 8-15; surface relief up to 8.

Material and occurrence.–Over 800 specimens. Upper Llandovery to Wenlock (*guerichi* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–The variation observed in the outer surface of this species may, in part, be ontogenetic. However, much of this variation appears to be preservational. When poorly preserved, the present species, *Secuicollacta bipola*, *S. multispinosa*, and *S. resodiosae* can appear very similar. When very poorly preserved, *S. glaebosa* can appear as little more than a siliceous blob. The construction of the shell can be quite fine in some specimens; these usually have a finer spicule with the apically concave curvature of the basal rays that is more typical of the genus. While the variation between these finer forms and heavier specimens may represent ontogeny, it is possible some belong to other species (refer to discussion on *S. multispinosa*).

Won et al. (2002) described *Parasecuicollacta nannoglobosa* from the Road River Formation, Alaska, and noted the similarity to *Secuicollacta glaebosa* as well as other species. Based on the present author's observations, *P. nannoglaebosa* consists of a mélange of less well-preserved specimens of other species. Won et al.'s (2002) figures 4.10-4.12 and 4.16 are identical to *S. multispinosa*; Won et al. (2002) also noted this similarity. Won et al's (2002) figures 4.13 and 4.17 could be assigned to *S. multispinosa*, but also bear similarity to *S. teli* MacDonald, 1998. The author is still examining specimens from the Cape Phillips Formation that are tentatively regarded as *S. teli* and reserves a judgement. The specimens presented in Won et al.'s (2002) figures 4.14 and 4.15 are consistent with *S. glaebosa* except for their somewhat larger size.

Noble and Maletz (2000) reported *Secuicollacta glaebosa* from the *turriculatus*

Zone of the Kallholn Shale, Dalarna, Sweden. The figured specimen (Noble and Maletz, 2000, pl. 1, fig. 9) appears to have a pronounced equatorial spine. Possibly this specimen is *S. teli* or *S. multispinosa* rather than *S. glaebosa*.

SECUICOLLACTA MALEVOLA MacDonald, 1998

Plate 1, Figures 6, 7

Plate 2, Figures 1, 3

Plate 5, Figures 7, 8

Plate 6, Figures 1-4

Secuicollacta malevola MACDONALD, 1998, p. 589, figs. 3.1-3.3, 6.1, 6.2.

Secuicollacta gliris MACDONALD, 1998, p. 589, figs. 4.4, 6.12-6.14.

Secuicollacta tatondukensis WON, BLODGETT, AND NESTOR, 2002, p. 951, figs. 1.14-1.20, 2.1-2.4, 6.5a, 6.5b.

Emended diagnosis.–Irregularly arranged lattice; main spines rodlike, numerous, long, length may exceed one shell diameter; secondary spines numerous, needles to fine rods.

Description.–Shell spherical. Primary units numerous; five or six primary bars to a primary unit; secondary bars usually narrower than primary bars, form irregular lattice; pores subangular to rounded, framed by three to six bars. Main spines from centres of primary units and lattice nodes, number generally more than 10, may be as few as seven, rodlike, slightly to strongly tapered, may flair out at base slightly when strongly tapered, length commonly exceeds one shell diameter. Spicule pentactine, rarely hexactine, ectopic; basal rays curved apically concave, may pass below shell surface or partially overridden by lattice bars; basal rays continue externally as basal spines, leave shell between shell pole and equator, continue curvature of rays; spicular spines equal main spines, basal spines occasionally finer. Secondary spines numerous, fine rods or needles, length less than one half main spine length.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 80-115; pore diameter 4-21; number of pores per one-half shell circumference 6-11; lattice bar width 2-7; main spine length 90-183; main spine base width 5-13; secondary spine length 18-49.

Material and occurrence.–Over 1000 specimens. Middle Llandovery to middle Wenlock (*curtus* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut (Goodbody, 1981; MacDonald, 1998; new data). Also noted in the *turriculatus* Zone of Dalrna, Sweden (Noble and Maletz, 2000) and Llandovery of the Road River Formation, Alaska (Won et al., 2002).

Discussion.–MacDonald (1998) distinguished *Secuicollacta gliris* from *S. malevola* on the basis of shell diameter and spine number. The larger database available to the present study demonstrates a gradation between these two species, and *S. gliris* is regarded here as a synonym of *S. malevola*. The diagnosis is emended to accommodate the morphologic variability as presently understood. There does not appear to be any difference between *S. tatondukensis* Won, Blodgett, and Nestor, 2002, and *S. malevola*; the two are regarded here as synonymous.

The specimens recovered in this study show more variability in spine morphology than noted by MacDonald (1998). The spines can be strongly tapered (refer to Plate 2, Figure 3; Plate 6, Figure 2) or very gently tapered, nearly cylindrical (Plate 2, Figure 1; Plate 6, Figures 3, 4). Most specimens fall between these two extremes.

The variation in the number of primary units is not established owing to the density of spines. In specimens where a clear view of the shell is possible, the number generally is five to seven. Specimens with larger shells have few or no spines arising from the lattice nodes.

Secuicollacta malevola is known with certainty from sample CM2-46.8 and higher. The lower stratigraphic range may extend to CM2-2.0; however, specimens recovered below CM2-46.8 are ambiguous and could be assigned to *S. resodiosae* (refer to discussion with *S. resodiosae*). Goodbody's (1981) new genus B new species A appears the same as *S. malevola*; however, it is possible that his species includes *S. sceptri*. Goodbody's (1981) unpublished data indicates *S. malevola* continues in the Wenlock, although it was not observed in the present study.

SECUICOLLACTA MULTISPINOSA (Won, Blodgett, and Nestor, 2002)

Plate 2, Figures 2, 4, 5, 7

Plate 7, Figures 1-8

Plate 8, Figures 1, 2

Parasecuicollacta multispinosa WON, BLODGETT, AND NESTOR, 2002, p. 955, figs. 4.4-4.9.

Emended diagnosis.–Five or more primary units; spine length not exceeding one shell diameter; by-spines as labyrinthine layer or irregular masses.

Description.–Shell spherical. Five to eight primary units, five or six primary bars; secondary bars narrower than primary bars, lattice commonly well developed; pores framed by three to five lattice bars, subangular to rounded. Main spines from centres of primary units, rodlike, tapered, may be nearly conical, length one third to slightly less than one shell diameter; occasionally one or more primary units without spine . Rarely additional spines from lattice nodes, shorter, finer than main spines. Spicule ectopic, pentactine, rarely hexactine or tetractine; basal rays curved apically concave, continue externally as basal spines, leave shell well above equator, shorter and finer than main spines, continue curvature of basal rays; apical spine equal to main spines. By-spines numerous, densely distributed, usually very irregular, expand or branch at or near distal end, link together, form variably developed labyrinthine layer, may obscure shell; less commonly some by-spines needle or rodlike, may extend beyond labyrinthine layer; labyrinthine layer elements may join laterally into irregular-shaped masses.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 43-95; pore diameter 2-13; number of pores per one-half shell circumference 4-10; lattice bar width up to 5; main spine length 30-75; main spine base width 8-11; by-spine length 10-20.

Material and occurrence.–Over 600 specimens examined. Lower Llandovery to Wenlock (*accuminatus* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut. Also reported from Llandovery of the Road River Formation, Alaska (Won et al., 2002).

Discussion.–Won et al. (2002) diagnosed this species on the presence of lumpy or ragged surface and the presence of multiple primary units. The diagnosis is emended here to accommodate the variations observed in the present study. In the present material, the skeleton is composed of a lattice shell overlain by branching by-spines which form a labyrinthine layer. This layer can be modified into the lumpy or ragged appearance described by Won et al. (2002) by the lateral coalescing of the labyrinthine by-spines. While this could be a within-species variation, in many specimens it appears to be preservational. Poorly preserved specimens of this species and poorly-preserved *Secuicollacta resodiosae* could easily be mistaken one for the other.

The number of primary units in *Secuicollacta multispinosa* may be fewer than described by Won et al. (2002). In this regard, the species overlaps with *S. hexactinia* (Won et al, 2002); however, most specimens of that species figured by Won et al. (2002) appear to belong to *S. resodiosae.*

There is a possible ambiguity between the present species and *S. glaebosa.* A number of specimens were recovered that possess equatorial primary units without spines. However, these specimens were quite finely constructed and occasionally presented remnants of a labyrinthine layer (Plate 8, Figure 3, 6). These specimens could be interpreted as juvenile *S. glaebosa*, a form of *S. multispinosa*, or possibly a separate species.

SECUICOLLACTA PARVITESTA Won et al., 2002

Plate 2, Figure 6

Plate 8, Figures 4, 5, 7, 8

Plate 9, Figure 6

Secuicolacta parvitesta WON, BLODGETT, AND NESTOR, 2002, p. 949, figs. 2.5-2.14, 2.18-2.21.

Secuicollacta alaskensis WON, BLODGETT, AND NESTOR, 2002, p. 949, figs. 2.15-2.17.

Description.–Shell spherical or slightly subspherical. Six to 11 primary units, four to six thin primary bars; secondary bars slightly finer than primary bars; lattice delicate, well developed, fairly regular; pores framed by four to six lattice bars, subangular, rectangular to subcircular. Main spines from centres of primary units, rodlike, gently tapered, length may exceed one shell diameter. Spicule pentactine, ectopic; basal rays curved apically concave, often pass below shell surface, leave shell as spines well above equator, curvature continues along spine length. Apical and basal spines subequal main spines, basal spines may be slightly finer and shorter than main spines. By-spines numerous, small thorns to short, fine rods, rarely absent.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 93-125; pore diameter 2-15; lattice bar width up to 3; basal ray width 4-5; spine length 68-113; spine base width 5-8.

Material and occurrence.–One hundred specimens examined. Lower to upper Llandovery (*cyphus* to *griestoniensis* zones), Cape Phillips Formation, Cornwallis Island, Nunavut. Also reported from the Llandovery of the Road River Formation, Alaska (Won et al., 2002).

Discussion.–*Secuicollacta parvitesta* is notable for its thin, well-developed lattice shell. The primary units generally are not presented as prominently as in other species of the genus owing to the dense construction.

Won et al. (2002) distinguished *Secuicollacta alaskensis* from *S. parvitesta* by a more delicate lattice and shorter, thinner spines. They noted that the spines could be longer in specimens from the Arctic. Their diagnosis of *S. alaskensis* indicated an absence of by-spines; however, one of the figured specimens (Won et al., 2002, fig. 2.15) appears to have small by-spines similar to those seen in Won et al.'s figures of *S. parvitesta*. Specimens that could be clearly distinguished into two species -- *S. alaskensis* and *S. parvitesta* -- were not recovered in the present study. The two species are regarded here as synonymous.

SECUICOLLACTA RESODIOSAE MacDonald, 1998

Plate 3, Figures 2, 3, 5, 6

Plate 9, Figures 1-5

Secuicollacta resodiosae MACDONALD, 1998, p. 592, figs. 4.1, 4.3, 7.3, 7.7.

Parasecuicollacta hexactinia WON, BLODGETT, AND NESTOR, 2002, p. 955, figs. 3.7-3.11, 3.13

Description.–Shell spherical. Up to seven primary units, five or six primary bars; secondary bars narrower than primary bars, edges often irregular; lattice variably developed, sparse secondary rods to well-developed lattice; pores framed by three to six lattice bars, subanglar to rounded, triangular, rectangular, oval, subcircular, or irregular shapes. Main spines from centres of primary units, conical, length variable, up to one-half shell diameter, surface may be slightly convex. Spicule pentactine, ectopic; basal rays may be partly overridden by lattice bars, basal rays curved apically concave, leave shell as spines well above equator. Apical spine subequal main spines; basal spines slightly shorter and finer. Secondary spines numerous, often densely packed, may obscure shell, thin rods to conical; length variable, may nearly equal main spines, may be extremely short giving shell a ragged outline. Secondary spines may be linked by wall of silica proximal to shell; secondary spines often with short, thornlike spinules at short distance from shell, spinules may link laterally, linked spinules may form crude shell.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 68-113; pore diameter 3-13; number of pores per one-half shell circumference 6-10; lattice bar width 3-8; main spine length 18-53; main spine base width 10-13; secondary spine length 5-50; secondary spine base width 4-7.

Material and occurrence.–Over 900 specimens observed. Middle to upper Llandovery (*curtus* to *sakmaricus* zones), Cape Phillips Formation, Cornwallis island, Nunavut. Also in the Llandovery Road River Formation, Alaska (Won et al. 2002).

Discussion.–Greater variability in the secondary spines was observed in this study than by MacDonald (1998). These may be short and blunt as in Plate 3, Figure 3 and Plate 9, Figure 5. When reduced enough, the spines may simply give a generally ragged appearance to the shell. The main spines are also reduced in size when the secondary spines are reduced. It is not entirely clear if this is an ontogenetic variation or preservational; however, this spine reduction does appear more frequently in more poorly preserved sample horizons. The lateral thorns off the secondary spines can be highly developed giving a specimen an appearance similar to that of *S. multispinosa,* such as seen in Plate 3, Figure 5 (compare to *S. multispinosa* Plate 2, Figure 2). Individuals such as Plate 3, Figure 6 may acquire a bladed appearance resulting from a "webbing" developed between the spines and lateral thorns. The distribution of the secondary spines may be less dense in some samples, and resulting in an appearance approaching *Secuicollacta malevola.* This was observed from samples in the lower half of the Cape Manning 2 section. The specimen figured in Plate 3, Figure 4 demonstrates the ambiguity that can occur from this thinning of the secondary spines. In the sample from which this specimen was collected (CM2-51.2), it is at the extreme end of the morphological gradation of *S. resodiosae*; however, it could just as easily be classified as *S. malevola* (compare to Plate 1, Figure 6 from CM2-46.8).

Won et al. (2002) described *Parasecuicollacta hexactina* from the Silurian Road River Formation of Alaska. They diagnosed this species as having six main spines an a ragged shell surface. From the figured specimens (Won et al., 2002, figs. 3.7-3.11, 3.13), plus the author's observation of the Cape Phillips Formation radiolarians, *P. hexactinia* is interpreted as a synonym of *Secuicollacta resodiosae*. The "ragged" shell depicted in Won et al's (2002) figures (in particular their figs 3.8-3.11) is consistent with poorly preserved *S. resodiosae* observed in the present study.

Goodbody's (1981) new genus B new species D is the same as *Secuicollacta resodiosae*. He noted the species in the lower Wenlock; however, his stratigraphic data indicated its presence only in the Llandovery. Goodbody's (1981) new genus B new species C could be either or both *S. resodiosae* or *S. multispinosa*. He noted the species in the *lundgreni* Zone of the Wenlock. If *S. resodiosae*, this significantly extends the stratigraphic range of the species.

SECUICOLLACTA cf. S. RESODIOSAE

Plate 10, Figures 1-4

<u>Description</u>.–Shell spherical. Six to (?)eight primary units, five to seven bars per primary unit; secondary bars thinner than primary bars; form well-developed lattice,

moderately irregular to slightly regular; pores subangular to rounded, framed by four to six, mainly five, lattice bars. Main spines from centres of primary units, rodlike, tapered, may be nearly conical, length one-half to nearly one shell diameter. Secondary spines rare to absent, shorter than main spines. Spicule ectopic, pentactine; basal rays curved apically concave, may be overridden by lattice bars, leave shell as external spines well above shell equator, continue curvature, slightly shorter than main spines; apical spine equal to main spines. By-spines numerous, fine needles to thin rods, may bifurcate distally, length up to one half main spine length.

Dimensions.–(in micrometres, from four specimens) Shell diameter 113-128; pore diameter 3-13; number of pores per one-half shell circumference 10-13; primary bar width 5-10; secondary bar width 3-4; main spine length 56-93; main spine base width 6-13; by-spine length 23-35.

Material and occurrence.–Six specimens observed. Wenlock (*instrenuus-kolobus* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–The present species could be regarded as a finely constructed variant of *Secuicollacta resodiosae*. However, it differs in that the fine by-spines do not develop into larger, more robust secondary spines as seen in S. *resodiosae*. Also, the by-spines lack the thorns commonly seen in *S. resodiosae*. *Secuicollacta* cf. *S. resodiosae* is quite similar to *Secuicollacta* new species A. However, the lattice of the present species is not as finely porous or regular as *Secuicollacta* new species A. Secondary spines are rarer in the present species, and the by-spines are longer as opposed to the mainly conical structures in *Secuicollacta* new species A.

SECUICOLLACTA SCEPTRI MacDonald, 1998

Plate 3, Figures 7, 8

Plate 11, Figures 1-6

Secuicollacta sceptri MacDONALD, 1998, p. 589, figs. 3.4, 3.5, 6.3, 6.4.

Description.–Shell spherical or slightly subspherical. Up to nine primary units, five or six primary bars per primary unit; secondary bars generally narrower than primary bars, form irregular lattice; pores subangular to rounded, framed by three to six lattice bars, most commonly four. Main spines from centres of primary units and lattice nodes, number more than eight, rodlike, gently tapered, length usually exceeds shell diameter. Spicule ectopic, pentactine; basal rays curved apically concave, continue externally as basal spines, leave shell well above equator, continue curvature of basal rays; spicular spines equal to main spines; basal spines may be slightly finer than main spines. Secondary spines sparse to absent, usually short, fine rods, may appear as knobs.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 80-126; pore diameter 5-25; number of pores per one-half shell circumference 6-8; lattice bar width 3-5; main spine length 103-193; main spine base width 5-10; secondary spine length 8-48.

Material and occurrence.–Over 400 specimens observed). Middle to upper Llandovery (*curtus* to *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

SECUICOLLACTA new species A

Plate 10, Figure 5-8

Diagnosis.–Well-developed, regularly arranged lattice; pores small, numerous. Main spines tapered, length approximately one-third shell diameter; several secondary spines, shorter and finer than main spines; by-spines conical to needlelike, densely distributed.

Description.–Shell spherical. Seven (?) primary units; secondary bars slightly narrower than primary bars; lattice well developed, regularly arranged; pores very small, fairly uniform size, framed by four to six bars, subcircular to circular or oval. Main spines from centres of primary units, rodlike, tapered, length about one-third shell diameter, may flair outward at base. Several secondary spines from lattice nodes, finer, shorter than main spines. By-spines densely distributed, small cones, may extend to thin needles, give shell hispid appearance. Spicule ectopic, pentactine; basal rays partially overridden by lattice bars, may pass below shell surface, extend as external spines between shell pole and equator; basal spines may continue curvature of rays, slightly smaller than main spines or nearly equal. Apical spine equal main spines.

Dimensions.–(in micrometres, from three specimens) Shell diameter 108-118; pore diameter 3-9; number of pores per one-half shell circumference 15-18; lattice bar width 3-5; main spine length 70-75; main spine base width 10-13; secondary spine length 50-55; secondary spine base width 5-10; by-spine length 5-20.

Material and occurrence.–Twelve specimens observed. Wenlock (*instrenuus-kolobus* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–This species was only observed from the Wenlock samples from the Cape Phillips Formation. The species is notable for its numerous, small pores in a finely arranged lattice. The variation in the number of primary units is not determined because of the only slight difference in lattice bar width and density of the lattice construction.

Genus DIPARVAPILA MacDonald, 1998

Diparvapila MACDONALD, 1998, p. 594, figs. 4.6, 4.10-4.12, 5.1-5.6, 8.4-8.11, 9.4, 9.5, 9.7; NOBLE AND MALETZ, 2000, 271, pl. 1, figs. 1, 3-5.

Parvalanapila MACDONALD, 1998, 597, figs. 5.7, 5.8, 5.10, 5.11, 9.1-9.3; NOBLE AND MALTEZ, 2000, p. 271, pl. 1, fig. 2.

Type species.–*Diparvapila hicocki* MacDonald, 1998, from the upper Llandovery of the Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Emended diagnosis.–Lattice sphere with ectopically placed spicule and single primary unit at or near antapical pole. Second, outer lattice shell or labyrinthine cover over lattice sphere with spicule. Principal spines arise from spicule and antapical primary unit.

Discussion.–The diagnosis of *Diparvapila* is emended here to include *D. fleischerorum*, which previously was placed in the monospecific genus *Parvalanapila* MacDonald, 1998. Consequently, species of *Diparvapila* may possess two lattice shells or a single lattice shell with a labyrinthine cover. Additionally, ray number is removed from the diagnosis; this can vary from four to six and does not appear to be diagnostic.

In this study, the labyrinthine cover of *Diparvapila fleischerorum* is interpreted as a variant of the radial beams and cortical shell of *D. larseni* and *D. hicocki*. In *D. fleischerorum*, the denser portion of the labyrinthine cover occurs at a short distance from the lattice sphere in some specimens. The curved beams between the lattice sphere and denser area are quite similar to radial beams. Additionally, the by-spines of *D. larseni* can develop into a labyrinthine layer very much like that of *D. fleischerorum*. In optical section, the two species can appear quite similar and can be misidentified if the internal features are not clearly visible.

MacDonald (1998) assigned small specimens of *Diparvapila* to *D. saintrochae* MacDonald, 1998. This species is not reported herein. Specimens that could be assigned to *D. saintrochae* were observed; however, it now seems more likely that these are diminutive specimens of *D. hicocki* or *D. larseni* that are either poorly developed or poorly preserved.

DIPARVAPILA FLEISCHERORUM (MacDonald, 1998)

Plate 3, Figure 1

Plate 12, Figs. 1-4;

Plate 14, Figs. 1-9

Parvalanapila fleischerorum MacDONALD, 1998, p. 599, figs. 5.7, 5.8, 5.10, 9.1-9.3.

Description.–Lattice shell with labyrinthine cover. Lattice shell spherical, lattice irregular; pores framed by four to six lattice bars, rounded or subangular; four, rarely five, primary bars at base of antapical spine. Labyrinthine cover formed by spinules off lattice, spinules bear distal branches, branches interlock or connect together; spinules may curve or form arches; labyrinthine cover may form as single layer or as two to three, rarely four, crude layers; each layer formed by spinules off preceding layer, spinules may curve or form arches, branch distally, branches interlock or join together; distance between lattice shell and densest branching of spinules variable. Spicule ectopically placed on lattice shell, pentactine, rarely hexactine; basal rays curved apically concave, leave lattice shell above equator. Six or seven spines, arise from spicule and medullary shell primary unit, length one-half to one time overall diameter, rodlike, tapered, may be nearly conical in small specimens, spines roughly orthogonal, antapical spine may be out of line of apical spine, at or near equator, basal spines commonly parallel plane of equator, may be declined, straight or slightly curved apically concave; additional spines off lattice shell rare.

Dimensions.–(in micrometres, from 12 specimens) Overall diameter 70-143; surface openings diameter 3-13; labyrinthine bar width up to 7; lattice shell diameter 40-58; lattice shell thickness 3-4; lattice shell bar width up to 5; lattice shell pore diameter 5-23; pores per one-half lattice shell circumference 3-5; spicule basal ray width 4-5; spine length from outer surface 38-100; spine base width 5-13.

Material and occurrence.–Over 250 specimens. Llandovery and Wenlock (*acuminatus* to *instrenuus-kolobus* zones, as far as known) of the Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–A fair amount of variability is seen in the labyrinthine cover over the lattice sphere of *Diparvapila fleischerorum*. The cover may be thick or thin, and may be densely or loosely constructed. It may occur as a single, fairly coherent layer, or as two or three layers built upon one another. The cover may develop close to the lattice sphere, or a space with little or no branching may occur between the lattice sphere and the denser outer portion of the labyrinthine cover. When a such a gap occurs, the species can appear quite similar to *D. larseni* in optical cross section. They differ in that in *D. fleischerorum* elements within the gap are curved or arched whereas in *D. larseni* there are distinct radial beams between the medullary shell and cortical shell. The similarity does suggest a close relationship between the two species. This gap in the labyrinthine cover of *D. fleischeroum* seems more common in samples from the upper part of the Llandovery.

Noble and Maletz (2000) presented a species identified as *Parvalanapila* ? sp. The species was not described. Noble and Maltez's (2000) remarks on the species are generally consistent with *Diparvapila fleischerorum*. Noble and Maletz (2000) noted a gap between the lattice sphere and labyrinthine cover and suggested there may be two shells and that the species may properly belong with *Diparvapila*. It is not reported if the gap is occupied with curved elements, consistent with *D. fleischerorum*, or with radial beams, which would be consistent with *D. larseni* or some other species. The single figured specimen (Noble and Maletz, 2000, pl. 1, fig. 2) shows several long, thin minor spines which is not consistent with *Diparvapila fleischerorum* as observed in this study and by MacDonald (1998). The present author concurs with Noble and Maletz (2000) that *Parvalanapila* ? sp. belongs with *Diparvapila* both as they interpret the genus and as it is interpreted herein. It is not clear, however, what the specific affiliation of the species is. Specimens from from the Canadian arctic figured by Won et al. (2002, figures 6.1-6.3, 6.6) are regarded here as *D. fleischerorum*.

Below CM2-46.8 specimens of *Diparvapila fleischerorum* are all diminutive and the labyrinthine elements are thicker. *Secuicollacta multispinosa* co-occuring in these samples are similarly diminutive and present a similar-appearing labyrinthine layer. In light of these similarities in specimens from the lower Llandovery of the Cape Phillips Formation, it is possible that at least some of the specimens assigned to *D. fleischerorum* are *S. multispinosa*. If this is true, an hypothesis on the phylogeny of the secuicollactinae may be offered. It is possible that *Diparvapila* originated as a species of *Secuicollacta* with irregular by-spines. Individuals within this species may have lost most of their primary units when size of the skeleton was diminished. This could have lead to a lineage with only a single, antapical primary unit plus a labyrinthine layer. Because the branching of the labyrinthine elements is concentrated distally, the layer may have modified into a lattice shell by the formation of linkages preferentially at the outer margin of the layer. This would have resulted in *D. larseni* and *D. hicocki*. More data are needed to test this hypothesis.

DIPARVAPILA HICOCKI MacDonald, 1998

Plate 12, Figs. 5-9

Plate 15, Figs. 1-11

Plate 16, Figs. 1-3

Diparvapila hicocki MACDONALD, 1998, p. 595, figs. 4.6, 4.10-4.12, 8.9-8.11;

NOBLE AND MALETZ, 2000, p. 271, pl. 1, fig. 5.

Diparvapila species B MACDONALD, 1998, p. 597, figs. 5.4-5.6, 9.7

Emended diagnosis.–Two lattice shells; pores small, five to six sided on cortical shell; spicule pentactine or hexactine, on medullary shell, rays continue directly as spines or broaden at cortical shell; six or seven spines, tapered rods or bladed.

Description.–*Forma A*. Two shells, spherical to slightly subspherical, both latticed. Cortical shell pores small, subangular to circular, framed by five to six lattice bars, arrangement usually very regular, rarely a pylomelike opening next to one spine; medullary shell pores small, subangular to circular, framed by four to six lattice bars. Single primary unit on medullary shell, composed of four or five straight and robust bars radiating from base of antapical spine. Spicule pentactine or hexactine, on medullary shell; basal rays curved apically concave or bell-like, may be straight proximal to apical ray. Six or seven spines, length may equal cortical shell diameter, one arises from antapical primary unit, others arise from spicule, rare additional spines arise from medullary shell; spine isometrically disposed, antapical spine may be out of line defined by apical spine; spines may broaden at cortical shell or continue directly from medullary without modification, basal spines buttessed on basal side where leave medullary and cortical shells, apical spine may bear buttresses at cortical shell, buttresses less common with antapical spine and less developed than with apical spine. Radial beams connect medullary and cortical shells, may continue as external by-spines or terminate at interior wall of cortical shell. By-spines continue from intershell beams or arise at lattice nodes; vary small cones to fine rods; apophyses arise from longer by-spines at short distance form terminus, may link to form incomplete second cortical.

Forma B. As for forma A but with the following differences. Lattice slightly less regular than most individuals of the species. Radial beams between shells absent. Branches arise from spicule rays and portion of antapical spine between shells, branches join inner surface of cortical shell.

Forma C. As for forma A but with the following differences. Spines bladed for approximately one-half length or more. Radial beams generally do not extend as by-spines. Conical by-spines may extend to fine rods; apophyses may arise terminally or near terminally, may link to form incomplete second cortical shell. May have a pylomelike opening alongside one spine.

<u>Dimensions</u>.–(in micrometres, from 14 specimens) Cortical shell diameter 75-105; cortical shell thickness 1-3; cortical bar thickness up to 5; cortical pore diameter 2-18; number of pores per 0.5 cortical circumference 12-19; medullary shell diameter 37-55; medullary thickness 1-3; medullary bar thickness up to 3; medullary pore diameter up to 8; number of pores per one-half medullary circumference 6-9; basal ray width 2-5; spine

length from cortical shell 45-155; spine base width 5-10, to 22 for forma C; by-spine length 3-35; distance cortical shell to by-spine apophyses (when present) 7.5-15.

Material and occurrence.–Over 300 specimens examined from the Middle to upper Llandovery (*curtus* to *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada (MacDonald, 1998; new data). Also reported from the *turriculatus* Zone, Kallholn Shale, Dalarna, Sweden (Noble and Maletz, 2000).

Discussion.–As treated here, *Diparvapila hicocki* includes *Diparvapila* species B of MacDonald (1998) as forma C. The diagnosis is emended accordingly. Spine length and relative sizes of the cortical and medullary shells are removed because they are not diagnostic.

There is a fair amount of variability within *Diparvapila hicocki*. Forma A describes the general, more common appearance of the species (Plate 12, Figures 5-7; Plate 15; Figures 1-7). Forma B and C describe two end-members in the variation. There are no clear morphological breaks between the three forms. Consequently, the significance of the variations are uncertain. The three could represent different species with very similar morphologies or one species affected by different environmental conditions. It could simply be the normal intraspecific variation of the species.

In forma B (Plate 15, Figures 8-11), the absence of radial beams could be preservational; a very few specimens displayed possible remnants of beams as tiny projections on the medullary shell. The branches seen in forma B are seen occasionally in specimens with radial beams, and specimens without beams may lack branches; however neither of these conditions are common. Full development of by-spines was not observed. Forma B has an apparent restriction to the upper *griestoniensis* Zone. In part this is because the internal details of specimens from the lower *sakmaricus* Zone could not be reliably observed.

Forma C (Plate 12, Figures 8, 9; Plate 16, Figures 1, 2) possibly represents a separate species as diagnosed by the bladed spines and the terminal or near terminal apophyses on the by-spines. In forma A, the apophyses, when present, are at a distance from the ends of the by-spines. Radial beams commonly do not extend as by-spines in forma C whereas more variability is seen in forma A. Also, the ontogeny of the two forms appears to differ; the studied specimens suggest that the bladed spines in forma C develop prior to the complete development of the byspines. However, many individuals assigned to forma A would likely be juvenile members of the species and indistinguishable from *Diparvapila hicocki*. Figure Plate 16, Figure 3 shows an individual intermediate to forma A and C. The apical spine is strongly butressed but not developed into blades in the sense of forma C. The antapical spine shows weaker butressing. If forma C is in fact a separate species, then this individual represents an early stage in ontogeny. Other, less developed individuals would be even more similar to *D. hicocki* forma A.

DIPARVAPILA LARSENI MacDonald, 1998

Plate 13, Figs. 1-4

Plate 16, Figs. 4-9

Diparvapila larseni MACDONALD, 1998, pp.595-597, figs. 5.1, 5.2, 8.4-8.6; NOBLE AND MALETZ, 2000, p. 271, pl. 1, figs. 3, 4.

Emended diagnosis.–Two shells, lattice irregular; spicule ectopically placed on medullary shell; spines rodlike to conical, arise from spicule, one spine from medullary shell at or near antapical pole.

Description.–Cortical shell spherical, rarely subspherical, lattice irregular; pores subangular to rounded, subelliptical to subcircular, framed by four to six lattice bars, mainly five lattice bars, bar lengths generally not equal, bars may pass over one another; medullary shell approximately one-half cortical shell diameter, spherical, lattice irregular, pores subangular to rounded, commonly elliptical, framed by four to six lattice bars, mainly five; single primary unit at or near medullary antapical pole, four primary bars, rarely five; radial beams link medullary and cortical shells, rarely continue as byspines; spicule pentactine, less commonly tetractine, rarely hexactine, at apical pole of medullary shell; basal rays curved apically concave along full length, or convex proximal to apical ray bending concave when leave medullary shell, basal rays leave medullary shell above equator, curved apically concave between shells, continue as external spines or join broader spine bases at cortical equator; five to six spines, arise from spicule and medullary shell primary unit, lengths about one cortical shell diameter, usually tapered rods, may be conical; apical and antapical spines rarely with proximal buttresses, basal spines buttressed on antapical side, spines roughly isometric, antapical spine often not in line with apical spine, rare additional spines arise from medullary shell; by-spines arise at lattice nodes, thorns or small rods when less developed, bear distal or terminal apophyses when better developed, apophyses branch in T or Y pattern or more complex branching, link laterally, may form second cortical shell or labyrinthine network.

Dimensions.–(in micrometres, from 31 specimens) Cortical shell diameter 68-115; cortical shell thickness 2-5; cortical shell bar width 2-7; cortical shell pore diameter 2-15; number of pores per one-half circumference cortical shell 6-11; medullary shell diameter 40-58; medullary shell thickness 2-3; medullary shell bar width 2-4; medullary shell pore diameter 5-15; number of pores per 0.5 circumference medullary shell 4-7; spicule ray width 3-8; intershell beam width up to 5; spine length from cortical 40-153; spine base width 7-16; by-spine length 5-28.

Material and occurrence.–Over 100 specimens observed from the Middle to upper Llandovery (*curtus* to upper *sakmaricus* zones), Cornwallis Island, Nunavut, Canada (MacDonald, 1998; new data). Also reproted from the *turriculatus* Zone, Dalarna, Sweden (Noble and Maletz, 2000).

Discussion.–The emended diagnosis allows for the variable number of spicule rays seen in the present study, whereas the original fixed the ray number at five. Redundant characters are removed; these include shell sphericity, relative size of cortical and medullary shells, spine length, and whether or not spines broaden at the cortical shell.

MacDonald (1998) noted the presence of by-spines with terminal apophyses in *Diparvapila larseni*; however, the current study provides a better understanding of the variability in this feature. Most commonly the apophyses arise from the distal or terminal parts of the by-spines, and may form an incomplete, or in rare cases complete, second cortical shell (Plate 16 Figures 8, 9). The apophyses may also branch in a more labyrinthine manner. The apophyses can make the external appearance of *D. larseni* identical to that of *D. fleischerorum*. *Diparvapila larseni* from the Telychian of Sweden (Noble and Maletz, 2000, pl. 1, figs. 3, 4) show by-spine development similar to that described herein. In some specimens of *D. larseni* the lattice bars of the cortical shell pass over one another. When this is pronounced, the cortical has a somewhat three dimensional arrangement which can cause further confusion of the species with *D. fleischerorum*.

A number of specimens *Diparvapila larseni* posses a tetractine spicule. This is more commonly observed in smaller specimens. Also, smaller specimens tend to have more coarsely constructed lattices.

DIPARVAPILA new species A

Plate 13, Figs. 5, 6

Plate 17, Figs. 1-4

Diagnosis.–Single sphere, lattice irregular; spicule pentactine, ectopically placed on sphere; short beams from sphere, branch distally or arch; main spines from spicule and single primary unit; several secondary spines from various locations on skeleton.

Description.–Single lattice shell, irregularly arranged lattice bars, generally very open; pores subangular to subrounded, framed by four to six lattice bars; single primary unit with four or five rods at or near antapical pole. Short beams arise from lattice sphere, branch distally to form arching elements, may link laterally, forms three-dimensional matrix over lattice sphere when well developed, gives impression of a crude second sphere when poorly developed. Thorns or arched elements may arise from matrix. Spicule pentactine, basal rays curved apically convex proximal to apical ray, curved apically concave for rest of length, leave lattice shell above equator. Antapical spine arises from lattice shell primary unit, out of line defined by apical spine. Spicule rays and antapical spine continue as external main spines directly or may broaden as leave shell, length less than one cortical shell diameter. Approximately eight secondary spines, shorter and finer than main spines or subequal, arise from lattice shell or outer matrix, spines off lattice shell larger than spines off outer matrix. All spines rodlike, tapered.

Dimensions.–(in micrometres, from five specimens) Overall diameter 105-110; lattice sphere diameter 72-80; inner sphere pore diameter 10-28; pores per one-half lattice sphere diameter 4-5; lattice bar width 2-5; spicule ray width 3-5; main spine length 82-100; main spine base width 5-10; secondary spine length 50-75; secondary spine base width 3-5.

Types.–Holotype, B79(1)#42 (Plate 17, Figures 1, 2); paratypes, B77.5(1)#472, B77.5(1)#478, B77.5(1)#470, B79(1)#212, B79(1)#421, B79(1)#402, B79(1)#377 (Plate 17, Figures 3, 4), B-79alc1NO12/01 (Plate 13, Figure 5), B-79alc4NO12/01 (Plate 13, Figure 6).

Occurrence.–Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada. Forty-six specimens recovered.

Discussion.–The present species is tentatively placed in the genus *Diparvapila*. The short beams arising from the lattice sphere may be equivalent to the irregular beams of *Diparvapila* n. sp. B and the matrix of *D. fleischerorum*. *Diparvapila* n. sp. A also possesses only a single primary unit at or near the antapical pole. However, the lattice sphere of the *Diparavpila* n. sp. A is larger and less regular than the medullary shell of other species of the genus. As with *Diparvapila* n. sp. B, this species produces multiple spines, unlike other species of *Diparvapila*.

Diparvapila n. sp. A apparently is restricted to the *griestoniensis* Zone in the Cape Phillips Formation. A single specimen from the lower *sakmaricus* Zone possibly belongs to this species.

DIPARVAPILA new species B

Plate 13, Figs. 7, 8

Plate 17, Figs. 5-8

Diagnosis.–Two lattice shells, medullary shell loosely constructed; pentactine spicule on medullary shell; cortical shell lattice irregular; main spines from spicule, primary unit; several secondary spines from various locations on skeleton.

Description.–Two shells; medullary shell loosely constructed by irregularly arranged lattice bars; pores subangular, framed by three to six lattice bars; one primary unit with four or five rods at or near antapical pole. Cortical shell irregular lattice, construction tighter than medullary shell, some lattice bars arch slightly; pores subangular to subrounded, framed by four to six lattice bars. Sparse network of beams arise from medullary shell, may connect directly to cortical shell, may loop back to medullary shell, continue in a curved path to cortical shell, or branch, branches may join either shell or other intershell beams; branches also arise from spicule rays and intershell portion of antapical spine. Spicule pentactine, basal rays curved apically convex proximal to apical ray, curved apically concave for most of length, leave medullary shell above equator, leave cortical shell near or above equator. Antapical spine arises from medullary shell primary unit, out of line defined by apical spine. Spicule rays and antapical spine continue directly as external main spines or broaden slightly at cortical, length approximately two-thirds cortical shell diameter or longer. Approximately 10 secondary spines, finer and shorter than main spines or subequal, arise from either shell or intershell network, may broaden slightly at cortical shell. All spines rodlike, tapered. Sparse thornlike by-spines, may branch distally or develop into arches, arches may join spines.

Dimensions.–(in micrometres, from five specimens) Cortical shell diameter 107-113; cortical shell thickness 2-3; cortical bar width up to 5; cortical pore diameter 4-17; number of pores per one-half cortical shell diameter 9-12; medullary shell diameter 45-55; medullary shell thickness 2-3; medullary bar width 2-3; medullary pore diameter 5-23; number of pores per one-half medullary shell diameter 3-4; spicule ray width 3-5; main spine length from cortical shell 80-113; main spine base width 6-8; secondary spine length 57-80; secondary spine base width 3-7; by-spine length 3-7.

Types.–Holotype, C20(1)#176 (Plate 17, Figures 5, 6); paratypes, B42.2(1)#116, B42.2(2)#438, C20(1)#108, C20(1)#410, C20(1)#470, C20(1)#153 (Plate 17, Figures 7, 8), C50.7alc3NO12/01 (Plate 13, Figure 7), C20alc5SE6/01 (Plate 13, Figure 8).

Occurrence.–Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada. Nineteen specimens recovered.

Discussion.–The inner sphere of *Diparvapila* n. sp. B is more open and more coarsely constructed than *D. hicocki*, and *D. larseni*. The size of the medullary shell is in accord with these species. The cortical shell may appear similar to that of *D. larseni*, but does not form the irregular by-spines seen in that species. Like *Diparvapila* n. sp. A, *Diparvapila* n. sp. B possesses multiple external spines. The beams linking the two lattice shells may be curved or irregularly disposed, suggesting an affinity with *Diparvapila* n. sp. A and *D. fleischerorum*. The species is very similar to an undescribed specimen figured by MacDonald (1998, fig. 4.2, 4.5).

Diparvapila n. sp. B is not common and is confirmed in only three samples (CM3-38.1, CM3-42.2 and CP-20). A single specimen from the Wenlock of the Cape Phillips Formation (CP-213) may belong to this species. A single, poorly preserved specimen from the *turriculatus* Zone also may belong to *Diparvapila* n. sp. B.

Subfamily ROTASPHAERINAE Noble, 1994

Rotasphaeridae NOBLE 1994, p. 19; MACDONALD, 1998, p. 599.

Emended diagnosis.–Shell formed of two or more primary units; primary units composed of five or more radially arranged primary bars, primary bars straight or curved outwardly convex; commonly spine at centre of primary unit, may be absent; primary bars coalesce to form shell. Second outer shell may occur.

Discussion.–Noble and Maletz (2000) did not formally establish the subfamily Rotasphaerinae when they distinguished spicule-bearing Secuicollactinae from members of the family Secuicollactidae without a spicule. By default, the subfamily is the same as the Rotasphaeridae as described by Noble (1994). The changes to the diagnosis made here simply accommodate the fewer number of primary units seen in *Rotasphaera* species C, the absence of spines in *Rotasphaera* species A and *Rotasphaera* species C, and the second shell of *Rotasphaera* species B. The generic diagnosis is similarly adjusted.

Genus ROTASPHAERA Noble, 1994

Type species.–*Rotasphaera marathonensis* Noble, 1994, from the Silurian of the Caballos Novaculite, west Texas.

Emended diagnosis.–One or two shells, or one shell with labyrinthine layer. Shell of single-shelled forms or inner shell of two-shelled forms consists of two or more primary units, shell spherical or polygonal. Spines with primary units commonly blunt-ended or tapered, may be bladed or grooved proximally, may be absent or domelike. Secondary spines thin rods or nodes.

ROTASPHAERA SEVERA MacDonald, 1998

Plate 18, Figures 1-6

Rotasphaera severa MACDONALD, 1998, 599, figs 5.9, 9.8.

Description.–Shell subspherical, spherical, or faintly polygonal. Six to eight primary units; six primary bars per primary unit, curved or straight, may be slightly tented. Secondary bars finer than primary bars, occasionally equal; form well-developed reticulum, slightly irregular to regular. Pores subangular to rounded, may be subcircular to circular; framed by three to six lattice bars. Spines emanate from centres of primary units, conical or tapered rods, length up to one-half shell diameter. By-spines small cones or thorns, often bent, may extend to fine rods, may bear lateral linkages, may be absent.

Dimensions.–(from 10 specimens, in micrometres) Diameter 63-108; primary bar width 3-5; secondary bar width 2-4; pore diameter 5-14; number of pores per one-half shell circumference 6-12; spine length 18-48; spine base width 3-7; by-spine length 3-15.

Material and occurrence.–Twenty specimens examined. Llandovery-Wenlock (*curtus* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–MacDonald (1998) noted as few as four primary units in *Rotasphaera severa*; however, specimens with less than six were not observed in the presented study. As with MacDonald (1998), by-spines were occasionally seen linking laterally. This could cause some confusion with *Rotasphaera* species A. Indeed, *R. severa* differs only in the lack of a well-developed labyrinthine layer. Similarly, the medullary shell of *Rotasphaera* species B is not significantly different from the single shell of *R. severa*. Some specimens assigned here to *R. severa* could be incompletely developed specimens of *Rotasphaera* species A or *Rotasphaera* species B.

ROTASPHAERA species A

Plate 18, Figures 7, 8

Plate 19, Figures 1-4, 6, 7

Rotasphaera species A MacDonald, 1998, p. 602, fig. 9.9.

Description.–Lattice shell subspherical to polygonal, four to eight primary units; five to nine primary bars per primary unit, generally curved or straight; secondary bars equal to or slightly less robust than primary bars all bars generally fine; reticulum varies from irregular to fairly regular squarish mesh; pores subangular to rounded, framed by four or five lattice bars. Spines variable, grade from absent, conical, to tapered rods; when present, length and thickness same as by-spines or up to three-quarters lattice shell diameter. Numerous by-spines arise from lattice nodes, less often between lattice nodes; irregular rods, may arch, branch distally, usually link to form loose or dense labyrinthine layer.

Dimensions.–(from 16 specimens, in micrometres) Diameter lattice sphere 68-103; primary bar width 2-5; secondary bar width 2-3; pore diameter 5-21; number of pores per one-half circumference 5-9; by-spine length/labyrinthine layer thickness 6-28; spine lenngth from lattice sphere up to 55; spine base width 3-5.

Material and occurrence.–Sixty-three specimens examined. Llandovery-Wenlock (*guerichi* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–There is considerable variation in the development of the spines in this species, varying from absent to tapered rods. This appears to be ontogenetic. The spines apparently develop abreast of the labyrinthine layer, then may or may not extend beyond it. Specimens without spines or with very weakly developed spines tend to have only irregular by-spines rather than a labyrinthine layer, as well as a more irregular lattice. It is possible that these specimens represent a different group, but they do inter-grade with specimens with denser labyrinthine layers and more robust spines. They also bear some similarity to the finer end of the morphologic range of *Rotasphaera* species C. These forms appear more often in the *griestoniensis* and *sakmaricus* zones.

ROTASPHAERA species B

Plate 19, Figures 5, 8-11

Description.–Medullary shell slightly subspherical to slightly polygonal; seven(?) to eight primary units, slightly tented, generally six primary bars per primary unit. All lattice bars delicate; primary bars straight or faintly curved, slightly wider than secondary bars; secondary bars form well-developed reticulum, slightly irregular; pores subangular to subrounded, framed by four to five lattice bars. Numerous fine beams from medullary shell, may continue externally as rodlike by-spines. Cortical shell in one to three closely spaced layers. Inner layer latticed, formed from terminal branches of radial beams from medullary shell or apophyses off beams that continue as external by-spines, lattice bars may be wide; pores circular to subcircular, framed by four or five lattice bars. Subsequent cortical layers form from short beams off previous layer, beams branch terminally or may continue as external by-spines, beams linked laterally by archlike lateral bars. Main spines from primary unit centres, rodlike, tapered, length may exceed diameter of medullary shell.

Dimensions.–(from three specimens, in micrometres) Medullary shell diameter 82-88; medullary shell pore diameter 7-13; number of pores per one-half medullary shell circumference 8-9; medullary shell primary bar width 2-3; medullary shell secondary bar width 1-2; cortical shell diameter 168-205; cortical shell pore diameter 4-13; cortical shell bar width 2-5; spine length from medullary shell 89-108; spine base width at medullary shell 4-5; spine length from cortical shell 43-63.

Material and occurrence.–Four specimens from sample CP-20, upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–This species is represented only by four specimens from a single horizon (CP-20); one specimen from CP-94.3 is similar but could be an incomplete specimen of *Rotasphaera* species A. Two specimens from CM2-85.2 also may belong to this species. The construction of the closely-spaced layers of the cortical shell create a labyrinthine-like appearance not unlike *Rotasphaera* species A. Unlike *Rotasphaera* species A, however, there is a distinct segregation into two shells. The present species appears to be the same as ?*Diparvapila* species A of Won et al. (2002); however the details of the inner shell of ?*Diparvapila* species A are not determined.

ROTASPHAERA species C

Plate 4, Figures 1-11

Description.–*Forma 1* Shell subspherical, polygonal, or ellipsoidal; two to seven primary units, usually strongly tented, generally six primary bars per primary unit; centre of primary unit usually a large dome or cone; primary bars thick laterally and radially, straight or gently curved, sides often irregular. Secondary bars variably developed, may be absent, noticeably finer than primary bars, may have irregular edges; when well developed form irregular to slightly regular lattice, openings commonly square or rectangular shape, or modifications thereof, subangular to rounded. Spines absent or present as tiny cones on centre dome of primary units, occasionally pronounced cone as an extension of primary unit dome. Irregular by-spines, small domes or thorns, may branch distally when well developed, when weakly developed give shell a ragged appearance, by-spines occasionally absent.

Forma 2 As for forma 1 but shell subspherical; five to seven primary units; primary unit centre less pronounced, primary bars finer; spines, if present, conical, short.

<u>Dimensions</u>.–(in micrometres, from 11 specimens) Long axis diameter 70-103; short axis diameter 63-92; primary bar width 5-10; secondary bar width 2-4; pore diameter 3-18; by-spine length 4-13; spine length 13-15 (two specimens).

<u>Material and occurrence</u>.– Eighty specimens examined. Llandovery (*guerichi* to mid *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

<u>Discussion</u>.–*Rotasphaera* species C is notable for its usually thick primary units that commonly bear a pronounced central siliceous mass. Sphericity of specimens improves with the number of primary units. There is some stratigraphic bias to by-spine development; these were best developed in samples from the upper *guerichi* to lower *griestoniensis* zones.

Forma 1 is the dominant form and encompasses the bulk of the variation within the species. Forma 2 is gradational with forma 1 and differs only in its better sphericity and finer construction. Also the spines, if present, are more readily differentiated from the centre of the primary unit. Forma 2 is differentiated from forma 1 to emphasis that this species, at the finer end of its morphological range, can be similar to the spineless or smaller-spined specimens of *Rotasphaera* species A. They differ by *Rotasphaera* species A's more delicate construction, with fine, even lattice bars. Nonetheless, some specimens could be mis-assigned.

Order ENTACTINARIA Kozur and Mostler, 1982

Family PALAEOSCENIDIIDAE Riedel, 1967

Emended diagnosis.–Five or more rays from ends of median bar or point centre, separated into apical and basal hemispheres, may be rays between hemispheres. With or without shell, formed by branching of basal rays, less commonly by all rays.

Discussion.–The emended diagnosis given here is essentially that of De Wever et al. (2001). It differs in removing the restriction on ray number to accommodate the emended diagnosis of *Palaeodecaradium*. In keeping with De Wever et al. (2001), *Protoentactinia* Kozur, Mostler, and Repetski, 1996, is included with the Palaeoscenidiidae. Kozur et al. (1996) placed this genus and the genus *Noblella* Kozur, Mostler, and Repetski, 1996, in the Protoentactiniidae Kozur, Mostler, and Repetski, 1996. De Wever et al. (2000) considered the two genera synonymous and included them in the Palaeoscenidiidae. Won and Iams (2002), however, inferred a close relationship between the Protoentactiniidae and the Palaeospiculumidae Won and Below, 1999. Further research is needed to clarify the relationships amongst these spicular radiolarians.

Won and Below (1999) noted that Goodbody's (1986) description of point-centred or bar to point-centred spicules was equivocal. With the exception of *Palaeopyramidium*, all individuals observed in the present study possessed bar-centred spicules. The length of the median bar is variable within species and may be quite small.

Much of the revision done here is based on the assumption that the geometric arrangement of the skeleton is not necessarily indicative of relationship, as was the assumption of Goodbody's (1986) classification. This was previously suggested by Won and Below (1999). Furutani (1990) made a similar suggestion with respect to the genus *Holdsworthum* Furutani, 1990. Consequently, species such as *Palaeotripus cancellatus* Goodbody, 1986, *Palaeoscenidium cancellatum* Goodbody, 1986, and *Palaeoephippium adraini* MacDonald, 1999, are considered one species. Species described by Renz (1990) that were placed in three genera (*Palaeoephippium octaramosum*, *Palaeotrifidus ballator*, *Palaeotripus sexabrachiatus*) are likely a single species. Some taxa from the Cape Phillips Formation, however, do show a stable skeletal configuration, such as *Goodbodium* Furutani,1990, which presents only four apical rays and four basal rays.

Genus GOODBODIUM Furutani, 1990

Type species.–*Palaeoscenidium flammatum* Goodbody, 1986, from the Wenlock of the Cape Phillips Formation, Cornwallis Island and Baillie-Hamilton Island, Nunavut, Canada.

Emended diagnosis.–Two apical rays and two basal rays from each end of short median bar; commonly one apical ray longer than other apical rays; spinules arise from lateral margins of basal rays proximal to median bar.

Discussion.–The genus *Goodbodium* as diagnosed by Furutani (1990) included the type species *Goodbodium flammatum* (Goodbody, 1986) and two species from the Wenlock or early Ludlow to Early Devonian of the Fukuji Area, Japan – *Goodbodium elegans* Furutani, 1990, and *G. nishiyamai* Furutani, 1990. The distinction between the three species was based on the details of the spinules arising from the basal rays and development of the principal apical ray. Amon et al. (1995), in their treatment of Ludlovian radiolarians from southern Urals, noted that *G. elegans* is essentially identical to *G. flammatum*. Noting that the details of the spinules could vary with ontogeny, these authors opted not follow Furutani's (1990) classification. Instead, Amon et al. (1995) followed Goodbody (1986) and placed *G. flammatum* in *Palaeoscenidium* Deflandre, 1953.

The present author concurs with Amon et al. (1995) that *Goodbodium flammatum* and *G. elegans* are likely synonymous. The "sub-spinules" noted and figured by Furutani (1990) are accounted for in Goodbody's (1986) description of the species and are present in the holotype of *G. flammatum* (Goodbody, 1986, pl. 1, fig. 4). The other feature used by Furutani (1990) to distinguish *G. elegans* from *G. flammatum* was the nature of the principal apical ray. Furutani (1990) described the principal apical of *G. elegans* as "distinguishable but not well developed." Both Goodbody (1986) and the author's own observations show that the development of the principal apical ray is variable within *G. flammatum*. The lack of development noted by Furutani (1990) can be accounted for by intraspecific variability, preservation, or a combination thereof. The second species of *Goodbodium* described by Furutani (1990), *G. nishiyamai,* is more problematic. The description states that of the spinules off the basal rays are amalgamated; however, this is not clearly seen in the figured specimens. It is uncertain if the amalgamation is similar to the interweaving of spinules as seen in *Insolitignum cancellatum* (Goodbody, 1986) or spinules arranged in parallel that are in contact. In *G. flammatum*, the spinules most proximal to the median bar may come into contact; however, on the whole, the spinules do not interact.

In spite of the uncertainty regarding *Goodbodium nishiyamai* and Amon et al.'s (1995) concerns about ontogeny, the genus *Goodbodium* does appear to be valid. *Goodbodium rarispinosum* (Goodbody, 1986), like *G. flammatum*, possesses a skeleton that is fixed at eight rays with one apical ray commonly better developed than the other three. Additionally, the spinules in both species are concentrated along the lateral margins of the basal rays. The two species differ only in the details of the spinules arising from the basal rays. The similarities suggest a close relationship and they are considered here as congeneric. The emended diagnosis presented here is essentially the same as Furutani's (1990), but removes the requirement that the spinules parallel each other.

Although species of *Goodbodium* are similar to both *Insolitignum cancellatum* and *I. vivanima*, they differ in the number and arrangement of skeletal rays. In *I. cancellatum*, both the number of rays and their position, apical versus basal, is variable.

In *I. vivanima*, there are always three basal rays and one intermediate ray. Usually there are two apical rays in *I. vivanima*; however, additional rays may be present. Species of *Goodbodium*, in contrast to these other taxa, are observed only with eight rays. These are almost exclusively arranged as four apical and four basal rays; only two specimens of *G. flammatum* were observed in the present material with the rays oriented as three apical, three basal, and two intermediate rays.

GOODBODIUM FLAMMATUM (Goodbody, 1986)

Plate 21, Figures 1, 2

Plate 24, Figure 1

Palaeoscenidium flammatum GOODBODY, 1986, p. 152, pl. 1, figs. 1-4; LI, 1994, p. 265, pl. 2, fig. 4; AMON, BRAUN, AND IVANOV, 1995, p. 7, text-fig. 10, pl. 2, fig. 5.

Goodbodium elegans FURUTANI, 1990, p. 43, pl. 7, fig. 10, pl. 8, figs. 1-3.

Description.–Eight rays, four at each end of median bar. Usually two apical rays and two basal rays at each end of median bar; very rarely at one end of median bar one apical ray horizontal or very shallowly declined, one basal ray very shallowly declined or horizontal, one steeply declined basal ray and one steeply reclined apical ray between the two horizontal rays. Apical rays rodlike, tapered, may be nearly conical; shallowly to moderately reclined, can vary within a specimen; often one ray longer than others, distally curves or bends outwards. Basal rays rodlike, taper to fine point, length five to seven times apical ray length, leave median bar steeply declined, commonly curve or bend to near pendant at one-half to one-third length; occasionally straight. Spinules on lateral margins of basal rays proximal to median bar, usually in three paired sets, oriented and curved basally to parallel spinules from neighbouring basal ray, do not link, distally may have small irregular projections; spinules extend approximately one-third basal ray length.

Dimensions.–(in micrometres, from 10 specimens) Apical ray length 20-45; apical ray base width 4-7; basal ray length 93-177; basal ray base width 7-10; length of spinule set 30-68.

Material examined.–Total one hundred twenty-one specimens observed. Figured specimens GSC 124730 (Fig. 2.1), GSC 124731 (Fig. 2.2), GSC 124732 (Fig. 6.1).

Occurrence.–Upper Llandovery to middle Wenlock (*griestoniensis* to *lundgreni-testis* zones) of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986, and new data); Middle Silurian, Keerhada, Xinjiang, China (Li, 1994); lower Ludlow, Southern Urals (Amon et al., 1995); and Wenlock or early Ludlow, Fukuji area, Japan (Furutani, 1990).

Discussion.–The observed specimens were notable in the stability of their form. Only two specimens out of 121 varied from the four apical and four basal ray configuration. These two specimens still had eight rays in total, but at one end of the median bar the orientation was skewed with two rays in a more intermediate position. This orientation is seen in *Insolitignum cancellatum*, which is somewhat similar to *Goodbodium* *flammatum*. *Insolitignum cancellatum* differs in having a variable number of rays and greater variation in ray orientation. The rays in *I. cancellatum* also are less robust than in *G. flammatum*. Additionally, the spinules of *I. cancellatum* intersect to form a lattice. *Goodbodium flammatum* differs from *G. rarispinosum* in the arrangement of the spinules (see below).

GOODBODIUM RARISPINOSUM (Goodbody, 1986)

Plate 24, Figures 2, 3

Palaeoscenidium rarispinosum GOODBODY, 1986, p. 152, pl. 1, figs. 9, 10.

Description.–Eight rays, two apical rays and two basal rays from each end of median bar, all rays rodlike, tapered. Apical rays shallowly to steeply reclined, lack ornamentation; usually one apical longer and thicker than other three, two to three times length of other apical rays, curves to horizontal or declined distally or at one-half length. Basal rays leave median bar moderately declined, curve along length to steeply declined or pendant, occasionally straight with bend at one-half length; length up to eight times apical ray length. Spinules on basal rays at short distance from median bar, extend one-third basal ray length, occasionally small spinules between median bar and main cluster of spinules; spinules concentrated on lateral margins of basal rays, may develop in one or two planes along each lateral margin, rare or absent on outer or inner margins; spinules in crudely paired sets; angled or curved basally, direction of individual spinules subparallel.

Dimensions.–(in micrometres, from 10 specimens) Apical ray length 28-65; apical ray base width 5-10; large apical ray length 100-175; large apical ray base width 8; basal ray length 138-353; basal ray base width 6-10.

Material examined.–Total 18 specimens observed. Figured specimens GSC 124733 (Fig. 6.2), GSC 124734 (Fig. 6.3).

Occurrence.–Upper Llandovery to middle Wenlock (*griestoniensis* to *lundgreni-testis* zones) of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986, and new data).

Discussion.–As with other species of the genus, the spinules of *Goodbodium rarispinosum* are along the lateral margins of the basal rays. Also, the species has the stable eight-ray configuration with one longer apical ray. Unlike *G. flammatum*, the spinules in *G. rarispinosum* do not occur in a single plane parallel to the length of the basal rays, although they are concentrated along the lateral margins. The rays tend to be longer and finer than in *G. flammatum*.

Amon et al. (1995) reported *Goodbodium rarispinosum* from the lower Ludlow of the Southern Urals. However, the figured specimen (Amon et al., 1995, pl. 2, fig. 2) more closely matches the description of *Palaeodecaradium apertum* (Goodbody, 1986) than *G. rarispinosum*. The two specimens presented in their text-fig. 11 (Amon et al., 1995, p. 8) are somewhat more ambiguous; *G. rarispinosum,* as presented by Goodbody (1986) and observed in the present study, lacks spinulation on the apical rays which Amon et al. (1995) figure. Also, the basal ray spinulation on *G. rarispinosum* is more orderly than seen in Amon et al.'s (1995, p. 8) text-figure 11.

INSOLITIGNUM MacDonald, 1999

Type species.–*Palaeoephippium dissimile* Goodbody, 1986, from the upper Llandovery-Wenlock of the Cape Phillips Formation, Nunavut, Canada.

Emended diagnosis.–One basal ray and one variably positioned ray from one end of median bar, two basal rays from other end of median bar; at least one apical ray from each end of median bar.

Discussion.–*Insolitignum dissimile* (Goodbody, 1986), the type species of *Insolitignum* MacDonald, 1999, was originally included with *Palaeoephippium* Goodbody, 1986. MacDonald (1999) noted that the basic morphology of *I. dissimile* included more than one species and separated the species from *Palaeoephippium* as treated by Goodbody. As diagnosed by MacDonald (1999), the genus was distinguished by the presence of two apical rays, one intermediate (or principal) ray, and three basal rays. In the present study, it was found that more than two apical rays may occur in an individual, although this is rarer than the two-apical-ray forms. The diagnosis is emended here accordingly. Most commonly, if more than two apical rays are present, then one additional ray occurs on each end of the median bar. Only rarely is there a configuration resulting in an odd number of rays.

An important feature of *Insolitignum* is the presence of a ray that does not have a fixed apical or basal position (the principal ray of MacDonald, 1999). The basic configuration of individuals in this genus consists of three basal rays, two apical rays, and the variable ray. Variation within species involves the number of apical rays and the position and development of the variable ray. One end of the median bar invariably possesses two basal rays and at least one apical ray. The other end of the median bar possesses one basal ray and at least one apical ray, plus the variable ray. In *I. dissimile* and *I. vivanima* the variable ray always takes a position intermediate to the apical and basal rays. In *I. cancellatum*, the variable ray may develop as an apical ray. Such individuals have the configuration of Goodbody's (1986) *Palaeotripus* or a previously undescribed eight-rayed form if the additional apical rays are present (Text-figure 8.2.1). The variable ray may also take an intermediate position as in *I. dissimile* or *I. vivanima* (Text-figure 8.2.2). Finally, the variable ray may develop as a basal ray. Such individuals coincide with Goodbody's (1986) diagnoses of *Palaeoephippium* and *Palaeoscenidium* (Text-figure 8.2.3). The same manner of variability is seen in *Palaeoephippium* as treated herein.

INSOLITIGNUM CANCELLATUM (Goodbody, 1986)

Plate 21, Figures 3-12

Plate 24, Figures 5, 6, 8, 9

Palaeoscenidium cancellatum GOODBODY, 1986, p. 150, pl. 1, figs. 5-7.

Palaeotripus cancellatus GOODBODY, 1986, p. 153, pl. 2, figs. 9-11; LI, 1994, p.265, pl. 2, fig. 22.

Palaeoephippium adraini MACDONALD, 1999, p. 2056, pl. 1, fig. 1; pl. 2, figs. 5, 6.

Emended diagnosis.–Apical rays conical to rodlike, basal rays rodlike; one variably positioned ray, may be similar to apical or basal rays, rodlike when intermediate; spinules from lateral margins of basal rays, form netlike tent.

Description.–Commonly six rays, three from each end of median bar; less commonly eight rays, four from each end of median bar; odd number of rays rare. Basal rays rodlike, taper to fine point, length up to 30 times apical ray length; may be straight, moderately to steeply declined, may bend or curve to steeper attitude at one-third to two-thirds length, may curve gently along length, rarely curve outwards. Apical rays rodlike, tapered, length variable, often conical when small; shallowly to steeply reclined. Most commonly one apical ray and two basal rays from one end of median bar; one apical ray, one basal ray, one intermediate ray from other end of median bar. Intermediate ray rodlike, tapered, attitude and length may be similar to apical rays, more commonly horizontal or shallowly declined; length usually longer than apical rays, may nearly equal basal ray length; at greater lengths commonly shallowly declined proximal to median bar, bends moderately declined near one-third or one-half length; when short may be strongly declined and partly incorporated into tent. Less common six-rayed form, one apical ray and two basal rays from each end of median bar. Eight-ray forms with two apical rays and two basal rays from each end of median bar. Alternate eight-ray form, two apical rays and two basal rays from one end of median bar; one apical ray, two intermediate rays, one basal ray from other end of median bar; one intermediate ray on each side of single apical ray; both intermediate rays rodlike, tapered, nearly horizontal, often slightly declined, less commonly slightly reclined, length often equal apical rays;

alternatively, length of one intermediate ray up to three-quarters basal ray length, straight or bends basally at one-half length. Spinules arise from lateral margins of basal rays at three or more levels, usually in paired sets, become finer and smaller distal to median bar; angled and curved basally; join to form netlike tent; tent extends one-third to one-half basal ray length, openings subangular to rounded, quadrangular to subcircular; net finer distally, intricate and finer when several spinule levels, may be detached from basal rays distally when highly developed, usually connected to intermediate ray proximal to median bar.

Dimensions.–(in micrometres, from 34 specimens) Apical ray length 7-46; apical ray base width 2-8; basal ray length 70-293; basal ray base width 3-10; intermediate ray length up to 258; tent length from median bar 20-90.

Material examined.–Over 500 specimens observed. Figured specimens GSC 124735-124738 (Fig. 2.3-2.6 respectively), GSC 124739 (Fig. 2.7, 2.10), GSC 124740 (Fig. 2.8, 2.11), GSC 124741 (Fig. 2.9, 2.12), GSC 124742 (Fig. 6.5), GSC 124743 (Fig. 6.6), GSC 124744 (Fig. 6.8, 6.9).

Occurrence.–Upper Llandovery to middle Wenlock (?*crispus* to *lundgreni-testis* zones) of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; MacDonald, 1999; new data); Middle Silurian, Keerhada, Xinjiang, China (Li, 1994).

Discussion.–*Insolitignum cancellatum* as treated here includes three previously described species -- *Palaescenidium cancellatum*, *Palaeotripus cancellatus*, and *Palaeoephippium adraini*. Specimens with ray number and orientation other than these three species were also observed. By far the most abundant are specimens that correspond to Goodbody's (1986) *Palaeotripus cancellatus*. In the specimens of this form figured by Goodbody (1986, pl. 2, figs. 9-11) and those observed in this study, one of the rays considered as "apical" by Goodbody (1986) is actually more variable in position and length, and is identical to the intermediate ray of *Insolitignum dissimile* and *I. vivanima*. It is the position occupied by this one ray that determines the number of basal rays and in part determines the number of apical rays in *I. cancellatum*. When more closely oriented into the apical hemisphere, this ray develops the same form as an apical ray; when more closely oriented in the basal hemisphere, it develops as a basal ray and produces lateral spinules contributing to the netlike tent of the basal hemisphere. Similarly, in *Palaeoephippium* (emended herein) the equivalent ray when fully in the basal hemisphere branches in the same pattern as the other basally oriented rays. While the morphological end members of *I. cancellatum* superficially appear quite distinct, prompting previous authors to erect species (Goodbody, 1986; MacDonald, 1999), in this study the gradation between the end members is readily apparent in the numerically dominant six-rayed form (Figs. 2.3-2.6, 6.5).

The total number of rays present depends on the number of apical rays. Most commonly the variability is one or two apical rays at each end of the median bar, resulting in a six-rayed or eight-rayed form. An odd number of apical rays occurs more rarely. The same pattern of apical ray presence or absence is seen in *Insolitignum dissimile*, *I. vivanima*, and species of *Palaeoephippium* (as emended herein). As with these other taxa, the total number of rays does not appear to have taxonomic significance.

Insolitignum cancellatum is placed here in the genus *Insolitignum*, because, like the other species of the genus, it is ornamented by spinules arising from the basal rays as opposed to branching of the rays as seen in *Palaeoephippium*. Specimens corresponding to Goodbody's (1986) *Palaeotripus cancellatus* are the dominant morphological variant. The similarity between this form and *I. vivanima* is striking, with a similar netlike tent in the basal hemisphere. The similarity of the intermediate ray is also readily apparent in this form. Unlike the other two species of *Insolitignum*, however, the intermediate ray can be modified into a fully developed basal ray.

Palaeotrifidus sp. and *Palaeoscenidium* sp. described by Goto et al. (1992, p. 163) from the Late Ordovician of the Mallongulli Formation, southeastern Australia, possibly belong to *Insolitignum cancellatum*; however, the preservation is inadequate for a positive identification. Similarly, *Palaeoscenidium* sp. figured by Iwata et al. (1995, fig. 2m) from the Ordovician Ballast Formation of southeastern Australia appears very similar to *I. cancellatum*. Because of the preservation, however, an affinity to *Goodbodium flammatum* cannot be discounted.

INSOLITIGNUM DISSIMILE (Goodbody, 1986)

Plate 22, Figures 1-3

Plate 24, Figures 4, 7, 10-12

Palaeoephippium dissimile GOODBODY, 1986, p.140, pl. 3, figs. 10-12.

Insolitignum dissimile (Goodbody). MACDONALD, 1999, p. 2053, pl. 1, figs. 2, 3; pl. 2, fig. 1; NOBLE AND MALETZ, 2000, p. 272, pl. 1, fig. 12.

Insolitignum peranima MACDONALD, 1999, p. 2054, pl. 1. fig. 4; pl. 2, figs. 2, 4.

Emended diagnosis.–One intermediate ray, three basal rays, at least two apical rays; all rays rodlike, tapered; one or more spinule verticils on each basal ray.

Description.–*Forma 1*. Usually six rays, three from each end of median bar; less commonly eight rays, four from each end of median bar; rarely seven rays; all rays rodlike, tapered; apicals rays may be nearly conical when small. When six rays, one apical ray at each end of bar, two basal rays at one end of median bar, one basal ray and one intermediate ray at opposite end of median bar. When eight rays, two apical rays at one end of median bar; at other end of bar, one steeply reclined apical ray flanked by one shallowly reclined to near horizontal apical ray and one ray in intermediate position; one basal ray at end of bar with two apical rays and intermediate ray; two basal rays at end of bar with two apical rays. Apical rays may bear single verticil of short spinules proximal to median bar. Intermediate ray near horizontal or slightly declined, without verticil, may hook distally, tip of hook may be helical. Basal rays moderately to steeply declined, may curve or bend to near pendant; length two to three times apical ray length; verticils of spinules at one to three or more levels, verticils less developed distally; better developed spinules may curve basally, may bear microspinules, better developed spinules often on lateral margins of basal rays. All rays may bear microspinules.

Forma 2. Number and orientation of rays as for forma 1. Lacks verticils on apical rays. Spinules on lateral margins of basal rays in paired sets, commonly one set, may be two, rarely three; spinules on outer margins of basal rays absent or weakly developed. Microspinules on all rays, usually large thorn to tuberclelike on basal rays proximal to median bar.

Dimensions.–(in micrometres, from 11 specimens) Apical ray length 28-85; apical ray base width 5-8; basal ray length 90-305; basal ray base width 8-11; intermediate ray length 50-88; intermediate ray base width 8-12; distance from median bar to first spinule set 35-65.

Material examined.–Over 1000 specimens observed. Figured specimens GSC 124745-124747 (Fig. 4.1-4.3 respectively), GSC 124748 (Fig. 6.4), GSC 124749 (Fig. 6.7), GSC 124750-124752 (Fig. 6.10-6.12 respectively).

Occurrence.–Upper Llandovery to middle Wenlock (*turriculatus* to *lundgreni-testis* zones), Cornwallis Island, Nunavut, Canada (Goodbody, 1986; MacDonald, 1999; new data); *turriculatus* Zone, Dalarna, Sweden (Noble and Maletz, 2000).

Discussion.–Goodbody (1986) considered the two forma of *Insolitignum dissimile* as a single species belonging to *Palaeoephippium*. MacDonald (1999) felt the differences warranted the erection of a separate species and thus described forma 2 as *I. peranima*. The larger data set available in this study, however, shows a greater degree of gradation between the two forms than was seen in the smaller collection of MacDonald (1999). Additionally, it is possible that some specimens assigned to forma 2 are underdeveloped *I. vivanima*. Because of the uncertain status of this form, it is described here as a variant of *I. dissimile* but the distinction of forma is made to aid future study that will hopefully clarify the relationships. The diagnosis is emended here to accommodate the additional apical rays noted in this study. Also, the presence of apical ray spinule verticils is removed from the diagnosis due to their variable occurrence.

INSOLITIGNUM VIVANIMA MacDonald, 1999

Plate 22, Figures 4, 5

Plate 24, Figures 13, 14

Insolitignum vivanima MACDONALD, 1999, p. 2055, pl. 1, figs. 5, 6; pl. 2, fig. 3.

Emended diagnosis.–One intermediate ray, three basal rays, at least two apical rays; all rays rodlike, tapered; one or more pairs of opposing spinules on basal rays, usually branched, form loose net.

Description.–Usually six rays, three from each end of median bar; rarely seven or eight rays. When six rays, one apical ray from each end of median bar, two basal rays at one end of median bar, one basal ray and one intermediate ray at other end of median bar. When seven rays, one apical ray and two basal rays at one end of median bar, two apical rays, one intermediate ray, and one basal ray at other end of median bar. When eight rays, two apical rays and two basal rays at one end of median bar, two apical rays, one intermediate ray, and one basal ray at other end of median bar. Apical rays moderately to strongly reclined, rodlike, tapered, occasionally almost conical when small. Intermediate ray shallowly to steeply declined, rodlike, tapered, may form hook distally, tip may be helical, generally longer and thicker than apical rays. Basal ray counter to intermediate ray curved or bent, occasionally straight, may be slightly shorter than other basal rays; remaining two basal rays usually straight; all basal rays rodlike, taper to fine point. Spines on lateral margins of basal rays, usually in three paired sets; on basal ray counter to intermediate ray often only one set of spinules; all spinules leave basal rays at or near 90°, curve basally, may branch, link to form loose net. Microspinules common on basal rays between median bar and top of net.

Dimension.–(in micrometres, from 10 specimens) Apical ray length 29-75; apical ray base width 5-10; intermediate ray length 45-85; intermediate ray base width 8-13; basal ray length 125-263; basal ray base width 8-13; tent length from median bar 73-120.

Material examined.–One hundred and five specimens observed. Figured specimens GSC 124753 (Fig. 4.4), GSC 124754 (Fig. 4.5), GSC 124755 (Fig. 6.13), GSC 124756 (Fig. 6.14).

Occurrence.–Upper Llandovery (*sakmaricus* Zone), Cornwallis Island, Nunavut, Canada (MacDonald, 1999; new data).

Discussion.–The diagnosis is emended here simply to accommodate the additional apical rays noted in this study. *Insolitignum vivanima* differs from *I. cancellatum* by being generally larger and more robust. The spinules in *I. vivanima* appear more circular in cross section than the flatter spinules of *I. cancellatum* and they produce a looser, coarser net. Additionally, the intermediate ray in the current species does not develop into a fully formed basal ray, as happens in *I. cancellatum*.

Genus PALAEODECARADIUM Goodbody, 1986

Type species.–*Palaeodecaradium umbelliforme* Goodbody, 1986, from the upper Llandovery-Wenlock of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada.

Emended diagnosis.–Six to 12 rays from ends of median bar; rays rodlike, tapered; rays unbranched, unornamented or with simple spinules or microspinules.

Discussion.–Goodbody (1986) included only *Palaeodecaradium umbelliforme* in this genus. *Palaeodecaradium umbelliforme* presents more variability in ray number than noted by Goodbody (1986), and this is accommodated in the emended diagnosis. The diagnosis is also revised to include Goodbody's (1986) *Palaeoscenidium apertum* and *Palaeotripus nudus*, plus the new species *Palaeodecaradium gordoni*. These species share in common the simple morphology of the rays with modest ornamentation in the form of microspinules or simple spinules.

PALAEODECARADIUM APERTUM (Goodbody, 1986)

Plate 22, Figures 6, 7

Plate 24, Figure 15

Palaeoscenidium apertum GOODBODY, 1986, p. 150, pl. 2, figs. 1-4.

Palaeotripus nudus GOODBODY, 1986, p. 154, pl. 1, fig. 8; LI, 1994, p. 265, pl. 2, fig. 2.

Emended diagnosis.–Six or eight rays, without branching; three or four apical rays, three or four basal rays; rays unornamented or with microspinules.

Description.–Eight rays, four from each end of median bar. All rays rodlike, tapered. Two apical rays from each end of median bar, leave bar shallowly to moderately reclined, curve along length to shallower angle or nearly pendant, or bend distally to subhorizontal; occasionally straight. Two basal rays at each end of median bar; length about twice apical ray length, may reach four times apical ray length, leave median bar shallowly to steeply declined, may curve along length to pendant, may bend outward at half length or distally to subhorizontal, less commonly curve outwards along length; occasionally straight. Orientation of rays may vary, three apical rays, two intermediate rays, three basal rays. All rays may bear sparse microspinules along entire length.

Dimensions.–(in micrometres, from 10 specimens) Apical ray length 78-230; apical ray base width 5-7; basal ray length 178-424; basal ray base width 5-8.

Material examined.–Over 100 specimens observed. Figured specimens GSC 124757 (Fig. 4.6), GSC124758 (Fig. 4.7), GSC 124759 (Fig. 6.15).

Occurrence.–Upper Llandovery to middle Wenlock (*griestoniensis* to *lundgreni-testis* zones), Cape Phillips Formation, Cornwallis and Baillie Hamilton islands, Nunavut, Canada (Goodbody, 1986; new data); middle Silurian, Keerhada, Xinjiang, China (Li, 1994).

Discussion.–No specimens identical to *Palaeotripus nudus* were recovered in this study. However, there does not appear to be any difference, other than ray number, between that species and *Palaeoscenidium apertum* as described and figured by Goodbody (1986) and as observed in the present study. Consequently the two species are synonymized and the diagnosis emended accordingly; only the observed eight-ray forms are described. Furthermore, *Palaeoscenidium apertum* is reassigned to *Palaeodecaradium*. Like *Palaeodecaradium umbelliforme*, *Palaeodecaradium apertum* possesses simple, unbranched rays. *Palaeodecaradium apertum* lacks the intermediate rays seen in *P. umbelliforme*. Microspinules, when present, occur on the entire skeleton. In *P. umbelliforme*, better-developed spinules occur in a localized area on the rays.

PALAEODECARADIUM GORDONI MacDonald, in press

Plate 22, Figure 8

Plate 25, Figures 1, 2, 4

Diagnosis.–Six rodlike rays; apical rays long, curve along length towards basal hemisphere; basal rays with spinules on lateral margins.

Description.–Six rays, three from each end of median bar. Most commonly one apical ray and two basal rays from one end of median bar, two apical rays and one basal ray from other end of bar; less commonly one apical ray and two basal rays from each end of median bar. All rays rodlike, tapered. Apical rays unadorned, length one-half to almost equal basal ray length, leave median bar horizontal or shallowly reclined, curve along length to declined or pendant. Basal rays leave median bar moderately to steeply declined, bend or curve to pendant at one-half length or more distally, rarely bend outwards. Spinules on lateral margins of basal rays, rarely on outer margins; usually at five levels at short distance from median bar, usually not paired, angled or curved basally.

Dimensions.–(in micrometres, from 8 specimens) Apical ray length 68-255; apical ray base width 5-10; basal ray length 170-384; basal ray base width 5-9.

Etymology.–For the Hon. Walter Gordon, Canadian Minister of Finance from 1963 to 1965.

Types.–Holotype, GSC 124721 (Fig. 7.2); paratypes, GSC 124724 (Fig. 4.8), GSC 124722 (Fig. 7.1), GSC 124723 (Fig. 7.4), GSC 124725-124729.

Occurrence.–Twelve specimens from the Wenlock (*instrenuus-kolobus* Zone) of the Cape Phillips Formation, Cape Phillips, Cornwallis Island, Nunavut.

Discussion.–This species is placed with *Palaeodeccaradium* based on the simple, unbranched nature of the rays. It is similar to *P. apertum* (*Palaeotripus nudus* sensu Goodbody, 1986), except the curvature of the apical rays is more pronounced and there are distinct spinules on the basal rays, rather than microspinules on all rays. An eight-ray form was not observed. The basal ray spinules mainly occur in planes parallel to the run of the rays similar to *Goodbodium flammatum*. They do not have the marked, parallel curvature seen in *G. flammatum*; unlike *G. rarispinosum,* the lateral spinules are in a single plane. The lower stratigraphic range of the species is not clear; some individuals from lower in the Cape Phillips Formation could be poorly preserved representative of the current species or belong to *Palaeoephippium echinatum* (sensu Goodbody, 1986). *Palaeodecaradium gordoni* is known with certainty from the Wenlock of the Cape Phillips Formation.

PALAEODECARADIUM UMBELLIFORME Goodbody, 1986

Plate 22, Figures 9, 10

Plate 25, Figures 3, 6, 9

Palaeodecaradium umbelliforme GOODBODY, 1986, p. 136, pl. 3, figs. 5-9.

Emended diagnosis.–Total nine to 12 rays, most commonly 10, rodlike, tapered; one intermediate ray extends from each end of median bar; rays unbranched, unornamented or bearing small spinules.

Description.–Usually 10 rays, less commonly nine, 11, or 12 rays. All rays rodlike, tapered. When 10 rays, five from each end of median bar; usually two apical rays, two basal rays, and one intermediate ray at each end of median bar; apical rays shallowly to steeply reclined, straight, gently curved or with distal, outward bend; basal rays moderately to steeply declined, straight or gently curved, length commonly twice apical ray length; intermediate rays straight or gently curved, horizontal or shallowly declined, length subequal basal rays, may be regarded as extension of median bar. Clear distinction apical versus basal hemispheres may be lacking. Ray orientation may vary; one end of median bar with one apical ray plus three basal rays, or one basal ray plus two subhorizontal rays. When nine rays, two apical rays, two basal rays, one intermediate ray at one end of median bar, two apical rays, one basal ray, one intermediate ray at other end of median bar. When 11 rays, two apical rays, two basal rays, one intermediate ray from one end of median bar, two apical rays, one subhorizontal basal ray, two more steeply oriented basal rays, one intermediate ray at other end of median bar. When 12 rays, two apical rays, one shallowly declined basal ray, two more steeply declined basal rays, one intermediate ray from each end of median bar. Small spinules may arise on rays at short distance from median bar, best developed on basal rays, commonly absent on intermediate rays, less developed or absent on apical rays; all rays may be unornamented.

Dimensions.--(in micrometres, from 10 specimens) Apical ray length 86-138; apical ray base width 5-10; basal ray length 158-268; basal ray base width 5-10; intermediate ray length 148-238; intermediate ray base width 5-12.

Material examined.–Over 100 specimens observed. Figured specimens GSC 124760 (Fig. 4.9), GSC 124761 (Fig. 4.10), GSC 124762-124764 (Fig. 7.3, 7.6, 7.9 respectively).

Occurrence.–Upper Llandovery to lower Wenlock (*griestoniensis* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; MacDonald, 1999; new data).

Discussion.–Goodbody (1986) diagnosed *Palaeodecaradium umbelliforme* as having specifically 10 rays. As previously noted by MacDonald (1999), the number of rays is variable. The orientation of the rays, apical versus basal, is also more variable than reported by Goodbody (1986) who described two rays in the apical hemisphere. The emended diagnosis allows for the variability in ray number and removes restrictions on how the rays are oriented, except for the two intermediate rays which extend from the ends of the median bar.

Fukujius yamakoshii Furutani, 1990, is likely the same as *Palaeodecaradium umbelliforme*. However, in the former, spinules arise proximal to the median bar and decrease distally from it. In *P. umbelliforme*, the spinules arise at a short distance from the median bar and do not diminish distally; rather, they are fairly constant in a localized part of the ray. The two specimens illustrated by Furutani (1990, pl. 9, figs. 4, 5) are both damaged, which hinders comparison and confirmation of the written description. Consequently, the two species are not synonymized here.

Genus PALAEOEPHIPPIUM Goodbody, 1986

Type species.–*Palaeoephippium bifurcum* Goodbody, 1986, p. 139, pl. 4, figs. 1-4.

Emended diagnosis.–At least six rays; basal rays branch once or repeatedly; apical rays branched or unbranched.

Discussion.–As originally diagnosed by Goodbody (1986), *Palaeoephippium* encompassed Radiolaria with two apical rays and four basal rays. However, *P. bifurcum* is not restricted to this basic morphology and shows the same manner of variability as seen in *Insolitignum* (Fig. 2). Six rays may be arranged with three in the apical and three in the basal hemisphere. Furthermore, it is common for one ray to be ambiguously positioned; the development of this ray can be intermediate between that of a basal ray and the less developed apical rays.

In addition to the variable ray positioning, the number of rays is not fixed at six. Eight rays are equally common in *P. bifurcum*. Again, one ray may be in an essentially intermediate position with an ambiguous level of development. Other numbers of rays do occur, but are rarer than the six and eight ray forms.

Because of the observations made in this study, the diagnosis of *P. bifurcum*, and consequently the genus for which it is the type species, requires emendment. The generic diagnosis as emended here removes the restriction on ray number and orientation. Instead the genus is diagnosed by ray branching.

Palaeotripus monospinosus Goodbody, 1986, and *Palaeoephippium spinosum* Goodbody, 1986, are identical except for the orientation of the skeletal rays. They are considered here to be one species. As with *P. bifurcum*, the species also has an eight-ray form and rarer forms with other numbers of rays. A ray may take an ambiguous position. The branching pattern is very similar to that of *P. bifurcum* suggesting a close relationship. *Palaeoephippium radices* Goodbody, 1986, as treated herein, also shows the same variability in ray number and orientation, and is related to *P. bifurcum* by the branching nature of the rays.

PALAEOEPHIPPIUM BIFURCUM Goodbody, 1986

Plate 22, Figures 11-13

Plate 25, Figures 5, 7, 8

Palaeoephippium bifurcum GOODBODY, 1986, p. 139, pl. 4, figs. 1-4.

Palaeoephippium aranea GOODBODY, 1986, p. 138, pl. 4, figs. 5-8.

Palaeoephippium ?aranea Goodbody. AMON, BRAUN, AND IVANOV, 1995, p. 5, text-fig. 4, pl. 2, fig. 4.

Emended diagnosis.–At least six rays; basal rays bifurcate once; apical rays with or without single bifurcation.

Description.–Usually six or eight rays, three or four on each side of median bar; odd number of rays rare. Apical rays shorter and less developed than basal rays; all rays rodlike, tapered. When six rays, two or three rays may take apical position, occasionally two rays apical and one ray in intermediate position; three rays in basal position. When eight rays, four rays in apical position and four in basal position; less commonly three basal rays, two apical rays paired with two basal rays at one end of median bar, one apical ray at other end of bar flanked by two rays in intermediate position, one intermediate ray equivalent to apical rays, second intermediate ray may be equal to apicals or more developed, may equal basal rays. Basal rays moderately to steeply declined, length up to five times apical ray length; rays bifurcate at one-tenth to one-third length; branches diverge at large angle, may remain straight or curve until branches nearly parallel. Spinules on lateral margins of basal branches at short distance from median bar; may be paired, in one or several sets, may be absent; smaller spinules may be present below main sets; microspinules rarely on basal rays between median bar and spinule sets. Apical rays shallowly to steeply reclined, bifurcate at about one-half length or less, may be unbranched and straight, branched and unbranched apical rays may occur in same specimen; branches unornamented, may curve slightly in basal direction.

Dimensions.–(in micrometres, from eight specimens) Unbranched apical ray length 38-90; apical ray length from median bar to bifurcation 20-43; apical ray branch length 25-100; apical ray base width 3-8; basal ray length from median bar to bifurcation 35-50; basal ray branch length 78-444.

Material examined.–Over 200 specimens observed. Figured specimens GSC 124765-124767 (Fig. 4.11-4.13 respectively), GSC 124768-124770 (Fig. 7.5, 7.7, 7.8 respectively).

Occurrence.–Upper Llandovery (*guerichi* Zone) to lower Ludlow, Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; new data); lower Ludlow, Southern Urals (Amon et al., 1995). Two probable occurrences are from China and Japan. Poorly preserved specimens identified as *Palaeoephippium* cf. *P. bifurcum* were reported from the Danfeng ophiolites, North Qinling Mountains, China, and only loosely dated as Ordovician to Silurian, possibly Devonian (Cui et al., 1996). Three poorly preserved radiolarians identified as *Palaeoephippium* spp. which are likely *P. bifurcum* are figured from late Early Devonian of the Kurosegawa Terrane, Konomori Area, Japan (Umeda, 1997, pl. 4, figs. 7-9).

Discussion.–Amon et al. (1995) suggested that *Palaeoephippium bifurcum* and *Palaeoephippium aranea* Goodbody, 1986, are the same species. Based on the present examination of Cape Phillips radiolarians, the present author agrees with their conclusion. According to Goodbody (1986), *P. bifurcum* differs from *P. aranea* by having unbranched apical rays, shorter overall basal ray length, and less spinulation on the basal rays. It appears more likely that these differences are due to ontogeny and, in some specimens, quality of preservation. As with Goodbody (1986), specimens in the present study that are closer to the diagnosis of *P. bifurcum* are rarer than the better-developed *P. aranea.*

Palaeoephippium bifurcum differs from *P. spinosum* in having a single bifurcation of the basal rays and spinules on the margins of the resultant branches.

PALAEOEPHIPPIUM RADICES Goodbody, 1986

Plate 23, Figures 1-4

Plate 26, Figures 1-5

Figures 5.1-5.4, 8.1-8.5

Palaeoephippium radices GOODBODY, 1986, p. 144, pl. 4, figs. 9-12; LI, 1994, p. 266, pl. 2, fig. 6; AMON, BRAUN, AND IVANOV, 1995, p. 6, text-fig. 7.

Palaeoephippium ramipendentes GOODBODY, 1986, p. 146, pl. 5, fig. 6.

Palaeoephippium reteforme GOODBODY, 1986, p. 146, pl. 5, figs. 9-12.

Emended diagnosis.–At least six rays; basal rays bifurcate repeatedly, one branch of each bifurcation bears poorly developed terminal branches or lacks branches; basal branches may link; apical rays with or without bifurcation.

Description.–Commonly six rays, three from each end of median bar; less commonly eight rays, four from each end of median bar. Apical rays shorter and less developed than basal rays, all rays rodlike, tapered. When six rays, commonly two apical rays, four basal rays; less commonly three apical rays, three basal rays; occasionally one ray equivalent to apical in intermediate position or very shallowly declined, or one intermediate position ray with development intermediate to apical and basal rays. When eight rays, usually two apical and two basal rays at each end of median bar; rarely one apical ray and one basal ray at same end of bar may be in near-horizontal position. Basal rays moderately to steeply reclined, overall length approximately three to four times apical ray length. Basal rays undergo repeated bifurcation; below initial bifurcation, one branch of each bifurcation under goes further bifurcation, other branch usually without further bifurcation or less developed. Branches of basal rays may connect to form loose net. On one basal ray, commonly one branch arises at or immediately below initial bifurcation, directed outwards, long, gently arched apically. Apical rays shallowly to steeply reclined, usually bifurcate distally.

Dimensions.–(in micrometres, from 11 specimens) Apical ray length from median bar to bifurcation 37-65; apical ray branch length 23-80; apical ray base width 3-6; overall basal ray length 226-384; basal ray length from median bar to first bifurcation 35-65; basal ray base width 3-8.

Material examined.–Over 200 specimens. Figured specimens GSC 124771-124774 (Fig. 5.1-5.4 respectively), GSC 124775-124779 (Fig. 8.1-8.5 respectively).

Occurrence.–Upper Llandovery (*turriculatus* Zone) to lower Ludlow of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; new data); lower Ludlow, Southern Urals (Amon et al., 1995); middle Silurian, Keerhada, Xinjiang, China (Li, 1994).

Discussion.–The emended diagnosis allows for the variability in ray number and orientation, and accounts for the coalescing of the basal ray branches that is sometimes observed. Goodbody's (1986) *Palaeoephippium radices* and *P. reteforme* grade into one another in the specimens of the present study, and are considered here to be ontogenetic variants of the same species. In addition to common branching, the two forms also share the commonly occurring, curved, outwardly directed basal ray branch. *Palaeoephippium* *ramipendentes* Goodbody, 1986, was diagnosed based on a single specimen. The figure presented by Goodbody (1986) is not appreciably different from *P. radices* as understood here, and no specimens that could be definitively assigned to *P. ramipendentes* were recovered. It is regarded here a synonym of *P. radices*. It is uncertain if *Palaeotripus impariramosus* Goodbody, 1986, ought to be included here. Several specimens did have the curved basal ray noted by Goodbody (1986); however, the significance of the feature is not certain. The material that was recovered, however, does indicate that *P. impariramosus* belongs with *Palaeoephippium* as treated herein.

Furutani (1990) erected the genus *Holdsworthum* based on the species *Holdsworthum japonicus* Furutani, 1990. This species is remarkably similar to *Palaeoephippium radices* as treated here. It possesses a netlike structure formed from the branching and linking of the basal rays. It also has the outwardly directed, curved basal ray branch seen both in the present study and in Goodbody (1986). Furutani (1990) described the presence of lamellae in the basal hemisphere proximal to the median bar, which is not seen in *P. radices*. Additionally, the meshwork of the basal hemisphere of *H. japonicus* appears finer and more complex than *P. radices*, and bifurcation of the basal rays appears to commence closer to the median bar. Noble(1994) assigned two specimens from the Silurian of the Caballos Novaculite, west Texas, to *Holdsworthum*, but noted that they lacked the proximal lamellae seen in *H. japonicus*. The precise affinity of *H. japonicus* is unclear, but it is likely a close relative of *P. radices*.

Occurring rarely in the Cape Phillips material are specimens similar to

Palaeoephippium radices, but with multiple branching apical rays. They are not treated here because, due to their paucity, it could not be determined if these are a variant of *P. radices* or *P. multiramosum* Goodbody, 1986.

PALAEOEPHIPPIUM SPINOSUM Goodbody, 1986

Plate 23, Figures 5, 6

Plate 26, Figures 6-9

Palaeoephippium spinosum GOODBODY, 1986, p. 147, pl. 5, figs. 1-5.

Palaeotripus monospinosum GOODBODY, 1986, p. 153, pl. 1, fig. 11.

Emended diagnosis.–At least six rays; basal rays bifurcate, one branch long, without further branching, other branch short with one or more subsequent bifurcations; apical rays with or without single bifurcation.

Description.–Commonly six rays, three from each end of median bar; less commonly eight rays, four from each end of median bar; seven and nine rayed forms rare. Apical rays shorter and less developed than basal rays, all rays rodlike, tapered. When six rays, most commonly one apical ray at each end of median bar, two basal rays at each end of median bar; less commonly two apical rays and one basal ray at one end of median bar, one apical ray and two basal rays at other end of median bar; one ray may take an intermediate position, may be equal to apical rays, nearly equal to basal rays, or intermediate stage of development. When eight rays, usually two apical rays and two basal rays from each end of median bar; rarely, one apical, one basal and two intermediate rays at one end of median bar, two apical and two basal rays at other end of median bar. Basal rays moderately to steeply declined, overall length approximately twice to 10 times apical ray length, bifurcate at short distance from median bar, angle between branches commonly large. One basal ray branch long, gently curved or curved to parallel initial trunk of ray. Second basal ray branch bifurcates at short distance from trunk of ray, each branch may bifurcate, additional bifurcation possible; lengths of branches usually short; number of bifurcations and branch lengths may vary within a specimen. Occasionally within a specimen one basal ray may bifurcate only once. Apical rays moderately to steeply reclined, usually bifurcate distally, may terminate in fine point, length of branches variable. Microspinules common, may be absent, least developed on apical rays, longest and densest on basal rays between median bar and first bifurcation, and on long branch below bifurcation.

Dimensions.–(in micrometres, from 10 specimens) Apical ray length from median bar to bifurcation 25-38, apical branch length 3-18; apical ray base width 5-8; basal ray length from median bar to bifurcation 30-45; long basal branch length 60-298; shorter basal branch length to its bifurcation 10-25.

Material examined.–Over 150 specimens. Figured specimens GSC 124780 (Fig. 5.5), GSC 124781 (Fig. 5.6), GSC 124782-124785 (Fig. 8.6-8.9).

Occurrence.–Upper Llandovery (*turriculatus* Zone) to upper Ludlow of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; new data).

Discussion.–As noted above, *Palaeoephippium spinosum* and *Palaeotripus monospinosum* are identical except for ray orientation and are treated here as a single species. The emended diagnosis accounts for this. Microspinulation is removed from the diagnosis because it is not a defining character; it can be absent or present with variable development. In this species, forms with six rays are more common than eight-ray forms. The comparison to *P. bifurcum* was stated in the discussion for that species. A ray that undergoes a single bifurcation can produce two nearly equal branches that are strikingly similar to those of *P. bifurcum*, but without the spinules.

Genus PALAEOPYRAMIDIUM Goodbody, 1986

Type species.–*Palaeopyramidium spinosum* Goodbody, 1986, from the upper Llandovery-Wenlock of the Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Diagnosis.–As per Goodbody (1986).

PALAEOPYRAMIDIUM SPINOSUM Goodbody, 1986

Plate 23, Figure 7

Plate 26, Figure 10

Palaeopyramidium spinosum GOODBODY, 1986, p. 148, pl. 2, figs. 5-8.

Description.–One apical ray and four basal rays emanating from a point centre; all rays rodlike, tapered. Apical ray length variable, always shorter than basal rays. Basal rays leave point centre shallowly to moderate reclined; straight or curve distally to steeply declined or pendant, rarely curve outwards to near horizontal. Spinules usually present on basal rays, development variable; best developed at short distance from point centre, decreasing in size and number distally, may be absent distally; usually short, rarely may extend to reach adjacent basal ray; some spinules may bear short terminal branches. Spinules commonly absent on apical ray, when present usually smaller and sparser than on basal rays, better developed nearer point centre.

Dimensions.–(in micrometres, from 10 specimens) Apical ray length 50-134; apical ray base width 5-10; basal ray length 140-278; basal ray base width 7-10.

Material examined.--Thirty-seven specimens observed. Figured specimens GSC 124786 (Fig. 5.7), GSC 124787 (Fig. 8.10).

Occurrence.–Upper Llandovery to middle Wenlock (*griestoniensis* to *lundgreni-testis* zones) of the Cape Phillips Formation, Cornwallis Island, Nunavut, Canada (Goodbody, 1986; new data).

Discussion.–Goodbody (1986) described the basal rays of *Palaeopyramidium spinosum* as being straight. The material studied here included specimens with curved basal rays. Specimens provisionally assigned to this species by Cui et al. (1996) appear to be hexactinellid sponge spicules (Cui et al., 1996, figs. 1f, g).

Genus PROTOENTACTINIA Kozur, Mostler, and Repetski, 1996

Type species.–*Protoentactinia gracilispinosa* Kozur, Mostler, and Repetski, 1996, from the Tremadocian Windfall Formation, Nevada, U. S. A.

Diagnosis.–As per Kozur et al. (1996).

PROTOENTACTINIA TRICORNE (Goodbody, 1986)

Plate 23, Figure 8

Genus novum 2 sp. Holdsworth, 1977, p. 171, pl. 2, fig. 8.

Palaeoephippium tricorne GOODBODY, 1986, p. 147, pl. 6, figs. 1-4.

Description.–Six rays, three from each end of median bar. Most commonly one apical ray and two basal rays from each end of median bar; less commonly one apical ray and two basal rays from one end of median bar, two apical rays and one basal ray from other end of bar. All rays rodlike, only distal branches tapered. Rays leave median bar moderately reclined or declined; rays trifurcate, each branch may trifurcate, occassionally third trifurcation occurs. Apical rays and basal rays essentially identical; occasionally basal rays distinguished by more trifurcations or slightly longer than apical rays, rarely basal rays have very small microspinules.

Dimensions.–(in micrometres, from nine specimens) Ray length to first trifurcation 60-115; ray base width 4-5.

Material examined.–Thirty-nine specimens observed. Figured specimen GSC 124788 (Fig. 5.8).

Occurrence.–Middle Llandovery to middle Wenlock (*curtus* to *lundgreni-testis* zones) of the Cape Phillips Formation, Cornwallis and Baillie-Hamilton islands, Nunavut, Canada (Goodbody, 1986; new data).

Discussion.–Goodbody (1986) placed this species in *Palaeoephippium* based on the number and orientation of the skeletal rays. Kozur et al. (1996) considered the species as belonging to *Protoentactinia* as indicated by their reference to Holdsworth's (1977) Genus Novum 2. *Protoentactinia tricorne* (Goodbody, 1986) is similar to the type species *Protoentactinia gracilispinosa* Kozur, Mostler, and Repetski, 1996; however, in the latter the branching produces a more close, shell-like structure than seen in *P. tricorne*. Also, *P. gracilispinosa* may have four rays emanating from the end of the median bar and may have bifurcating rays in addition to the more common trifurcations, whereas *P. tricorne* does not vary from three rays from each end of the median bar and trifurcating rays. *Protoentactinia tricorne* is most similar to *P. gracilispinosa* sensu lato described by Won and Iams (2002) from the Late Cambrian of Newfoundland. The latter differs, however, in having bifurcating rays in addition to trifurcating rays.

Order SPUMELLARIA Ehrenberg, 1875

Family HAPLOTAENIATUMIDAE Won, Blodgett, and Nestor, 2002

Emended Diagnosis.–Spherical skeleton; small, inner sphere surrounded by irregularly arranged or discontinuously spiral layers or concentrically arranged layers; skeleton may be segregated into inner and outer portions with connecting elements; commonly pylomate; no internal spicule.

Discussion.–Won et al. (2002) united *Haplotaeniatum* Nazarov and Ormiston, 1993, and *Orbiculopylorum* Noble et al., 1998, into a single family, the Haplotaeniatumidae, based on the common presence of a central spherical structure (the proloculus in Won et al., 2002) and a generally spiraliform arrangment of the shell. *Haplotaeniatum* was previously assigned to the spicular family Haplentactinidae. *Orbiculopylorum* was regarded by Noble et al. (1998) as an incertae sedis. The diagnosis given here is essentially that of Won et al. (2002). It removes comments on spine and shell-wall construction because the variability of these features is not diagnostic.

In their description of the family Haplotaeniatumidae, Won et al. (2002) noted that the spiral arrangement of the shell is discontinuous and that the appearance of the construction (spiral versus concentric) may depend on the orientation of a cross-section through a specimen. The present author's observations confirm this apparent variability. However, it seems possible that this is due to a tortuous coiling pattern as seen in *Grandetortura* as described by Sashida and Tonishi (1991). This genus is very similar in appearance to *Haplotaeniatum* (cf. Sashida and Tonishi, 1991, pl. 1, 2). A more detailed study of the coiling in *Haplotaeniatum* would prove most elucidating. In the species description given here, the appearance of construction is described without the intention of explaining the appearance.

Of note here is the apparent absence of an internal spicule in *Haplotaeniatum*. Nazarov (1988, and in Nazarov and Ormiston, 1993) regarded the genus as a member of the Haplentactiniidae, a family characterized by the presence of this feature. However, the figures of the species described by Nazarov and Ormiston (1993, pl. 3, figs. 9-16) do not show this character, nor is a spicule specifically mention in the species descriptions. Subsequent studies do not clarify the presence of a spicule (Goto et al., 1992; Noble et al., 1998; Noble and Maletz, 2000; Kurihara and Sashida, 2000a). Poor preservation is a consideration in these studies. *Haplotaeniatum* from the Cape Phillips Formation described herein is generally very well preserved and does not show indications of an internal spicule. A re-examination of Nazarov's material should be done to determine if he was mistaken in his evaluation of the genus or if subsequent work has failed to observe or understand this feature.

The above caveat being stated, the Cape Phillips Formation *Haplotaeniatum* and *Orbiculopylorum* appear closely related and the author concurs with Won et al. (2002) that the two genera belong to a common family.

Genus HAPLOTAENIATUM Nazarov and Ormiston, 1993

Haplotaeniatum NAZAROV, 1988, nom. nud., p. 66, pl. 11, figs. 7, 8, 10; NAZAROV AND ORMISTON, 1993, p. 40, pl. 3, figs. 9-16; GOTO, UMEDA, AND ISHIGA, 1992, p. 157, pl. 6, figs. 1-3, pl. 7, figs. 1-3; NOBLE, BRAUN, AND McCLELLAN., 1998, p. 721, fig. 4.4, 4.6; NOBLE AND MALETZ, 2000, p. 267, pl. 1, figs. 13, 14, 16, 17; KURIHARA AND SASHIDA, 2000a, p. 151, figs. 7.1-7.16.

Gyrosphaera NOBLE AND MALETZ, 2000, p. 267, pl. 2, figs. 1-5.

Type species.–*Haplotaeniatum labyrintheum* Nazarov and Ormiston, 1993, from the middle to upper Llandovery of the Sakmarskaya Suite, southern Urals.

Emended diagnosis.–Tiny inner lattice sphere overlain by several spiral, discontinuously spiral, or concentric layers. Commonly pylomate.

Discussion.–The diagnosis given here is essentially that of Nazarov and Ormiston (1993) except that reference to the Haplentactiniidae is removed and shell construction centred around an inner sphere (proloculus of Won et al., 2002) is added. As noted above, the haplentactinid spicule is not observed in *Haplotaeniatum*. The diagnosis differs from that of Won et al. (2002) in that it removes non-diagnostic comments about pore size and presence or absence of major spines.

Gyrosphaera Noble and Maletz, 2000, is considered here a junior synonym of *Haplotaeniatum*. The key feature of *Gyrosphaera* is the spirally arranged labyrinthine mesh. This does not appear to be significantly different from the construction of *Haplotaeniatum* except there is less tissue to the skeleton. That is, the seemingly complex array of lateral bars in *Gyrosphaera* is essentially a less developed *Haplotaeniatum* layering. In the species described herein -- *Haplotaeniatum* species A, *Haplotaeniatum* species B, and *Haplotaeniatum* cf. *H. raneatela* -- there is gradation between the ideal *Gyrosphaera* construction and a more typical *Haplotaeniatum* construction (Plate 27, Figures 11-15; Plate 28, Figures 1, 2). The specimens from the Cape Phillips Formation which could be assigned to *Gyrosphaera* also show the same inner sphere as in *Haplotaeniatum*. Specimens may also bear a pylome. Noble and Maletz (2000) noted that *Gyrosphaera* was likely a close relative of *Haplotaeniatum*, but did not press the issue due to the presumed presence of a spicule in *Haplotaeniatum*. As understood herein, *Haplotaeniatum* does not bear a spicule.

HAPLOTAENIATUM ?CATHENATUM Nazarov and Ormiston, 1993

Plate 32, Figures 1-6

Description.–Shell subspherical. Small sphere at centre of shell overlain by three to four spiraliform or concentric layers. Layers of shell latticed, layers may bulge outwards; pores generally small, circular, framed by four to six lattice bars; layers may be concentrically arranged, more commonly in two or more discontinuous spirals. Pylome common. Layers formed by distal branching of beams arising from previous layer; interlayer beams may be thick, flaired or branched where join layers, may be thin and rodlike. Additional beams crossing layers common, number variable, arise at different layers or at centre sphere. Numerous short external spines direct continuation of translayer beams or arise at shell surface as incomplete interlayer beams; spines thornlike, rodlike, or flaired similar to interlayer beams.

Dimensions.–(in micrometres, from seven specimens) overall diameter 175-243; diameter centre sphere 28-33; pore diameter 3-22; lattice bar width 3-8; spine length 17-33 (one specimen to 60); spine base width 5-7.

Material and occurrence.–Forty-three specimens examined. Lower to upper Llandovery (*acuminatus* to *guerichi* zones).

Discussion.–The present species is questionably assigned to *Haplotaeniatum cathenatum* Nazarov and Ormiston, 1993. Nazarov and Ormiston (1993) described the species as having short, rodlike spines, occasionally with thin short secondary spines. The Cape Phillips specimens possess numerous short spines with no clear distinction between primary and secondary spines. Nazarov and Ormiston (1993) noted four to five layers between the centre sphere and outer layer, which is slightly more than seen in the present material. A pylome is common in the material described here but rare in the Sakmarskaya Suite. The type material is also larger than observed in this study. These differences appear minor and could reflect normal variation. The Cape Phillips specimens appear identical to radiolarians from the Early Silurian of Sweden assigned to *H. cathenatum* by Noble and Maletz (2000). The only notable difference is that Noble and Maletz's (2000) description indicates that all spines extend inwards to the centre sphere. This is not observed in the present material; the spines may originate at the outer surface or at any level in the shell.

The present author must admit he does not fully understand Nazarov and Ormiston's (1993) distinction between *Haplotaeniatum cathenatum* and *H. tegimentum* Nazarov and Ormiston, 1993. This is the chief reason for the questionable assignment made here. *Haplotaeniatum tegimentum* possesses conical spines and "half-closed" shells unlike *H. cathenatum* with short, rodlike spines and (presumably) open shells. Additionally, the inner sphere is described as eccentrically placed in *H. tegimentum* whereas it is described as rarely eccentric in *H. cathenatum*. Based on the provided figures, however, the two species appear identical (Nazarov and Ormiston, 1993, pl. 3, fig 11 for *H. cathenatum*; pl.3, figs. 14-15 for *H. tegimentum*). The figures for neither species clearly show spines, the inner spheres in both appear essentially central, and the "half-closed" shells of *H. tegimentum* appear no different than any of the other species of the genus figured by Nazarov and Ormiston (1993). The number of layers is fewer in the figured specimens of *H. tegimentum* (Nazarov and Ormiston, 1993, pl. 3, figs. 14-15) than *H. catehnatum* as described or figured by Nazarov and Ormiston (1993, pl. 3, fig. 11). In this regard, *H. tegimentum* is similar to the Cape Phillips specimens described here. The size range of *H. tegimentum* given by Nazarov and Ormiston (1993; 240-264 μm) is closer to that for the present material.

Kurihara and Sashida (2000a) assigned radiolarians from the Llandovery of the Hida "Gaien" Belt of Japan to *Haplotaeniatum tegimentum*. They also noted difficulty in comparing Nazarov and Ormiston's (1993) figures of *H. cathenatum* and *H. tegimentum*. The number of shell layers in their material is consistent with the species as figured in Nazarov and Ormiston (1993, pl. 3, figs. 14-16) and the size is consistent. They note that inner sphere is often eccentrically placed. Kurihara and Sahida (2000a) described the presence of a few short, conical spines that arise from the shell surface. Spines are visible in their figures 7.1, 7.3, 7.6, 7.9, and 7.10. They appear as short, pluglike protuberances in these figures. It is not clear if their morphology represents the original morphology or if it is an artefact of preservation.

Considering the ambiguity noted above between *Haplotaeniatum cathenatum* and *H. tegimentum* coupled with the similarities noted between the latter and the material described here, it is possible that the Cape Phillips radiolarians could be *H. tegimentum*. Another hypothesis to consider, is that *H. cathenatum* and *H. tegimentum,* as described by Nazarov and Ormiston (1993), are synonymous. *Haplotaeniatum cathenatum*, with its additional shell layers and larger size, could be a more developed form of *H. tegimentum*. A re-examination of the type material would prove useful.

Of the co-occurring species of *Haplotaeniatum* in the Cape Phillips Formation, *H. ?cathenatum* is most similar to *Haplotaeniatum labyrintheum* in the construction of the shell. It lacks the large spines seen in *H. labyrintheum*. Also, translayer beams may originate at centre sphere in the present species, but this was not observed in *H. labyrintheum*. Alternatively, the translayer beams seen originating at the centre sphere in the present species may be equivalent to the main spines of *H. labyrintheum* which do originate at the centre sphere. The two species could be confused if the spines of *H. ?labyrintheum* were broken off or poorly developed.

Haplotaeniatum cathenatum in the strict sense is known from the middle to upper Landovery of the Sakmarskaya Suite, southern Urals (Nazarov and Ormiston, 1993) and from the Telychian (*turriculatus* Zone) of Dalarna, Sweden (Noble and Maletz, 2000). Noble et al. (1998) described *Haplotaeniatum* sp. aff. *H. cathenatum* from the early Llandovery of the Cherry Spring Chert, Nevada.

HAPLOTAENIATUM ADOBENSIS (Noble, Braun, and McClellan, 1998)

Plate 27, Figures 1-4

Plate 32, Figures 7, 8

Plate 33, Figure 1

Orbiculopylorum adobensis NOBLE, BRAUN, AND MCCLELLAN, 1998, p. 721, fig. 4.3.

Haplotaeniatum adobensis (Noble, Braun, and McClellan, 1998) WON, BLODGETT, AND NESTOR, 2002, 961, fig. 5.10.

Description.–Shell spherical or subspherical; formed by several concentric or spiraliform layers. Innermost sphere centrally located or slightly eccentric. Several beams extend from innermost sphere. Layers of shell formed from apophyses off beams and elements from adjacent layers. One or two layers between innermost sphere and outer layer; elements joining layers less dense in interior than outer portion of shell. All layers latticed, pores generally small, may be large opening penetrating multiple layers in some individuals, lattice bars often broad in relation to pores; lattice somewhat three-dimensional, often domed; layers commonly spirally arranged with whorls ending abruptly, subsequent whorl originating independently; occasionally layers appear concentric. Outermost layer may be single, densely labyrinthine layer of branching and interlocking elements; less commonly branching forms a second surface giving a double-walled appearance. Less commonly additional layers formed from irregular, distally branched by-spines. Pylome usually penetrates outer layer. Beams from centre sphere may continue as very short rodlike spines; irregular curved or thornlike by-spines common; when additional layers present, by-spines forming layers extend as numerous needle-like byspines, gives hispid appearance.

Dimensions.–(In micrometres, from seven specimens) Overall diameter 212-343; diameter of centre sphere 30-48; distance form central sphere to first internal layer 11-28; distance centre sphere to base of outer layer 50-80; thickness of outer layer 15-75; pore diameter 4-15; lattice bar width 2-10; pylome diameter 35-40 (two specimens).

Material and occurrence.–Over 50 specimens examined. Lower to upper Llandovery (upper *cyphus* to *guerichi* zones; questionably in *turriculatus* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada. Also reported in the early Llandovery, Cherry Spring Chert, Nevada (Noble et al., 1998); early Silurian, Road River Formation, Alaska (Won et al., 2002).

Discussion.–The material described here matches almost perfectly *Haplotaeniatum adobensis* (Noble et al., 1998) from the Early Silurian of Nevada and Germany. The material of the present study is essentially identical to the specimens in Noble et al.'s (1998) figure 4.3 in that they have a centre structure surrounded by loose material and a more densely constructed outer layer. As with Noble et al.'s (1998) specimens, the spines are weakly expressed. Unlike Noble et al.'s (1998) material, some specimens from the Cape Phillips Formation show numerous, thin by-spines (Plate 27, Figure 3). Also unlike the Nevadan specimens, the radiolarians described here may have large openings in the shell, much like those of ?*Haplotaeniatum aperturatum* Noble et al., 1998. These openings appear to be genuine features of the shell, rather than a result of preservation. Only rarely are ragged end of lattice bars observed; mainly, the borders of the openings are smooth and continuous.

The Radiolaria describe here also seem to coincide with *Haplotaeniatum* sp. aff. *cathenatum* described by Noble et al., 1998, from the Early Silurian of Nevada. In their remarks on the species, Noble et al. (1998) noted separation within the shell, but felt this was not sufficient to identify a distinct cortical shell. Noble et al. (1998) suggested that it is intermediate with *Haplotaeniatum* and *H. adobensis* which Noble et al. (1998) placed with *Orbiculopylorum*. The figures of the species (Noble et al., 1998, fig. 4.4a, 4.4b) do not clarify the clarify the interior of the species; their figure 4.4b appears as a uniformly pseudospongiose mass. In their description of *Haplotaeniatum* sp. aff. *cathenatum*, Noble et al. (1998) do not mention a bimodal pore size distribution similar to ?*Haplotaeniatum aperturatum* or *H. adobensis* as described here. Their remarks, however, do imply such a distribution. The figures of the species are ambiguous (Noble et al., 1998, fig. 4.4a, 4.4b). Won et al. (2002) assigned specimens from the Llandovery of the Road River Formation to *H. aperturatum* and noted the presence of the species in the material of the present study. My own observations did not reveal radiolarians I would unequivocally assign to that species. Interiors of specimens with large openings were more akin to the interior of *H. adobensis* as described by Noble et al. (1998); however, in some samples the interiors seemed more densely constructed than in others. Won et al. (2002) also discussed the somewhat gradational characteristics of these taxa and concluded that the distinction was artificial. They suggested that taxonomic assignment depends on which characteristics the taxonomist emphasizes. This may explain why Won et al. (2002) noted *H. aperturatum* in the Cape Phillips Formation whereas the present author does not.

Won et al. (2002) concluded that in *Orbiculopylorum* there is a definite separation between inner and outer portions of the skeleton. Additionally, the outer part forms a two-dimensional lattice. In contrast, Won et al. (2002) noted that in *Haplotaeniatium* many elements form the framework of the skeleton even when segregated into inner and outer parts, as in *H. adobensis*. Consequently, these authors moved the species to *Haplotaeniatum* from *Orbiculopylorum*. As mentioned above, the Cape Phillips material and Noble et al.'s (1998) figure 4.3 are in accord. The difference between the two regions of the shell appear more a matter of amount of material as opposed to manner of construction. Problematic, however, is the specimen in Noble et al.'s (1998) figure 6.5. Unlike the specimens in their figure 4.3 and the Cape Phillips specimens, this specimen appears to have a distinct lattice shell overlain by a labyrinthine layer. This specimen also does not appear appreciably different to specimens assigned to *Orbiculopylorum* sp. (Noble et al., 1998, fig. 6.4) and *Syntagentactinia* ? sp. (Noble et al, 1998, fig. 6.1).

The material described here is also similar to *Syntagentactinia excelsa*. The principal difference is that the outer part of the shell of *S. excelsa* is formed of more-or-less distinct layers (Nazarov and Ormiston 1993, pl. 6, figs. 13, 14), whereas in *H. adobensis* the outer layer is labyrinthine. The present material can form a crude layering as seen in the double-wall construction of some specimens. This does not appear to be as distinct as in *S. excelsa*. The distinct spheres are particularly noticeable in *S. excelsa* as described by Kurihara and Sashida (2000a) from the Early Silurian of Japan. *Syntagentactinia excelsa*, as described by Nazarov and Ormiston (1993), is also different from *H. adobensis* in that its innermost sphere is in an eccentric position, and it possesses two to four spines. Neither Noble et al. (1998) nor the present study noted an eccentric position for the centre sphere in *Haplotaeniatum adobensis*; additionally neither study determined the spine number of the species.

The size range seen in *Haplotaeniatum adobensis* from the Cape Phillips Formation is in part related to ontogeny, especially in the level of development of the outermost layers. Preservation and within-species variation also likely affect the size of an individual. The very large opening in the shell of some specimens are particularly common in sample CM2-85.5.

HAPLOTAENIATUM ?LABYRINTHEUM Nazarov and Ormiston, 1993

Plate 27, Figures 5-7

Plate 33, Figures 4-7

Description.–Shell spherical to subspherical. Small lattice sphere at centre of shell, overlain by three to four concentric or spiraliform layers. Layers of shell latticed, individual lattice bars may be oriented at angles to layer, layers may bulge outwards; pores generally small, subcircular to circular, less commonly larger with more angular outline, framed by four to six lattice bars; layers may be concentrically arranged, more commonly in two or more discontinuous whorls. Usually with large pylome penetrating multiple layers. Layers formed by distal branching of beams arising from previous layer; interlayer beams often stout and flaired outwards at both ends, also thinner and rodlike, often curved, at angle to layers, branched, or linked laterally; external by-spines apparently incomplete interlayer beams. Construction of layers and interlayer beams commonly loose, grades to densely packed layers. Development of beams crossing layers variable, absent to numerous, translayer beams arise from two layers below outermost layer, not observed arising from centre sphere, extend externally as short, rodlike secondary spines. Main spines massive, rodlike, slight taper, length may exceed one shell diameter, originate as beams from centre sphere, beams broaden to outermost layer; commonly five spines, maybe six or fewer, usually one spine adjacent to pylome.

Dimensions.–(in micrometres, from 28 specimens) Overall diameter 177-454; diameter centre sphere 21-43; pore diameter 2-19; lattice bar width 1-8; spine length to 480; spine base width 7-25; pylome diameter 45-100 (four specimens).

Material and occurrence.–Over 200 specimens examined. Lower to middle Llandovery (*acuminatus* to *curtus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada..

Discussion.–The uneven lattice bar orientation, subspherical shape of layers, plus the branching and curving of interlayer beams can give the shell of *Haplotaeniatum labyrintheum* a three-dimensional, "pseudospongy" appearance. Otherwise, the construction is the same as seen in the co-occurring *H. ?cathenatum*. There is no apparent preference for a loose or compact construction of the concentric layers, and the compactness is gradational amongst the observed specimens. One spine is usually adjacent to the pylome. Some specimens have only a single spine. There is some stratigraphic variation in the range of morphology -- in CM2-44.5 and CM2-46.8 a more irregular form without translayer beams predominates, whereas in CM2-42.5 and CM2-51.2 the full suite of morphologic variation is observed. The species is rare in CM2-31.9 and is compactly constructed and diminutive.

Haplotaeniatum labyrintheum, as described by Nazarov and Ormiston (1993), possesses one to six spines that are short. The material described herein possess the same number of spines, but these are longer than in Nazarov and Ormiston's (1993) specimens. It is quite likely that the difference is preservational. The Cape Phillips specimens also have fewer shell layers than *H. labyrintheum* as described by Nazarov and Ormiston (1993). In this regard, the present material is more like *H. ?primordialis* (Rüst, 1892) as described by Nazarov and Ormiston (1993). Nazarov and Ormiston

(1993) do not state spine number in *H. ?primordialis* and report the spine length as shorter than in *H. labyrintheum*. They distinguished the two species based on the number of shell layers and the size of the radiolarians. The size range of the Cape Phillips material overlaps both *H. labyrintheum* and *H. ?primordialis*. It is possible that the two species are conspecific and the apparent difference reflects variations in development or preservation, as was suggested above for *H. cathenatum* and *H. tegimentum*. Because of the similar variability in spine number, the Cape Phillips radiolarians are conditionally assigned to *H. ?labyrintheum*.

Haplotaeniatum ?labyrintheum is similar to an undescribed specimen figured by Nobel et al. (1998, fig. 5.5) from the early Llandovery Cherry Spring Chert of Nevada. Both possess well-expressed spines. *Haplotaeniatum ?labyrintheum* is also similar to *H. spinatum* Goto, Umeda, and Ishiga, 1992, from the Late Ordovician of southeastern Australia. *Syntagentactinia afflicta* Nazarov and Ormiston, 1993, bears similarity to *Haplotaeniatum ?labyrintheum*. Nazarov and Ormiston (1993) described the former as having several half-closed shells and two to four, rarely six, spines. However, unlike *Haplotaeniatum ?labyrintheum*, *S. afflicta* is described as having an internal spicule and does not possess a pylome.

Haplotaeniatum labyrintheum in the strict sense is reported form the middle to upper Llandovery of the Sakmarskaya Suite, southern Urals (Nazarov and Ormiston, 1993).

HAPLOTAENIATUM cf. H. RANEATELA (Noble and Maletz, 2000)

Plate 28, Figures 1, 2

Plate 34, Figures 3-6

Description.–Shell subspherical. Small lattice sphere at centre; overlain by three layers, concentric or in two discontinuous spirals. Layers latticed, irregular outline, locally bulged, arise from rodlike beams arising at centre sphere or other layers; less commonly additional beams restricted between layers, flaired or branched at ends. Pores subcircular to circular, framed by five to six lattice bars. Pylome may be present. Spines continue directly from radial beams and arise at outer layer, rodlike, slight taper, approximately 12 per hemisphere, length commonly two-thirds shell diameter may exceed one shell diameter, may be hollow.

Dimensions.–(in micrometres, from six specimens) Overall diameter 175-250; centre sphere diameter 22-32; pore diameter 3-13; lattice bar width 2-9; spine length 50-140; spine base width 5-13.

Material and occurrence.–Sixty specimens examined. Upper Llandovery (*griestonisensis* to *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–*Haplotaeniatum* cf *H. raneatela* is very similar to *Haplotaeniatum raneatela* (Noble and Maletz, 2000). The two have similar spine numbers. The shell construction is similar, but appears looser in the specimens figured by Noble and Maletz (2000, pl. 2, figs. 1-3). *Haplotaeniatum raneatela* was not described as having a pylome, as is seen in some specimens of *H.* cf. *H. raneatela*. Externally, the present species seems more similar to *H. siljanensis* as figured by Noble and Maletz (2000, pl. 2, figs. 4, 5). The only real differences are that the present species possesses more spines and it may bear a pylome, a feature not noted in *H. siljanensis*.

From the co-occurring radiolarians in the Cape Phillips Formation, *Haplotaeniatum* cf. *H. raneatela* differs from *Haplotaeniatum* new species A and *Haplotaeniatum* species B by having fewer spines. *Haplotaeniatum* species B is larger than the present species and has a looser shell construction. *Haplotaeniatum ?labyrintheum* has fewer spines which are also somewhat more robust. The construction of the shell of *Haplotaeniatum* cf. *H. raneatela* is generally looser than *Haplotaeniatum ?labyrintheum*.

Haplotaeniatum raneatela in the strict sense is reported only from the Telychian (*turriculatus* Zone) of Dalarna, Sweden (Noble and Maletz, 2000).

HAPLOTAENIATUM species A

Plate 27, Figures 11-13

Plate 33, Figures 8, 9

Plate 34, Figures 1, 2

Description.–Shell subspherical to spherical. Small lattice sphere at centre of shell; overlain by three, rarely four, layers usually in two or more discontinuous whorls, may be one spiral, less commonly concentric. Layers of shell latticed, arise from radial beams and arching bars linking beams, arches create local bulges, layers joined and partially formed by curved and branching elements between layers; lattice bars oriented at different angles; pores subcircular to circular, may be oval, less commonly subangular, framed by four to six lattice bars, outermost layer may be more open and angular than inner layers. May possess a pylome. Spines numerous, continue directly from radial beams arising at centre sphere or shell layers, rodlike, slender, slightly tapered, may be hollow, length usually one third shell diameter, rarely longer; spines arising at outermost layer may be slightly shorter and finer than others.

Dimensions.–(in micrometres, from 11 specimens) Overall diameter 225-343; centre sphere diameter 27-44; pore diameter 3-22; lattice bar width 2-10; spine length 55-168; spine base width 5-8.

Material and occurrence.–Ninety specimens examined. Upper Llandovery (*griestoniensis* to lower *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–The construction of the skeletal meshwork is essentially the same as most species of *Haplotaeniatum* observed in this study and in Noble and Maletz (2000); this includes *Gyrosphaera* Noble and Maletz, 2000, which is regarded here as a synonym of *Haplotaeniatum*. In this species and *Haplotaeniatum reneatela* (Noble and Maletz, 2000) the construction of the meshwork is simplified with fewer bars. This creates a more open appearance than seen in most species of the genus.

Haplotaeniatum species A differs from *H. raneatala*, by having more spines. Also, the spines are shorter and finer than in *H. raneatala*. *Haplotaeniatum* new species

A can be quite similar to *Haplotaeniatum* species B. However, the outer layers of the shell in *Haplotaeniatum* species B are generally more loosely constructed than in *Haplotaeniatum* species A. The spines in *Haplotaeniatum* new species A are shorter than in *Haplotaeniatum* species B. The spines in *Haplotaeniatum* species B also are more robust, may curve, and are slightly fewer in number. Additionally, the overall size of *Haplotaeniatum* new species B tends to be larger.

HAPLOTAENIATUM species B

Plate 27, Figures 14, 15

Plate 34, Figures 7-10

Description.–Shell subspherical. Small lattice shell at centre; overlain by three to four layers. Inner two layers commonly a single spiral, construction compact; pores small, circular to subcircular; pylome may be present in second layer. Third and fourth layer usually loosely constructed, angular meshwork formed by arches off radial beams, may be areas of better developed lattice, less commonly entire lattice better developed; pore size highly variable within a specimen, generally large, subangular to subcircular where lattice better developed; commonly additional lateral beams between layers, layers may be linked by curved and branched elements, forms complex three-dimensional network. Spines numerous, originate as beams from centre sphere or layers, rodlike, faintly tapered, may be curved, may be hollow, length one-half to nearly one shell diameter.

Dimensions.–(in micrometres, from six specimens) Overall diameter 283-404; centre sphere diameter 30-40; outer layer pore diameter 10-60; lattice bar width 3-10; spine length 140-374; spine base width 5-10.

Material and occurrence.–Twelve specimens examined. Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–A notable feature of this species is the tendency for two modes of skeletal construction. The outer layers commonly are loosely constructed and form a more angular meshwork. When there are four layers to the shell, the outer two layers may be difficult to distinguish from each other because of the complicated additional linkages between the two layers.

Comparison to *Haplotaeniatum* new species A was made with that species. *Haplotaeniatum* species B differs from *H. raneatela* by its more numerous and longer spines, and has a greater size range. The construction of the skeleton appear similar in the specimens figured by Noble and Maletz (2000, pl. 2, figs. 1-3). *Haplotaeniatum siljanensis* (Noble and Maletz, 2000) has fewer spines than *Haplotaeniatum* species B and has a smaller diameter. Noble and Maletz (2000) noted looser outer layers in some specimens *H. siljanensis*.

The species is known with certainty from the *griestoniensis* Zone of the Cape Phillips Formation. Diminutive individuals from sample CM2-106.5 (*turriculatus* Zone) are somewhat similar. Very rare problematic specimens that are also similar were noted in CP-94.3 (*sakmaricus* Zone). Because only a few specimens recovered, the species is left in open nomenclature.

HAPLOTAENIATUM species C

Plate 27, Figures 8-10

Plate 33, Figures 2, 3

Description.–Lattice shell subspherical to polygonal; pores numerous, small, may be larger near spine bases, circular and circular-oval, framed by 5-6 bars; bars commonly broad; pylome large, lipped, may be partially covered by curved lattice bars. Radial beams extend from near centre of sphere, connect to base of spines. Internal structure tiny central sphere. Two to three concentric (spiral?) layers, loosely constructed, interconnected by curved beams, layers occupy most of shell interior. Six to nine main spines, rodlike, slight taper, length may exceed shell diameter, may be discontinuously hollow; base may be buttressed, may flair out to merge with polygonal shape of shell. Secondary spines rodlike, slight taper, length up to 2/3 main spine length, may be discontinuously hollow, may be absent. Rarely with sparse by-spines, thornlike, may curve.

Dimensions.–(in micrometres, 5 specimens) Diameter 173-343; shell thickness 2-5; pore diameter 7-10; lattice bar width up to 5; pylome diameter 35-60; main spine length 147-404; main spine base width 18-25; secondary spine length 70-140; secondary spine base width 10-17.

Material and occurrence.–Twenty specimens examined. Lower to middle Llandovery (*acuminatus* to upper *curtus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–Based on the internal layering, the described species is placed with *Haplotaeniatum*. However, the more perforate-plate construction of the shell layers differs from other species of this genus. *Haplotaeniatum* species C can be favourably compared to *Cessipylorum apertum* (Nazarov,1975). As diagnosed by Nazarov (in Afanas'eva, 1986), *Cessipylorum* possesses seven spines and seven rays from the centre sphere. From descriptions of the species in the genus, the spines are connected to the internal rays. However, Nazarov and Popov (1980) described *C. apertum* as having five to eight rays which join the external spines, although the genus is described as having specifically seven spines. This ray number (and presumably spine number if the rays connect to spines) is consistent with the material being described herein, which possess six to nine spines which are connected to the internal rays. Nazarov et al. (1975, in translation 1977) and Nazarov and Popov (1980) also described *C. apertum* as having groups of apophyses at various distances along the rays and noted that these apophyses could link together. This is consistent with poorly preserved layering similar to the two to three layers observed here, rather than a single, partially developed sphere as noted in the genus diagnosis. The spines of *C. apertum* are more rodlike, similar to the present species, rather conical, as noted in the generic diagnosis. Another species of *Cessipylorum*, *C. rimata*, has a shell pierced by widely spaced pores similar to *Haplotaeniatum* species C.

Beyond the similarities above, the type species of *Cessipylorum*, --*C. insuetum* (Nazarov, 1975)-- and *C. rimata* are described as having specifically seven spines. All three species of the genus are described as having two spines situated with the pylome.

This was not observed with *Haplotaeniatum* species C, which was seen having one spine with the pylome in some specimens. In *C. insueta*, the apophyses on the internal rays form only a single inner sphere, whereas in *C. rimata* they are not known to coalesce. The central sphere of all three published species is described as an imperforate sphere, rather than a lattice; however, this imperforate character could be a preservational feature. Considering the similarities noted in the previous paragraph, it is possible that *C. apertum* is more closely related to the present species than to *C. insueta* and *C. rimata*. Conversely, the differences between the present species and *Cessipylorum* may reflect an incomplete understanding of these species due to preservation.

Aciferpylorum Nazarov and Ormiston, 1993, is diagnosed as having a well-developed sphere between the outer shell and centre structure, unlike the multiple, loosely constructed layers of *Haplotaeniatum* species C. Also, the genus possesses numerous spines, several of which border the pylome. Externally, the shell of *A. admirandum* is similar to the present species with small, circular-oval pores, and similar buttressing of the spines (Nazarov and Ormiston, 1993, pl. 4, figs. 9, 10).

Genus ORBICULOPYLORUM Noble, Braun, and McClellan, 1998

Orbiculopylorum NOBLE, BRAUN, AND MCCLELLAN, 1998, p. 718, figs. 4.1, 4.2 [non *O. adobensis* fig. 4.3]; WON, BLODGETT, AND NESTOR, 2002, p. 961, figs. 5.18-5.20.

Type species.–*Orbiculopylorum marginatum* Noble, Braun, and McClellan, 1998, from the Llandovery Cherry Spring Chert, Nevada, USA.

Emended diagnosis.–Tiny inner lattice sphere overlain by loose, three-dimensional meshwork; meshwork denser nearer to inner sphere. Radial beams extend from inner sphere. Cortical shell lattice, commonly pylomate.

Discussion.–The emended diagnosis given here is essentially the same as that of Noble et al. (1998) except that it includes the presence of the inner lattice sphere. Similar to Won et al.'s (2002) emended diagnosis, it notes that the inner meshwork is denser closer to the centre of the skeleton. Additional details given in Won at al.'s (2002) diagnosis are excluded here. The key features are the internal sphere with the overlying meshwork and the lattice cortical shell that normally is pylomate. When present, skeletal material external to the cortical shell may be latticed, labyrinthine, or in multiple, closely spaced layers. This outer material may be absent in some specimens and its presence is not necessary to diagnosis the genus; consequently, it is not included in the emended diagnosis.

Noble et al. (1998) erected the genus *Orbiculopylorum* based on radiolarians collected from the Early Silurian of Nevada and Germany. *Orbiculopylorum adobensis* was re-assigned to *Haplotaeniatum* by Won et al. (2002). The type species of *Orbiculpylorum*, *O. marginatum* Noble et al., 1998, and *O. splendens* Noble et al., 1998, are constructed in the same manner as the species observed in this study. Noble et al. (1998) distinguished *Orbiculopylorum* from *Kalimnasphaera* based on the absence of the long, massive spines seem in *Kalimnasphaera*. As seen in the Cape Phillips radiolarians, the spines can be diminutive as seen in *Orbiculopylorum* cf. *O. marginatum*, massive as in *Orbiculopylorum* sp. A, or variable within a species as in *Orbiculopylorum* sp. B.

Orbiculopylorum, as diagnosed by Noble et al. (1998), does not possess an inner sphere as noted herein. This sphere was noticed principally under transmitted light microscopy, and is easily missed under scanning electron microscopy. Viewed under the SEM, the interior of *Orbiculopylorum* cf. *O. marginatum* (Plate 28, Figure 5) is essentially identical to that of *O. marginatum* as described and figured by Noble et al. (1998). Won et al. (2002) rediagnosed *Orbiculopylorum* and noted the presence of an inner sphere surrounded by a dense mass or incomplete layer surrounding it. The present author concurs with Won et al. (2002) that the apparent absence of the inner sphere in Noble et al.'s (1998) material is artefactual due to the difficultly of observing it through the overlying meshwork.

The Cape Phillips radiolarians assigned to *Orbiculopylorum* are consistent with the *Kalimnasphaera* Webby and Blom, 1986, in the following respects. The radiolarians possess a lattice cortical shell with a pylome; the cortical shell is usually overlain by additional skeletal material that presents a variation on the fenestrated layer in *K. maculosa*; and spine number, or more precisely, radial beam number, is consistent with *Kalimnasphaera*. Vital to the diagnosis of *Kalimnasphaera* is the nature of the internal features. In this detail, there is an incompatibility between this genus and *Orbiculopylorum*. As treated herein, *Orbiculopylorum* possesses an inner lattice shell with an overlying meshwork. In Webby and Blom's (1986) diagnosis of

Kalimnasphaera and description of the type-species, *K. maculosa*, the interior of the skeleton consists of two lattice medullary shells connected by tiny radial beams. Webby and Blom's (1986) fig. 4.1, however, appears consistent with observations made on the Cape Phillips radiolarians. Also, their description of hooklike spinules on one radial beam and the corresponding figure (Webby and Blom, 1986, fig. 4.8) seem consistent with a poorly preserved meshwork as seen in the present study. Their figure 4.8 appears to present a close up of the fenestrated layer, the cortical shell, and a remnant of the innermost sphere; the second medullary shell of Webby and Blom (1986) appears to absent with the spinules occupying its position. Webby and Blom (1986, p. 154) commented that the spinules could represent remnants of poorly preserved medullary shells. This comment seems to indicate that the interior of the type material was not fully preserved and understood. The spinules could also be interpreted as remnants of a three-dimensional meshwork as observed herein. The other two figures of the interior of the type species are somewhat ambiguous. The inner structure in figure 4.3 (Webby and Blom, 1986) appears somewhat three dimensional and is quite similar to the interior of *Orbiculopylorum marginatum* Noble et al., 1998 (Noble et al., 1998, pl. 4, fig. 1a, b). The inner features in Webby and Blom's (1986) figure 3.4 are broken open to present a cross section. While this gives the appearance of two shells, the three dimensional meshwork noted herein can take the same appearance in the Cape Phillips material when poorly preserved (Plate 36, Figure 2, 7). While *Kalimnasphaera* and *Orbiculopylorum* appear closely related, this uncertainty regarding the interior of *Kalimnasphaera* hinders a clears statement on the nature of the relationship -- two related but separate genera or a single genus. A re-examination of *Kalimnasphaera* would help clarify this relationship.

ORBICULOPYLORUM cf. O. MARGINATUM Noble et al., 1998

Plate 28, Figures 3-5

Plate 35, Figures 1-4

Description.–Lattice cortical shell; pores rounded, subcircular to circular, size variable, generally large; lattice bars generally thick. Labyrinthine layer on cortical shell, thickness variable, may be absent, formed from interlocking apophyses off spines and by-spines. Large pylome in cortical shell and labyrinthine layer. Medullary structure a tiny sphere overlain by loose meshwork. Number of external main spines uncertain, 5-7(?), short, rodlike, slightly tapered, continue directly from radial beams linking medullary structure and cortical shell. Numerous secondary spines sparse, finer than main spines, rodlike, faint taper. By-spines densely distributed, arise at lattice nodes, rodlike, may link laterally at base.

Dimensions.–(in micrometres, from four specimens) Overall diameter 333-354; cortical shell diameter 263-293; cortical shell thickness 5-10; pores per one-half cortical shell circumference 11-15; cortical shell pore diameter 8-30, lattice bar thickness 5-10; labyrinthine layer thickness 28-55; main spine length 52-85, main spine base width 10-15; secondary spine length 18-43; pylome diameter 63-76 (two specimens); inner sphere diameter 38; medullary meshwork diameter 118 (one specimen); thickness of beams from medullary sphere 3-5.

Material and occurrence.–Fifty specimens examined. Upper Llandovery (*guerichi* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–The present species appears somewhat similar to *Orbiculopylorum marginatum* (Noble et al., 1998). Noble et al. (1998) described *O. marginatum* as having more spines originating from the centre structure (eight to ten) with a total of more than 15 spines per hemisphere. The secondary spines in the specimens figured by Noble et al. (1998, fig 4.1) are similar to the by-spines observed in *Orbiculopylorum* cf. *O. marginatum*. The present species also differs in developing a labyrinthine outer layer, which was not noted in *O. marginatum*. It is possible that this outer layer is an ontogenetic variant on the morphology observed by Noble et al. (1998). *Orbiculopylorum* cf. *O. marginatum* is also similar to *O. splendens* Noble et al., 1998, but lacks the raised interior of the latter. Additionally, *O. splendens* lacks the by-spines and labyrinthine layer seen in the present species.

Unlike *Orbiculopylorum* species B, the spines of *Orbiculopylorum* cf. *O. marginatum* are consistently short, whereas they can be quite long in the former species. While the outer labyrinthine layer of *Orbiculopylorum* cf. *O. marginatum* is at the cortical shell, the outer layers of *Orbiculopylorum* sp. B originate at a short distance from the cortical shell and have a latticed initial layer.

Orbibulopylorum marginatum is reported from the lower Llandovery of the Cherry Spring Chert, Nevada (Noble et al., 1998) and the Llandovery of the Road River Formation, Alaska (Won et al., 2002).

ORBICULOPYLORUM species A

Plate 28, Figures 6-8

Plate 35, Figures 5-8

Description.–Principal cortical shell latticed, bars oriented either in two dimensions or arched with some bars overriding others; pores generally small, circular or subcircular, fairly regular arrangement, framed by six bars, less often five, pylome usually present. Second cortical shell usually present, latticed, formed by distal branches on beams off principal cortical shell; pores smaller than principal cortical shell, circular or subcircular, regular arrangement, framed by six bars. Incomplete third cortical may be present; forms from distal branches off beams arising from principal and second cortical shells. When second or third shell not developed, supporting beams present as numerous by-spines on principal cortical shell, may bear terminal branches. Medullary structure small, loosely constructed sphere overlain by loose irregular meshwork, meshwork forms off medullary sphere and apophyses on beams extending from sphere. Five to six beams arise at medullary sphere, thick, broaden at principal cortical shell, continue as external spines. Spines thick, rodlike, may be discontinuously hollow, negligible taper, length up to one inner cortical shell diameter.

Dimensions.–(in micrometres, from six specimens) Diameter inner cortical shell 183-213; thickness inner cortical shell wall 2-3; inner cortical shell pore diameter 5-14; pores per one-half inner cortical shell diameter 14-17; inner cortical cortical bar width to 6; pylome diameter 48-53; diameter second cortical shell 253-353; thickness second cortical shell wall 1-3; second cortical shell pore diameter 5-10; second cortical shell bar width to 3; third cortical shell diameter 298; diameter medullary sphere 32-48; diameter medullary meshwork 72.5; width of beams from medullary sphere 6-8; spine length from inner cortical 160-225; spine base width at inner cortical 14-21.

Material and occurrence.–Sixty specimens examined. Lower Llandovery (upper *cyphus* Zone), Cape Phillips Formation, Cornwallis Island Nunavut.

Discussion.–Superficially, *Orbiculopylorum* species A is similar to the Inaniguttidae by possessing concentric lattice spheres and massive external spines. The internal structure, however, is consistent with *Orbiculopylorum* as understood herein. The species is most similar to *Orbiculopylorum* species B. A comparison is given in the discussion for that species. *Orbiculopylorum* species A is very similar to genus novum B described by Noble et al. (1998); however, the shell diameter in genus novum B is much larger than observed in the present species. Genus and species indeterminate D described by Won et al. (2002) likely is *Orbiculopylorum* species A. Alternatively, it could be assigned to *Orbiculopylorum* species B forma 2; however, the robustness of the spines in the figured specimen (Won et al., 2002, fig. 5.21) are more consistent with the present species.

ORBICULOPYLORUM species B

Plate 29, Figures 1-6

Plate 36, Figures 1-7

Description.–*Forma 1* Principal cortical shell grades to two styles: 1) two dimensional lattice sphere; pores generally small, rounded, subcircular to circular, regularly arranged, framed by 5-6 bars; bars thin; 2) three dimensional lattice sphere, bars oriented at angles, may bear short curved apophyses on surface, form thin labyrinthlike sphere; pores small, regularly arranged, rounded, subcircular to circular. Second cortical shell at short distance from principal cortical shell, formed by apophyses off numerous beams from principal cortical shell, commonly similar to principal cortical shell; pores regularly arranged, rounded, subcircular to circular; may be irregularly arranged. Labyrinthine layer on second cortical shell, formed from apophyses off by-spines; additional labyrinthine layers may be present, forms concentrically constructed outer shell. Apophyses may arise off beams between principal and second cortical shells, may fill intershell space. Pylome present in principal cortical shell; overridden in whole or part by outer layers. Medullary structure tiny sphere overlain by loose meshwork. Six to eight spines, rarely 5, externally short, tapered rods or conical, direct continuation of beams arising from medullary structure.

Forma 2 As for forma 1 but spines longer, may exceed one-half inner cortical shell diameter. Outer portion of cortical shell often less developed than in forma 1; second cortical shell may be absent.

Dimensions.–(in micrometres, from 17 specimens) Overall diameter 258-323; principal cortical shell diameter 200-263; principal cortical shell thickness 2-5; principal cortical shell pore diameter 3-14; pores per one-half principal cortical shell diameter 16-23; pylome diameter 43; principal cortical shell lattice bar width 2-8; space between principal and second cortical shells 18-40;; medullary sphere diameter 33-45; medullary meshwork diameter 68-105; radial beam from medullary sphere width 3-5; spine length from principal cortical shell 48-207; spine base width at principal cortical shell 5-14.

Material and occurrence.–Over 100 specimens examined. Lower to middle Llandovery (upper *cyphus* to upper *curtus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–Forma 1 is the more common form of *Orbiculopylorum* species B, and is found in all samples in which the species is positively identified. Forma 2 is found in samples CM2-44.5, CM2-46.8, and possibly in CM2-42.5. The difference between the two forms is gradational. The distinction between the two forms is made here to highlight uncertainty in classification. *Orbiculopylorum* species A is very similar to *Orbiculopylorum* species B forma 2. However, *Orbiculopylorum* species A is distinguished by its very robust spines whereas *Orbiculopylorum* species B forma 2 has finer spines that are similar to *Orbiculopylorum* species B forma 1, albeit somewhat longer. It is possible that *Orbiculopylorum* species B forma 2 and *Orbiculopylorum* species A are conspecific; however, *Orbiculopylorum* species B forma 2 is considered here as *Orbiculopylorum* species B due to the gradual overlap with *Orbiculopylorum* species B forma 1.

An additional quandary is the ontogeny of the *Orbiculopylorum* species B. In forma 1, the spines evidently grow in pace with the development of the outer shell layers. In forma 2, it appears that the spines develop in advance of the shell layers. In some specimens, it should be noted, the long spines are an artefact of preservation. The outer shell layers are preferentially removed, thus exposing the spines.

Orbiculopylorum species B is found with certainty in the upper *cyphus* to upper *curtus* zones (CM2-42.5 to CM2-51.2). However, rare, poorly preserved specimens from lower *guerichi* to *turriculatus* zones (CM2-71.1 to CM2-106.1) possibly belong to this species.

?ORBICULOPYLORUM species C

Plate 36, Figures 8, 9

Plate 37, Figures 1-3

Description.–Shell spherical to slightly subspherical; lattice slightly irregular, lattice bars may be hollow; pores framed by five to six lattice bars, rarely four, rounded to well rounded, oval to subcircular or shaped after lattice bars. Spines numerous, arise nodally, fine rods, slightly tapered, may be partially or wholly hollow, length one-quarter to one-third shell diameter; occasionally some spines longer than others, usually continue inward as radial beams. Eight (?) radial beams emanate from near centre of sphere, these attach to loose central meshwork where preserved.

Dimensions.–(in micrometres, from 10 specimens) Shell diameter 218-258; shell thickness 3-5; pore diameter 3-20; number of pores per one-half shell diameter 12-20; lattice bar width 5-13; spine length 15-98; spine base width 5-8.

Material and occurrence.–Over 100 specimens examined. Middle to upper Llandovery (uppermost *curtus* to *griestoniensis* zones), Cape Phillips Formation, Cornwallis Island, Nunavut, Canada.

Discussion.–In general, specimens assigned to ?*Orbiculopylorum* species C do not have obvious pylomes, but some specimens suggest a sieve plate over a pylome. One sample (CM2-75.9) has specimens similar to those described here, but with a bimodal size distribution. Smaller specimens are identical to those described here except they each possess a definite pylome. The larger forms also have a definite pylome, plus they tend to have spines longer than majority on an individual. Unlike other species of the genus, ?*Orbiculopylorum* species C does not possess shell material beyond the cortical shell. The species described here is tentatively place in *Orbiculopylorum* based on the loose, central meshwork seen in some specimens This was not observed fully preserved and the innermost sphere was not confirmed. It is possible that the incomplete inner structure actually formed a complete sphere and that the species should be assigned to the Inaniguttidae.

Externally, the species resembles *Inanihella bakanasensis* (Nazarov, 1975; figured in Nazarov and Popov, 1980, pl. 16, fig. 7); however, a second cortical shell is characteristic of *Inanihella*. A few specimens from sample CP-20 have lateral linkages on the spines, but this feature does not develop into a structure approximating a shell, nor is it seen in other samples. The present species is slightly similar to *Oriundogutta miscella* (Nazarov and Popov, 1980, pl. 16, fig. 6), except in that species, the shell is smaller and the secondary spines are described as being few in number. From other species of the genus recovered from the Cape Phillips Formation, ?*Orbiculopylorum* species C is distinguished by its fairly simple lattice shell without a labyrinthine or second layer.

?ORBICULOPYLORUM species D

Plate 29, Figures 7-9

Description.–Cortical shell latticed, bar arrangement fairly irregular; pores subangular to nearly circular when small, framed by four to six lattice bars; small pylome may be present. Loose network of beams link spines, usually arise from spines at one level, arrangement very irregular, development variable. Interior not fully preserved, beams arising near centre continue directly as external spines; proximal part of beams bear branches. External spines numerous, may continue from internal beams or arise at cortical shell; rodlike, may be hollow, length one-third to two-thirds cortical shell diameter.

Dimensions.–(in micrometres, from nine specimens) Overall diameter 219-246; cortical shell diameter 150-186; pore diameter 11-29; lattice bar width 7-17; spine length 52-132.

Material and occurrence.–Over 100 specimens examined. Lower to middle Llandovery (*cyphus* to upper *curtus* zones), Cape Phillips Formation, Nunavut.

Discussion.–As with ?*Orbiculopylorum* species C, the ubiquity of the pylome is not demonstrated in ?*Orbiculopylorum* species D. Unlike the former, no evidence of sieve plates were observed that might explain an apparent absence of a pylome. Also like ?*Orbiculopylorum* species C, the interior of ?*Orbiculopylorum* species D is not completely preserved. Branches on the proximal ends of some radial beams are suggestive of an interior meshwork. Tentatively, the species is assigned to *Orbiculopylorum*.

Family INANIGUTTIDAE Nazarov and Ormiston, 1984

Diagnosis.–As per Noble(1994).

Discussion.–The Inaniguttidae are characterized by multiple concentric spheres; an internal framework in the form of a sphere, polygon, or modifications of these; and six or more rays from the internal framework which connect with the external spines. The species described here possess these characters and are thus regarded here as inaniguttids. The described species share in common a small inner lattice sphere (centre sphere), two subsequent shells, and at least seven rays arising from the centre sphere. The centre sphere and first shell commonly are not preserved. Inaniguttid species A possesses two additional concentric shells; inaniguttid species cf. A, and inaniguttid species B each possess one additional shell. The inner two shells of these three species are essentially identical. Consequently, forms with only two shells could not be positively assigned to these species. Inaniguttid species H and inaniguttid species D both possess only two shells, but differ from the previously mentioned species in spine length and shell form.

The centre sphere is presumably equivalent to the inaniguttid internal framework. In their diagnosis, Nazarov and Ormiston (1984) noted that the diameter of the internal framework of inaiguttids was 45 to 60 μm. The centre sphere of the Cape Phillips radiolarians is somewhat smaller (33 to 50 μm) but does overlap with Nazarov and Ormiston's (1984) diagnosis.

An immediate question is to which genus the Cape Phillips species should be assigned. They do not appear to correspond to the previously described genera. As noted above, the Cape Phillips inaniguttids have two concentric shells as the fundamental form of the skeleton. Additional shells, when present, are not as robust as the inner two, and often are not present. The number of shells, one versus two, has been taken as a genus-level character in inaniguttid taxonomy (Nazarov and Ormiston, 1984, 1993; Nazarov, 1988; Furutani, 1990; Noble, 1994). No described genera are diagnosed on more than two shells, although the family diagnosis does allow for more than two shells. *Inanihella* Nazarov and Ormiston, 1984, possesses two shells and more than six spines connected to internal rays. The two shells are situated close to one another, unlike the Cape Phillips specimens. The exception is *I. penrosei* (Ruedemann and Wilson, 1936) described by Nazarov (in Nazarov and Popov, 1980) and Wang (1993). The spacing between the two shells of this species seems intermediate to other species of the genus described by Nazarov (Nazarov, 1975; Nazarov and Popov, 1980; Nazarov and Ormiston, 1993) and the Cape Phillips specimens. The shell size of the Cape Phillips inaniguttids is smaller than *I. penrosei.*

Inanibigutta Nazarov, 1993, is diagnosed, in part, by the presence of two shells. The size of the shells in species of this genus are in good accord with those of the Cape Phillips radiolarians. However, *Inanibigutta* is also diagnosed on the presence of six spines, while the Cape Phillips specimens have more than six.

Fusalfanus Furutani, 1990, was originally diagnosed as possessing a spongy cortical shell with pylome, a doubled medullary shell, and the variable presence of a second, delicate cortical shell. The diagnosis was emended slightly by Noble (1994). Both Noble (1994) and Amon et al. (1995) suggested that *Fusalfanus* is synonymous with *Inanihella*.

Furutani (1990) described three genera of inaniguttids with double-walled medullary shells -- *Fusalfanus*, *Futobari*, and *Zadrappolus*. As noted by Noble (1994), the details of this feature are not clear. The diameter of the outer medullary shell is generally in agreement with the diameter of the inaniguttid internal framework as discussed by Nazarov and Ormiston (1984). Noble (1994) described species of *Zadrappolis* from the Silurian of Texas. A double wall was not observed, and the medullary shell of the Texas material is apparently the same as Nazarov and Ormiston's (1984) internal framework. It is possible that the inner wall of Furutani's (1990) double walled medullary shell is equivalent to the centre sphere of the Cape Phillips specimens described here. This would indicate that Nazarov and Ormiston's (1984) size range for the inaniguttid internal framework is an unnecessary restriction. Indeed, Nazarov and Popov (1980) describe the inner shell of *Inanibigutta excurrens* as 45 to 50 μm. consequently, the internal inaniguttid framework of this species must be much smaller than called for in the familial diagnosis.

Although the Cape Phillips specimens can be conveniently assigned to the Inaniguttidae, relationship to other taxa ought to be considered. Inaniguttid species B may possess a pylome whereas inaniguttid species C and inaniguttid species E usually have a pylome. *Kalimnasphaera*, *Cessipylorum*, and *Aciferpylorum* bear pylomes. However, in these genera, the pylome is a persistent and diagnostic feature. In the species described below, a pylome may be common, but does not appear to have the diagnostic implication of the three genera just named. Nazarov and Ormiston (1984) included the variable presence of a pylome in their diagnosis of the Inaniguttidae, and Nazarov (1988) allowed for the presence of a pylome in *Inanihella*. Amon et al. (1995) confirmed the pylome in *Inanihella tarangulica* Nazarov and Ormiston, 1984.

Internally, the inaniguttids from the Cape Phillips Formation may be compared to the interior of *Kalimnasphaera*. This genus possesses two medullary shells. In the type species, *K. maculosa*, the outer medullary sphere is 40 μm in diameter and the inner is 13 μm in diameter. In size, the outer of the two medullary shells corresponds with the centre sphere of the Cape Phillips radiolarians and is nearly in agreement with the outer shell of Furutani's (1990) double walled medullary sphere. Indeed, it is possible that Furutani's double-walled shell and the two shells of *Kalimnasphaera* are identical structures. As noted above, size differences in the internal spheres may be only normal variations within a common taxonomic group.

The Cape Phillips inaniguttids are also similar to *Kalimnasphaera* externally. The cortical shell of *Kalimnasphaera* takes the equivalent position of the second shell of the current material. Also the construction of these shells appears to be similar. Also like the Cape Phillips radiolarians, *Kalimnasphaera* can possess additional shell layers. In the type species, *K. maculosa*, an additional fenestrated layer occurs. The number of spines in *K. maculosa* differs, however, from the present material. Webby and Blom describe three to six, commonly four, main spines as opposed to seven or more in the Cape Phillips inaniguttids. Renz (1990) also described four to six spines for

Kalimnasphaera sp. aff. *K. maculosa* from the Ordovician of Nevada. Otherwise, it is tempting to assign the species described herein to *Kalimnasphaera*.

Won et al. (2002, p. 959) noted in Canadian Arctic samples the presence of radiolarians with concentrically arranged shells that they interpreted as belonging to the Haplotaeniatumidae. Won et al. (2002) noted the presence of a remnant spiral structure in the innermost shell. Inaniguttid species A, inaniguttid cf. species A, and inaniguttid species B may bear curved or irregular linkages between the centre sphere and first shell in addition to the regular radial beams. These irregular linkages are rare and not well observed. Their rarity could be preservational. Interpreting these structures as homologous to the spiraliform structures of the Haplotaeniatumidae is not unreasonable and warrants further investigation.

As noted by De Wever et al. (2001), the exact nature of the inaniguttid internal structure is not fully known owing to the preservation of the originally described material. From the foregoing comments, it seems possible that the Inaniguttidae, *Kalimnasphaera*, *Cessipylorum*, *Aciferpylorum* and Won et al.'s (2002) Haplotaeniatumidae comprise a common taxonomic group. The only real question is the taxonomic importance the pylome (ubiquitous versus variably present). If they are a common group, then the Haplotaeniatumidae are a junior synonym of the Inaniguttidae. If the haplotaeniatumids and inaniguttids are distinct families, then the species described here are somewhat problematic in having characteristics common to both families.

While it is tempting to describe a new genus for the Cape Phillips specimens, because of the uncertainties outlined above, and in particular the similarity to

Kalimnasphaera, the author opts to leave the specimens unassigned to avoid confusing the taxonomy.

One further family that should be mention here is the Palaeoactinosphaeridae Noble, 1994. This family possess only two concentric shells and have six to nine spines. Noble (1994) noted they are generally smaller than the Inaniguttidae and that the spines also differ from inaniguttids in being more variable in form, particularly in better developed grooving or blading. In these characters, the palaeoactinosphaerids are distinct from the Cape Phillips specimens. According to Noble (1994), *Palaeosphaera* differs from inaniguttids in having a lattice shell as opposed to a more complex, somewhat three-dimensional shell of inaniguttids. My observations of the Cape Phillips inaniguttids shows a gradation within species between ordinary lattice-type construction and an intertwined construction. Descriptions of inaniguttids in Nazarov and Popov (1980) similarly do not indicate a persistent intertwining of the shell construction amongst all species.

INANIGUTTID species A

Plate 30, Figures 1-3

Plate 37, Figures 4-7

Plate 38, Figure 1

Description.–Centre structure plus four concentric shells. Centre structure small subspherical to spherical lattice sphere, loosely constructed, bars of shell may arch, curved beams may link centre structure to first shell. First shell spherical or slightly subspherical; lattice, pores subcircular to circular. Second shell spherical, lattice, bars may interweave three-dimensionally; pores framed by four to six lattice bars, rounded, occasionally subangular or surrounded, polygonal to circular, occasionally oval. Third shell latticed, spherical, lattice bars may interweave three-dimensionally; pores framed by four to six lattice bars, more commonly four or five, rarely three, subrounded to rounded, oval or circular, often rectangular or squarelike to polygonal. Fourth shell spherical, latticed, bars usually delicate, may be incomplete or present as lateral bars and apophyses on radial beams; pores framed by four to six lattice bars, subangular to rounded, often rectangular to oval. At least seven rays leave centre structure, more rays possible, continue between first and second shell, other radial elements between shells one and two rare, rays may bear apophyses near mid-point between shells one and two, apophyses may link. At shell two, rays join wider bases of spines; spine bases branched, branches merge into lattice of shell two; no significant changes in spine thickness at shells three and four. Numerous radial beams connect shells two and three, generally branch distally to form shell three, may continue as external spines; numerous radial beams connect shells three and four, generally branch distally to form shell four, may continue as external by-spines. By-spines numerous fine rods, may bear lateral bars or arches to shell four. Main spines rodlike, gently tapered, length may exceed diameter of shell two.

Dimensions.–(in micrometres, from 7 specimens) Diameter shell one 90-103; diameter shell two 263-283; shell two pore diameter 5-25; shell two lattice bar width 3-7;

diameter shell three 414-475; shell three pore diameter 5-28; shell three lattice bar width 3-9; diameter shell four 506-646; shell four pore diameter 8-25 (three specimens); shell four lattice bar width up to 3 (three specimens); spine length from shell two 288-434; spine base width at shell two 23-58 (two specimens); external length of spines 163-230 (three specimens); spine width at shell four 15-25 (three specimens); by-spine length 5-75.

Material and occurrence.–Fourteen specimens recovered. Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–The centre sphere in specimens assigned to this species is generally not preserved or is obscured. Consequently, it is not well understood. The first shell also is often difficult to observe or is absent. Shell three usually has circular openings; however, in sample C-20 the lattice can have a square trellis appearance. In all shells, a three dimensional weaving of the lattice bars is not pronounced when present.

Tentatively this species includes three shell forms which often have evidence of developing fourth shell. In contrast, inaniguttid cf. species A has a weakly developed third shell, shorter spines, no evidence of a fourth shell. This difference in the third shell could be ontogenetic.

In an unpublished account of radiolarians from the uppermost Llandovery and Wenlock of the Cape Phillips Formation, Goodbody (1981) described *Caryomma* new species A from the middle to upper Wenlock and *Cromyechinus* new species A from the upper Llandovery to upper Wenlock. Both may be compared favourably to inaniguttid species A, although a detailed comparison from Goodbody's (1981) descriptions and figures is difficult. *Caryomma* new species A shares the same number of shell and basic construction as inaniguttid species A, although Goodbody (1981) did not note the interweaving of lattice bars seen in some of the specimens described here. The first shell of *Caryomma* new species A is larger than observed in inaniguttid species A (120μm), but the other shells are of similar size. The main spines are longer (up to 900 μm from shell two) and are about ten in number. *Cromyechinus* new species A differs from both inaniguttid species A and *Caryomma* new species A in having on less shell. The diameter of the first shell is in accord with inaniguttid species A, but both major and minor spines are longer (for major spines, up to 700 μm from shell two). Assuming ontogeny is the reason for the absence of the outer shell in *Cromyechinus* new species (as may be the case for inaniguttid species A described herein), either or both of Goodbody's species may be conspecific with the species described here. This would give the species a longer stratigraphic range than understood here.

INANIGUTTID cf. species A

Plate 37, Figures 8-10

Plate 38, Figures 2-7

Description.–Centre structure plus three concentric shells. Centre structure loosely constructed sphere, may have irregular linkage to first sphere. First shell spherical, lattice, pores framed by five or six lattice bars, rounded, subcircular or oval. Second shell spherical, lattice, lattice bars archlike, may interweave; pores framed by five or six lattice bars, less often four, rounded, subcircular or circular, some oval, lattice pattern slightly trellis-like. Third shell spherical, latticed, delicate, lattice bars interweave; pores framed by four to five lattice bars, less often six, subrounded to rounded, rectangular, polygonal, or subcirular to oval; lattice bars form trellis-like pattern. Number of rays leaving centre structure not clear, seven to nine (?), continue to shell two, other radial elements between shells one and two rare; rays bear apophyses near midpoint between shells one and two. At shell two, rays join broad bases of spines, bases of spines branch, branches merge with lattice of shell two. Numerous radial beams between shells two and three, few continue past shell three as by-spines, most branch distally to form shell three, branching can occur at short distance before shell three, radial beams rarely linked by lateral bars. By-spines sparse to numerous, short cones or thorn to fine rods. Main spines rodlike, tapered; may not developed externally, taper rapidly and nearly equal by-spines, or blunt ended.

Dimensions.–(in micrometres, from four specimens) Diameter centre structure 38-50; diameter first shell 95-100; pore diameter shell one 5-9 (one specimen); lattice bar width shell one 3-5 (one specimen); diameter shell two 253-273; pore diameter shell two 5-28; lattice bar width shell two 2-5; diameter shell three 394-434; pore diameter shell three 6-28; lattice bar width shell three up to 5; by-spine length up to 55; spine length from shell two 150-183 (two specimens).

Material examined.–Nine specimens examined. Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cronwallis Island, Nunavut.

Discussion.– Main spines in this species can be diminutive. This appears to be a genuine feature of the skeleton. The third shell is delicate and often incomplete. In contrast, inaniguttid species A has a well-formed third and a fourth shell. Additionally the spines are more robust in inaniguttid species A. These differences are likely ontogenetic; however, no clear gradation between the forms was noted. Consequently, they are described separately for clarity.

INANIGUTTID species B

Plate 30, Figures 4-7

Plate 38, Figures 8, 9

Plate 39, Figures 1-7

Plate 40, Figures 1-8

Description.–*Forma 1.* Centre structure plus three concentric shells. Centre structure small spherical lattice sphere, loosely constructed, rare curved beams may link centre structure to first shell. First shell spherical or slightly subspherical; lattice bars may overlap; pores framed by five or six lattice bars, subcircular to circular, rarely oval. Second shell spherical, lattice, bars may interweave three-dimensionally; pores framed by four to six lattice bars, rounded or subrounded, subcircular to circular, occasionally oval or polygonal. Third shell spherical, lattice, bars fine; pores framed by four or five lattice bars, often angular to subangular, rectangular or polygonal, may be rounded, subcircular to circular. Third shell lattice may bear small thornlike byspines or arched bars. Pylome may pierce second and third shells. Seven to 10 rays leave centre structure, continue between first and second shells, rarely other radial elements between first and second shells; may bear apophyses near mid-point between first and second shells. At second shell, rays join bases of main spines; spine bases broad and branched, branches merge into lattice of shell two; no significant changes in spine thickness at shell three. Numerous radial beams from second shell, long rods untapered, continue as external by-spines, rarely branch terminally to form third shell; as byspines, rodlike, may bear lateral bars.

Forma 2. Third shell loosely constructed; formed by lateral bars from radial beams off second shell, delicate, irregularly arranged, arise from several levels off radial beams, may be concentrated near one level; additional radial beams or arches may arise from lateral bars

Dimensions.–(in micrometres, from 9 specimens) Diameter centre structure 33 (one specimen); diameter first shell 83-98; pore diameter first shell 5-7 (two specimens); bar width first shell 2-7 (two specimens); diameter second shell 240-303; pore diameter second shell 5-14; bar width second shell 3-5; diameter third shell 384-495; pore or openings diameter third shell 5-26 (six specimens); bar width shell three up to 5; spine length from shell two 128-419; external spine lenght 178-334.

Material and occurrence.–Twenty specimens examined. Upper Llandovery (*griestoniensis* to upper *sakmaricus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–It is not clear if the two forma described here are two separate species or a result of intraspecific morphologic variation. The arching elements on the third shell of forma 1 plus additional lateral bars on by-spines can give forma 1 a markedly three dimensional external appearance. Consequently, distinguishing forma 1 from forma 2 can be difficult.

Unlike inaniguttid species A, the present species has no evidence of a fourth shell.

Commonly, the radial elements arising from shell two in inaniguttid species B continue through shell three and emerge as external by-spines. In inaniguttid species A and especially inaniguttid cf species A, the radial beams from shell two branch terminally to form shell three. Inaniguttid species B may bear a pylome. This was not observed in inaniguttid species A and inaniguttid cf. species A.

Some stratigraphic variability was noted in inaniguttid species B. In sample B-89.9, the speciemens tended to be smaller than in other samples. Specimens from C-42.3-42.4 also were smaller and had more pronounced pylomes.

Cromyechinus new species A described by Goodbody (1981) in an unpublished work was mentioned in the discussion for inaniguttid species A. *Cromyechinus* new species A is also comparable to inaniguttid species B. The number of shells is the same. The second shell is larger than the present species (380 μm). Goodbody does not give the diameter of the third shell. Goodbody (1981) did not describe the variability in the outermost layer that was observed in inaniguttid species B; it is described only as a lattice shell. The radial beams from the third shell continue beyond the fourth shell in similar to inaniguttid species B. Just as *Cromyechinus* new species A could conspecific with inaniguttid species A, it could equally be argued it is the same as inaniguttid species

B. This would extend the stratigraphic range of inaniguttid species B to the upper Wenlock.

INANIGUTTID species C

Plate 30, Figures 8, 9

Plate 41, Figure 1-8

Description.–Centre structure plus two lattice shells. Centre structure not clearly observed, spherical. First shell spherical or slightly subspherical, latticed, bars may interweave; pores framed by five or six lattice bars, subcircular. Second shell spherical, latticed, bars may interweave; pores framed by five or six bars, subcircular or circular, rarely oval. Numerous beams off second shell, needle or rodlike, may be conical; when better developed, branch terminally or bear distal apophyses; branches and apophyses coalesce to form irregular lattice. By-spines rod or thornlike, some are continuations of radial beams off second shell, others arise off irregular outer lattice. In rare specimens an additional irregular lattice may arise from by-spines. Pylome penetrates second shell and irregular outer layers. Seven (?) rays arise from centre structure; may bear apophyses between first and second shell; at second shell join bases of main spines; no other radial elements between first and second shells. Main spines diminutive, may be subequal radial beams off second shell or absent (?); when better developed, fine rods, slightly tapered; bases slightly flaired and buttressed.

Dimensions.–(in micrometres, from seven specimens) Diameter centre structure 33-40 (two specimens); diameter first shell 80-90; pore diameter first shell 3-8 (two specimens); bar width first shell 3-4 (two specimens); diameter second shell 208-252; pore diameter second shell 5-10; bar width second shell 3-5; diameter of irregular outer lattice 263-306; maximum spine length from second shell 153; spine base width 15.

Material and occurrence.–Over thirty specimens examined. Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Occurrence.–B89.9 ?C20, C42.2-42.3 (where get longer spns), C50.7, C56

Discussion.–Inaniguttid species C is noted for its weakly developed spines. The spine bases lack the more pronounced widening and branching seen in the other species describe here. The pylome is also more ubiquitous.

The centre structure and first shell generally are not preserved or are obscured. Consequently, they are only poorly understood.

INANIGUTTID species D

Plate 31, Figures 1, 2

Plate 42, Figures 1-4

Description.–Centre structure plus two shells. Centre structure poorly known, spherical. First shell subspherical, latticed, bars may interweave; pores framed by five lattice bars, subcircular. Second shell spherical, lattice, bars may interweave; pores framed by four to six lattice bars, rounded, square or rectangular to subcircular; second shell usually with pylome, may be capped my arched lattice bars. Seven (?) to 11 rays from centre structure, bear apophyses between first and second shell; no other radial structures between first and second shells. At second shell, rays join bases of main spines; main spines rodlike, tapered, bases branched or butressed; branches and buttresses merge into lattice. By-spines sparse, short rods.

Dimensions.–(in micrometres, from four specimens) Diameter first shell 101 (one specimen); pore diameter first shell 6-10; lattice bar width first shell 2-5 (one specimen); diameter second shell 263-311; pore diameter second shell 4-15; bar width second shell 3-8; main spine length 102-209; main spine base width 31-37; by-spine length 14-40.

Material and occurrence.–Ten specimens examined. Upper Llandovery (*griestoniensis* Zone), Cape Phillips Formation, Cornwallis Island, Nunavut.

Discussion.–The centre structure and first shell were visible only in one specimen. In contrast to the other inaniguttids described here, the shell of inaniguttid species D is slightly more delicate with slightly less regularly arranged pores. A sieve plate formed by arched lattice bars was observed over the pylome in some specimens. This feature was not observed in the other Cape Phillips inaniguttids, but was noted in ?*Orbiculopylorum* species C. The by-spines of the present species are not a numerous as the other species describe here.

Inaniguttid species D is nearly identical in appearance to *Cessipylorum apertum* figured in Nazarov and Popov (1980, pl. 4, figs. 3, 4; pl. 5, figs. 6-7; pl. 14, figs. 5-6). *Cessipylorum apertum* possesses only seven main spines whereas the present species possesses up to 11 main spines. However, Nazarov (in Navarov and Popov, 1980) described *C. apertum* as having five to eight internal rays connecting to the bases of the main spines. This might suggest additional spines in *C. apertum*. Nazarov also described a definite arrangement to the main spines of *C. apertum* -- two symmetrically about the pylome and five at under 90 degrees to one another. No such spine arrangement was seen in inaniguttid species D. Also unlike the present material, the genus *Cessipylorum* possesses only a single, small inner sphere.

Family uncertain

Genus LABYRINTHOSPHAERA Noble and Maletz, 2000

Type species.–*Labyrinthosphaera macdonaldi* Noble and Maletz, 2000, from the upper Llandovery (*turriculatus* Zone) of the Kallholn Shale, Dalarna, Sweden.

Emended diagnosis.–Spherical or subspherical shell, formed by layered labyrinthine mesh; spines tribladed.

Discussion.–The original diagnosis allowed for six to 12 primary spines. The number of spines is not diagnostic unto itself and is removed in the emended diagnosis. Indeed, *Labyrinthosphaera* species B may have as few as three spines. Also, the reference to secondary spines is removed; because secondary spines may be present or absent, they are not a diagnostic feature. In their description of the genus, Noble and Maletz (2000) suggested that the layering in *Labyrinthosphaera* may be spiral rather than concentric; however, spiral layering was not observed in the present study.

Noble and Maletz (2000) described one species of *Labyrinthosphaera*, *L.*

macdonaldi. Two additional species are described here, but are left in open nomenclature. The three species co-occur stratigraphically, and to some extent overlap morphologically. However, the ontogeny of the three forms seem to differ, suggesting the possibility that the morphologic overlap represents similarities at certain stages of development. This is elaborated in the discussions for *Labyrinthosphaera* species A and *Labyrinthosphaera* species B. Alternatively, the three species may be conspecific and the differences are the result of some external influence. Only in the uppermost Llandovery does the abundance of *Labyrinthosphaera* species A match or exceed that of *L. macdonaldi*.

LABYRINTHOSPHAERA MACDONALDI Noble and Maletz, 2000

Plate 42, Figures 5, 6

Plate 43, Figures 1-3

Arachnosphaera new species A Goodbody, 1981, p. 37, pl. 1, figs. 7, 8, pl. 2, figs. 1-8.

Labyrinthosphaera macdonaldi NOBLE AND MALETZ, 2000, p. 268, pl. 2, figs. 6-11.

Emended diagnosis.–Spherical to subspherical shell, formed of labyrinthine layers; five or more tribladed spines, long, tapered.

Description.–Shell subspherical to spherical; small central sphere overlain by two to five layers. Layers concentric, formed from short beams arising from previous level; beams may curve or branch, may flair at either end; bars linking beams may arch or be oriented at angles to shell surface; construction gives a labyrinthine appearance; inner two layers more labyrinthine in construction, may be indistinct. Occasionally beams crossing one or more layers may originate at second or third layer. Fourth or fifth layer may consist of an angular meshwork. Five to eight spines, most commonly seven; originate as rods from central sphere, become bladed at second layer and broaden gradually to outer layer; external continuation tribladed, taper gently to fine point, length may exceed one shell diameter. Secondary spines may be absent, more common when more than two layers; when present numerous, thorn to rodlike, arise from outer layer or continuation of translayer beams; may be bladed in specimens with maximum number of layers.

Dimensions.–(in micrometres, from 23 specimens) Diameter 80-240; spine length 75-283; spine base width 10-30; secondary spine length 12-107.

Material and occurrence.–Over 400 specimens examined. Upper Llandovery (*guerichi* Zone) to middle Wenlock, Cape Phillips Formation, Nunavut (new data and Goodbody, 1981). Early Silurian (*turriculatus* Zone), Dalarna, Sweden (Noble and Maletz, 2000).

Discussion.–The emended diagnosis allows for the fewer number of spines seen in some individuals, and removes limitations on the number of concentric layers in the shell. Because secondary spines are not diagnostic, they are not included in the emended diagnosis. Noble and Maletz (2000) noted the presence of flat-bladed secondary spines. These where not seen in this study; however, thorn or rodlike secondary spines were observed. Comparisons to *Labyrinthosphaera* species A and *Labyrinthosphaera* species

B are given with those species.

Labyrinthosphaera macdonaldi is apparently identical to *Arachnosphaera* new species A described by Goodbody (1981) in his unpublished account of uppermost Llanoverian to Wenlockian radiolarians from the Cape Phillips Formation. Goodbody's description differs only in the number main spines -- eight to 10 rather than five to eight in the present study. Goodbody (1981) noted the species in the upper Llandovery to middle Wenlock of the Formation.

LABYRINTHOSPHAERA species A

Plate 42, Figure 7

Plate 43, Figures 4, 5

Cubosphaera new species A Goodbody, 1981, p. 59, pl. 9, figs. 1-8.

Description.–Shell spherical, small central sphere surrounded by labyrinthine meshwork, meshwork consists of looping and interlocked bars, usually shows two indistinct layers. Six spines, bladed, faintly tapered, length two to three times shell diameter, flaired outwards slightly at base, orthogonally arranged; originate as rods from central sphere, join base of external spines at outer surface of shell. May be sparse rodlike or bladed secondary spines, may bear apophyses, apophyses may link to form incomplete layers.

Dimensions.–(in micrometres, from four specimens) Diameter 105-143; spine length up to 525; spine base width 27-32; secondary spine length 17-42.

Material and occurrence.–Over 100 specimens examined. Upper Llandovery (*griestoniensis* Zone) to upper Wenlock, Cape Phillips Formation, Nunavut (new data and Goodbody, 1981).

Discussion.–*Labyrinthosphaera* species A is distinguished by its consistently small sphere with six long spines that are orthogonally disposed. In contrast, *L. macdonaldi* has a greater size range for the shell with more labyrinthine layers that are generally more distinct. Spine length is not as great in *L. macdonaldi*; however, the length in the two species does overlap.

Labyrinthosphaera species A could be included with *L. macdonaldi* as diagnosed herein. However, when ontogeny is considered, the spine development is inconsistent. In *L. macdonaldi*, the primary spines originate at the centre sphere as rods. These become bladed at the second layer, then broaden to the outer surface. The external length of the spines tapers to a point. In *Labyrinthosphaera* species A, the spines similarly originate as rods at the centre sphere. They become bladed at the outer surface, which in terms of layering is essentially equivalent to the second layer in *L. macdonaldi*. One could argue that *Labyrinthosphaera* species A develops into *L. macdonaldi* by the subsequent addition of additional labyrinthine layers. However, in *Labyrinthosphaera* species A the rods from the centre sphere connected to the well-broadened bases of fully developed spines, not to spines that show evidence of a gradual, outwardly broadening development. *Labyrithosphaera* species A is most abundant in sample CP-147.5. Only in this sample are the secondary spines bladed. This species is identical to *Cubosphaera* new species A described by Goodbody (1981) who noted its presence in the upper

Llandovery to upper Wenlock of the Cape Phillips Formation. Goodbody (1981) described the minor spines as being more numerous than in the present study and did not note their shape. Goodbody (1981) also suggested a close relationship with his *Arachnosphaera* new species A (*L. macdonaldi*), but assigned the species to separate genera owing to the inadequacies of Haeckelian systematics. The specimen figured in Noble and Maletz's (2000) plate 2, figures 10, 11 possibly belongs with *Labyrinthosphaera* species A.

LABYRINTHOSPHAERA species B

Plate 42, Figure 8

Plate 43, Figure 6

Description.–Shell subspherical to spherical; sphere in centre; labyrinthine over centre sphere, interlocking and intermeshed curved bars, dense, commonly structureless, may show two to four vague to distinct layers, usually with irregular outline. Three to eight main spines, originate as rods from centre sphere, become tribladed at shell surface, occasionally one or two layers into shell, tapered, length one half to two-thirds shell diameter. Secondary spines sparse to numerous, shorter than main spines, most commonly rodlike, may be nearly conical or weakly bladed when better developed.

Dimensions.–(in micrometres, from six specimens) Diameter 125-170; spine length 70-82; spine base width 15-33; secondary spine length 32-50.

Material and occurrence.–Fifty-two specimens examined. Upper Llandovery to

Wenlock (*guerichi* to *instrenuus-kolobus* zones), Cape Phillips Formation, Cornwallis Island, Nunavut.

Remarks.–Unlike *Labyrinthosphaera macdonaldi* and *Labyrinthosphaera* species A, *Labyrinthosphaera* species B possesses shorter, stubbier main spines. Secondary spines are always present, unlike *L. macdonaldi* and *Labyrinthosphaera* species A. Also in contrast to the other two species, the labyrinthine meshwork of the sphere is often without definitive layering.

Some specimens assigned to the present species possibly belong to *Labyrinthosphaera macdonaldi.* Occasional specimens show the within-shell broadening of the main spines as seen in *L. macdonaldi.* As with *Labyrinthosphaera* species A, the present species could be interpreted as an early developmental stage of *L. macdonaldi.* At odds with this interpretation are the secondary spines which are a persistent feature in *Labyrinthosphaera* species B but a variable feature in *L. macdonaldi.* If *Labyrinthosphaera* species B is an early form of *L. macdonaldi,* secondary spines should be persistent in the latter.

CHAPTER 9 - CONCLUSIONS

1. Well-preserved and well-dated Radiolaria were collected from a near continuous sequence of Llandovery strata from the Cape Phillips Formation, Nunavut. Only the earlier work of Nazarov (1975, 1988) provided a comparable level of stratigraphic completeness in this interval. The present study thus provides a baseline of data on Llandovery radiolarian taxonomy and stratigraphic distribution for future comparative studies.

2. Fifty-one species are described herein. These fall into 12 genera and five families. The Inaniguttidae are not assigned to genera. Twenty species are new and five are conditionally assigned at the species level. The systematic treatment of the Lower Silurian Cape Phillips radiolarians is still incomplete. In particular, the entactinids (sensu lato) are not described. The species of *Secuicollacta* are being re-evaluated.

3. The presence of an ectopic spicule is confirmed in *Secuicollacta* contrary to the observations of Won et al. (2002). *Parvalanapila* is synonymized with *Diparvapila*. The suprageneric classification of Noble and Maletz (2000) is acknowledged herein as the most appropriate for describing the relationships between *Secuicollacta*, *Diparvapila*, and the nonspicular genus *Rotasphaera*.

4. The relationship between *Haplotaeniatum* and *Orbiculopylorum* suggested by Won et al. (2002, family Haplotaeniatumidae) is confirmed herein. *Gyrosphaera* is synonymized with *Haplotaeniatum*. Large radiolarians with concentric spherical shells are treated here as Inaniguttidae, rather than Haplotaeniatumidae as suggest by Won et al. (2002). The internal features of the two groups as observed in the Cape Phillips material supports a close affiliation. However, the internal features of the Inaniguttidae as originally presented by Nazarov require clarification. If the same as those of the Cape Phillips Formation, then Haplotaeniatumidae is potentially a junior synonym of the Inaniguttidae.

5. The inaniguttids from the Cape Phillips Formation do not conveniently fall within existing genera. While two shells appear fundamental (and broadly consistent with *Inanihella*), morphological variability is chiefly in shells external to these.

6. Goodbody's (1986) classification of the Palaeoscenidiidae is inadequate and is revised herein. The new classification is based on morphological similarity of individuals rather than geometric arrangement of the skeleton. Goodbody's (1986) classification resulted in single species being assigned to several genera.

7. The radiolarian fauna in the studied sections of the Cape Phillips Formation changed at three stratigraphic levels.

i) At the Rhuddanian-Aeronian boundary there is a shift in abundance from a predominace of *Haplotaeniatum* to *Secuicollacta*. *Orbiculopylorum* also appears at this level.

ii) No radiolarians were recovered from the upper *turriculatus* to *crispus* zone interval. However, within this interval *Orbiculopylorum* disappears, as do some species of *Haplotaeniatum*, and the Inaniguttidae first appear in the formation.

iii) No radiolarians were recovered across the Llandovery-Wenlock boundary. Within this interval there is a rearrangement of species abundances. *Insolitignum dissimile* which was the principal palaeoscenidiid species in the Llandovery became less important in the Wenlock while other palaeoscenidiid species increased in abundance. *Ceratoikiscum* and *Helenifore* appear in the Wenlock, as do two species of *Secuicollacta* and one new palaeoscenidiid species. Disappearances of taxa across the Llandovery-Wenlock boundary are equivocal given the data of Goodbody (1981).

8. The changes in the radiolarian fauna allow the definition of four radiolarian biozones. Because of nonrecovery of radiolarians, most boundaries between intervals are not firmly established.

i) The *Haplotaeniatum* Zone extends from basal Llandovery to topmost *cyphus* graptolite Zone.

ii) The *Orbiculopylorum* Zone extends from the topmost *cyphus* graptolite Zone to presumably the *crispus* graptolite Zone.

iii) The Inaniguttid Zone presumably includes strata between the *crispus* graptolite Zone and the Llandovery-Wenlock boundary.

iv) The *Ceratoikiscum* Zone lies above the Inaniguttid Zone. Its top is not established.

The four zones described herein are largely modifications of the preliminary zonation of Noble and Aitchison (2000). The *Haplotaeniatum* and *Orbiculopylorum* zones are subdivisions of Noble and Aitchison's (2000) Pylomate-large concentric sphaerellarian Zone 2. The Inaniguttid Zone is essentially the same as their Long-spined inaniguttid Zone 2. The lower boundary of the Inaniguttid Zone is better constrained than Noble and Aitchison's (2000) zone, in spite of the absence of radiolarians between the Inaniguttid Zone and the underlying *Orbiculopylorum* Zone.

9. An association of the above changes in the radiolarian fauna with sea-level fall or with graptoloid or conodont bioevents is absent with the Rhuddanian-Aeronian change and problematic with the upper *turriculatus-crispus* zone change. There is, however, a shift in graptoloid dominance associated with the Rhuddanian-Aeronian boundary. There is no radiolarian response associated with the *Parakidograptus acuminatus* graptoloid Event nor with the *Stimulograptus sedgwickii* graptoloid Event (Sandvika Event).

10. The radiolarian faunal change across the Llandovery-Wenlock boundary apparently coincides with one or two graptoloid events (*Cyrtograptus lapworthi* and *Cyrtograptus murchisoni*). The Ireviken Event involving the stepwise extinction and replacement of conodonts also occurred in this interval. Because of the nonrecovery of Radiolaria, the

timing of the radiolarian fauna change in relation to the graptoloid and conodont changes cannot be established. The changes in the radiolarian fauna are principally abundance shifts. Abundance changes are known to occur in the conodonts through the Ireviken Event.

Future Work

1. The systematics is still incomplete (entactinids) and, for some groups, in need of verification (*Secuicollacta*, inaniguttids).

2. Additional sampling is needed in the Cape Phillips Formation. The faunal changes and the informal biostratigraphic scheme presented herein need to be verified from other localities. Also, radiolarian data are needed from the barren intervals of this study.

3. Changes in skeletal morphology ought to be studied statistically. For example, size variations may have either palaeoenvironmental or taxonomic significance in some taxa. The variations in number and orientation of palaeoscenidiid rays may be linked to palaeoenvironmental conditions.

4. Results of this study need to be further integrated into the other ongoing Cape Phillips Formation studies (graptolites, conodonts, chitinozoa, geochemistry).

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APPENDIX A - SAMPLE PHYSICAL DATA

TABLE A-1--Physical data for Cape Manning 2 samples.

Level	mass digested (g)	Fraction	physical state	beaker radius (mm)	cover slip area (mm2)	initial water height (mm)	final water height (mm)	stand height (mm)	transects counted	possible transects
2.0A	114.06	all	picked							
4.25A	81.66	sand	picked							
		silt	strewn	52.5	2200	98	116	84	25	25
31.9	89.92	all	picked							
42.5	71.91	all	picked							
44.5A	121.55	sand	picked							
		silt	strewn	52.5	2200	96.4	113.7	45.1	25	25
46.8A	115.68	sand	picked							
		silt	strewn	52.5	2200	105.2	117	44.9	19.25	25
51.2	80.82	sand	picked							
		silt	strewn	52.5	2200	82	86	34	14.5	25
57	68.99	all	picked							
71.1	110.08	sand	picked							
		silt	strewn	52.5	2200	88	101.5	51	21.25	25
72	91.93	sand	picked							
		silt	strewn	52.5	2200	94	108	78	25	25
75.5(+A)	219.1	all	picked							
75.9(+A)	174.02	all	picked							
82.4(+A)	199.3	all	picked							
84	71.39	all	picked							
85.2	67.44	sand	picked							
		silt	strewn	52.5	2200	72	78	45	25	25
91.7	76.28	sand	picked							
		silt	strewn	52.5	2200	103	124.1	90	14.5	25
96.1	14.22	all	picked							
97.4	86.71	all	picked							
106.5	77.79	sand	picked							
		silt	strewn	52.5	2200	92	105.4	56.4	14.5	25
107(+A)	178.62	all	picked							

TABLE A-2--Physical data for Cape Manning 3 samples.

Level	mass digested (g)	Fraction	physical state	beaker radius (mm)	cover slip area (mm2)	initial water height (mm)	final water height (mm)	stand height (mm)	transects counted	possible transects
38.1	78.9	sand	picked							
		silt	strewn	52.5	2200	81	88.4	29	18.5	25
42.2	93.83	sand	strewn	52.5	2200	99.1	104.1	18	16.5	25
		silt	strewn	52.5	1100	78.5	85.9	24.7	2	12.5
48	51.32	sand	picked							
		silt	strewn	52.5	2200	99	104	18	14.5	25
77.5	106.13	sand	strewn	52.5	1100	68	76.4	34	3	12.5
		silt	strewn	52.5	704	99	117.4	78.2	1	12.5
79	110.45	sand	strewn	52.5	1100	97.5	100.2	17.1	5	12.5
		silt	strewn	52.5	1100	94.3	119.2	56.5	2	12.5
89.9	111.67	sand	see notes	52.5	2200	86.5	92.3	23.1	25	25
		silt	strewn	52.5	2200	86.5	92.3	23.1	25	25

TABLE A-3--Physical data for Cape Phillips samples.

Level	mass digested (g)	Fraction	physical state	beaker radius (mm)	cover slip area (mm2)	initial water height (mm)	final water height (mm)	stand height (mm)	transects counted	possible transects
10.3-10.4	69.19	all	picked							
20	112.26	sand	strewn	52.5	1100	70	77.5	29	10.75	12.5
		silt	strewn	52.5	1100	87.5	100	61.9	4	12.5
40	82.44	sand	strewn	52.5	1100	91	102.3	45.1	12.5	12.5
		silt	strewn	52.5	1100	101.4	117.2	79.1	2	12.5
42.3-42.4	126.59	sand	strewn	52.5	2200	88.1	93.3	23.2	25	25
		silt	strewn	52.5	1100	113.3	127	90.1	6	12.5
50.7	77.82	all	picked							
56	104.75	all	picked							
65	47.31	all	picked							
89	85.61	all	picked							
94.3	120.1	sand	strewn	52.5	2200	101.5	120	90.1	14.5	25
		silt	strewn	52.5	1100	118.5	143	112.1	4	12.5
99.7	122.09	sand	picked							
		silt	strewn	52.5	1100	117.5	140.1	101	6	12.5
122	77.75	all	picked							
130.8	70.26	sand	picked							
		silt	strewn	52.5	2200	114.3	118	17	22.25	25
140.6	313.87	all	picked							
147.5	129.14	sand	picked							
		silt	strewn	52.5	2200	110	123	56.2	14.5	25
160	99.53	sand	strewn	52.5	1100	94.9	101	23.1	12.5	12.5
		silt	strewn	52.5	1100	79.4	88.1	34.3	10.75	12.5
162.5	70.35	sand	strewn	52.5	1100	91.3	104	56.7	8.75	12.5
		silt	strewn	52.5	1100	87.1	100.4	56.9	5	12.5
162.7	165.19	sand	strewn	52.5	1100	80	90.1	45.5	2	12.5
		silt	strewn	52.5	528	74.3	86.9	56.3	1	12.5
196	86.3	sand	strewn	52.5	616	95.2	102.1	23	1	12.5
		silt	strewn	52.5	858	109.1	124.1	68	1	42.5
213	99.48	sand	strewn	52.5	1100	104.9	110.3	23.1	1	12.5
		silt	strewn	52.5	1100	89	105.5	67.5	1	42.5
216	113.24	sand	strewn	52.5	550	78.4	91.9	56.3	1	12.5
		silt	strewn	52.5	814	92.3	112	78.8	1	42.5

APPENDIX B - STREWN SLIDE COUNTS

TABLE B-1.–Strewn slide counts for Cape Manning 2 samples.

sample	fraction	S. ?bipola	S. glaebosa	S. ?glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. ?parvitesta	S. resodiosae	S. ?resodiosae	S. sceptri	S. ?sceptri	Secuicollacta sp. indet.	D. fleischerorum	D. ?fleischerorum	D. hicocki	D. ?hicocki	D. larseni	D. ?larseni	D. ?sp. B	Diparvapila sp. indet	pentactines
4.25A	silt	0	0	0	0	0	28	5	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
44.5A	silt	0	0	0	0	0	111	35	2	0	13	11	0	0	31	0	0	0	1	0	0	0	0	0
46.8A	silt	0	0	1	41	28	82	13	14	2	0	7	9	10	58	4	1	0	1	1	0	0	6	11
51.2	silt	0	0	0	8	7	77	44	1	4	54	33	8	8	91	0	0	1	0	0	0	0	5	2
71.1	silt	0	0	0	4	5	17	31	8	1	275	34	2	6	27	0	0	0	0	0	0	0	0	0
72	silt	0	4	9	2	0	6	5	0	0	212	33	1	1	35	0	0	0	0	2	1	0	2	0
85.2	silt	1	57	21	3	0	7	10	10	3	81	13	14	3	60	1	0	0	0	0	0	0	2	0
91.7	silt	0	79	9	1	3	14	5	5	4	16	5	1	0	29	10	0	1	2	2	0	0	18	6
106.5	silt	0	84	14	7	3	43	16	12	0	32	3	10	5	29	39	1	2	3	11	5	1	30	6

Continues next page.

TABLE B-1--Continued.

sample	fraction	R. severa	R. ?severa	R. sp. A	R. ?sp. A	R. sp. C	R. ?sp. C	R. sp. indet.	I. dissimile	Pep. bifurcum	Pep. radices	Pep. spinosum	Pep. ?spinosum	palaeoscenidiid indet.	Haplotaeniatum sp. indet	Labyrinthosphaera sp. indet.	unassigned	slide count
4.25A	silt	0	0	0	0	0	0	0	0	0	0	0	0		302	0	79	422
44.5A	silt	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	33	287
46.8A	silt	0	1	0	1	0	0	0	0	0	0	0	0	33	0	0	92	416
51.2	silt	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	61	405
71.1	silt	0	0	0	1	0	0	0	0	0	0	0	0	1	2	1	3	418
72	silt	0	0	0	0	0	0	1	0	2	0	0	0	19	0	0	5	340
85.2	silt	0	1	0	0	0	0	1	0	0	0	0	0	7	0	0	21	324
91.7	silt	14	13	2	1	10	1	2	0	0	0	0	0	23	0	7	126	409
106.5	silt	0	1	0	2	5	0	1	1	0	1	3	1	9	0	0	32	412

TABLE B-2--Strewn-slide counts for Cape Manning 3 samples.

sample	fraction	S. bipola	S. ?bipola	S. glaebosa	S. ?glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. resodiosae	S. ?resodiosae	S. sceptri	S. ?sceptri	Secuicollacta sp. indet.	D. fleischerorum	D. ?fleischerorum	D. hicocki	D. ?hicocki	D. larseni	D. ?larseni	D. n.sp A
38.1	silt	48	1	17	4	10	2	29	8	1	15	8	2	3	13	11	1	3	0	10	1	0
42.2	sand	2	0	1	0	97	9	0	0	0	0	0	32	18	95	6	1	25	1	9	0	0
42.2	silt	7	0	16	0	3	6	28	12	0	0	1	4	0	27	12	2	26	1	21	4	0
48	silt	6	0	15	1	4	7	30	1	0	1	3	4	1	23	16	0	21	0	18	0	0
77.5	sand	1	1	0	0	100	14	0	0	0	0	1	20	16	24	4	2	12	0	1	0	16
77.5	silt	13	3	74	16	7	3	0	6	0	16	6	6	2	39	22	0	14	3	20	2	2
79	sand	0	0	0	0	151	22	0	0	0	0	0	33	23	50	11	0	16	1	4	0	21
79	silt	46	10	141	29	22	9	2	7	0	12	3	3	4	46	17	0	9	3	20	3	0
89.9	**sand**	0	0	0	0	56	3	0	0	0	0	0	5	1	2	0	0	3	0	0	0	0
89.9	silt	3	1	29	9	46	9	0	1	0	2	1	19	6	29	17	2	58	1	13	0	0

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TABLE B-2--Continued.

sample	fraction	D. n.sp. B	Diparvapila sp. indet	pentactines	R. severa	R. ?severa	R. sp. A	R. ?sp. A	R. sp. C	R. ?sp. C	R. sp. indet.	G. flammatum	G. ?flammatun	G. rarispinosum	I. cancellatum	I. dissimile	I. ?dissimile	Insolitignum sp. indet.	Pdec. apertum	Pdec. umbelliforme	Pep. bifurcum	Pep. radices	Pep ?radices	Pep. spinosum
38.1	silt	2	3	3	0	0	2	0	5	0	0	0	0	0	73	56	7	1	0	0	2	0	1	0
42.2	sand	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2
42.2	silt	1	13	5	2	1	7	0	8	0	1	0	0	0	4	46	1	0	0	0	0	2	2	3
48	silt	0	12	3	2	1	11	1	11	0	2	0	0	4	15	134	4	3	0	2	1	0	1	0
77.5	sand	0	1	0	0	1	0	0	0	0	0	0	0	1	0	3	0	0	0	21	0	0	1	0
77.5	silt	0	5	2	5	2	8	2	11	0	3	1	0	0	9	67	2	2	1	2	1	0	0	2
79	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
79	silt	0	6	3	2	0	8	0	16	0	2	0	2	0	5	67	0	1	0	0	0	0	0	0
89.9	**sand**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
89.9	silt	0	5	5	0	0	8	0	1	2	0	0	0	0	3	41	2	0	0	0	0	0	0	0

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TABLE B-2--Continued.

sample	fraction	Pep. sp.indet.	Pyr. spinosum	palaeoscenidiid indet.	H. sp. A	H. ?sp. A	H. sp. B	H. sp. C	Haplotaeniatum sp. indet	?O. sp. C	inan. sp. A	inan. sp. B	inan. sp. C	inan. sp. indet.	L. macdonaldi	L. ? macdonaldi	L. sp. A	L.?sp. A	L. sp. B	L. ?sp. B	Labyrinthosphaera sp. indet.	unassigned	slide count
38.1	silt	2	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	1	60	412
42.2	sand	1	0	3	0	0	0	0	0	1	1	0	0	1	54	0	0	0	1	6	2	23	398
42.2	silt	3	0	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2	1	51	329
48	silt	0	0	5	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	56	424
77.5	sand	0	2	5	8	4	0	0	2	0	8	0	0	10	83	0	2	1	3	2	9	18	397
77.5	silt	0	0	4	1	0	0	0	0	0	0	0	0	0	6	0	0	2	0	0	3	38	433
79	sand	0	0	6	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	1	1	8	417
79	silt	0	0	6	0	0	0	0	0	0	0	0	0	0	9	6	0	2	0	0	4	29	554
89.9	**sand**	0	0	0	8	3	0	0	0	0	0	10	2	2	79	0	0	1	3	2	11	7	**199**
89.9	silt	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	0	5	10	13	9	29	390

TABLE B-3--Strewn-slide counts for Cape Phillips samples

sample	fraction	S. bipola	S. ?bipola	S. glaebosa	S. ?glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. resodiosae	S. ?resodiosae	S. cf. S. resodiosae	S. ?cf. S.	S. sceptri	S. ?sceptri	S. n.sp. A	S. ? n. sp. A	Secuicollacta sp.	D. fleischerorum	D. ?fleischerorum	D. hicocki
20	sand	5	0	0	0	69	11	5	0	0	1	1	0	0	33	11	0	0	60	8	1	30
20	silt	19	0	11	3	3	3	62	12	0	4	7	0	0	4	2	0	0	60	12	0	24
40	sand	0	0	0	0	66	58	2	2	0	0	2	0	0	58	10	0	0	45	4	0	7
40	silt	2	1	4	3	2	2	4	12	0	5	1	0	0	8	4	0	0	22	3	3	1
42.3-42.4	sand	0	0	0	0	69	8	0	1	0	0	2	0	0	13	4	0	0	34	0	0	5
42.3-42.4	silt	23	2	24	1	13	4	16	10	0	48	3	0	0	5	1	0	0	23	28	1	33
94.3	sand	0	0	0	2	118	25	0	1	1	5	2	0	0	84	11	0	0	57	1	0	13
94.3	silt	2	1	64	3	16	12	2	0	0	14	5	0	0	6	1	0	0	39	9	4	16
99.7	silt	0	0	148	14	47	40	5	12	0	2	6	0	0	6	5	0	0	114	5	0	3
130.8	silt	0	0	49	8	11	9	6	12	0	27	26	0	0	3	0	0	0	40	4	0	3
147.5	silt	0	0	6	1	2	0	0	4	0	26	2	0	0	0	0	0	0	24	0	0	0
160	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
160	silt	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
162.5	sand	0	0	0	0	3	5	0	0	0	0	0	0	0	0	1	0	0	6	0	0	0
162.5	silt	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
162.7	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0
162.7	silt	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0
196	sand	0	0	1	0	0	0	4	0	0	0	0	3	0	0	0	1	0	0	1	0	0
196	silt	0	0	14	0	0	0	47	0	0	0	0	0	0	0	0	0	0	10	15	0	0
213	sand	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	8	0	0
213	silt	0	0	18	0	0	0	16	11	0	0	0	0	11	0	0	5	4	37	2	0	0
216	sand	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	3	1	4	3	0	0
216	silt	0	0	11	0	0	0	10	5	0	0	0	0	0	0	0	1	0	10	8	0	0

Continues

TABLE B-3--Continued.

sample	fraction	D. ?hicocki	D. larseni	D. ?larseni	D. n.sp A	D. ?n. sp. A	D. n.sp. B	D. ?sp. B	Diparvapila sp. indet	pentactines	R. severa	R. ?severa	R. sp. A	R. ?sp. A	R. sp. B	R. sp. B	R. sp. C	R. ?sp. C	R. sp. indet.	G. flammatum	G. ?flammatun	G. rarispinosum
20	sand	3	9	1	0	0	13	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0
20	silt	2	44	2	0	1	0	0	4	3	1	0	0	0	0	0	2	1	1	0	0	0
40	sand	6	2	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
40	silt	0	2	0	1	0	0	0	6	6	2	0	5	0	0	0	6	0	0	0	2	0
42.3-42.4	sand	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
42.3-42.4	silt	7	26	5	0	0	0	0	13	4	1	1	1	0	0	0	4	2	1	0	0	1
94.3	sand	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94.3	silt	2	25	3	0	0	0	0	10	7	5	0	0	0	0	1	5	0	1	0	0	0
99.7	silt	0	5	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	1	0	0	0
130.8	silt	0	2	0	0	0	0	0	2	0	1	1	5	1	0	0	3	0	0	1	0	0
147.5	silt	0	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0	0	1	3	1	0
160	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	silt	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
162.5	sand	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
162.5	silt	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
162.7	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162.7	silt	0	0	0	0	0	0	0	1	1	5	0	0	0	0	0	0	0	0	0	0	1
196	sand	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	8	0	2
196	silt	0	0	0	0	0	0	1	0	0	4	2	5	0	0	0	0	0	1	31	1	0
213	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
213	silt	0	0	0	0	0	0	0	0	0	5	1	1	0	0	0	0	0	0	24	1	0
216	sand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	2
216	silt	0	0	0	0	0	0	0	0	1	2	2	0	0	0	0	0	0	0	42	0	1

Continues

TABLE B-3--Continued.

sample	fraction	I. cancellatum	I. dissimile	I. ?dissimile	I. vivanima	I. ?vivanima	Insolitignum sp.	Pdec. apertum	Pdec. ?apertum	Pdec. gordoni	Pdec. ?gordoni	Pdec. umbelliforme	Pdec. sp. indet.	Pep. bifurcum	Pep. ?bifurcum	Pep. radices	Pep ?radices	Pep. spinosum	Pep. ?spinosum	Pep. sp.indet.	Pyr. spinosum	Pr. tricorne
20	sand	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	silt	9	43	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
40	sand	6	32	5	0	0	1	0	0	0	0	44	0	0	0	0	0	0	0	0	0	0
40	silt	30	245	16	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0
42.3-42.4	sand	0	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
42.3-42.4	silt	3	72	11	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
94.3	sand	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
94.3	silt	2	64	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99.7	silt	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130.8	silt	7	39	3	0	0	13	1	0	0	0	5	0	0	0	0	1	0	0	0	4	0
147.5	silt	31	78	3	44	2	3	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0
160	sand	0	13	0	7	0	0	0	0	0	0	6	0	0	1	0	0	0	0	0	0	0
160	silt	3	28	0	33	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
162.5	sand	4	10	0	0	0	0	0	0	0	0	7	0	10	0	4	1	1	0	0	5	1
162.5	silt	19	14	0	0	0	1	0	0	0	0	3	0	0	1	0	1	0	0	0	3	2
162.7	sand	7	5	0	13	0	0	0	0	0	0	3	0	3	0	10	2	1	0	1	2	0
162.7	silt	20	7	0	8	1	1	0	0	0	0	2	0	3	0	0	1	0	0	0	1	0
196	sand	31	28	0	0	0	0	24	1	2	0	1	1	60	0	51	12	34	0	2	0	22
196	silt	68	12	1	0	0	0	7	0	0	0	0	0	8	0	11	3	31	0	1	0	3
213	sand	12	11	0	0	0	0	29	0	7	1	5	0	37	0	70	10	39	0	0	2	4
213	silt	33	36	1	0	0	1	5	0	1	0	0	0	8	0	7	2	8	0	3	0	4
216	sand	37	4	0	0	0	0	49	0	1	0	1	0	98	3	52	11	30	1	1	3	0
216	silt	142	8	0	0	0	1	10	0	1	0	0	0	14	3	18	2	15	1	5	2	1

Continues

TABLE B-3--Continued.

sample	fraction	palaeoscenidiid	H. cf. H. raneatela	H. ?cf. H. raneatela	H. sp. A	H. ?sp. A	H. sp. B	H. sp. C	Haplotaeniatum sp. indet	?O. sp. C	inan. sp. A	inan. ?sp. A	inan. cf. sp. A	inan. sp. B	inan. ?sp. B	inan. sp. C	inan. sp. D	inan. sp. indet.	L. macdonaldi	L. ? macdonaldi	L. sp. A	L.?sp. A	L. sp. B
20	sand	2	2	0	0	3	13	0	3	2	6	4	4	0	0	1	2	10	135	0	0	6	0
20	silt	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	3	0
40	sand	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
40	silt	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42.3-42.4	sand	1	0	0	35	0	0	0	1	0	0	6	0	15	10	28	0	41	38	1	16	7	7
42.3-42.4	silt	3	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	5	0
94.3	sand	0	19	3	1	0	0	0	4	0	0	0	0	0	0	0	0	10	23	2	0	1	6
94.3	silt	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
99.7	silt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130.8	silt	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	0
147.5	silt	13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	5	1	4
160	sand	2	1	0	0	0	0	0	0	0	0	0	0	2	3	0	0	19	0	0	13	3	0
160	silt	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
162.5	sand	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	13	6	0
162.5	silt	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162.7	sand	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	6	3	0
162.7	silt	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
196	sand	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
196	silt	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	sand	15	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
213	silt	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
216	sand	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
216	silt	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cont.

TABLE B-3--Continued.

sample	fraction	L. ?sp. B	Labyrinthosphaera sp. indet.	unassigned	slide count
20	sand	0	0	28	488
20	silt	0	2	71	437
40	sand	0	0	7	368
40	silt	0	0	14	425
42.3-42.4	sand	4	6	1	376
42.3-42.4	silt	0	8	27	443
94.3	sand	1	2	9	410
94.3	silt	0	2	58	385
99.7	silt	0	0	3	423
130.8	silt	0	1	106	414
147.5	silt	1	3	149	419
160	sand	0	3	4	78
160	silt	0	0	23	100
162.5	sand	0	4	22	111
162.5	silt	0	3	39	92
162.7	sand	0	4	25	105
162.7	silt	0	1	35	99
196	sand	0	0	72	388
196	silt	0	0	96	400
213	sand	2	0	159	421
213	silt	0	0	66	330
216	sand	0	0	72	398
216	silt	0	0	49	393

APPENDIX C - COUNTS FOR PICKED SAMPLES

TABLE C-1--Counts for picked Cape Manning 2 samples.

sample	S. bipola	S. glaebosa	S. ?glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. ?parvitesta	S. resodiosae	S. ?resodiosae	S. sceptri	S. ?sceptri	Secuicollacta sp. indet.	D. fleischerorum	D. larseni	D. fleisch/larsen	Diparvapila sp. indet	pentactines	R. severa	I. dissimile	Pep. bifurcum	palaeoscenidiid indet.	H. adobensis
2.0A	0	0	0	0	11	335	15	0	0	0	49	0	0	0	93	0	0	0	0	0	0	0	0	0
31.9	0	0	0	0	10	73	13	4	0	0	0	0	1	5	0	0	0	0	0	1	0	0	1	0
42.5	0	0	0	0	3	4	4	6	2	2	8	0	0	13	0	0	0	0	0	0	0	0	2	0
57	0	0	0	1	1	0	0	4	2	331	4	0	0	76	0	0	0	0	0	0	0	0	0	0
75.5 (+A)	20	0	0	0	0	0	0	8	0	109	13	5	0	0	0	0	0	0	0	0	0	0	0	12
75.9 (+A)	2	0	0	8	11	0	0	0	3	10	0	0	2	10	0	0	0	0	0	0	0	0	0	12
82.4 (+A)	0	2	0	29	0	0	0	16	0	75	22	0	4	25	0	0	0	0	0	0	0	0	9	0
84	0	5	0	17	0	0	0	4	0	37	0	5	0	22	0	0	0	0	1	0	0	0	4	0
96.1	0	0	48	0	2	0	33	0	2	0	0	0	0	10	**9**	**1**	**6**	5	0	0	0	3	31	0
97.4	0	180	0	0	0	18	0	0	15	0	0	0	0	41	**10**	**5**	0	0	0	0	0	0	22	0
107 (+A)	0	0	42	0	0	138	0	13	0	0	0	0	0	39	**4**	0	0	1	0	0	1	0	16	0

Continued next page.

TABLE C-1--Continued.

sample	H. ?labyrintheum	H. aff. H. ? labrintheum	Haplotaeniatum sp. indet	O. cf. O. marginatum	O. sp. A	O. sp. B	?O. sp. C	?O. sp. D	Orbiculopylorum sp. indet.	Devoniglansus	unassigned	totals
2.0A	0	0	3733	0	0	0	0	0	0	0	35	4279
31.9	16	0	0	0	0	0	0	904	0	0	66	1094
42.5	265	28	82	0	59	17	39	0	0	1	43	578
57	0	0	0	0	0	0	0	0	0	0	0	419
75.5 (+A)	0	0	2	11	0	0	0	0	0	0	74	254
75.9 (+A)	0	0	0	0	0	0	49	0	24	0	3	134
82.4 (+A)	0	0	0	0	0	0	0	0	0	0	20	202
84	0	0	0	0	0	0	0	0	0	0	10	128
96.1	0	0	0	0	0	0	0	0	0	0	61	211
97.4	0	0	0	0	0	0	0	0	0	0	80	371
107 (+A)	0	0	0	0	0	0	0	0	0	0	28	282

TABLE C-2--Counts for picked Cape Phillips samples.

sample	S. bipola	S. glaebosa	S. ?glaebosa	S. malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. ?parvitesta	S. resodiosae	S. ?resodiosae	S. sceptri	S. ?sceptri	Secuicollacta sp. indet.	D. fleischerorum	D. hicocki	D. larseni	D. fleisch/larsen	D. n.sp A	D. ?n. sp. A	R. severa	R. ?severa	R. sp. A	R. sp. C	I. cancellatum	I. dissimile	Insolitignum sp. indet.
10.3-10.4	16	0	15	128	51	0	2	1	0	0	33	15	159	**8**	10	**6**	**16**	0	0	0	0	0	0	2	10	29
50.7	0	37	0	207	3	0	0	0	80	0	7	0	44	**77**	39	**19**	**36**	9	2	0	5	1	0	10	87	0
56	20	0	0	78	0	0	0	12	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0	6	273	0
65	0	5	1	128	0	0	0	0	28	8	0	0	28	**5**	141	**14**	**9**	0	0	0	0	0	0	1	14	0
89	0	0	1	525	23	20	0	0	0	0	29	0	23	0	0	17	0	0	0	0	0	0	0	0	0	0
122	0	33	0	122	0	0	0	0	136	45	31	0	77	**23**	19	**47**	**18**	0	0	1	0	33	1	4	19	0
140.6	0	0	0	0	0	12	0	0	13	0	0	7	11	0	0	0	0	0	0	1	0	0	0	22	107	0

sample	Pdec. apertum	Pdec. umbelliforme	Pep. bifurcum	Pep. ?bifurcum	Pep. spinosum	Pyr. spinosum	palaeoscenidiid indet.	H. cf. H. raneatela	H. sp. A	H. ?sp. A	inan. sp. B	inan. ?sp. B	inan. sp. C	inan. sp. D	inan. sp. indet.	L. macdonaldi	L. ? macdonaldi	L. sp. A	L.?sp. A	L. sp. B	Labyrinthosphaera sp. indet.	unassigned	totals
10.3-10.4	0	0	0	0	0	0	1	0	26	0	0	5	81	7	0	13	0	0	0	0	8	37	679
50.7	1	61	7	0	1	0	11	0	0	0	3	0	39	0	7	44	0	0	3	1	0	122	963
56	0	180	4	0	0	3	41	0	7	0	0	0	3	0	1	2	0	0	0	0	0	0	710
65	0	15	0	0	0	1	5	3	5	0	5	0	0	0	51	56	0	0	5	11	0	37	576
89	0	4	0	0	1	0	1	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0	672
122	0	25	0	1	0	1	7	9	0	1	0	6	0	0	13	0	1	2	1	1	10	237	924
140.6	0	10	5	0	0	3	6	22	0	5	0	0	0	0	16	18	0	0	2	0	0	9	269

APPENDIX D - COUNTS FOR PICKED COARSE FRACTIONS

TABLE D-1--Counts for picked Cape Manning 2 coarse fractions.

sample	S. glaebosa	S. ?glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. parvitesta	S. ?parvitesta	S. resodiosae	S. ?resodiosae	S. sceptri	S. ?sceptri	Secuicolacta sp. indet.	D. fleischerorum	D. hicocki	D. larseni	D. ?larseni	Diparvapila sp. indet.	pentactine	R. severa	Pr. tricorne	palaeoscenidiid indet.	H. ?cathenatum	H. aff. ?cathenatum
4.25A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44.5A	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	1	0
46.8A	0	0	100	7	0	0	32	7	0	0	2	2	29	0	0	0	1	1	0	0	0	2	0	0
51.2	0	0	40	2	0	1	40	3	0	0	7	37	15	0	0	0	0	0	0	0	0	2	41	6
71.1	0	0	26	2	0	0	27	0	1	0	4	2	9	0	0	0	0	0	0	0	0	0	0	0
72	0	0	30	0	0	0	10	0	0	0	0	0	25	0	0	0	0	0	0	0	0	1	0	0
85.2	1	0	19	0	0	0	39	0	0	0	2	6	31	0	0	0	0	0	0	0	0	0	1	0
91.7	1	3	0	0	1	2	7	21	0	3	2	2	55	1	1	0	0	2	2	1	0	7	0	0
106.5	0	0	40	2	0	0	27	0	81	1	4	9	53	0	0	1	0	1	0	0	0	5	0	0

Continues next page.

TABLE D-1--Continued.

sample	H. adobensis	H. ?labyrintheum	H. aff. H. ?labyrintheum	H. ?cf. raneatela	H. sp. A	H. ?sp. B	H. sp. C	Haplotaeniatum sp. indet.	O. cf. O. marginatum	O. ?cf. O. marginatum	O. sp. A	O. sp. B	O. ?sp. B	?O. sp. C	?O. sp. D	Orbiculopylorum sp. indet.	inan. ?sp. C	L. macdonaldi	L. ?macdonaldi	L. sp. B	L. sp. indet.	unassigned	sand totals
4.25A	0	0	0	0	0	0	0	882	0	0	0	0	0	0	0	0	0	0	0	0	0	1	957
44.5A	0	109	1	0	0	0	7	1	0	0	1	276	1	471	17	4	0	0	0	0	0	39	997
46.8A	0	744	10	0	5	0	1	8	0	0	5	77	0	3	23	1	0	0	0	0	0	7	1062
51.2	0	324	8	14	0	0	11	8	0	0	0	62	2	0	38	0	0	0	0	0	0	39	701
71.1	19	0	0	0	0	0	0	1	14	3	0	0	25	0	0	0	0	0	0	0	0	8	141
72	33	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	129	257
85.2	235	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	8	400
91.7	23	0	0	0	0	1	0	1	0	4	0	0	0	0	0	0	0	1	1	1	39	63	245
106.5	0	0	17	7	0	12	0	1	0	0	0	0	0	0	0	0	2	1	0	1	27	116	426

TABLE D-2--Counts for picked Cape Manning 3 coarse fractions.

sample	S. malevola	S. sceptri	D. fleischerorum	D. hicocki	D. larseni	D. fleisch/larsen	Pdec. umbelliforme	Pep. bifurcum	Pep. radices	Pep. spinosum	Pep. sp. indet.	palaeoscenidiid indet.	H. sp. A	H. ?sp. A	inan. sp. A	inan. sp. B	inan. sp. C	inan. sp. indet.	L. macdonaldi	L. sp. A	L. ?sp. A	L. sp. B	L. sp. indet.	unassigned	sand totals
38.1	69	0	1	0	3	**1**	0	0	0	0	1	1	0	0	0	0	0	2	11	13	0	0	6	4	127
48	72	0	0	10	0	**4**	1	0	1	0	0	3	0	0	7	0	0	0	66	0	0	0	0	11	213
89.9	n/a	n/a	0	14	0	0	0	0	0	1	0	0	45	3	0	41	2	26	191	0	3	11	11	n/a	**787**

TABLE D-3--Counts for picked Cape Phillips coarse fractions.

sample	S. bipola	S. glaebosa	S. malevola	S. ?malevola	S. multispinosa	S. ?multispinosa	S. resodiosae	S. sceptri	S. ?sceptri	Secuicollacta sp. indet.	D. hicocki	Pdec. umbelliforme	Pdec. sp. indet.	Pep. bifurcum	Pep. radices	Pep. ?spinosum	palaeoscenidiid indet.	H. cf. H. raneatela	H. ?cf. H. raneatela	H. ?sp. A	H. sp. indet.	inan. sp. indet.	L. macdonaldi	L. ?macdonaldi	L. sp. A
99.7	0	0	86	0	8	0	0	1	0	12	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
130.8	0	0	21	0	0	0	0	0	1	5	2	0	1	0	1	0	1	0	0	0	0	0	23	0	0
147.5	0	0	1	5	0	1	3	4	1	4	0	4	0	3	0	1	4	41	1	6	3	27	25	11	50

sample	L. ?sp. A	L. sp. B	L. ?sp. B	L. sp. indet.	unassigned	sand totals
99.7	0	0	0	0	1	112
130.8	3	1	0	0	4	63
147.5	20	7	27	6	32	293

APPENDIX E - TOTAL SPECIMENS PER SAMPLE AND TOTAL PER GRAM SAMPLE

Cape Manning 2

sample	per sample	per gram
2.0A	4279	37.5
4.25A	6044	74.0
31.9	1094	12.2
42.5	578	8.0
44.5A	2584	21.3
46.8A	4165	36.0
51.2	5035	62.3
57	419	6.1
71.1	3514	31.9
72	4450	48.4
75.5(+A)	254	1.2
75.9(+A)	134	0.8
82.4(+A)	202	1.0
84	128	1.8
85.2	3182	47.2
91.7	8628	113.1
96.1	211	14.8
97.4	371	4.3
106.5	5675	73.0
107(+A)	282	1.6

Cape Phillips

sample	per sample	per gram
10.3-10.4	679	10
20	31135	277
40	60258	731
42.3-42.4	24167	191
50.7	963	12
56	710	7
65	576	12
89	672	8
94.3	45765	381
99.7	20959	172
122	924	12
130.8	2135	30
140.6	269	1
147.5	4975	39
160	2099	21
162.5	6035	86
162.7	58543	354
196	415703	4817
213	308408	3100
216	666447	5885

Cape Manning 3

sample	per sample	per gram
38.1	3115	39
42.2	23494	250
48	3525	69
77.5	189012	1781
79	50621	458
89.9 (1)	2898	26
89.9 (2)	2706	24

(1) strewn data

(2) picked data

APPENDIX F - RELATIVE ABUNDANCES OF GENERA, PALAEOSCENIDIIDAE AND INANIGUTTIDAE

TABLE F-1--CapeManning 2 relative abundances of genera, Palaeoscenidiidae, and Inaniguttidae.

sample	Secuicollacta	Diparvapila	Rotasphaera	Palaeoscenidiidae	Goodbodium	Insolitignum	Palaeodecaradium	Palaeoephippium	Palaeopyramidium	Protoentactinia	Haplotaeniatum	Orbiculopylorum	inaniguttids	Labyrinthosphaera
2.0A	10	2	0	0	0	0	0	0	0	0	87	0	0	0
4.25A	7	2	0	0	0	0	0	0	0	0	76	0	0	0
31.9	10	0	0	0	0	0	0	0	0	0	1	0	0	0
42.5	7	0	0	0	0	0	0	0	0	0	65	13	0	0
44.5	44	0	0	11	0	0	0	0	0	0	5	11	0	0
46.8	52	2	1	6	0	0	0	0	0	0	18	2	0	0
51.2	74	2	0	0	0	0	0	0	0	0	8	1	0	0
57	100	0	0	0	0	0	0	0	0	0	0	0	0	0
71.1	96	0	0	0	0	0	0	0	0	0	1	1	0	0
72	87	1	0	6	0	0	0	1	0	0	1	1	0	0
75.5	61	0	0	0	0	0	0	0	0	0	6	30	0	0
75.9	34	0	0	0	0	0	0	0	0	0	9	18	0	0
82.4	86	0	0	4	0	0	0	0	0	0	0	0	0	0
84	70	0	0	3	0	0	0	0	0	0	18	0	0	0
85.2	82	1	1	2	0	0	0	0	0	0	9	0	0	0
91.7	42	8	10	6	0	0	0	0	0	0	0	0	0	2
96.1	45	10	0	16	0	0	0	1	0	0	0	0	0	0
97.4	68	4	0	6	0	0	0	0	0	0	0	0	0	0
106.5	62	21	2	3	0	0	0	1	0	0	1	0	0	1
107	82	2	0	0	0	0	0	0	0	0	0	0	0	0

TABLE F-2--Cape Manning 3 relative abundances of genera, Palaeoscenidiidae, and Inaniguttidae.

sample	Secuicollacta	Diparvapila	Rotasphaera	Palaeoscenidiidae	Goodbodium	Insolitignum	Palaeodecaradium	Palaeoephippium	Palaeopyramidium	Protoentactinia	Haplotaeniatum	Orbiculopylorum	inaniguttids	Labyrinthosphaera
38.1	40	7	2	33	0	32	0	1	0	0	0	0	0	3
42.2	35	23	5	17	0	14	0	3	0	0	0	0	0	3
48	24	15	6	38	1	35	0	0	0	0	0	0	0	3
77.5	44	15	6	20	0	17	1	1	0	0	1	0	1	5
79	62	11	4	13	0	11	0	0	0	0	0	0	0	6
89.9 (1)	**n/a**	**18**	**2**	**8**	**0**	**8**	**0**	**0**	**0**	**0**	**2**	**0**	**3**	**17**
89.9 (2)	**38**	**17**	**2**	**8**	**0**	**8**	**0**	**0**	**0**	**0**	**2**	**0**	**2**	**24**

(1) picked data

(2) strewn data

TABLE F-3--Cape Phillips relative abundances of genera, Palaeoscenidiidae, and Inaniguttidae.

sample	Secuicollacta	Diparvapila	Rotasphaera	Goodbodium	Palaeoscenidiidae	Insolitignum	Palaeodecaradium	Palaeoephippium	Palaeopyramidium	Protoentactinia	Haplotaeniatum	Orbiculopylorum	inaniguttids	Labyrinthosphaera
10.3-10.4	62	6	0	0	6	6	0	0	0	0	4	0	14	3
20	43	19	3	0	10	9	0	0	0	0	1	0	1	8
40	20	4	3	0	68	65	3	0	0	0	0	0	0	0
42.3-42.4	39	24	2	0	20	18	1	0	0	0	1	0	2	6
50.7	39	19	1	0	18	10	6	1	0	0	0	0	5	5
56	27	0	0	0	66	39	25	1	0	0	1	0	1	0
65	34	29	0	0	6	2	3	0	0	0	1	0	10	12
89	92	3	0	0	1	0	1	0	0	0	0	0	4	0
94.3	49	15	3	0	15	14	0	0	0	0	1	0	1	2
99.7	94	4	1	0	1	1	0	0	0	0	0	0	0	0
122	48	12	4	0	6	2	3	0	0	0	1	0	2	2
130.8	46	3	3	0	21	15	1	0	1	0	0	0	0	3
140.6	16	0	0	0	57	48	4	2	1	0	10	0	6	7
147.5	15	0	0	1	41	36	1	0	0	0	1	0	1	7
160	3	0	1	1	59	52	4	0	0	0	0	0	11	9
162.5	8	0	1	0	46	27	4	7	4	2	0	0	0	11
162.7	8	2	4	1	48	35	2	6	1	0	0	0	0	4
196	15	3	3	7	57	19	3	19	0	2	0	0	0	0
213	26	1	2	6	48	19	3	13	0	1	0	0	0	0
216	8	2	1	9	76	31	5	24	1	0	0	0	0	0

APPENDIX G - RELATIVE ABUNDANCES OF SPECIES

TABLE G-1--Cape Manning 2 species relative abundances.

sample	S. bipola	S. glaebosa	S. malevola	S.	S. parvitesta	S. resodiosae	S. cf. S.	S. sceptri	S. n.sp. A	D.	D. hicocki	D. larseni	D.	D. n.sp A	D. n.sp. B	R. severa	R. sp. A	R. sp. B	R. sp. C	G. flammatum	G.	I. cancellatum	I. dissimile	I. vivanima	Pdec. apertum
2.0A	0	0	0	8	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.25A	0	0	0	6	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31.9	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42.5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44.5	0	0	0	24	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46.8	0	0	10	15	3	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51.2	0	0	2	16	1	11	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	1	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71.1	0	0	2	4	3	63	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	1	1	2	0	59	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
75.5	8	0	0	0	3	43	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75.9	1	0	6	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82.4	0	1	14	0	8	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	4	13	0	3	29	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85.2	0	15	1	2	4	22	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91.7	0	19	0	3	1	4	0	0	0	2	0	0	0	0	0	3	0	0	2	0	0	0	0	0	0
96.1	0	0	0	0	0	0	0	0	0	**4**	0	**0**	**3**	0	0	0	0	0	0	0	0	0	0	0	0
97.4	0	49	0	5	0	0	0	0	0	**3**	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
106.5	0	19	2	10	3	9	0	2	0	9	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0
107	0	0	0	49	5	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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TABLE G-1--Continued.

sample	Pdec. gordoni	Pdec.	Pep. bifurcum	Pep. radices	Pep. spinosum	Pyr. spinosum	Pr. tricorne	H. ?cathenatum	H. adobensis	H. ?labyrintheum	H. cf. H. raneatela	H. sp. A	H. sp. B	H. sp. C	O. cf. O.	O. sp. A	O. sp. B	?O. sp. C	?O. sp. D	inan. sp. A	inan. cf. sp. A	inan. sp. B	inan. sp. C	inan. sp. D	L. macdonaldi
2.0A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.25A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31.9	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	83	0	0	0	0	0	0
42.5	0	0	0	0	0	0	0	0	0	46	0	0	0	0	0	10	0	7	0	0	0	0	0	0	0
44.5	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	11	18	1	0	0	0	0	0	0
46.8	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	5	2	0	1	0	0	0	0	0	0
51.2	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71.1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
75.5	0	0	0	0	0	0	0	0	5	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
75.9	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0
82.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85.2	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96.1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106.5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continues next page.

TABLE G-1--Continued.

sample	L. sp. A	L. sp. B
2.0A	0	0
4.25A	0	0
31.9	0	0
42.5	0	0
44.5	0	0
46.8	0	0
51.2	0	0
57	0	0
71.1	0	0
72	0	0
75.5	0	0
75.9	0	0
82.4	0	0
84	0	0
85.2	0	0
91.7	0	0
96.1	0	0
97.4	0	0
106.5	0	0
107	0	0

TABLE G-2--Cape Manning 3 species relative abundances.

sample	S. bipola	S. glaebosa	S. malevola	S. multispinosa	S. parvitesta	S. resodiosae	S. cf. S. resodiosae	S. sceptri	S. n.sp. A	D. fleischerorum	D. hicocki	D. larseni	D. fleisch/larsen	D. n.sp A	D. n.sp. B	R. severa	R. sp. A	R. sp. B	R. sp. C	G. flammatum	G. rarispinosum	I. cancellatum	I. dissimile
38.1	0	0	2	0	0	0	0	0	0	3	1	2	0	0	0	0	0	0	1	0	0	17	13
42.2	2	4	4	8	0	0	0	2	0	3	8	6	0	0	0	1	2	0	2	0	0	1	12
48	1	3	3	7	0	0	0	1	0	4	5	4	0	0	0	0	2	0	2	0	1	3	30
77.5	3	15	4	0	0	3	0	2	0	5	3	4	0	1	0	1	2	0	2	0	0	2	14
79	7	21	10	0	0	2	0	2	0	3	2	3	0	1	0	0	1	0	2	0	0	1	10
89.9 (1)	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**3**	**11**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**7**
89.9 (2)	**1**	**5**	**17**	**0**	**0**	**0**	**0**	**5**	**0**	**3**	**10**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**7**

(1) Picked data
(2) Strewn data

Continues next page.

TABLE G-2--Continued.

sample	I. vivanima	Pdec. apertum	Pdec. gordoni	Pdec. umbelliforme	Pep. bifurcum	Pep. radices	Pep. spinosum	Pyr. spinosum	Pr. tricorne	H. ?cathenatum	H. adobensis	H. ?labyrintheum	H. cf. H. raneatela	H. sp. A	H. sp. B	H. sp. C	O. cf. O. marginatum	O. sp. A	O. sp. B	?O. sp. C	?O. sp. D	inan. sp. A	inan. cf. sp. A	inan. sp. B	inan. sp. C
38.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42.2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77.5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89.9 (1)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**
89.9 (2)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**

(1) Picked data
(2) Strewn data

Continues next page.

TABLE G-2--Continued.

sample	inan. sp. D	L. macdonaldi	L. sp. A	L. sp. B
38.1	0	0	0	0
42.2	0	2	0	0
48	0	3	0	0
77.5	0	4	0	0
79	0	4	0	0
89.9 (1)	**0**	**9**	**0**	**2**
89.9 (2)	**0**	**15**	**0**	**2**

(1) Picked data
(2) Strewn data

TABLE G-3--Cape Phillips species relative abundances.

sample	S. bipola	S. glaebosa	S. malevola	S. multispinosa	S. parvitesta	S. resodiosae	S. cf. S.	S. sceptri	S. n.sp. A	D.	D. hicocki	D. larseni	D. fleisch/larsen	D. n.sp A	D. n.sp. B	R. severa	R. sp. A	R. sp. B	R. sp. C	G. flammatum	G. rarispinosum	I. cancellatum	I. dissimile	I. vivanima
10.3-10.4	**2**	**0**	**19**	**8**	**0**	0	0	**5**	0	**1**	1	**1**	0	0	0	0	0	0	0	0	0	0	1	0
20	4	2	3	11	0	1	0	2	0	3	6	8	0	0	1	0	1	0	0	0	0	2	8	0
40	0	1	2	1	0	1	0	3	0	1	0	0	0	0	0	0	1	0	1	0	0	7	54	0
42.3-42.4	5	5	4	3	0	10	0	1	0	6	7	5	0	0	0	0	0	0	1	0	0	1	15	0
50.7	0	4	22	0	0	8	0	1	0	**8**	4	**2**	**4**	1	0	0	0	0	0	0	0	1	9	0
56	3	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	38	0
65	0	1	22	0	0	5	0	0	0	**1**	24	**2**	**2**	0	0	0	0	0	0	0	0	0	2	0
89	0	0	78	3	0	0	0	4	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
94.3	0	13	9	0	0	3	0	5	0	2	4	6	0	0	0	1	0	0	1	0	0	0	13	0
99.7	0	35	11	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
122	0	4	13	0	0	15	0	3	0	**2**	2	**5**	**2**	0	0	0	4	0	0	0	0	0	2	0
130.8	0	11	4	1	0	6	0	1	0	1	1	0	0	0	0	0	1	0	1	0	0	1	9	0
140.6	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	40	0
147.5	0	1	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	18	10
160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2	24	24
162.5	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	14	13	0
162.7	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	18	7	9
196	0	3	0	10	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	7	0	15	4	0
213	0	5	0	4	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	6	0	9	10	0
216	0	2	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	8	0	29	2	0

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TABLE G-3--Continued.

sample	Pdec. apertum	Pdec. gordoni	Pdec.	Pep. bifurcum	Pep. radices	Pep. spinosum	Pyr. spinosum	Pr. tricorne	H. ?cathenatum	H. adobensis	H. ?labyrintheum	H. cf. H. raneatela	H. sp. A	H. sp. B	H. sp. C	O. cf. O.	O. sp. A	O. sp. B	?O. sp. C	?O. sp. D	inan. sp. A	inan. cf. sp. A	inan. sp. B	inan. sp. C
10.3-10.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
20	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
40	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42.3-42.4	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
50.7	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
56	0	0	25	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
65	0	0	3	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0
89	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
94.3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
99.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
130.8	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140.6	0	0	4	2	0	0	1	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
147.5	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
162.5	0	0	4	4	2	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162.7	0	0	2	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
196	3	0	0	5	5	8	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	2	1	0	3	4	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
216	5	0	0	9	7	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continues next page.

TABLE G-3--Continued.

sample	inan. sp. D	L. macdonaldi	L. sp. A	L. sp. B
10.3-10.4	1	2	0	0
20	0	7	0	0
40	0	0	0	0
42.3-42.4	0	2	0	0
50.7	0	5	0	0
56	0	0	0	0
65	0	10	0	2
89	0	0	0	0
94.3	0	1	0	0
99.7	0	0	0	0
122	0	0	0	0
130.8	0	2	0	0
140.6	0	7	0	0
147.5	0	1	2	1
160	0	0	7	0
162.5	0	1	5	0
162.7	0	1	1	0
196	0	0	0	0
213	0	0	0	0
216	0	0	0	0

APPENDIX H - LITHOLOGIC DESCRIPTIONS OF STUDY SECTIONS

Cape Manning 2

Unit	Lithology
1 (0-4.5m)	Calcareous shale, sparse limestone beds (≤30cm), rare concretions.
2 (15.5-16.1m)	Vuggy dolostone.
3 (16.1-18.3m)	Dolomitic shale, black, sparse concretions
4 (18.3-20m)	Vuggy dolostone, bituminous; interbedded black, dolomitic shale.
5 (20-29.2m)	Dolostone, light brown, mottled, vuggy.
6 (29.2-37.8m)	Calcareous shale, black, weathering light grey, 1-2cm laminae, sparse concretions becoming common up-section.
7 (37.8-39.1m)	Dolostone, 15cm beds, massive, light brown.
8 (39.1-59.5m)	Calcareous shale, 1.5-3cm laminae, black, weathering light grey, abundant concretions (up to 0.5m diameter parallel bedding).
9 (59.5-65m)	Dolomitic shale, brown; interbedded with grey calcareous shale in lower part.
10 (65-69.5m)	Dolostone and dolomitic shale.
11 (69.5-87m)	Calcareous shale or laminated limestone, slightly cherty, concretions common but rarer at centre of unit.
12 (87-88m)	Shaly limestone.
13 (91-108m)	Calcareous shale, dolomitic shale, limestone with shaly interbeds; concretions.
14 (108-114m)	Dolomitic shale, brown weathering grey; one massive dolostone bed (30cm).

Cape Manning 3

1 (0-170m)	Calcareous shale, weather grey-brown; concretions rare, concentrated in some horizons; intercalated calcarenitic debris flows, generally <1m, up to 3.4m thick; sparse limestone beds, <50cm thick.

Cape Phillips

1 (0-16m)	Shaly limestone and limestones 1 to 15cm thick; medium grey, wethering light grey; shale may be black (?cherty).
2 (16-35m)	Interbedded limestone and shale; concretions more common, occur in ls, may link to form uneven beds. Limestones thicken upsection.
3 (35-40m)	Calcareous shales and thin beds of limestone; concretions present.
4 (40-59m)	Calcareous shales with cherty layers, especially up section; small concretions.
5 (59-65m)	Coarse-grained limestone beds up to 30cm thick, mottled concretions; interbedded with micritic limestone. Concretions generally small.
6 (65-84m)	Platy limestone (limy shale), beds to 20cm thick. Few concretions.
7 (84-106m)	At base cherty shale interbedded with limestone-shale; cherty shale grey to black, weathers light grey. Grades into argillaceous calcareous shale, some chert, weathers light grey; concretions increase up unit.
8 (106-115.4m)	Platy shale, some limestone beds up to 20cm thick. Some beds uneven. No concretions.

9 (115.4-120m)	Argillaceous calcareous shale, weathers light grey, interbedded with laminated limestone.
10 (120-122.5m)	Platy limestone with some limestone beds to 30cm thick.
11 (122.5-124m)	Shale, abundant concretions.
12 (124-127m)	Platy limestone and limestone.
13 (127-133m)	Limestone beds to 15cm thick; mottled or with small concretions.
14 (133-138m)	Platy, uneven beds, mottled or with small concretions, bed to 15cm thick.
15 (138-145.5m)	Limestone, becoming arenaceous at ~140m. Beds 3-20cm thick, uneven in arenaceous part.
16 (145.5-161.5m)	Platy limestone, few concretions.
17 (161.5-163.1m)	Platy limestone with concretion; top shalier with abundant concretions.
18 (163.1-195.9m)	Platy limestone, no concretions.
19 (195.9-284m)	Platy limestone with concretion-rich intervals.

APPENDIX I - PLATES

Plate 1

Scanning electron micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1, 2.–*Secuicollacta bipola. 1*, B77.5#3MR29/00; *2*, B42.2#3MR29/00.

Figures 3-5.–*Secuicollacta glaebosa. 3*, B38.1#12FE28/01, apical ray at 12 o'clock position; *4*, B42.2#18MR6/01, apical ray at 12 o'clock position, note finer construction and apically concave curvature of basal rays; *5*, B79#12MR6/01, apical ray at 11 o'clock position.

Figures 6, 7.–*Secuicollacta malevola. 6*, AD4862oct599, junction of spicule rays in lower right quadrant of specimen; *7*, C20#28FE28/01.

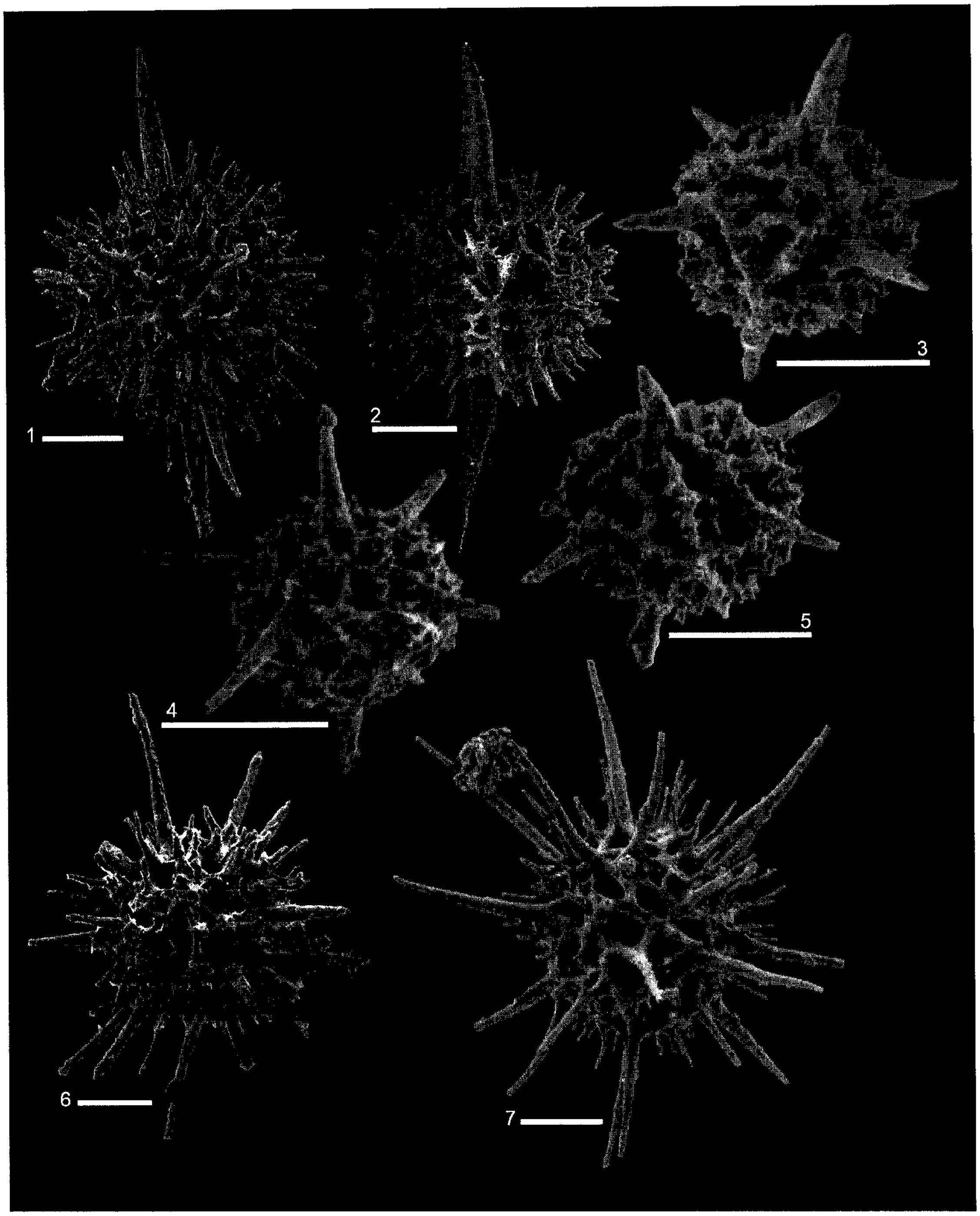


Plate 1

Plate 2

Scanning electron micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1, 3.–*Secuicollacta malevola*. *1*, C89#8JA22/01; *3*, C122#5JA22/01, apical ray at 11 o'clock position.

Figures 2, 4, 5, 7.–*Secuicollacta multispinosa*. *2*, B48#2MR29/00, shows a well-developed labyrinthine outer layer; *4*, B42.2#8MR29/00, less developed labyrinthine layer, apical ray at 11 o'clock position; *5*, C99.7MR5/01, outer layer as irregular masses; *7*, AT4687oc5/99, poorly preserved specimen, apical ray at 11 o'clock position.

Figure 6.–*Secuicollacta parvitesta*. AT4683oc5/99, apical ray at 11 o'clock position.

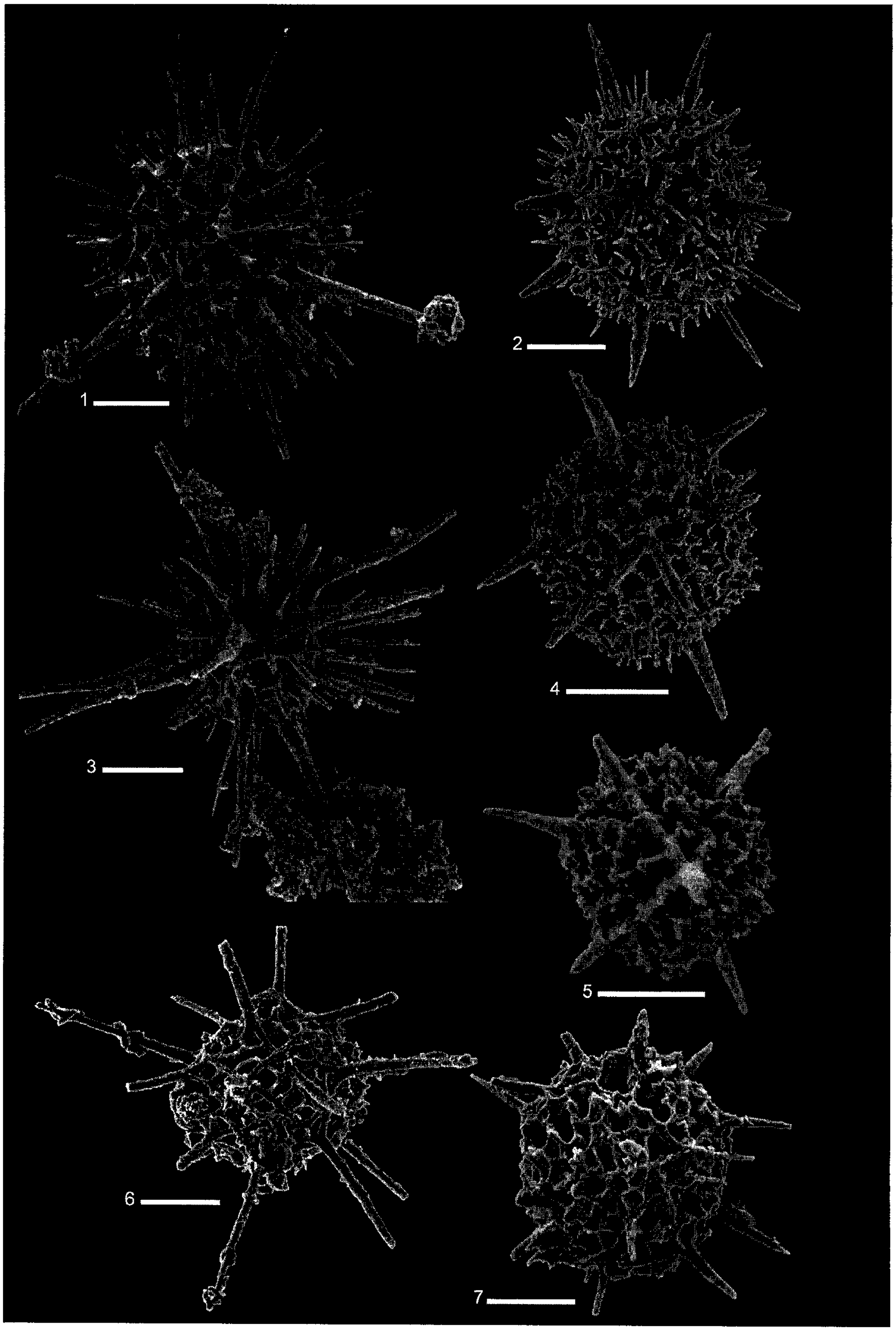


Plate 2

Plate 3

Scanning electron micrographs - *Diparvapila*

All scale bars 50 μm

Figure 1.–*Diparvapila fleischerorum*. A2.0JL4/01, apical spine at 4 o'clock position.

Figures 2, 3, 5, 6.–*Secuicollacta resodiosae*. *2*, A85.2#4ja25/00; *3*, A71.1#3ja25/00; *5*, A71.1#5ja25/00; *6*, A57#6ja25/00.

Figure 4.–*Secuicollacta ?resodiosae*. A51.2#7oc5/99, could also be classified as *S. malevola*, junction of spicule rays in upper right quadrant of specimen.

Figures 7, 8.–*Secuicollacta sceptri*. *7*, C94.3#35fe28/01; *8*, C20#3fe28/01.

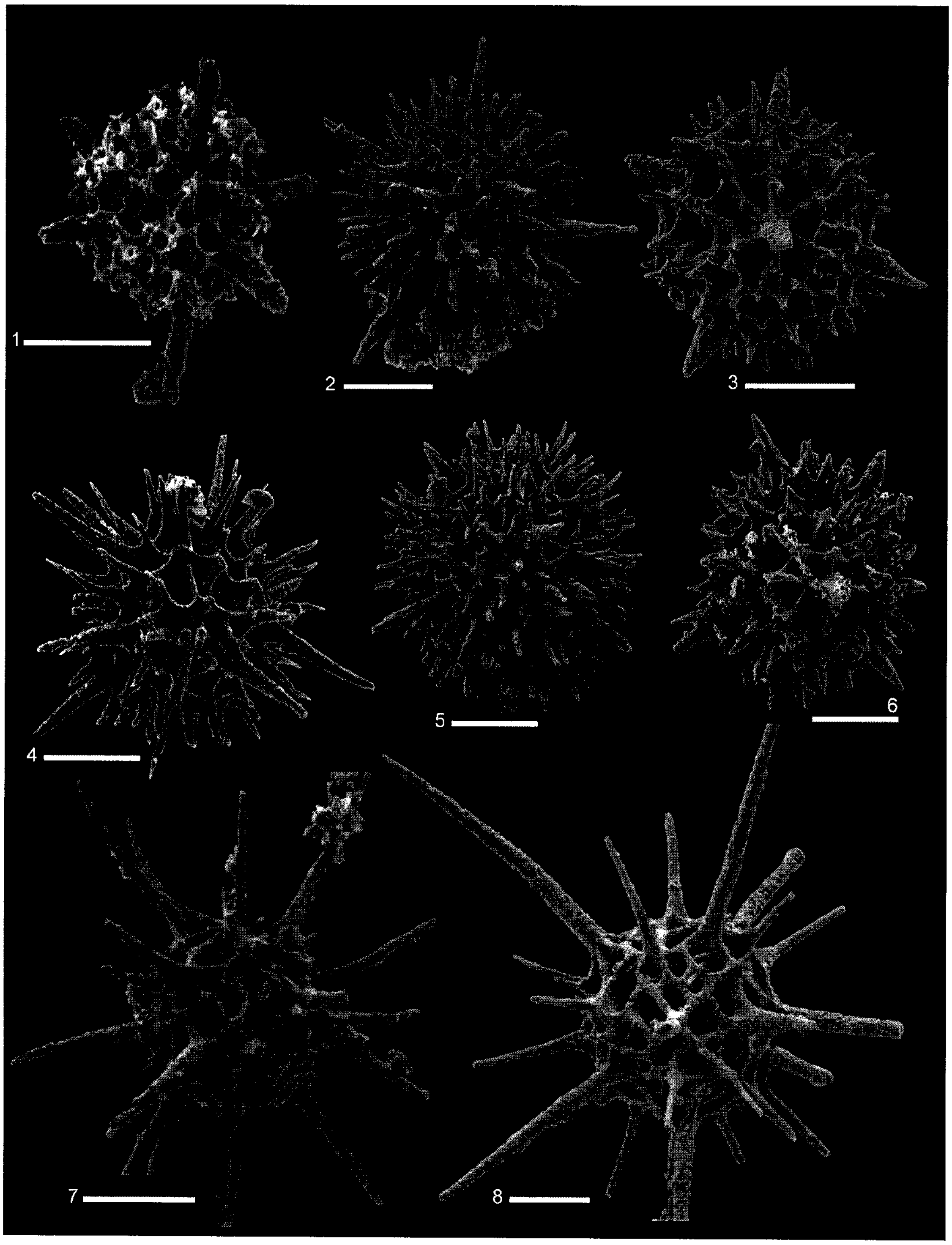


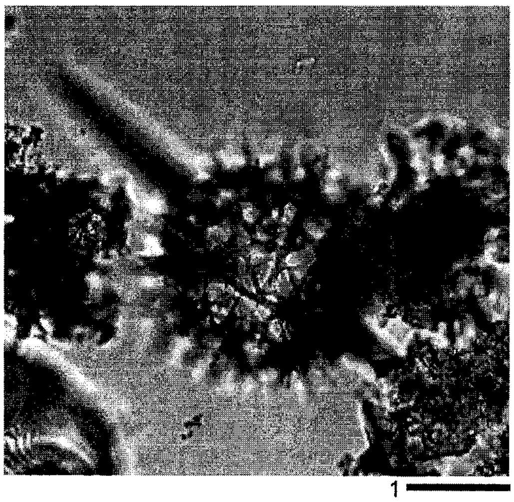
Plate 3

Plate 4

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-6.–*Secuicollacta bipola. 1, 3*, B48(1)#238, apical spine at 10 o'clock position; *2*, *4*, B38.1(1)#76, apical spine at 12 o'clock position, diminutive basal spines visible (*4*); *5*, *6*, B77,5(3)#301, apical spine at 11 o'clock position, basal spines enlarged.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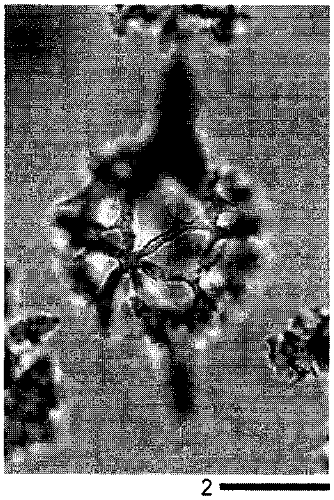
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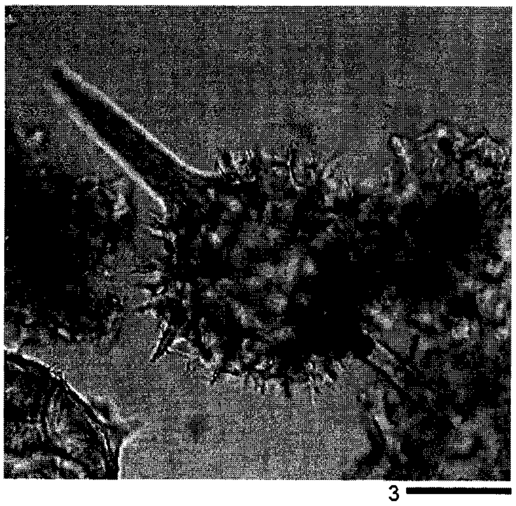
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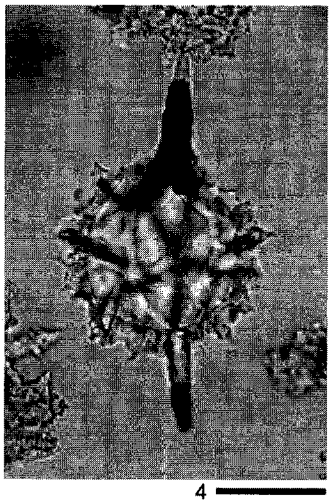
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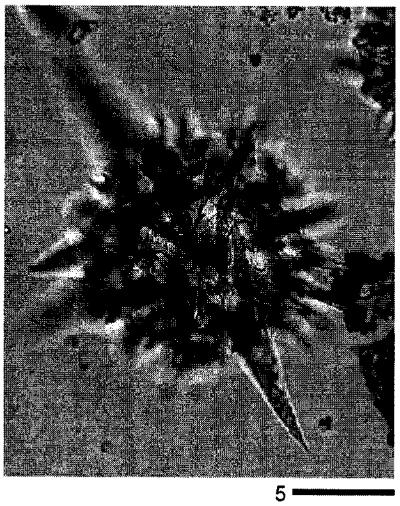
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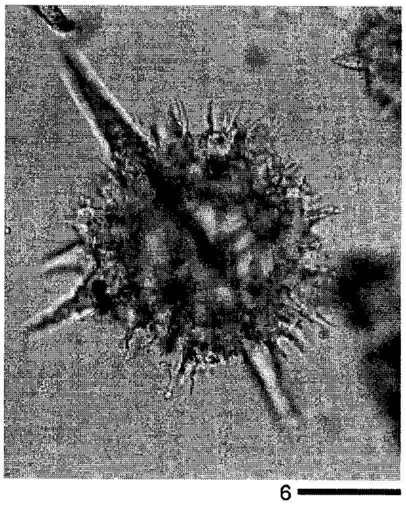
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Plate 4

Plate 5

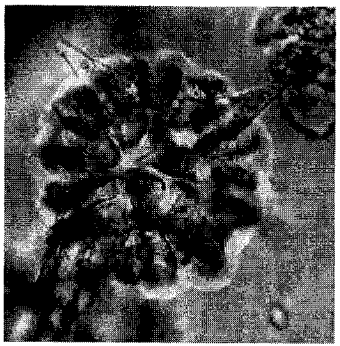
Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-6.–*Secuicollacta glaebosa. 1*, *4*, C99.1(1)#2, apical ray at 12 o'clock position; *2*, *5*, B77.5(3)#231, apical ray at 2 o'clock position; *3*, *6*, B79(3)#99, apical ray at 11 o'clock position.

Figures 7, 8.–*Secuicollacta malevola.* C94.3(1)#296.


1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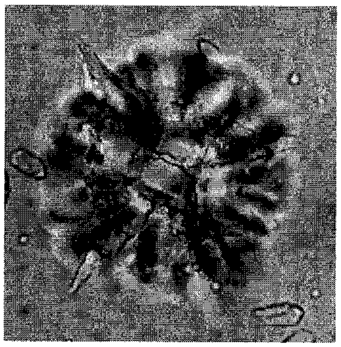
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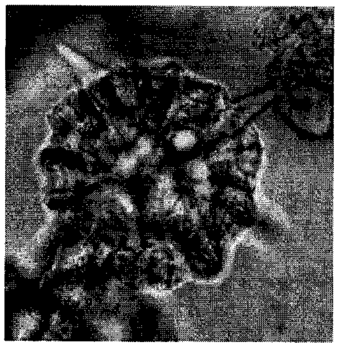
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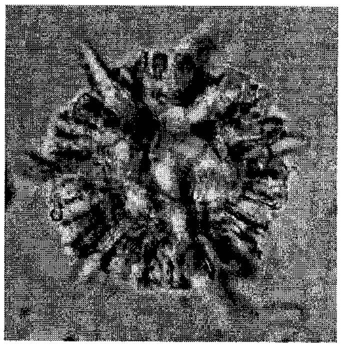
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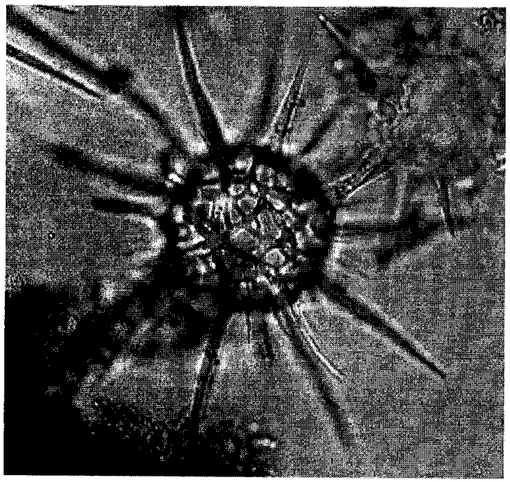
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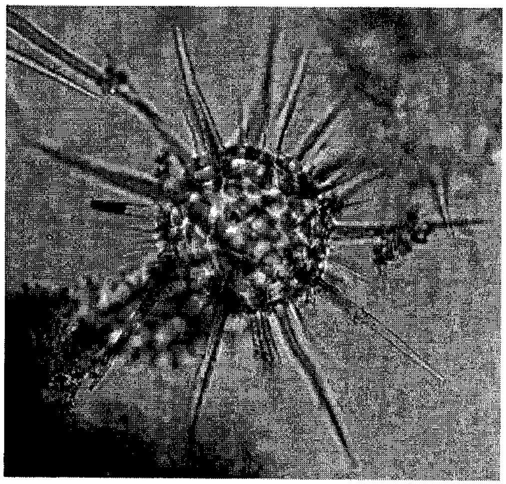
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Plate 5

Plate 6

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-4.–*Secuicollacta malevola. 1*, C20(1)#263; *2*, B77.5(1)#108; *3*, *4*, B79(1)#6.

Figures 5, 6.–*Secuicollacta ?multispinosa.* Finer construction and fairly long spines are reminiscent of *Diparvapila fleischerorum*.

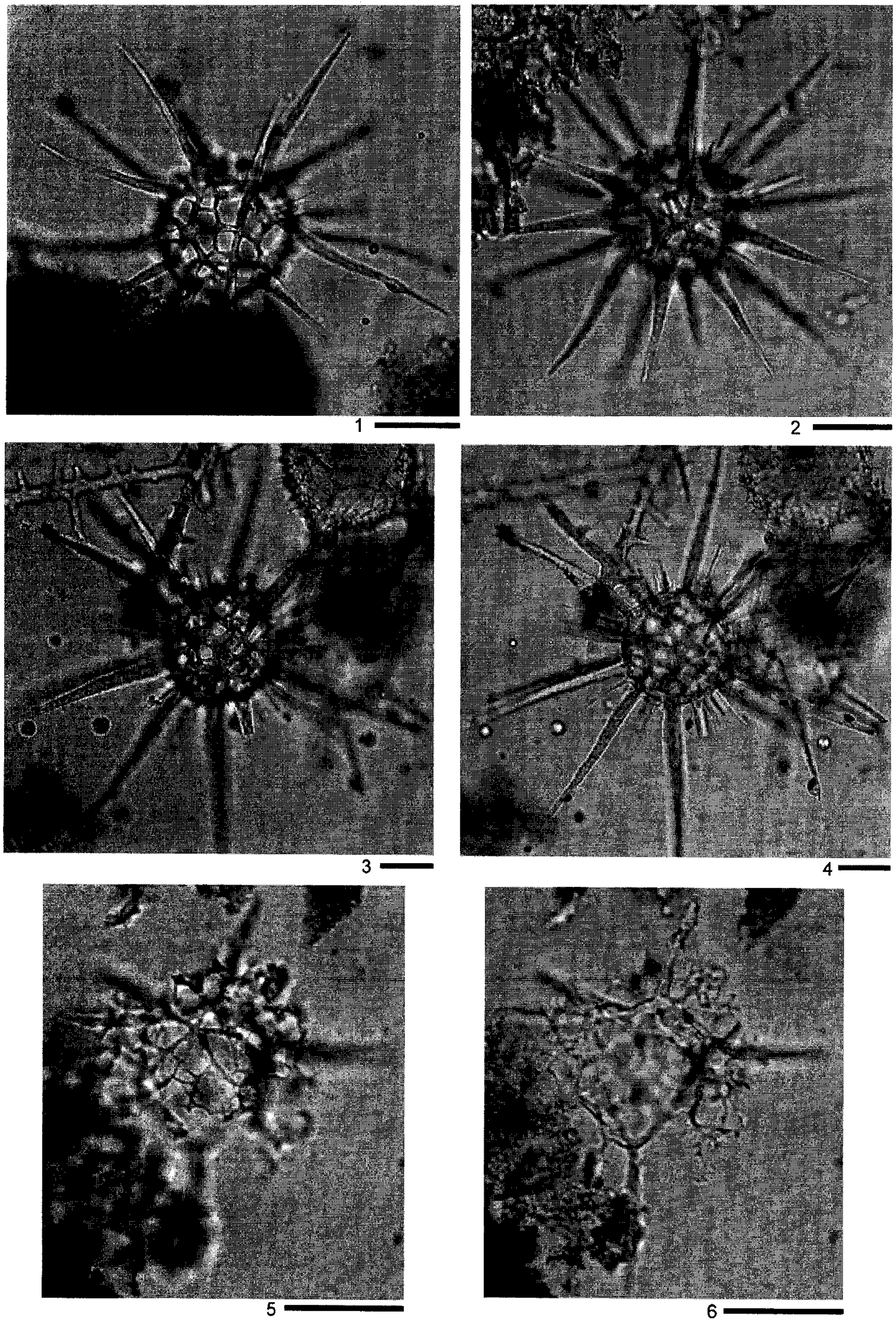


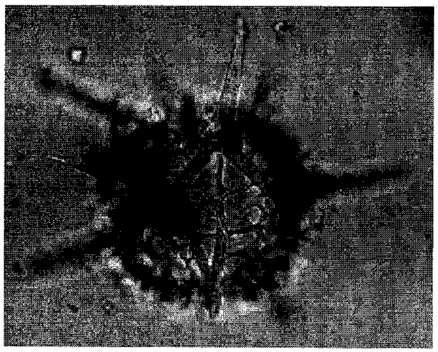
Plate 6

Plate 7

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-8.–*Secuicollacta multispinosa. 1*, *2*, C20(1)#62, apical ray at 12 o'clock position; *3*, *4*, C20(3)#21; *5*, *6*, B48(1)#17, apical ray at 1 o'clock position; *7*, *8*, A44.5(3)#112.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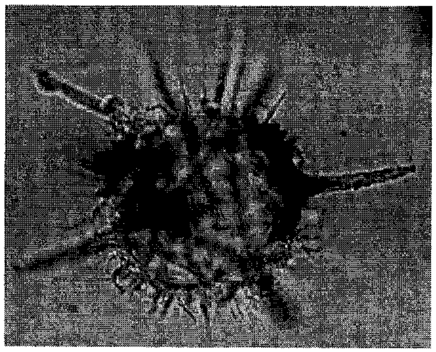
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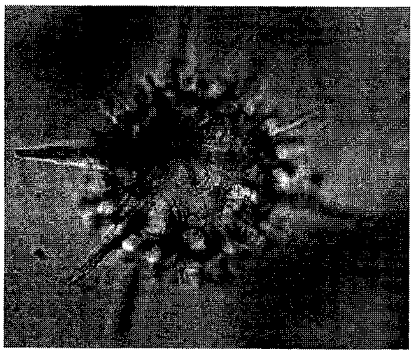
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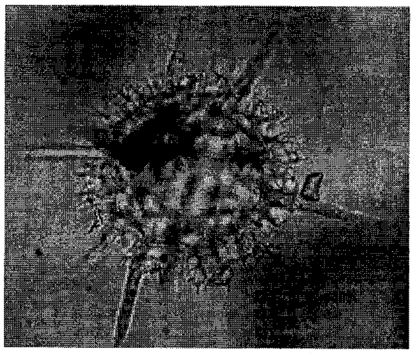
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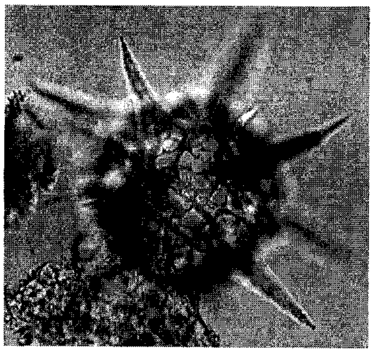
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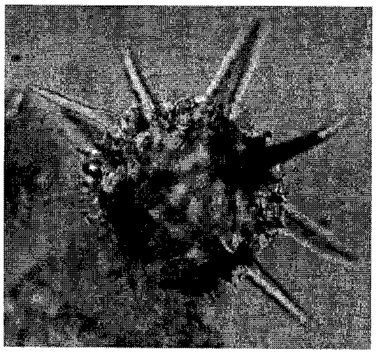
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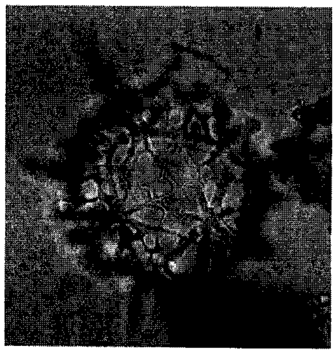
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8

Plate 7

Plate 8

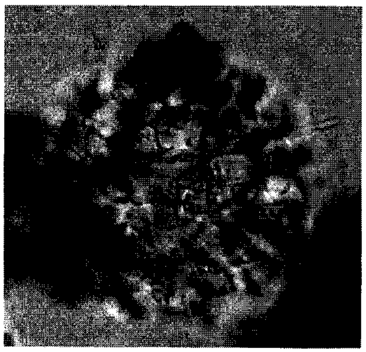
Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1, 2.–*Secuicollacta multispinosa*. A44.5(3)#82.

Figures 3, 6.–*Secuicollacta glaebosa*. C196(3)#202, finer construction and apparent labyrinthine material is suggestive of *S. multispinosa*.

Figure 4, 5, 7, 8.–*Secuicollacta parvitesta*. *4, 5*, A46.8(4)#290 ;*7, 8*, A46.8(3)#57.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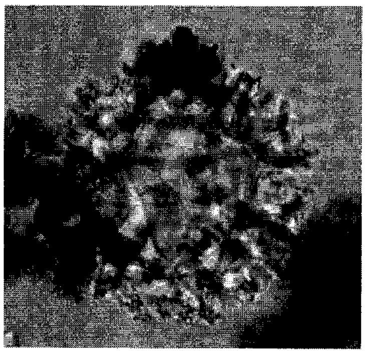
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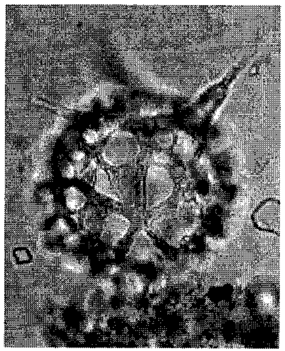
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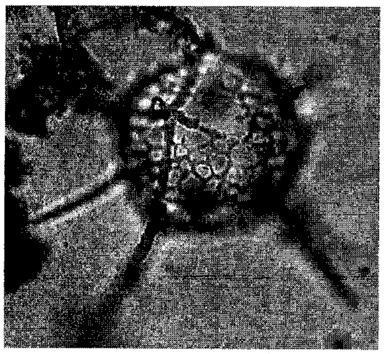
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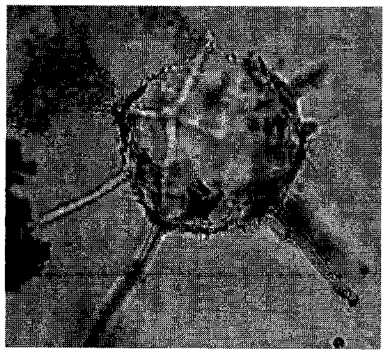
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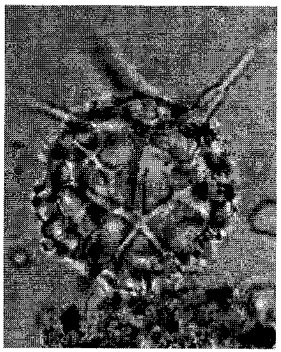
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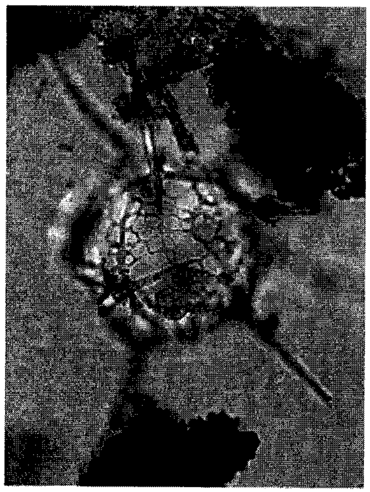
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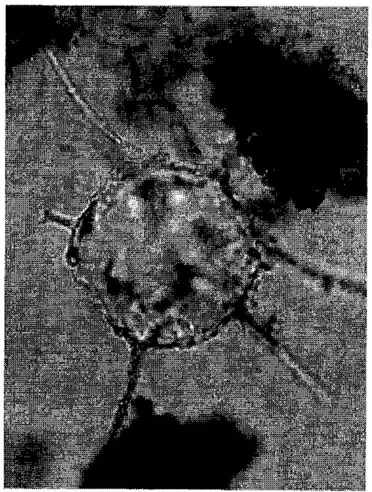
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Plate 8

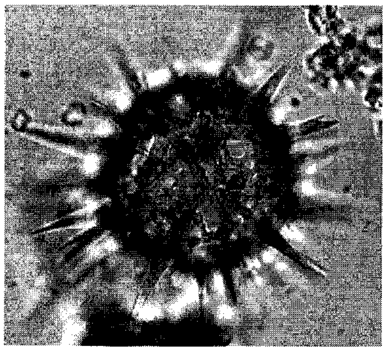
Plate 9

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-5.–*Secuicollacta resodiosae*. *1*, *2*, C42.3-42.4(1)#209; *3*, *4*, A71.1(4)#448; *5*, A71.1(4)#421.

Figure 6.–*Secuicollacta parvitesta*. A106.5(1)#4, apical spine at 9 o'clock position.



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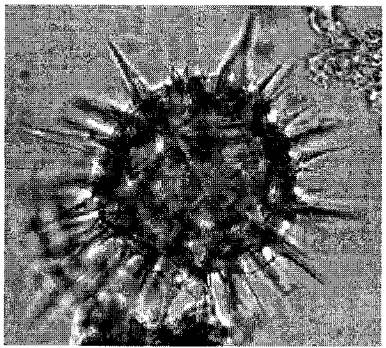

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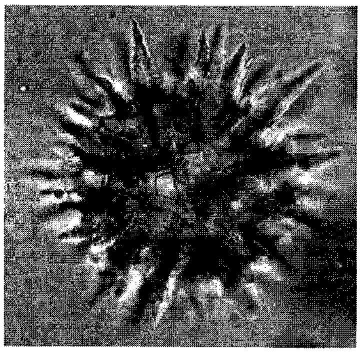

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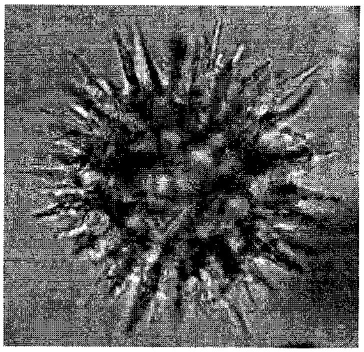

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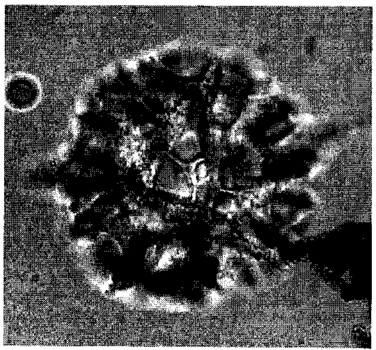

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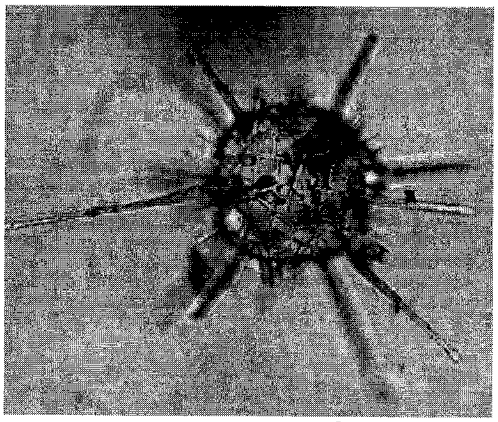

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Plate 9

Plate 10

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-4.–*Secuicolacta* cf. *S. resodiosae. 1*, *2*, C196(1)#353, junction of spicule rays in top right quadrant of specimen; *3*, *4*, C196(3)#316.

Figures 5-8.–*Secuicollacta* new species A. *5*, *6*, C216(3)#251; *7*, *8*, C213(3)#298, spicule at top edge of specimen.

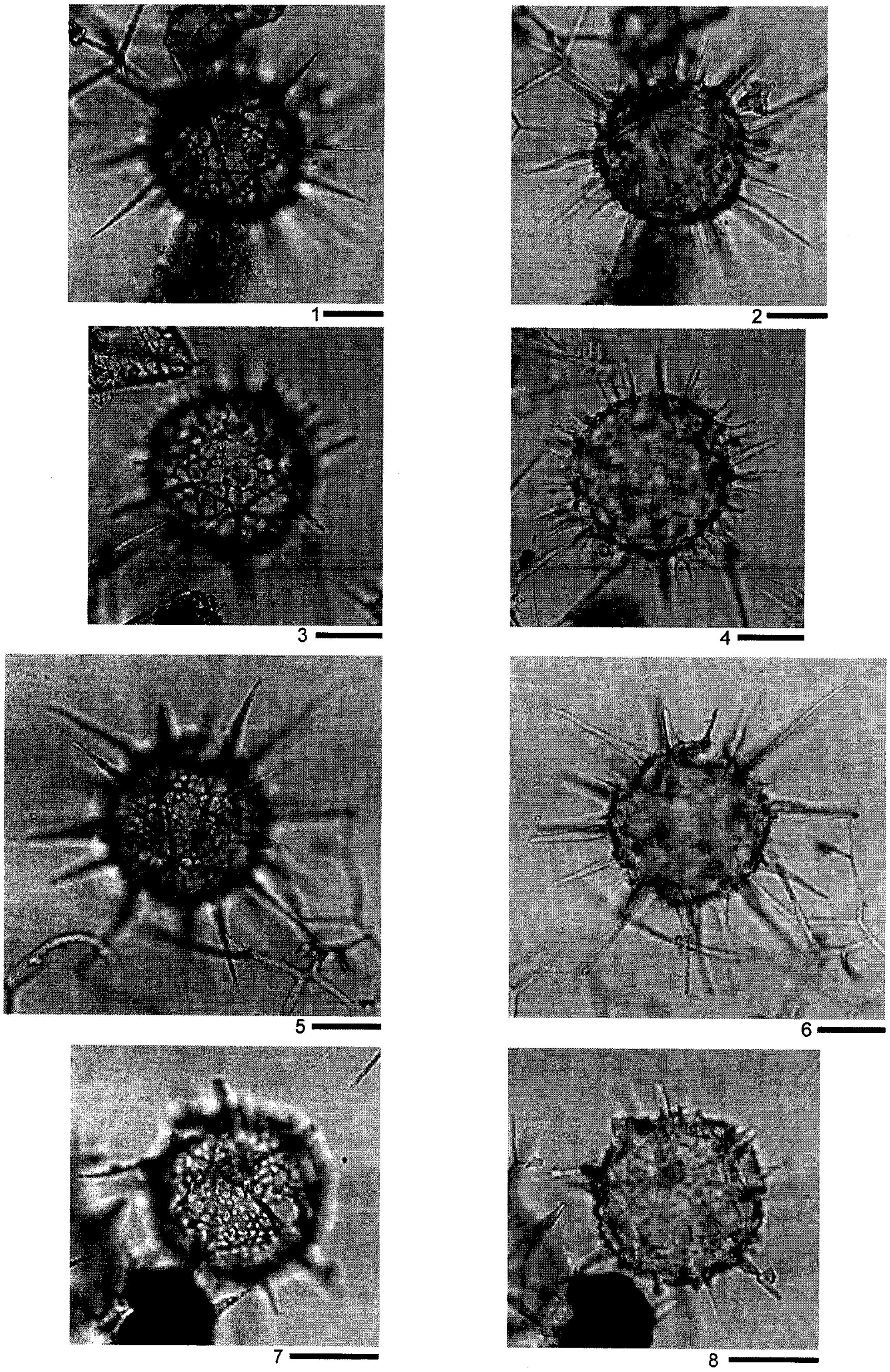


Plate 10

Plate 11

Transmitted light micrographs - *Secuicollacta*

All scale bars 50 μm

Figures 1-6.–*Secuicollacta sceptri*. *1*, *2*, C20(1)#68, spicule at top edge of specimen; *3*, C94.3(1)#72; *4*, B77.5(1)#183; *5*, *6*, C94.3(1)#72.

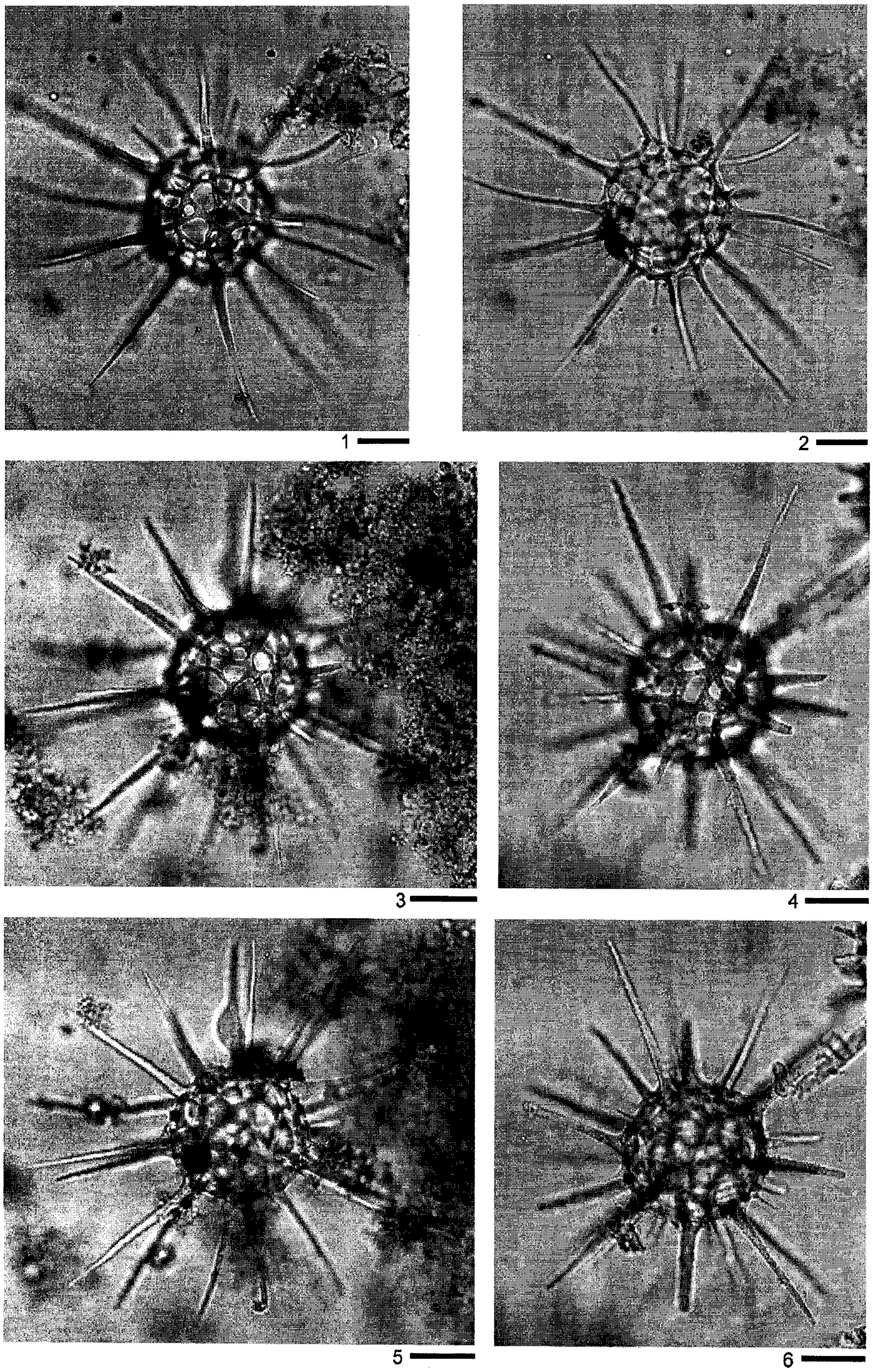


Plate 11

Plate 12

Scanning electron micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1-4.–*Diparvapila fleischerorum. 1*, C20alc8SE6/01; *2*, B42.2alc3SE17/01; *3*, cross-section through specimen, C94.331JL9/01; *4*, partially broken specimen revealing inner lattice shell, apical spine at 10 o'clock position, antapical spine at 4 o'clock position, B79#1JL4/01.

Figures 5-7.–*Diparvapila hicocki* forma A. *5*, C94.3#27JL9/01; *6*, more pronounced buttresses on spines, B42.2alc8SE17/01; *7*, more pronounced spine buttresses, more fully developed by-spines with laterally linking apophyses, B89.9#5JL4/01.

Figures 8, 9.–*Diparvapila hicocki* forma C. *8*, C94.3#31JL9/01; *9*, C20#13JL4/01.

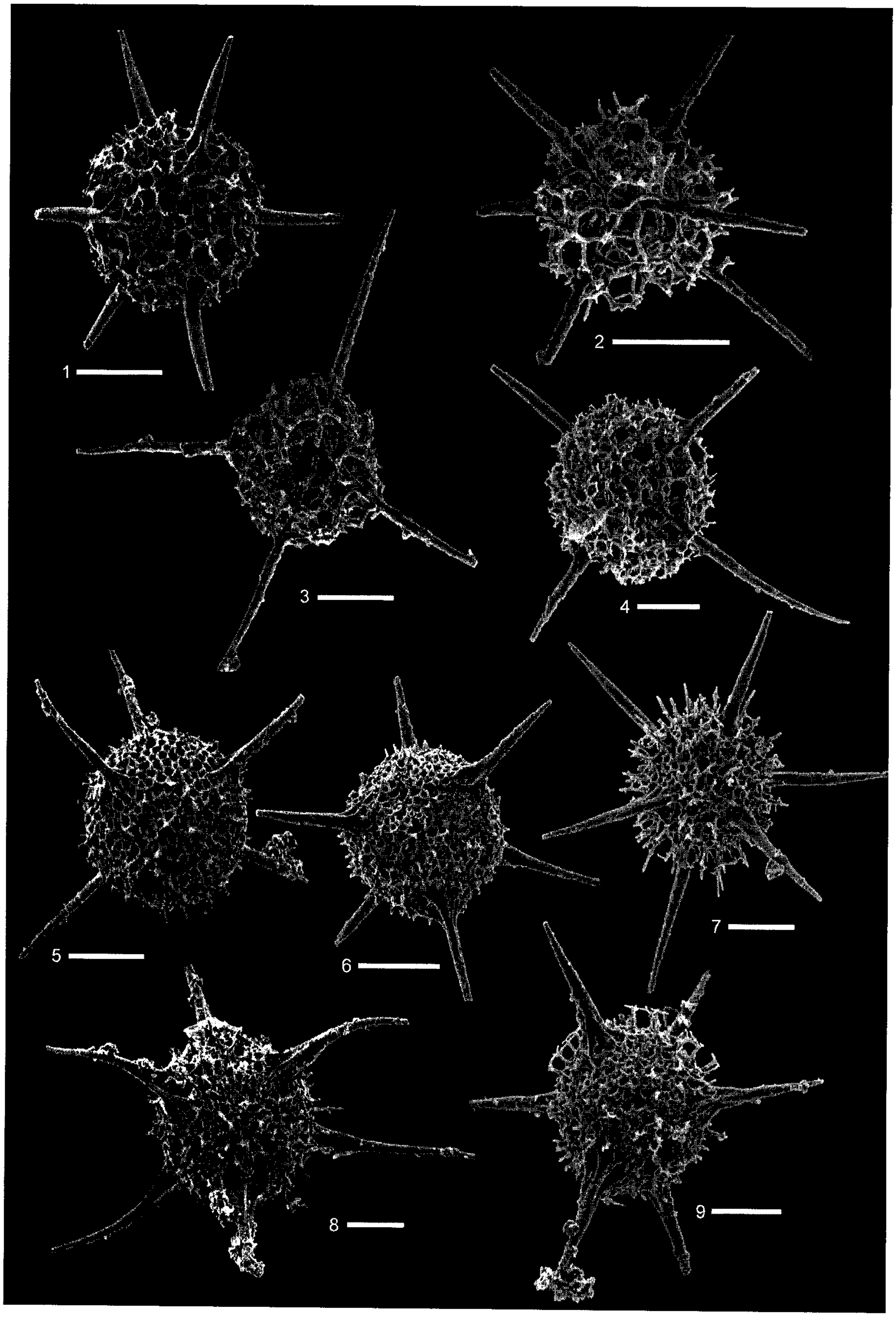


Plate 12

Plate 13

Scanning electron micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1-4.–*Diparvapila larseni*. *1*, by-spines lacking distal apophyses, C20alc6SE6/01; *2*, C42.3-42.4alc10SE6/01; *3*, lattice bars pass over each other plus labyrinthine development of by-spines, C42.2-42.4alc15SE6/01; *4*, cortical shell obscured by labyrinthine by-spines, C20alc11SE6/01.

Figures 5, 6.–*Diparvapila* new species A. *5*, paratype, B79alc1NO12/01; *6*, paratype, B79alc4NO12/01.

Figures 7, 8.–*Diparvapila* new species B. *7*, paratype, C50.7alc3NO12/01; *8*, paratype, C20alc5SE6/01.

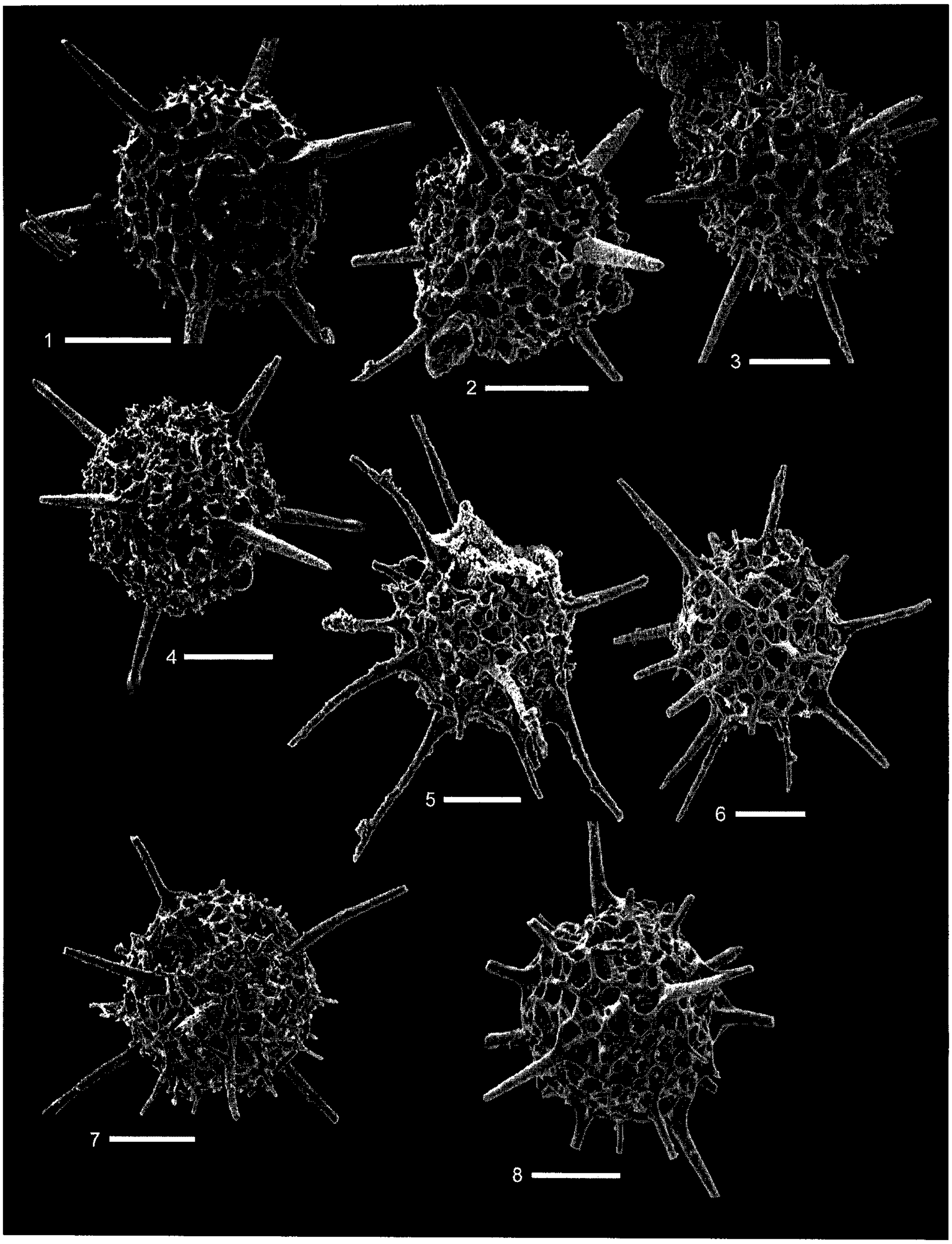


Plate 13

Plate 14

Transmitted light micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1-9.–*Diparvapila fleischerorum*. *1, 2*, A106.5(3)#177, apical ray at 3 o'clock position; *3, 4*, gap between lattice sphere and denser part of labyrinthine cover visible in optical section (*4*), B42.2(3)#285; *5*, optical section, crude multiple layers visible, B79(1)#157; *6, 7*, detail of lattice shell (*6*), thinly developed labyrinthine layer, C94(3)#310; *8, 9*, B79(1)#441.

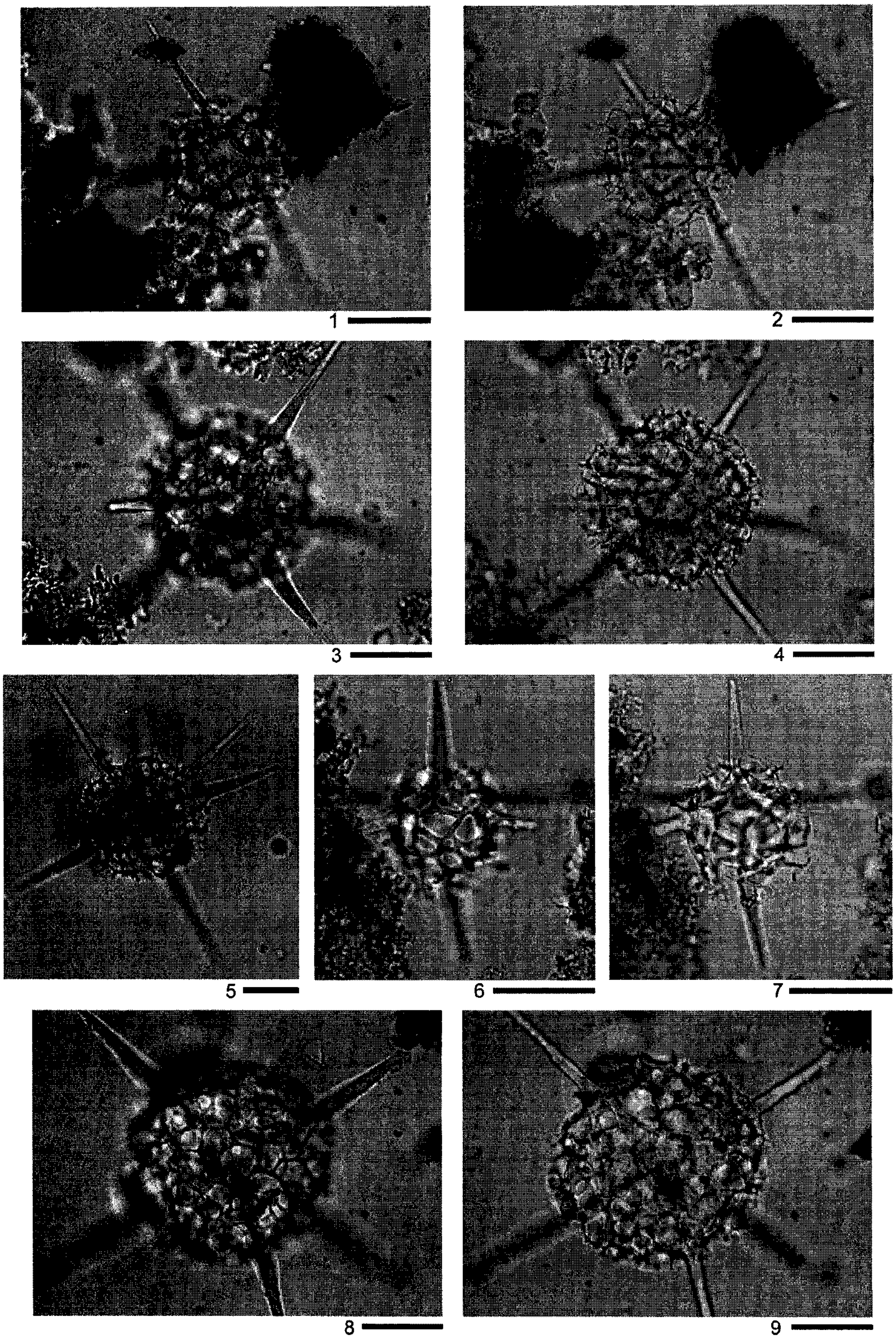


Plate 14

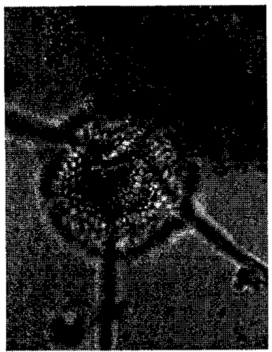
Plate 15

Transmitted light micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1-7.–*Diparvapila hicocki* forma A. *1, 4, 7*, simple development of by-spines, *4*, detail of medullary shell, C94.3(2)#358; *2, 5*, by-spines with distal apophyses, C20(1)#471; *3, 6*, complex by-spine development, apophyses linked to form weak second cortical, C20(1)#53.

Figures 8-11.–*Diparvapila hicocki* forma B. *8, 10*, branches off one basal ray and antapical spine visible in optical section (*10*), C20(1)#7; *9, 11*, branches visible off basal rays and antapical spine in optical section (*11*), B77.5(1)#402.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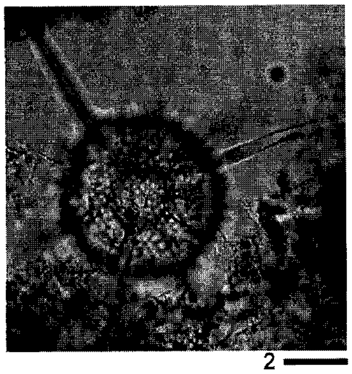
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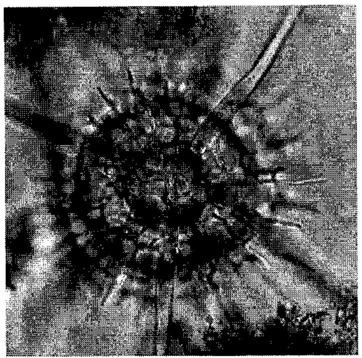
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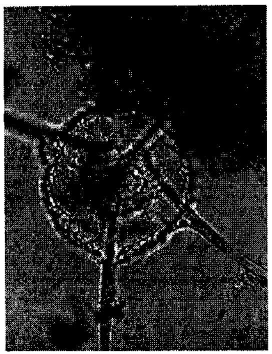
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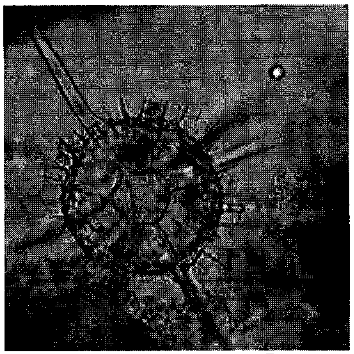
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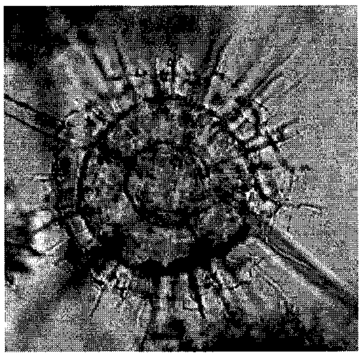
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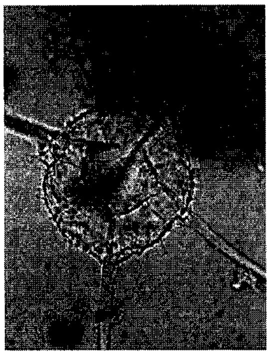
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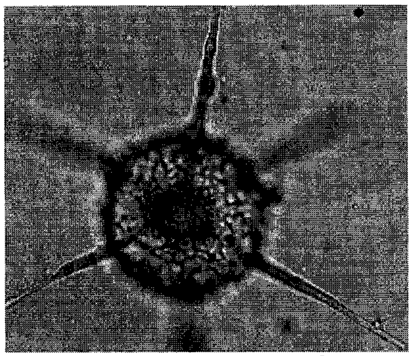
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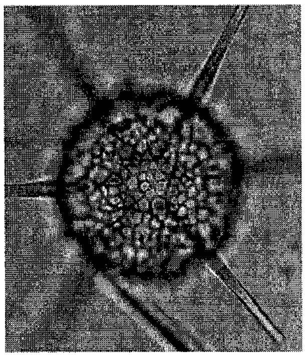
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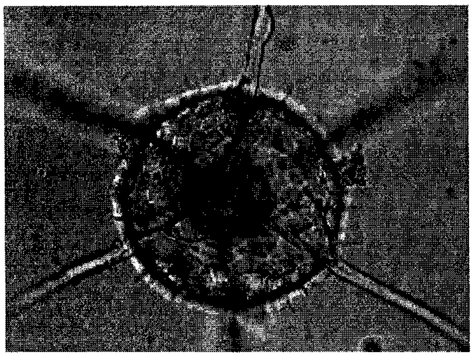
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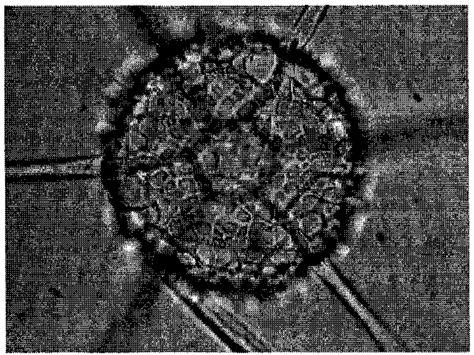
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Plate 15

Plate 16

Transmitted light micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1, 2.–*Diparvapila hicocki* forma C. B89.9(3)#184.

Figure 3.–*Diparvapila hicocki*. Form intermediate to formas A and C, apical spine strongly buttressed, C20(1)#469.

Figures 4-9.–*Diparvapila larseni*. *4, 5*, B79(3)#5; *6, 7*, by-spines developed as labyrinthine layer, B70(1)#238; *8, 9*, byspines linked to form second cortical shell, labyrinthine by-spines developed on second cortical, C20(3)#367.

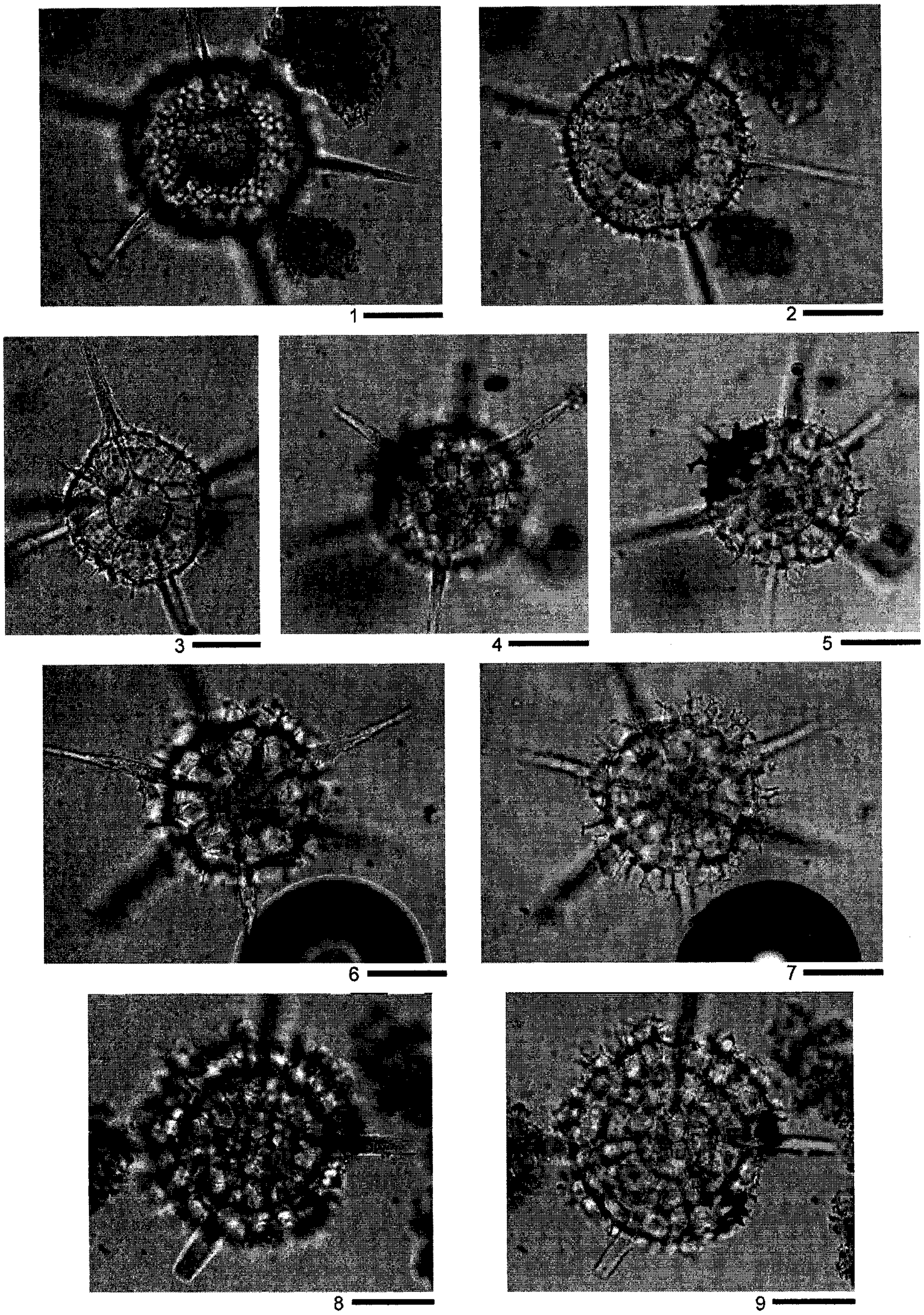


Plate 16

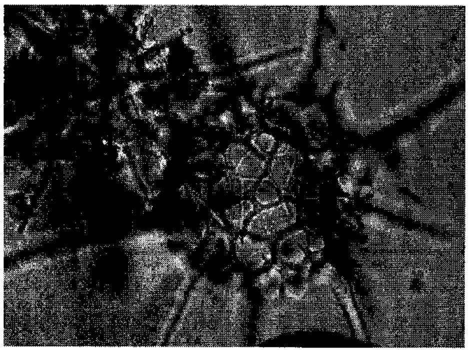
Plate 17

Transmitted light micrographs - *Diparvapila*

All scale bars 50 μm

Figures 1-4.–*Diparvapila* new species A. *1, 2*, holotype, B79(1)#42, apical spine at 2 o'clock position (*2*); *3, 4*, paratype B79(1)#377, *3*, focus on spicule.

Figures 5-6.–*Diparvapila* new species B. *5, 6*, holotype, C20(1)#176, apical spine at 11 o'clock position (*6*); *7, 8*, paratype, C20(1)#153, apical spine at 10 o'clock position (*8*).



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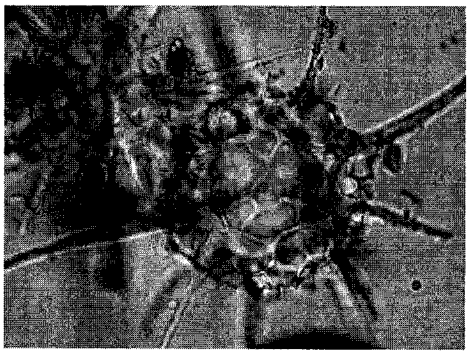

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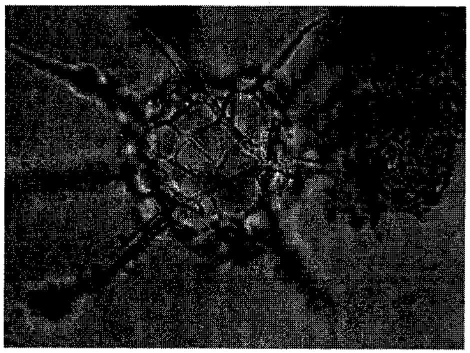

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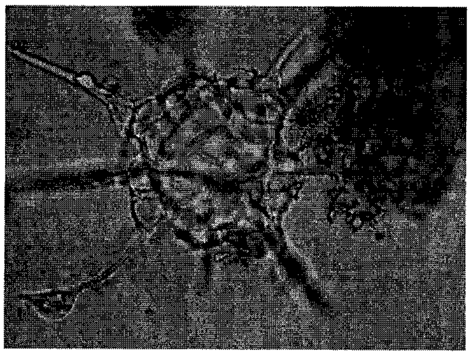

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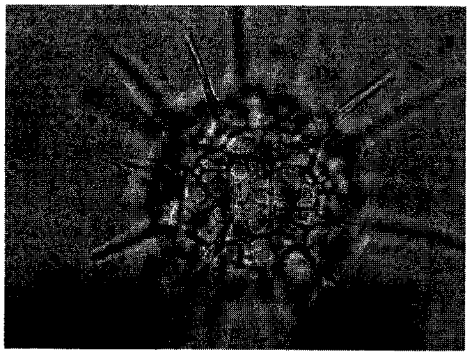

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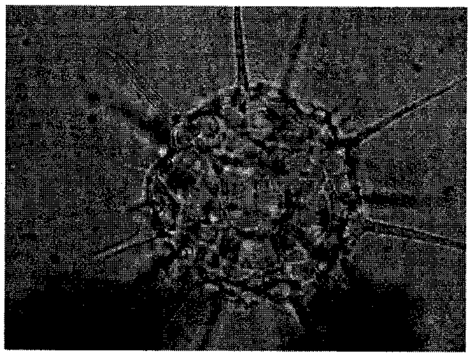

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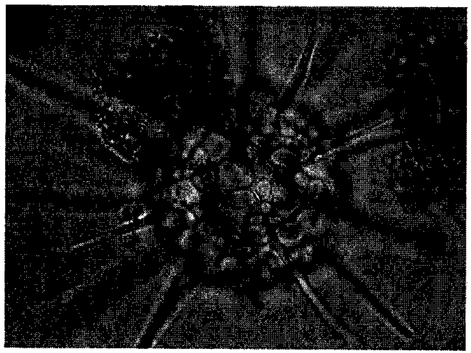

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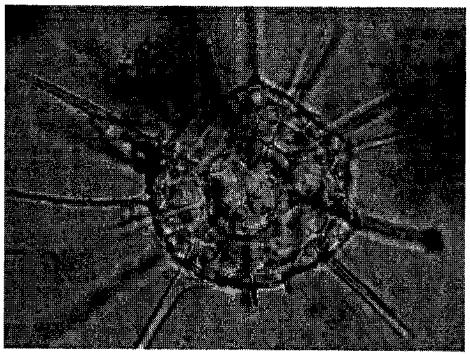

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Plate 17

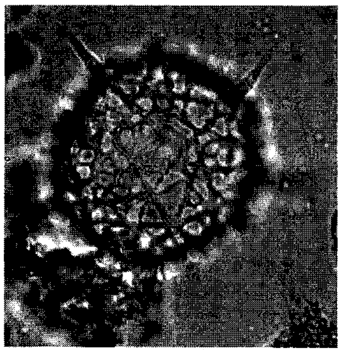
Plate 18

Transmitted light micrographs - *Rotasphaera*

All scale bars 50 μm

Figures 1-6.–*Rotasphaera severa. 1, 2,* B42.2(3)#207; *3, 4,* C167.7(3)#31; *5, 6,* C196(3)#286.

Figures 7, 8.–*Rotasphaera* species A. C196(3)#153.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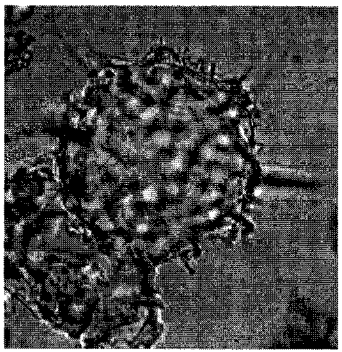
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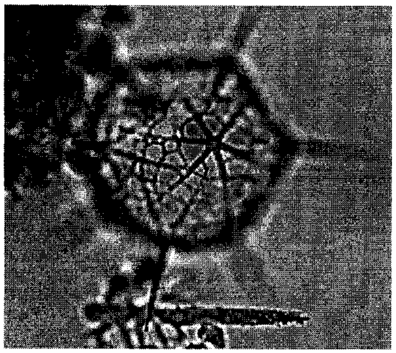
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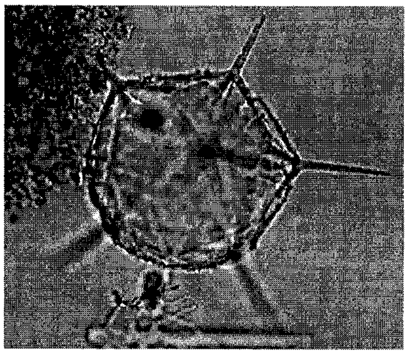
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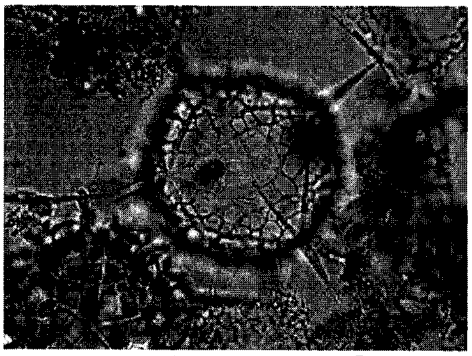
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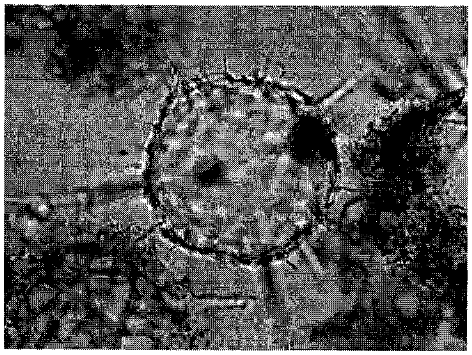
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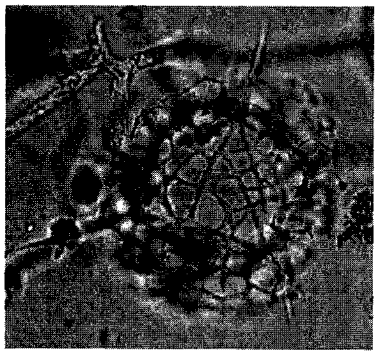
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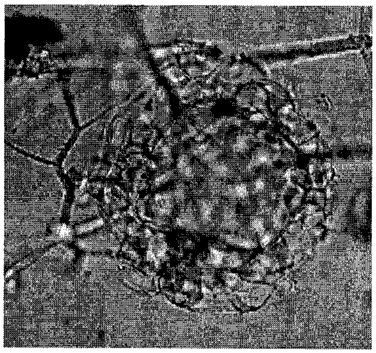
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Plate 18

Plate 19

Transmitted light micrographs - *Rotasphaera*

All scale bars 50 μm

Figures 1-4, 6, 7.–*Rotasphaera* species A. *1*, *2*, C20(3)#122; *3*, *6*, C20(3)#188; *4*, *7*, B89.9(4)#359.

Figures 5, 8-11.–*Rotasphaera* species B. *5*, *8*, *10*, C20(1)#374; *9*, *11*, C20(1)#95.

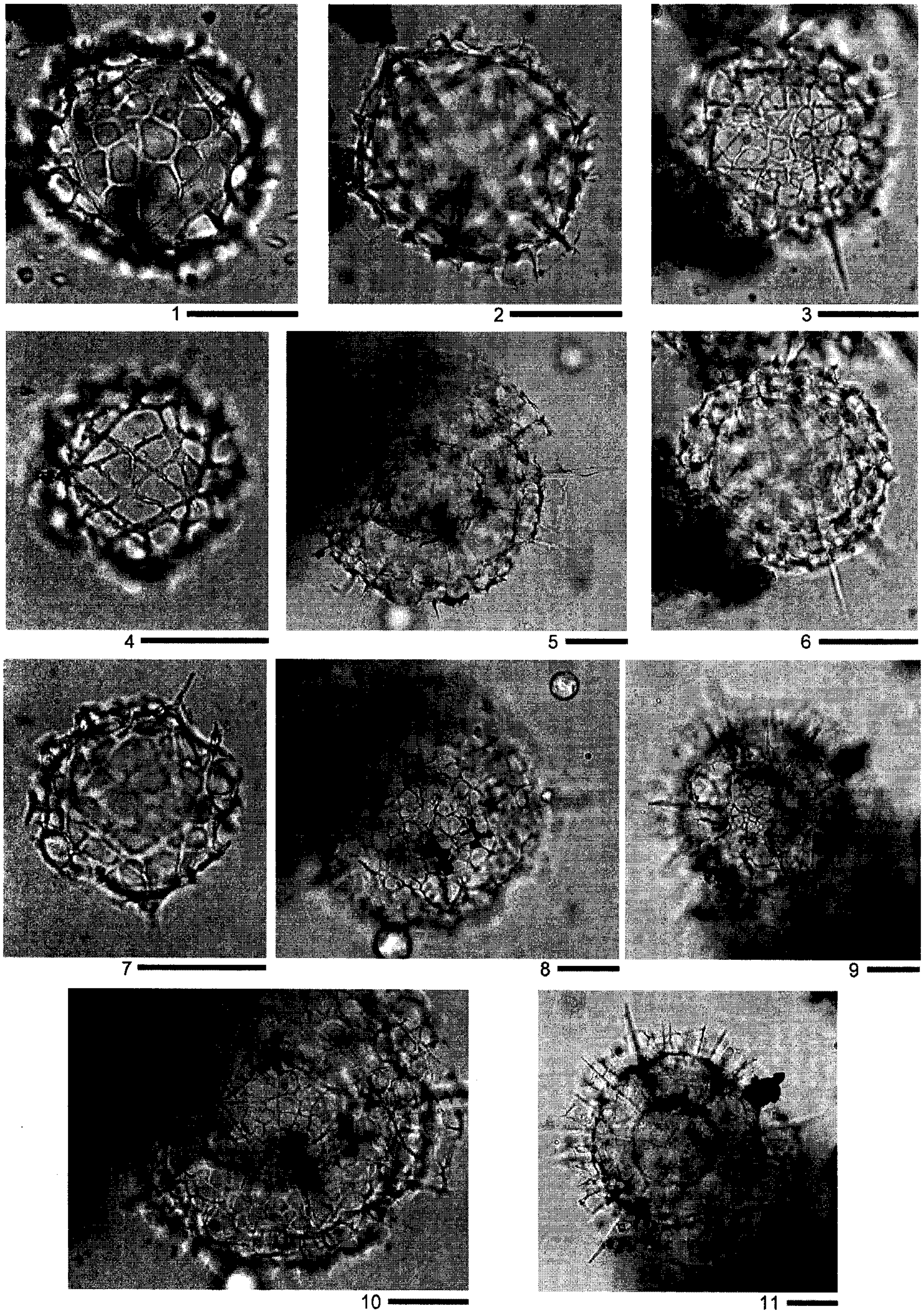


Plate 19

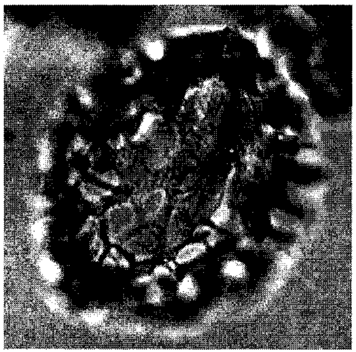
Plate 20

Transmitted light micrographs - *Rotasphaera*

All scale bars 50 μm

Figures 1-3, 6-9.–*Rotasphaera* species C forma 1. *1*, *2*, A106.5(3)#39; *3*, *6*, B79(3)#3; *7*, *8*, B48(2)#376; *9*, C130.8(2)#305.

Figures 4, 5, 10, 11.–*Rotasphaera* species C forma 2. *4*, *5*, B42.2(3)#53; *10*, *11*, B79(3)#190.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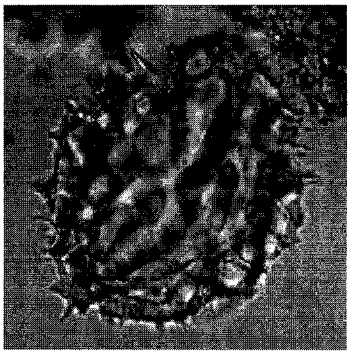
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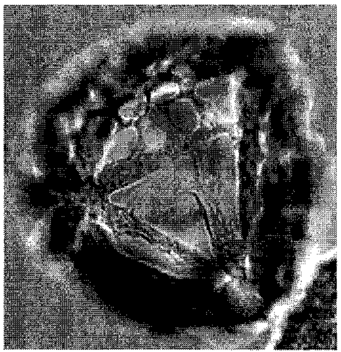
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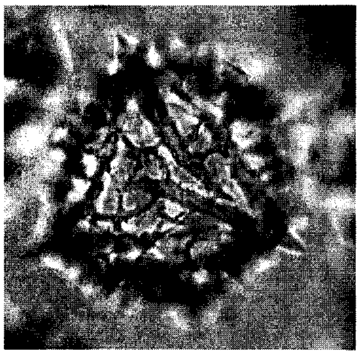
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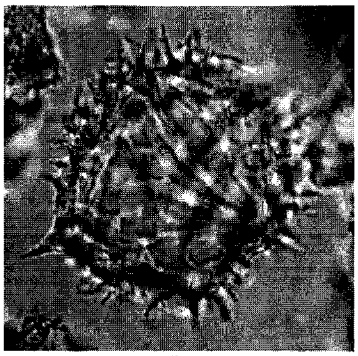
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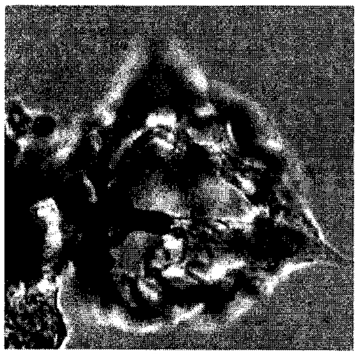
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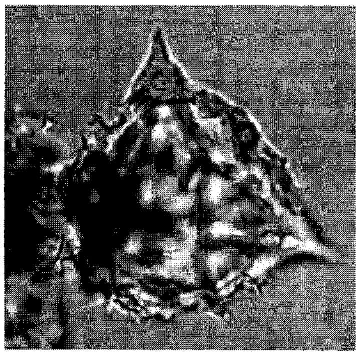
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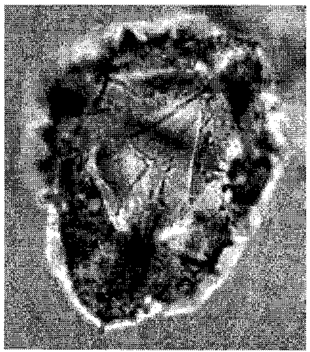
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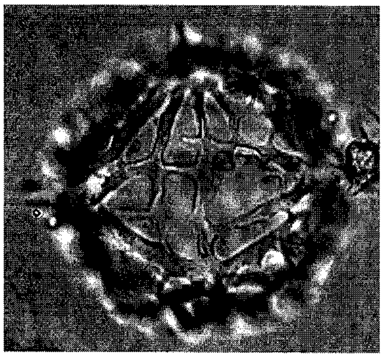
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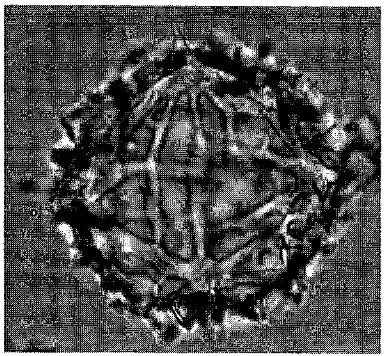
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Plate 20

Plate 21

Scanning electron micrographs - *Goodbodium*, *Insolitignum*

All scale bars 50 μm

Figures 1, 2.–*Goodbodium flammatum*. *1*, GSC 124730, *2*, GSC 124731.

Figures 3-12.–*Insolitignum cancellatum*; *3, 4*, three apical and three basal rays, GSC 124735 (*3*), GSC 124736 (*4*); *5*, GSC 124737, two apical rays, three basal rays, and one intermediated ray; *6*, GSC 124738, two apical and four basal rays; *7*, *10*, GSC 124739, four apical and four basal rays; *8*, *11*, GSC 124740, four apical rays, three basal rays, one intermediate ray; *9*, *12*, GSC 124741, four apical rays, three basal rays, one intermediate ray

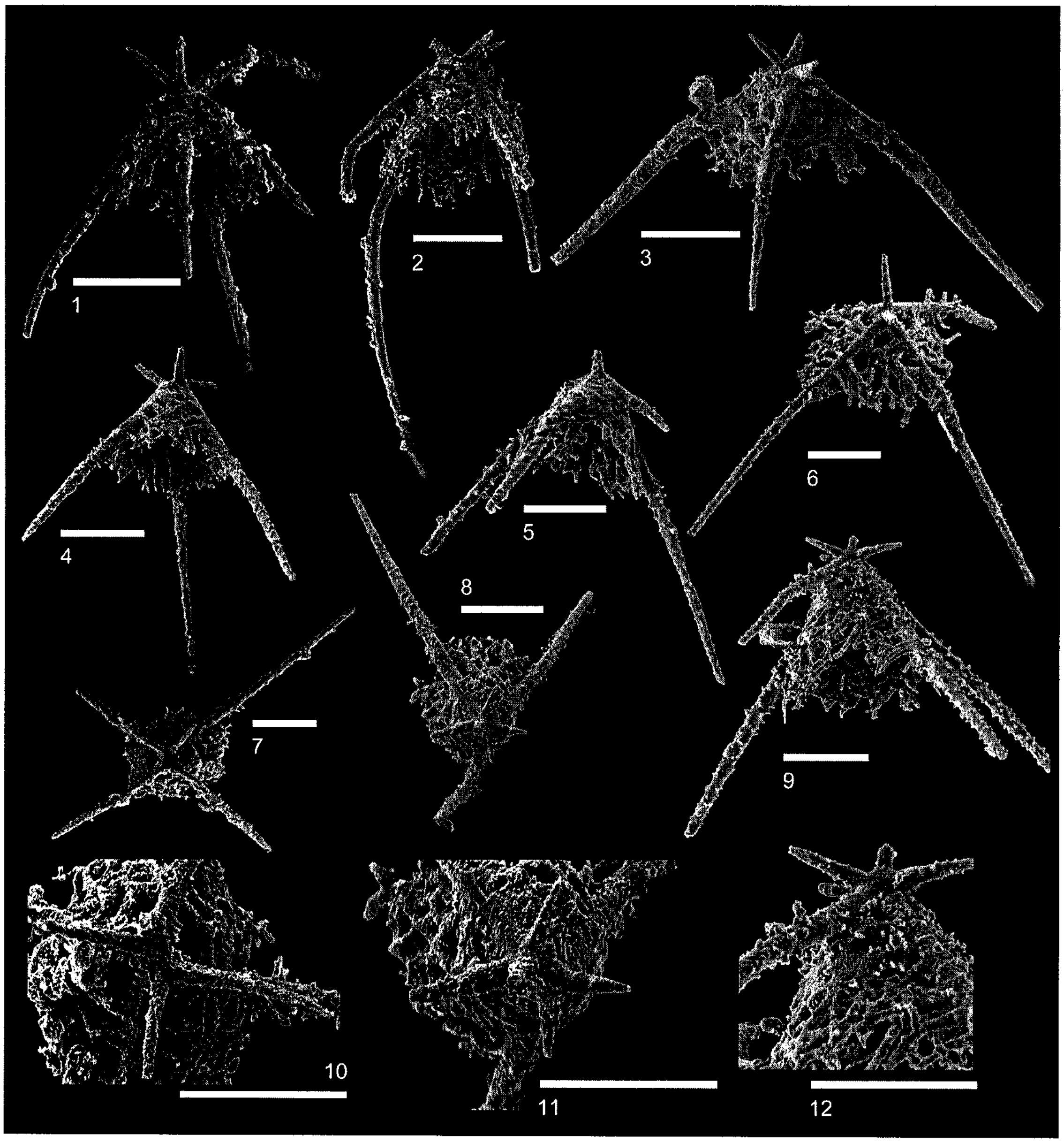


Plate 21

Plate 22

Scanning electron micrographs - *Insolitignum*, *Palaeodecaradium*,*Palaeoephippium*
All scale bars 50 μm

Figure 1-3.–*Insolitignum dissimile*. *1*, *2*, forma 1, GSC 124745 (*1*), GSC 124746 (*2*); *3*, forma 2, GSC 124747.

Figures 4, 5.–*Insolitignum vivanima*. *4*, GSC 124753; *5*, GSC 124754.

Figures 6, 7.–*Palaeodecaradium apertum*. *6*, GSC 124757; *7*, GSC 124758.

Figure 8.–*Palaeodecaradium gordoni* new species. Paratype, GSC 124724.

Figures 9, 10.–*Palaeodecaradium umbelliforme*. *9*, GSC 124760, ten-rayed form; *10*, GSC 124761, nine-rayed form.

Figures 11-13.–*Palaeoephippium bifurcum*. *11*, GSC 124765, three apical and three basal rays; *12*, GSC 124766, two apical and four basal rays; *13*, 13, GSC 124767, four apical and four basal rays.

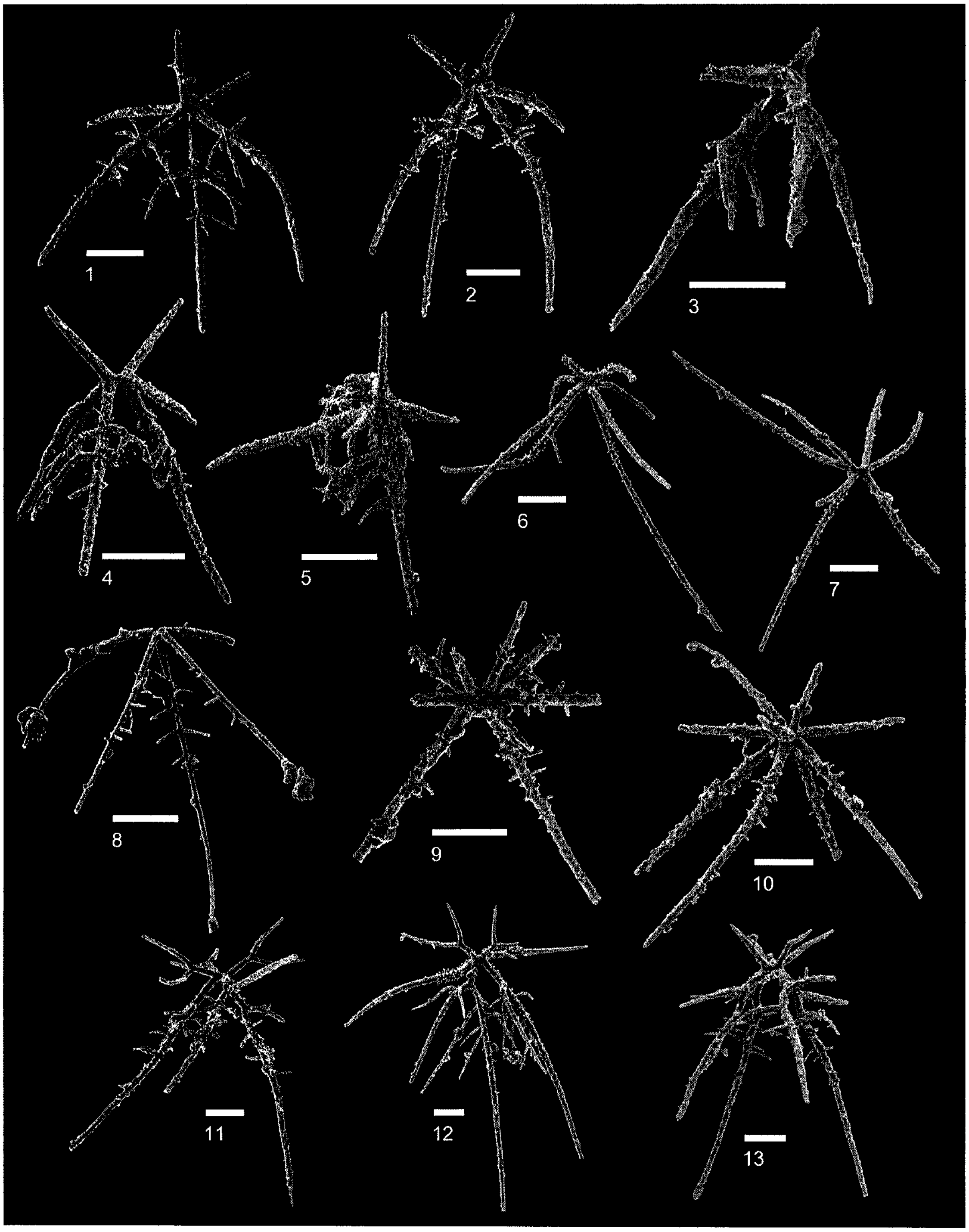


Plate 22

Plate 23

Scanning electron micrographs - *Palaeoephippium*, *Palaeopyramidium*, *Protoentactinia*

All scale bars 50 μm

Figures 1-4.–*Palaeoephippium radices. 1*, GSC 124771, three apical and three basal rays; *2*, GSC 124772, two apical and four basal rays; *3*, GSC 124773, two apical and four basal rays, some basal ray branches link; *4*, GSC 124774, four apical and four basal rays.

Figures 5, 6.–*Palaeoephippium spinosum. 5*, GSC 124780, three apical and three basal rays; *6*, GSC 124781, two apical and four basal rays.

Figure 7.–*Palaeopyramidium spinosum.* GSC 124786.

Figure 8.–*Protoentactinia tricorne.* GSC 124788.

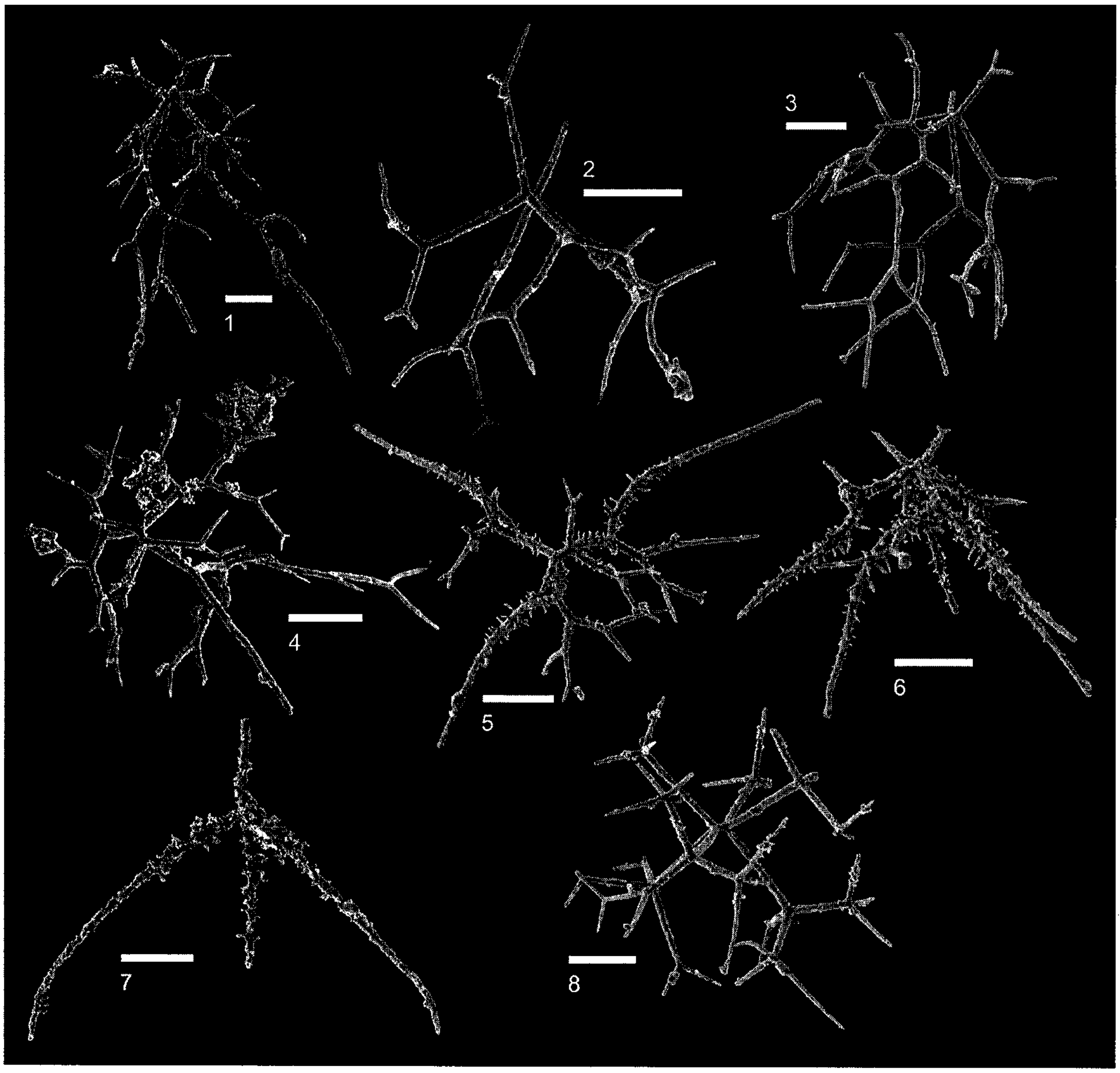


Plate 23

Plate 24

Transmitted light micrographs - *Goodbodium*, *Insolitignum*, *Palaeodecaradium*

All scale bars 50 μm

Figure 1.–*Goodbodium flammatum*. GSC 124732.

Figures 2, 3.–*Goodbodium rarispinosum*. *2*, GSC 124733; *3*, GSC 124734.

Figures 4, 7, 10-12.–*Insolitignum dissimile*. *4, 7*, four apical rays, GSC 124748 (*4*), GSC 124749 (*7*); *10*, GSC 124750, forma 1; *11*, GSC 124751, intermediate to formas 1 and 2; *12*, GSC 124752, forma 2.

Figures 5, 6, 8, 9.–*Insolitignum cancellatum*. *5*, GSC 124742, two apical rays, three basal rays, one intermediate ray lengthened to mimic a basal ray; *6*, GSC 124743, four apical and four basal rays; *8, 9,* GSC 124744, four apical rays, three basal rays, one intermediate ray.

Figures 13, 14.–*Insolitignum vivanima*. *13*, GSC 124755, three apical rays, three basal rays, one intermediate ray (hidden behind left basal ray), spine bisecting specimen across median bar is from an adjacent radiolarian; *14*, GSC 124756.

Figure 15.–*Palaeodecaradium apertum*. GSC 124759.

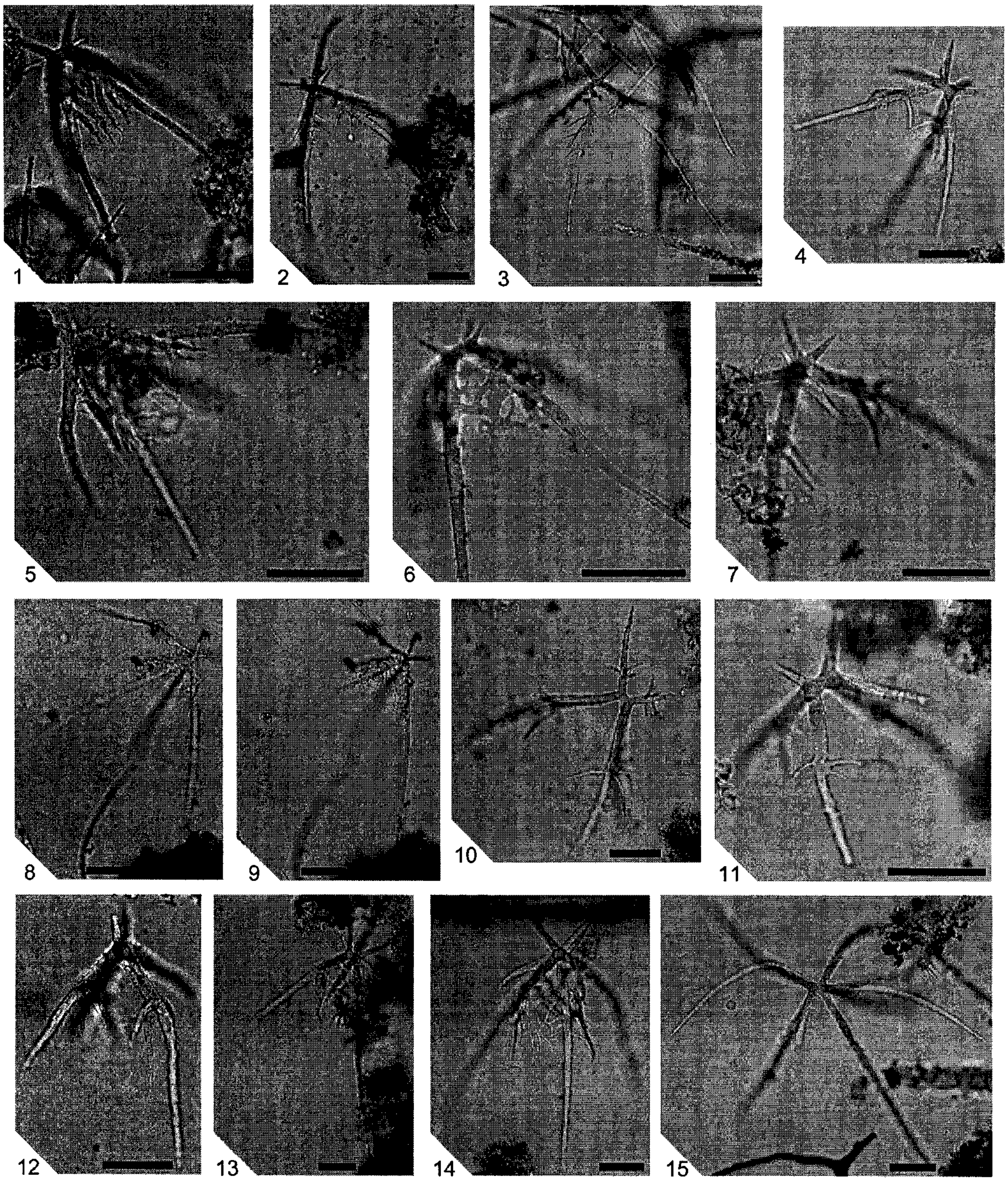


Plate 24

Plate 25

Transmitted light micrographs - *Palaeodecaradium*, *Palaeoephippium*

All scale bars 50 μm

Figures 1, 2, 4.–*Palaeodecaradium gordoni* new species. *1*, GSC 124722, paratype; *2*, GSC 124721, holotype; *4*, GSC 124723, paratype.

Figures 3, 6, 9.–*Palaeodecaradium umbelliforme. 3*, GSC 124762, ten-ray form; *6*, GSC 124763, eleven-ray form; *9*, GSC 124764, twelve-ray form.

Figures 5, 7, 8.–*Palaeoephippium bifurcum. 5*, GSC 124768, three apical and three basal rays; *7*, GSC 124769, three apical rays, three basal rays, two intermediate rays; *8*, GSC 124779, two apical and four basal rays,.

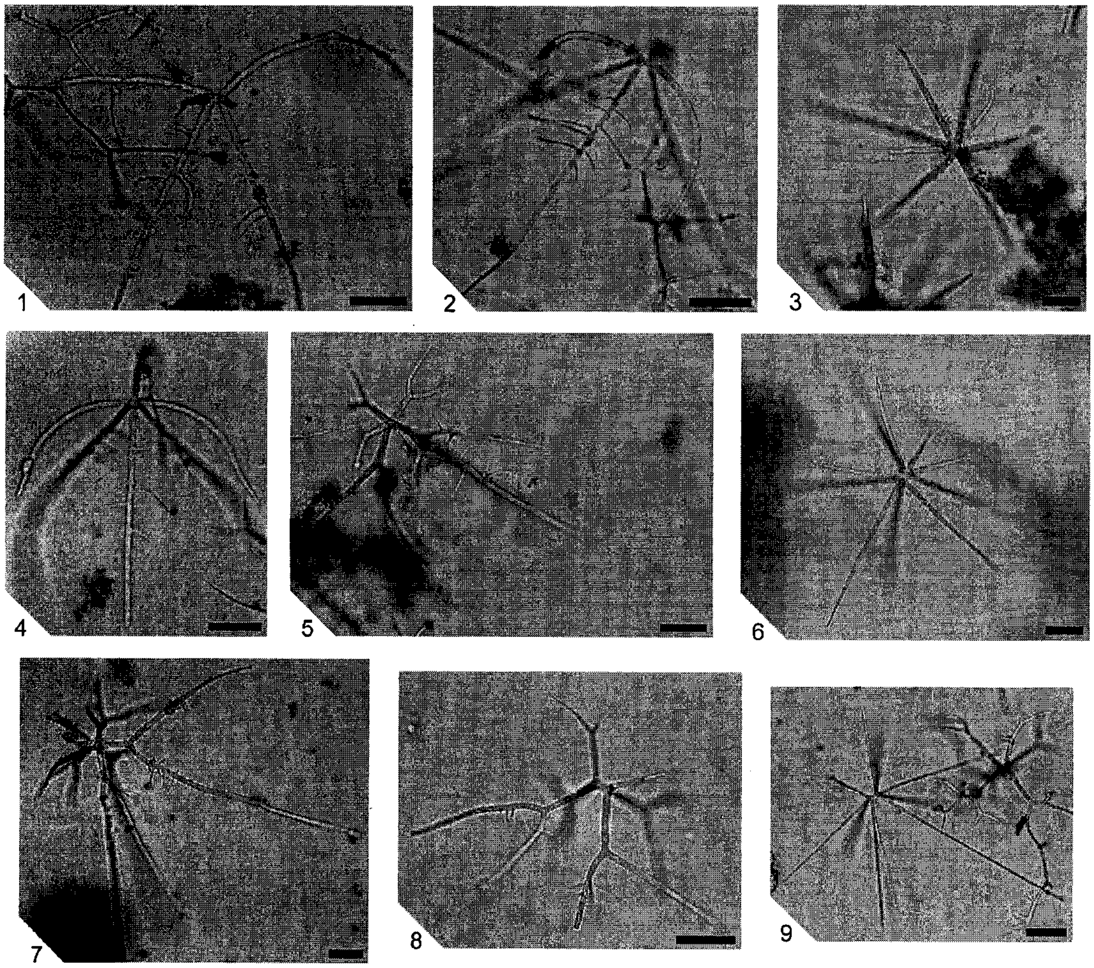


Plate 25

Plate 26

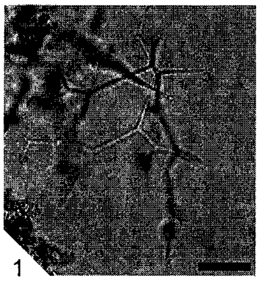
Transmitted light micrographs - *Palaeoephippium*, *Palaeopyramidium*

All scale bars 50 μm

Figures 1-5.–*Palaeoephippium radices*. *1*, GSC 124775, three apical and three basal rays; *2*, GSC 124776, two apical rays, three basal rays, one intermediate ray, basal ray branches link; *3*, GSC 124777, four apical and four basal rays; *4*, GSC 124778, two apical and four basal rays, some basal ray branches link; *5*, GSC 124779, two apical and two basal rays.

Figures 6-9.–*Palaeoephippium spinosum*. *6*, GSC 124782, three apical and three basal rays; *7*, GSC 124783, two apical and four basal rays; *8*, GSC 124784, two apical and four basal rays, no microspinulation; *9*, GSC 124785, four apical and four basal rays.

Figure 10.–*Palaeopyramidium spinosum*. GSC 124787.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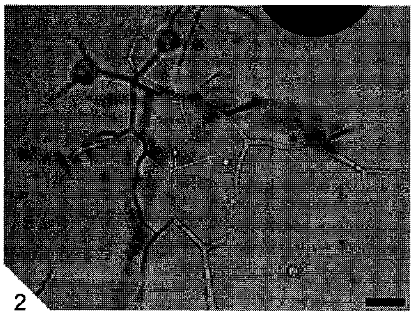
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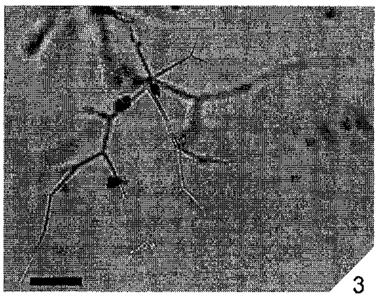
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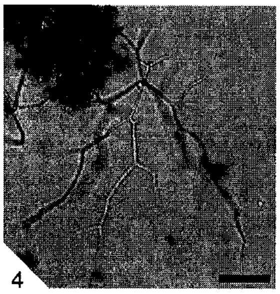
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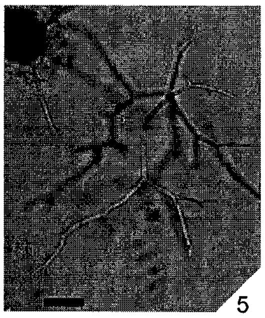
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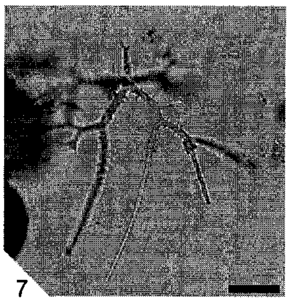
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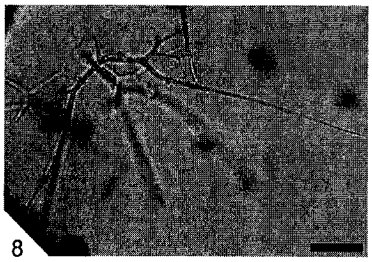
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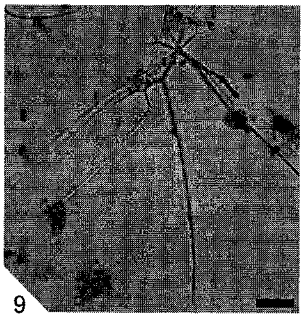
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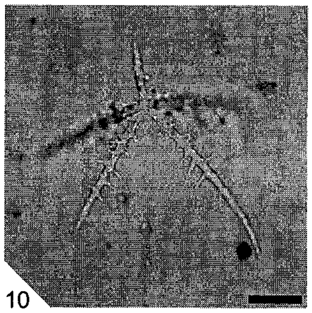
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Plate 26

Plate 27

Scanning electron micrographs - *Haplotaeniatum*

All scale bars 50 μm

Figures 1-4.–*Haplotaeniatum adobensis*. *1*, A71.1#1DE4/01; *2*, A85.2#1DE4/01, note numerous large pores; *3*, A85.2#4DE4/01, note hispid by-spines; *4*, A71.1#2DE4/01.

Figures 5-7.–*Haplotaeniatum ?labyrintheum*. *5*, A46.8#2DE4/01; *6*, A46.8#6DE4/01; A46.8#4DE4/01.

Figures 8-10.–*Haplotaeniatum* species C. *8*, A44.5#7NO12/01; *9, 10*, A44.5#6NO12/01, (*10*) close-up of one of the internal layers.

Figures 11-13.–*Haplotaeniatum* species A. *11*, C42.3-42.4#36JL5/01; *12*, C42.3-42.4#39JL5/01; *13*, C42.3-42.4#37JL5/01.

Figures 14, 15.–*Haplotaeniatum* species B. *14*, C20#45JL5/01; *15*, C20#45JL5/01.

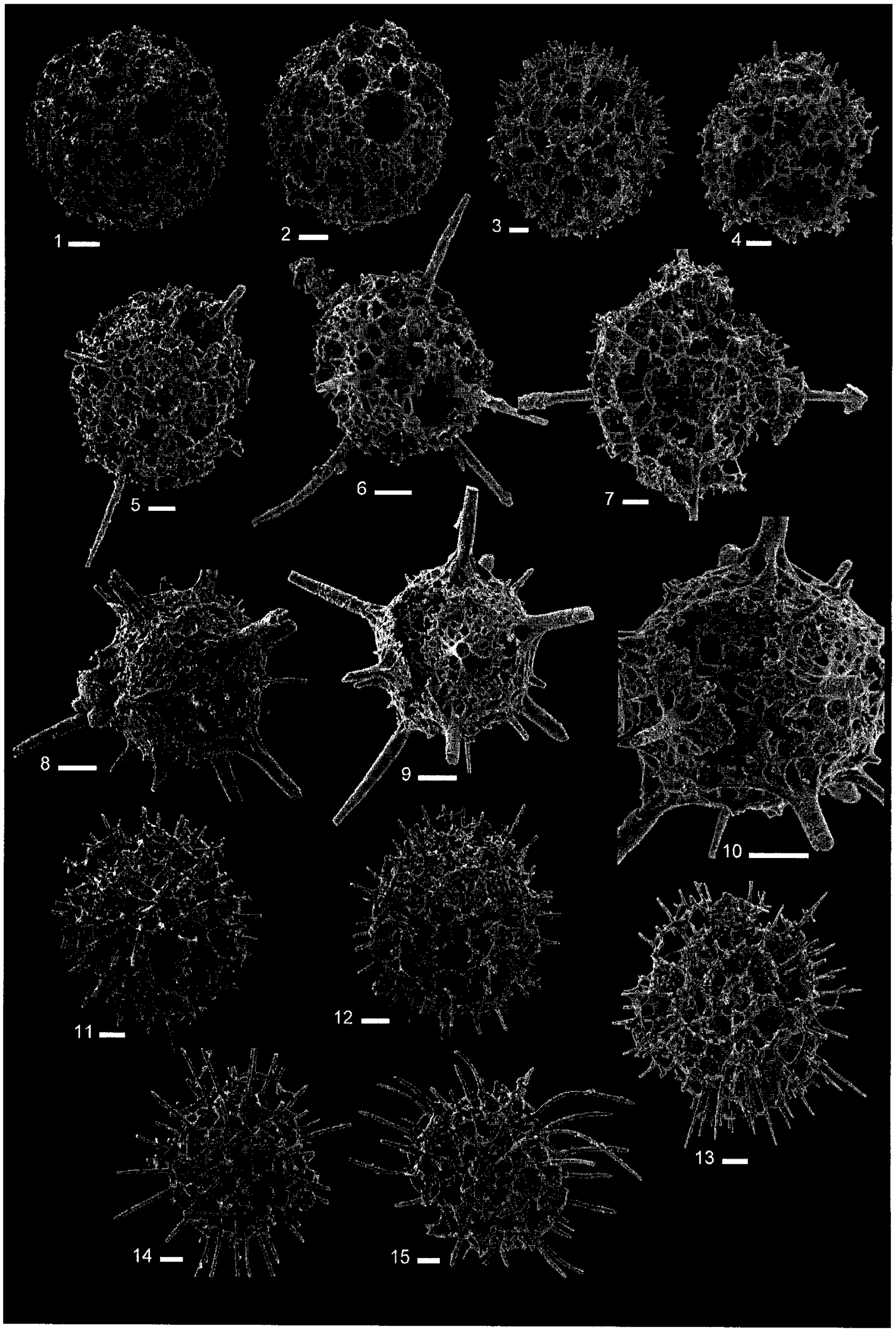


Plate 27

Plate 28

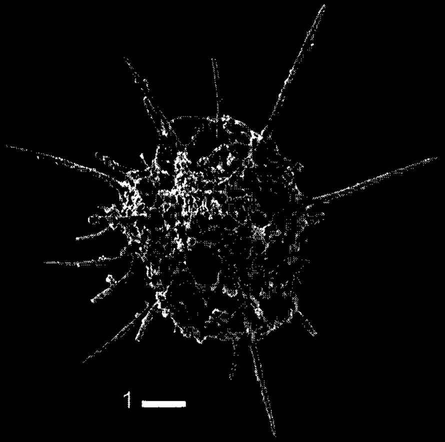
Scanning electron micrographs - *Haplotaeniatum*, *Orbiculopylorum*

All scale bars 50 μm

Figures 1, 2.–*Haplotaeniatum* cf. *H. raneatela*, C94.3#55JL10/01.

Figures 3-5.–*Orbiculopylorum* cf. *O. marginatum*. *3*, A71.1#4NO12/01; *4*, A71.1#5NO12/01; *5*, A71.1#6NO12/01.

Figures 6-8.–*Orbiculopylorum* species A. *6*, A42.5#6NO12/01; *7*, A42.5NO12/01; *8*, A42.5#7NO12/01.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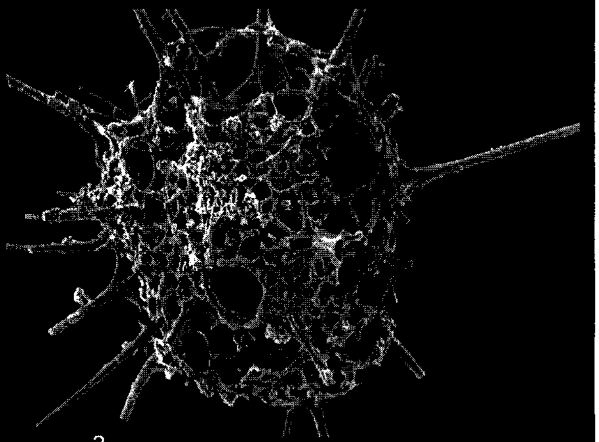
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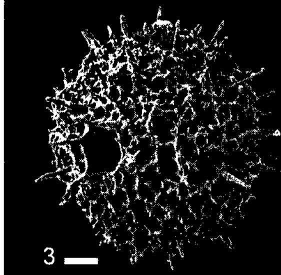
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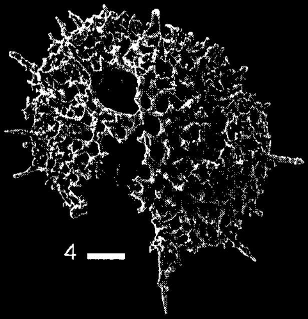
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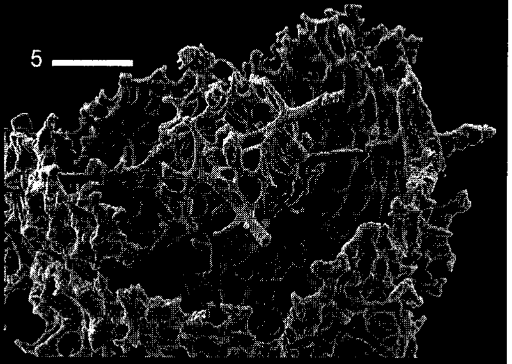
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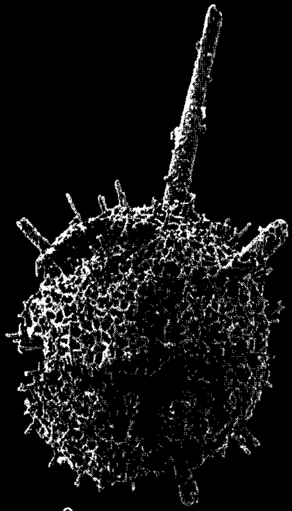
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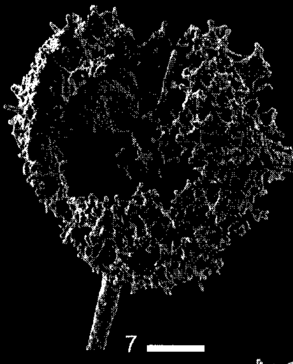
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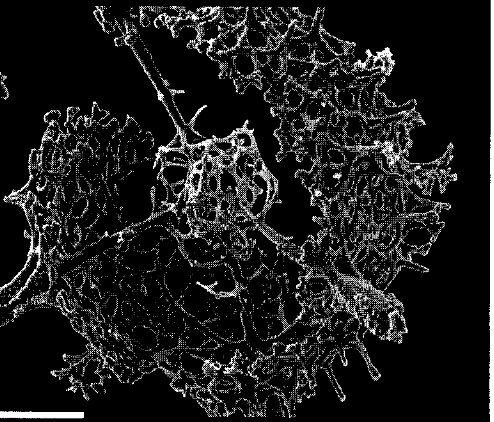
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Plate 28

Plate 29

Scanning electron micrographs - *Orbiculopylorum*, ?*Orbiculopylorum*

All scale bars 50 μm

Figures 1-6.–*Orbiculopylorum* species B. *1*, forma 1, A42.5#1NO12/01; *2*, forma 1, A51.2#1NO12/01; *3, 5*, forma 1, A46.8#1NO12/01; *4*, forma 2, A44.5#5NO12/01; *6*, forma 2, A44.5#4NO12/01.

Figures 7-9.–?*Orbiculopylorum* species D. *7*, A31.9#1JA3/02; *8*, A31.9#6JA3/02; *9*, A31.9#4JA3/02.

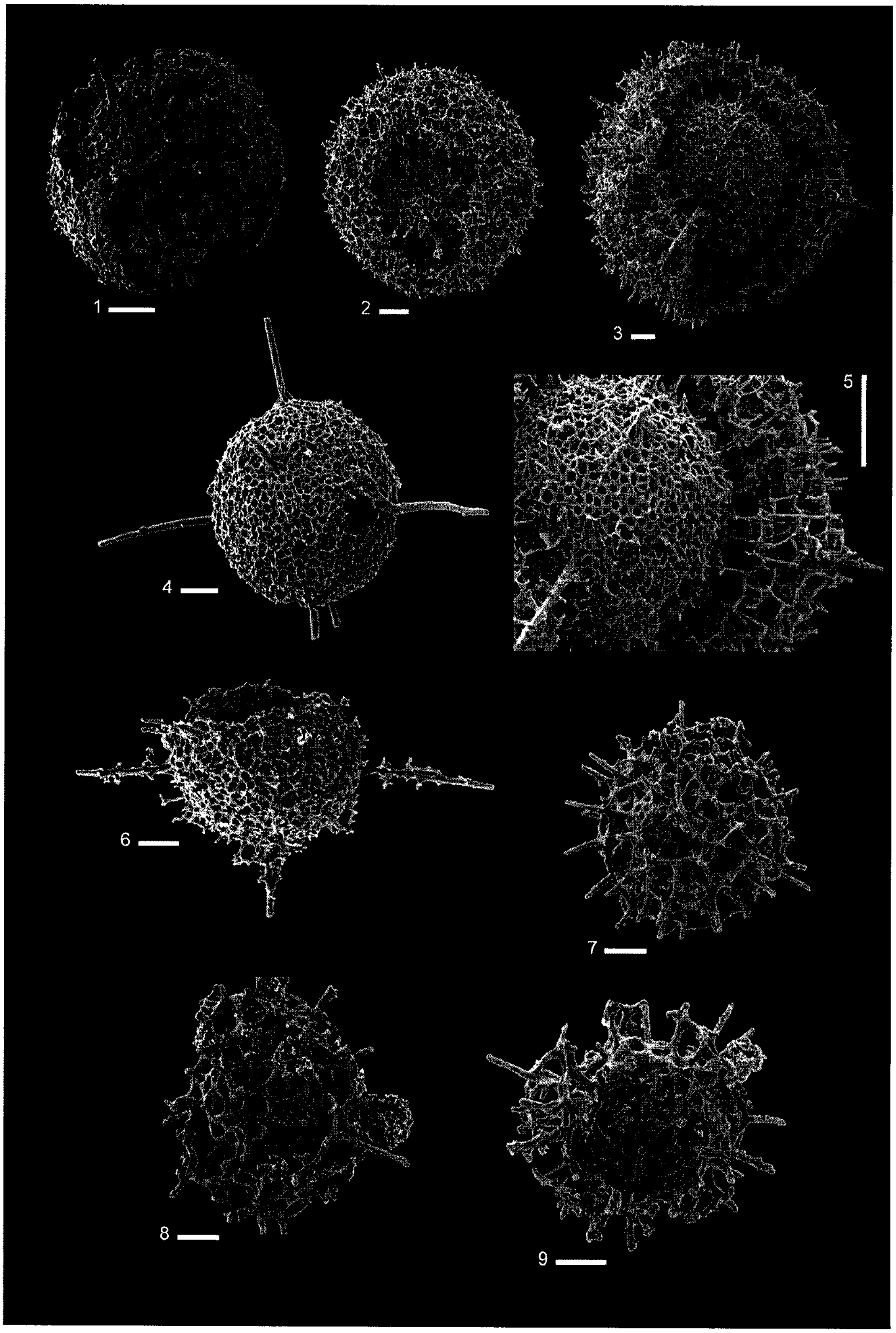


Plate 29

Plate 30

Scanning electron micrographs - Inaniguttids

All scale bars 50 μm

Figures 1-3.–Inaniguttid species A. *1*, B48#3MA28/2002; *2*, B48#2MA29/2002; *3*, C20#3MA28/2002.

Figures 4-7.–Inaniguttid species B. *4*, forma 2, B77.5#1NO16/2000; *5*, forma 1, B89.9#3MA28/2002; *6*, forma 1, B77.5#4NO16/2000; *7*, forma 2, B89.9#6MA28/2002.

Figures 8, 9.–Inaniguttid species C. *8*, C50#10NO16/2000; *9*, C42.3#16MA28/2002.

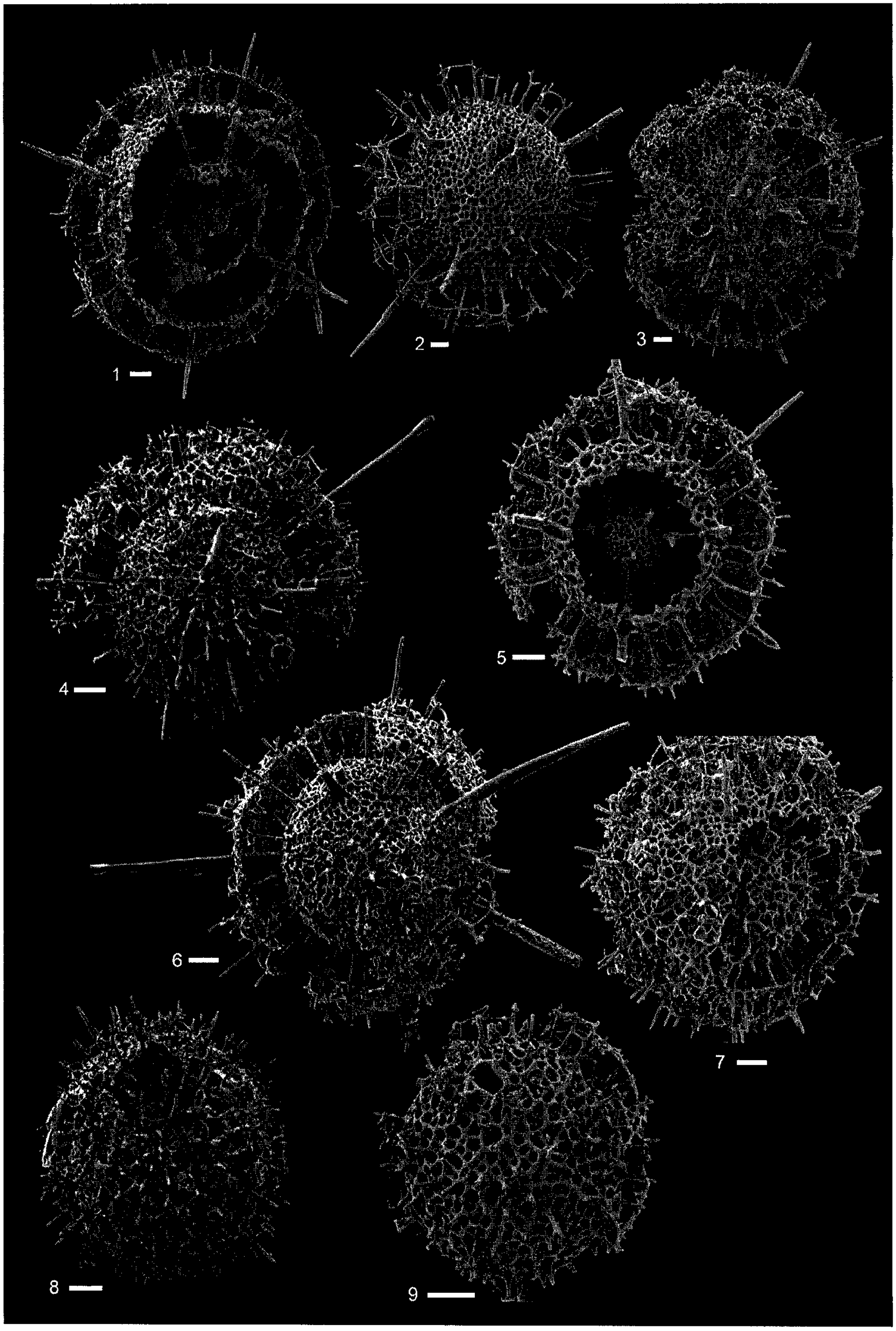


Plate 30

Plate 31

Scanning electron micrographs - Inaniguttids

All scale bars 50 μm

Figures 1, 2.–Inaniguttid species D. *1*, C10.3#1NO16/2000; *2*, C10.3#2NO16/2000.

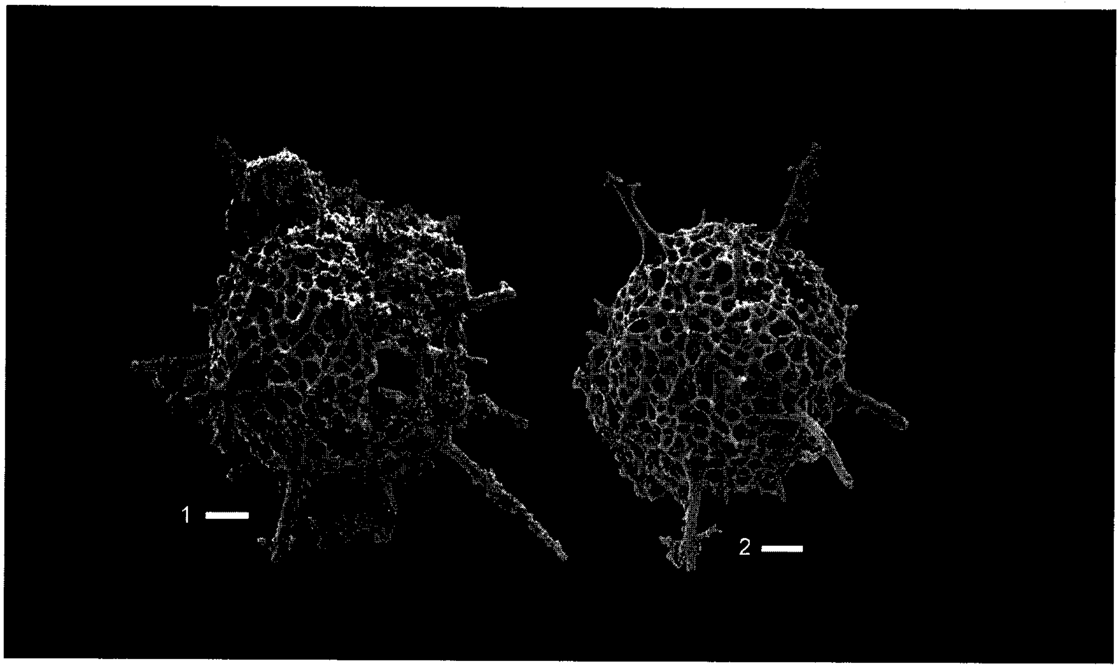


Plate 31

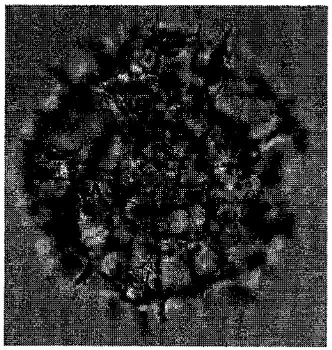
Plate 32

Transmitted light micrographs - *Haplotaeniatum*

All scale bars 50 μm

Figures 1-6.–*Haplotaeniatum ?cathenatum*. *1, 2*, A51.2(1)#3; *3, 4*, A51.2(2)#250, (*4*) centre sphere faintly visible; *5, 6*, A51.2(2)#145.

Figures 7, 8.–*Haplotaeniatum adobensis*, A85.2(1)#31, (*8*) centre sphere visible.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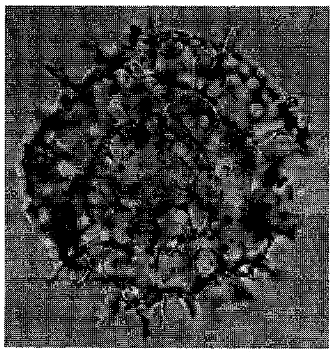
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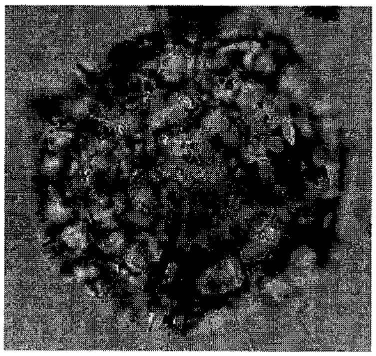
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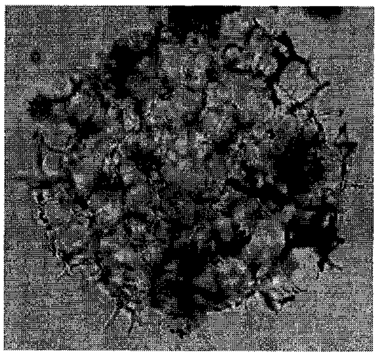
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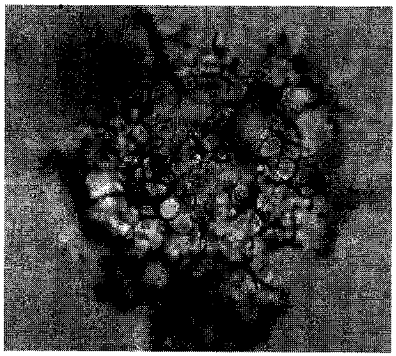
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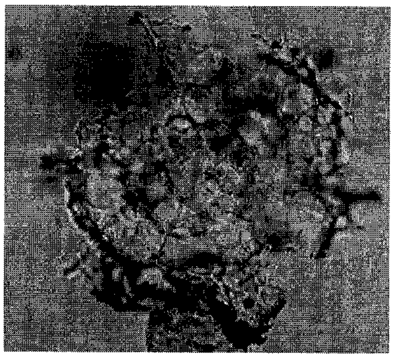
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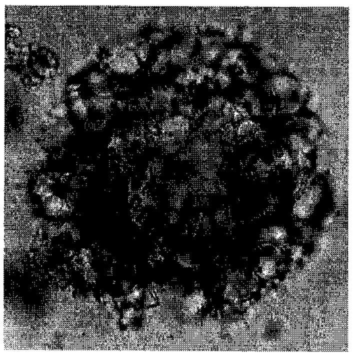
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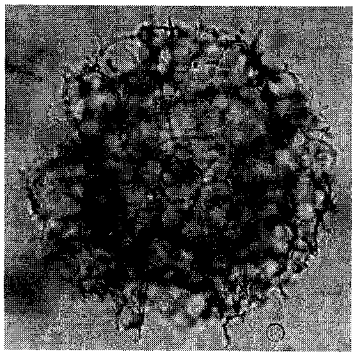
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Plate 32

Plate 33

Transmitted light micrographs - *Haplotaeniatum*

All scale bars 50 μm

Figure 1.–*Haplotaeniatum adobensis*, A85.2(1)#9.

Figures 2, 3.–*Haplotaeniatum* species C, A51.2(1)#119.

Figures 4-7.–*Haplotaeniatum ?labyrinthosphaera*. *4, 5*, A42.8(1)#26; *6, 7*, A51.2(1)#10.

Figures 8, 9.–*Haplotaeniatum* species A, A42.3-42.4(2)#166.

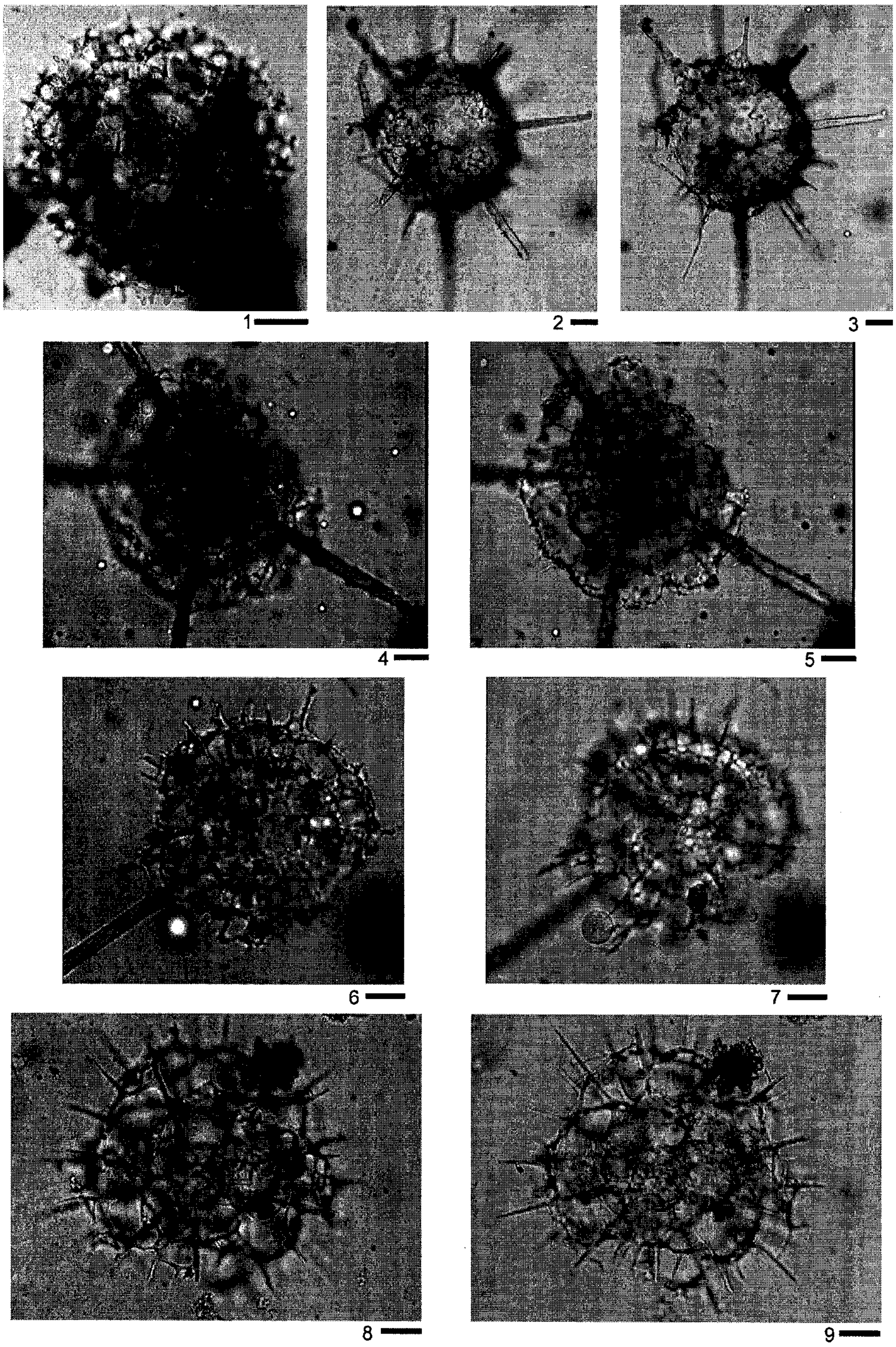


Plate 33

Plate 34

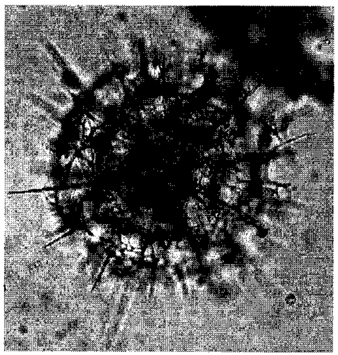
Transmitted light micrographs - *Haplotaeniatum*

All scale bars 50 μm

Figures 1, 2.–*Haplotaeniatum* species A, C42.3-42.4(2)#319.

Figures 3-6.–*Haplotaeniatum* cf. *H. raneatela*. *3, 6*, C147.5(2)#83; *4, 5*, C94.3(1)#186.

Figures 7-10.–*Haplotaeniatum* species B. *7, 8*, C20(1)#130; *9, 10*, C20(1)#392.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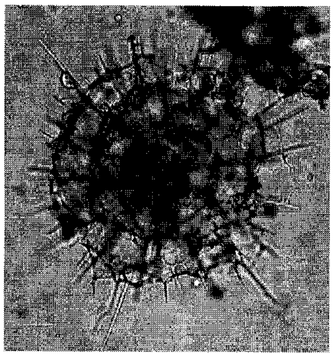
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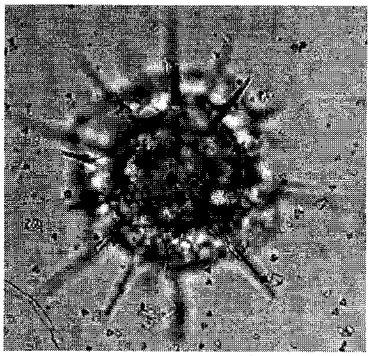
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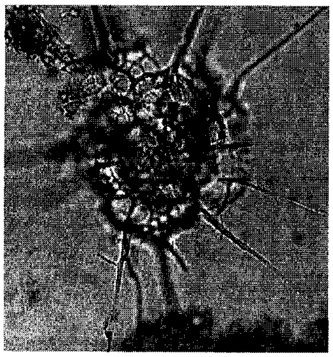
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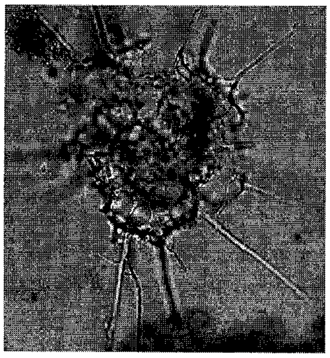
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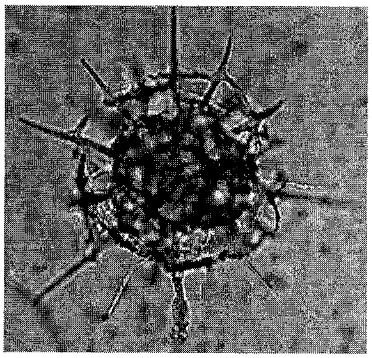
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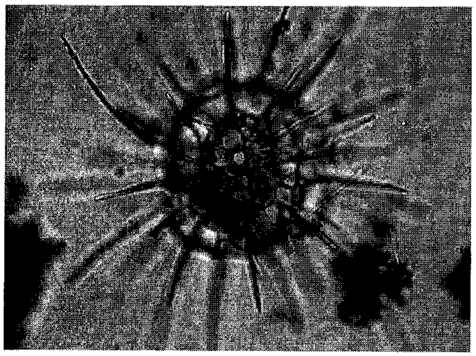
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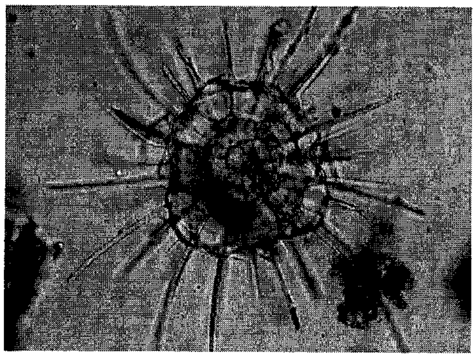
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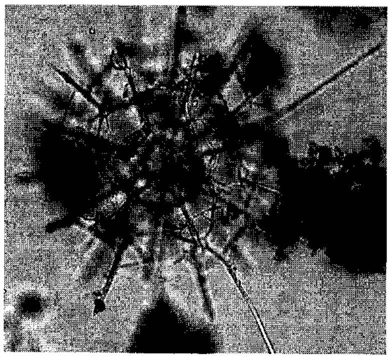
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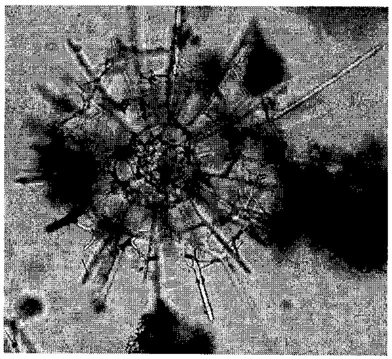
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Plate 34

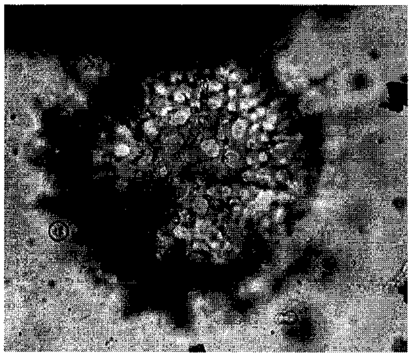
Plate 35

Transmitted light micrographs - *Orbiculopylorum*

All scale bars 50 μm

Figures 1-4.–*Orbiculopylorum* cf. *O. marginatum*. *1, 2*, A71.1(2)#37A; *3, 4*, A71.1(2)#28.

Figures 5-8.–*Orbiculopylorum* species A. *5, 6*, A42.5(1)#21; *7, 8*, A42.5(2)#119.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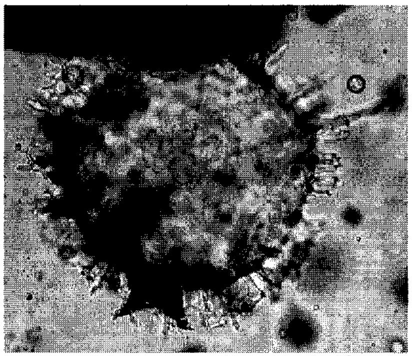
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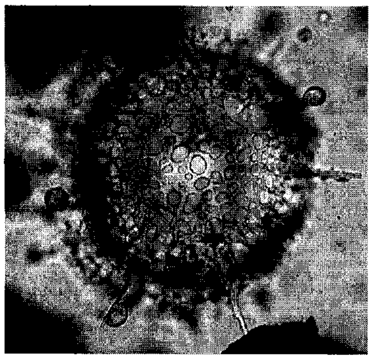
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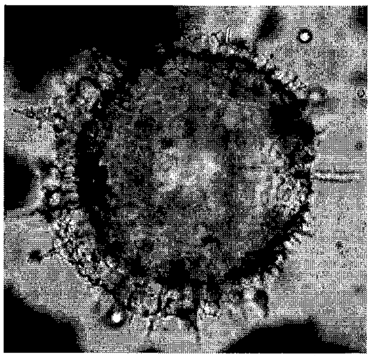
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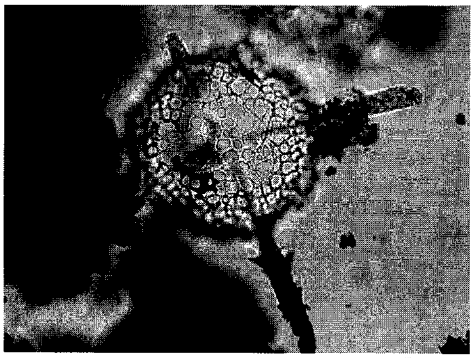
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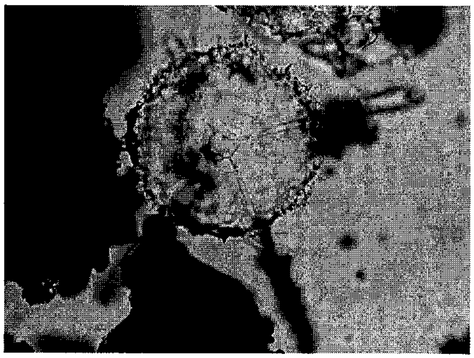
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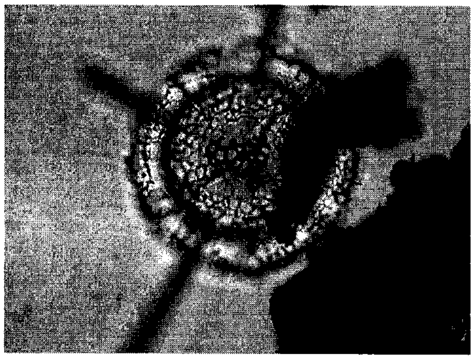
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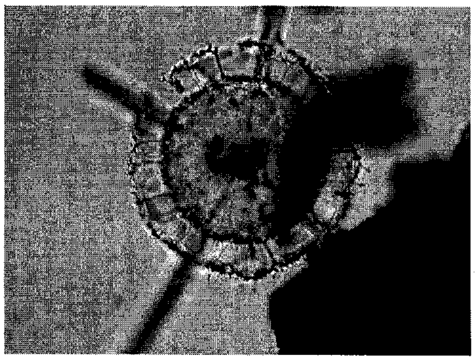

8

Plate 35

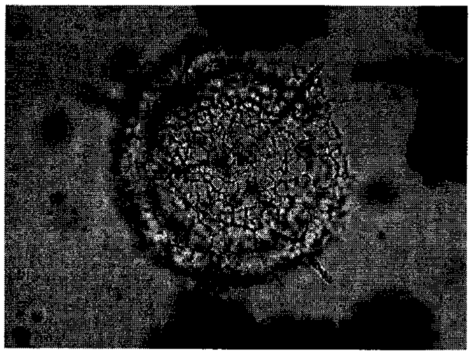
Plate 36

Transmitted light micrographs - *Orbiculopylorum*, ?*Orbiculopylorum*

All scale bars 50 μm

Figures 1-7.–*Orbiculopylorum* species B. *1, 2*, forma 1, A46.8(2)#146; *3-5*, forma 2, A44.5(1)#4, (*3*) remnant of additional shell material on spine at 8 o'clock position; *6, 7*, forma 1, A46.8(1)#94.

Figures 8, 9.–?*Orbiculopylorum* species C, A44.5(1)#11.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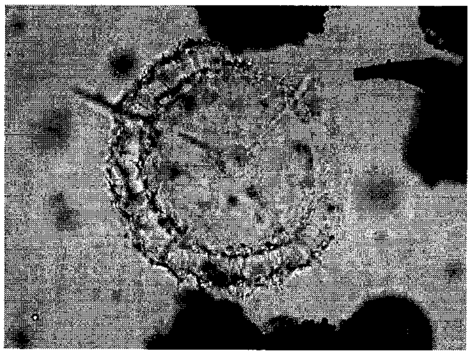
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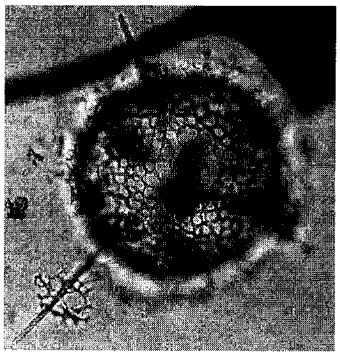
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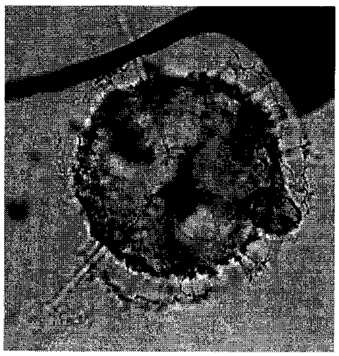
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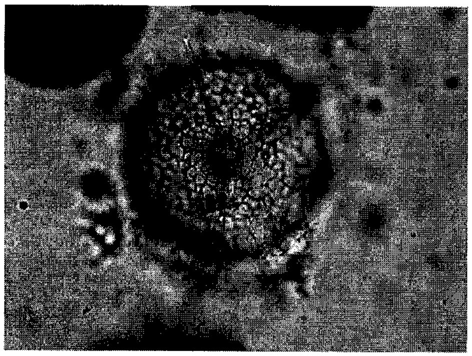
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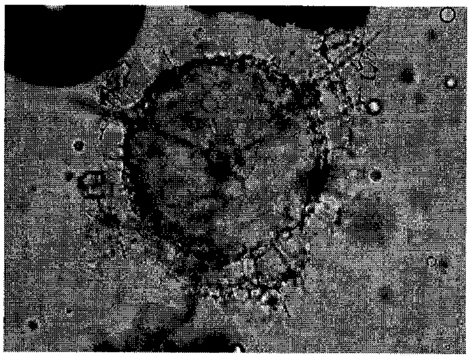
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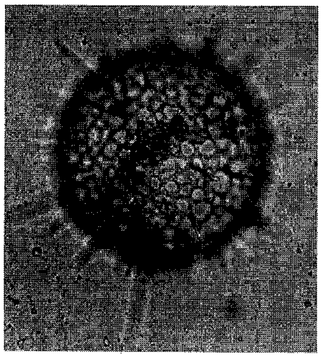
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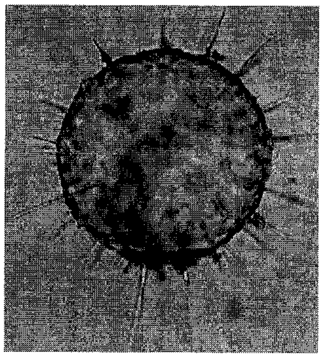

9

Plate 36

Plate 37

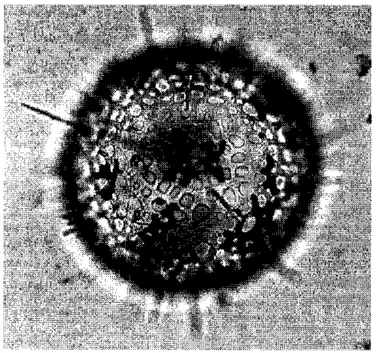
Transmitted light micrographs - ?*Orbiculopylorum*, Inaniguttids

All scale bars 50 μm

Figures 1-3.–?*Orbiculopyloum* species C, A44.5(1)48, (*3*) remnant of inner structure faintly visible (arrow heads).

Figures 4-7.–Inaniguttid species A. *4*, C20(1)#6; *5*, C20(1)#239; *6, 7*, B42.2(2)#456.

Figures 8-10.–Inaniguttid cf. species A, C20(1)#97, (*8*) optical cross section, (*9*) focus on second shell, (*10*) focus on third shell.



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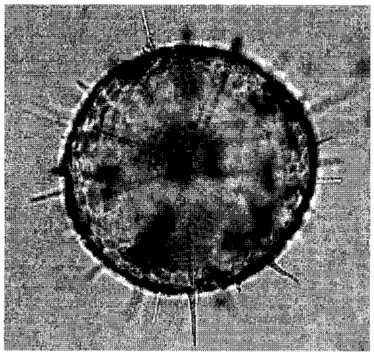

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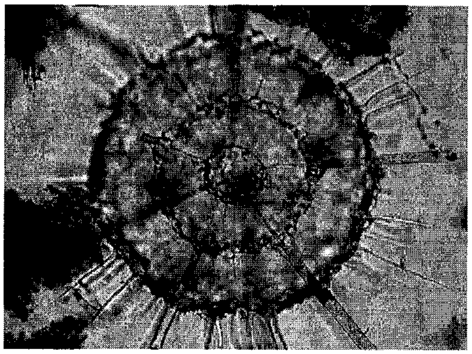

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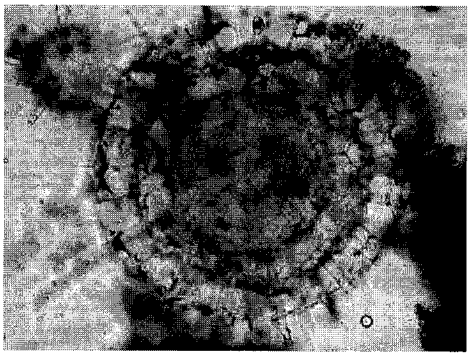

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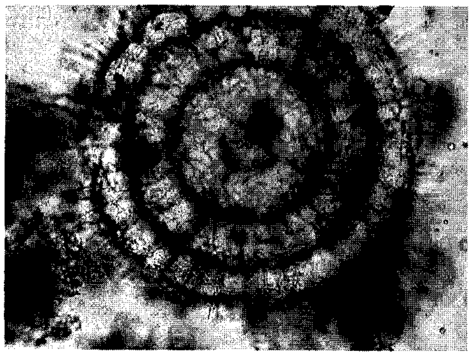

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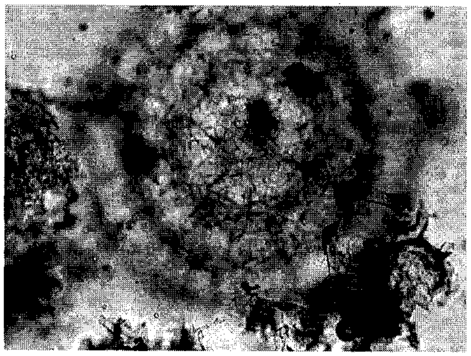

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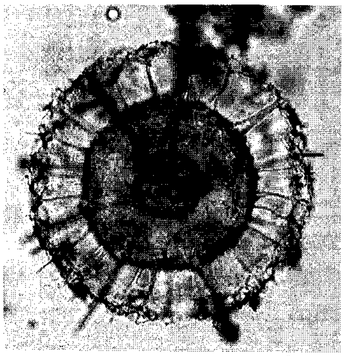

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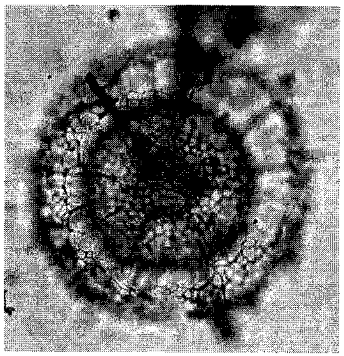

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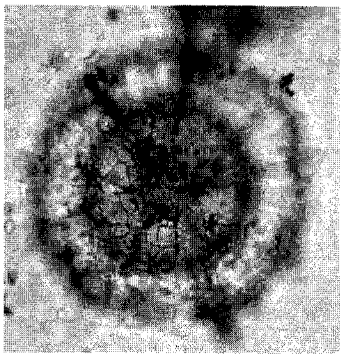


10

Plate 37

Plate 38

Transmitted light micrographs - Inaniguttids

All scale bars 50 μm

Figure 1.–Inaniguttid species A, C20(1)#232.

Figures 2-7.–Inaniguttid cf. species A. *2-4*, C20(1)#104, (*2*) focus on second shell, (*3*) optical cross section, (*4*) focus on third shell; *5-7*, C20(1)#93, (*5*) optical cross section, (*6*) focus on second shell, (*7*) focus on third shell.

Figures 8, 9.–Inaniguttid species B forma 1, B89.9(2)#86, (*8*) focus on second shell, (*9*) optical cross section.

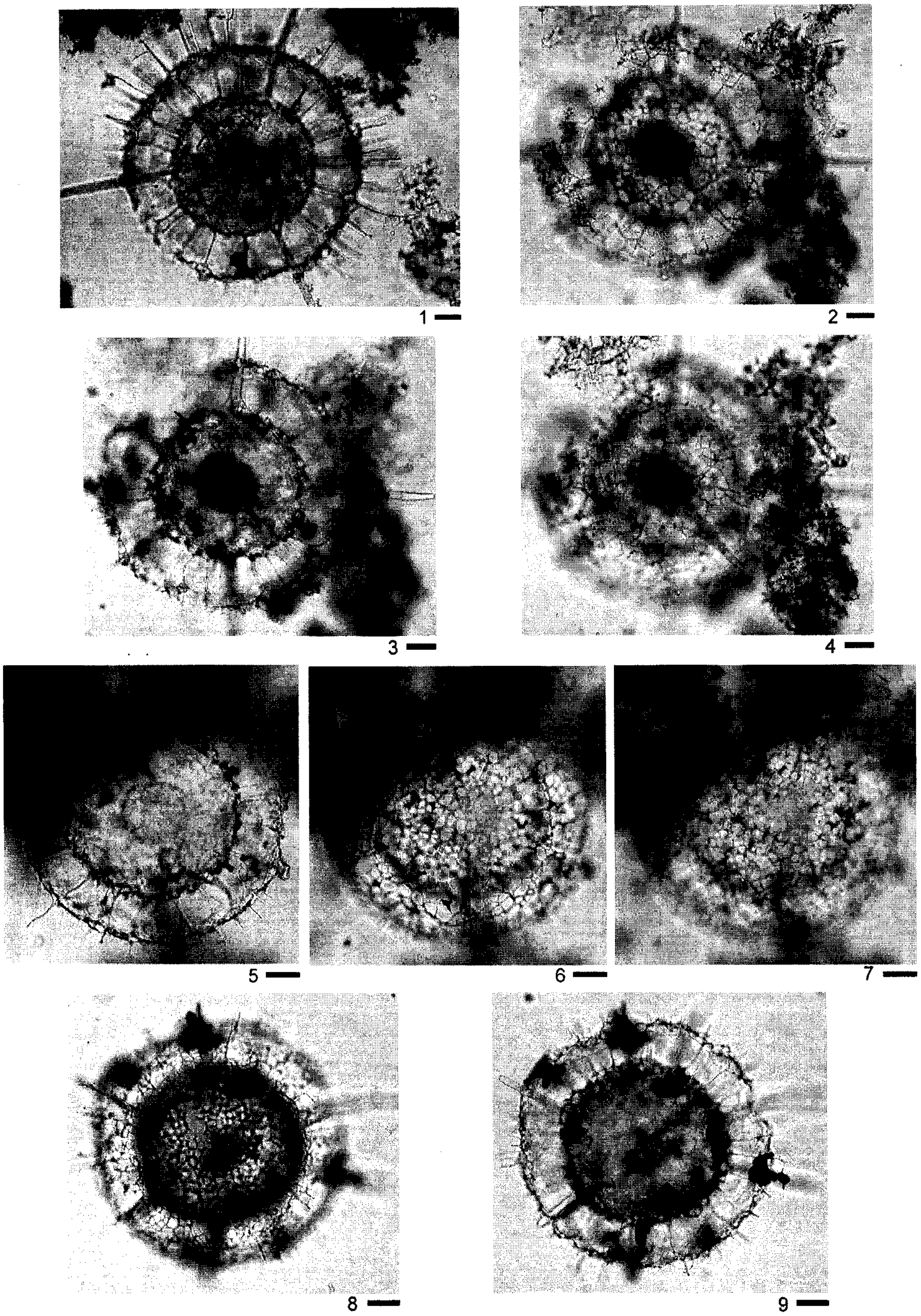


Plate 38

Plate 39

All scale bars 50 μm

Figures 1-7.–Inaniguttid species 1 forma B. *1*, *4*, B89.9(2)#93B; *2, 3*, C42.3(1)#19; *5-7*, B77.5(1)#B, (*5*) optical cross section, (*6*) focus on third shell, (*7*) focus on second shell.

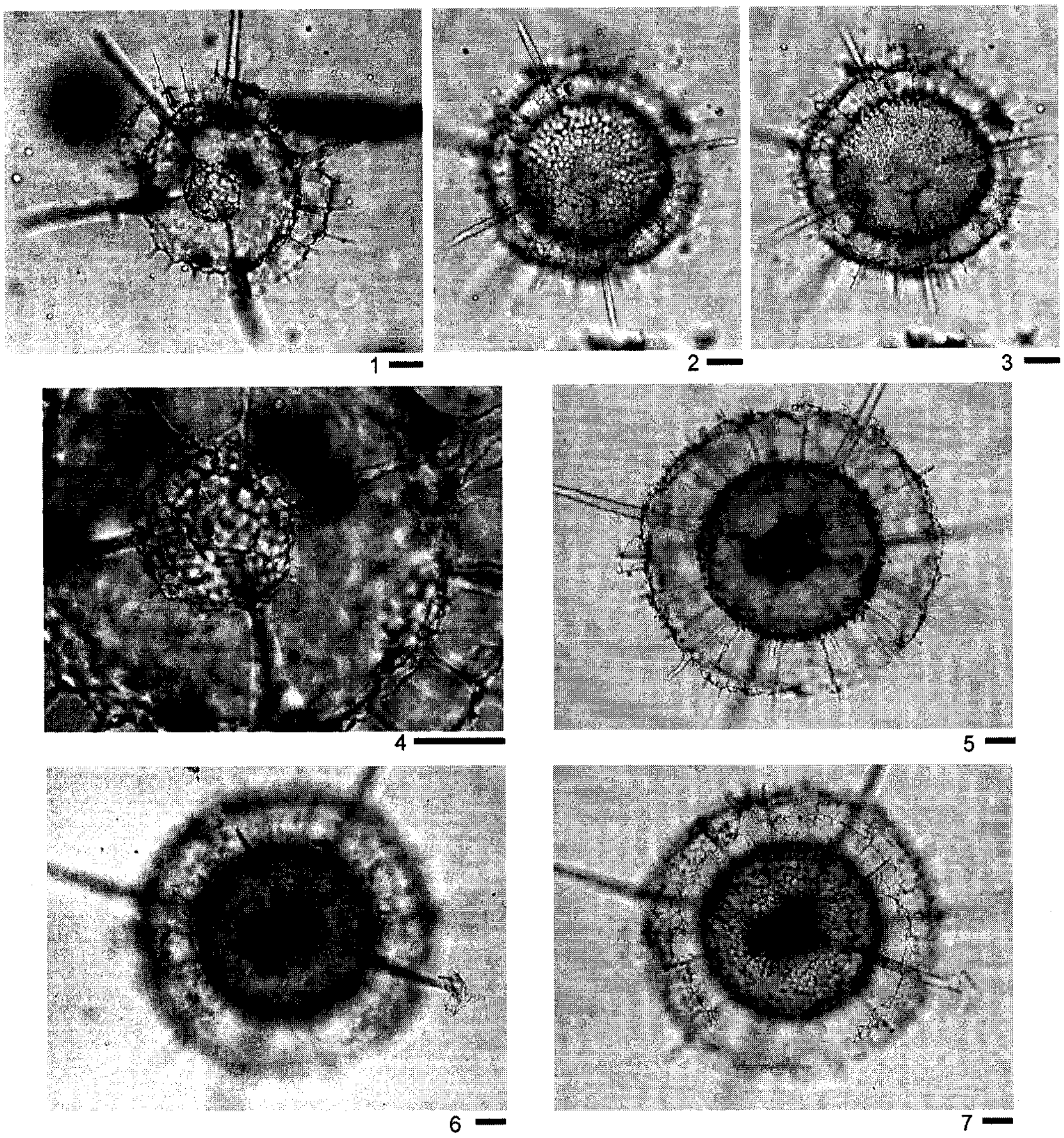


Plate 39

Plate 40

Transmitted light micrographs - Inaniguttids

All scale bars 50 μm

Figures 1-8.–Inaniguttid species B forma 2. *1-4*, B77.5(2)#252, (*1*) cross section, (*2*) focus on second shell, (*3*) optical cross section showing centre structure, (*4*) focus on first shell; *5, 6*, B77.5(2)#256; *7, 8*, B77.5(1)#A.

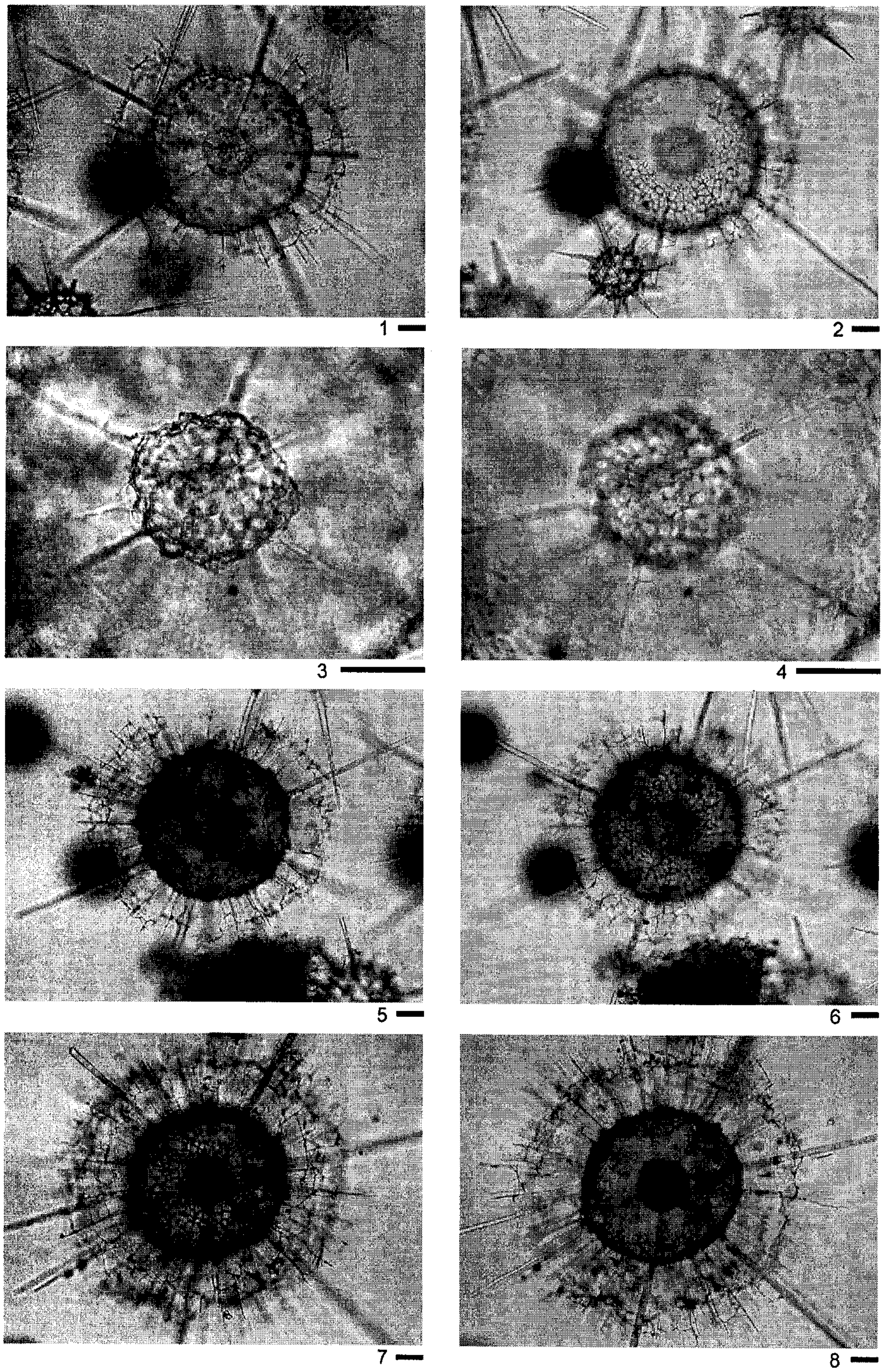


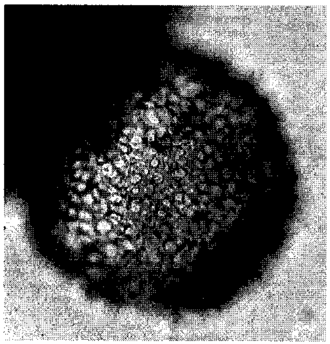
Plate 40

Plate 41

Transmitted light micrographs - Inaniguttids

All scale bars 50 μm

Figures 1-8.–Inaniguttid species C. *1, 2*, C42.3(1)#51; *3, 4*, C42.3(2)#167; *5, 6*, C42.3(2)#205; *7, 8*, C42.3(2)#303.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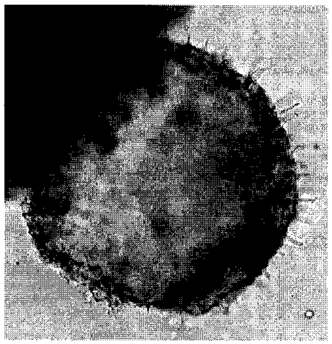
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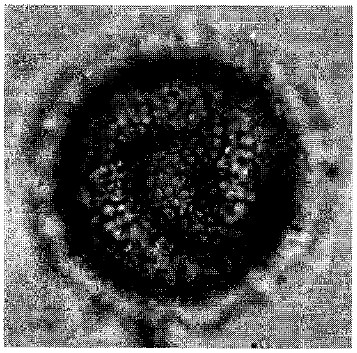
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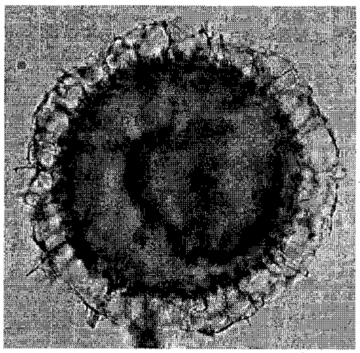
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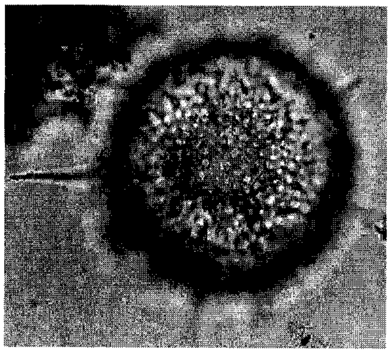
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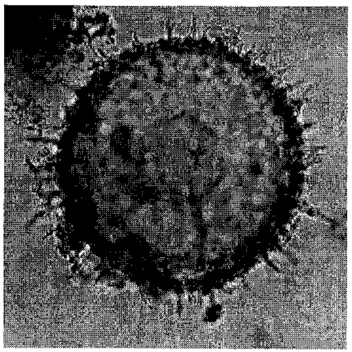
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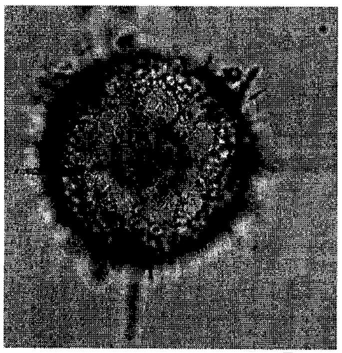
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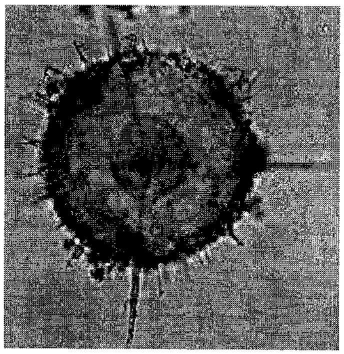
8

Plate 41

Plate 42

Transmitted light micrographs - Inaniguttids, *Labyrinthosphaera*

All scale bars 50 μm

Figures 1-4.–Inaniguttid species D. *1, 2*, C20(1)#78; *3, 4*, C20(1)#300.

Figures 5, 6.–*Labyrinthosphaera macdonaldi*. *1*, C42.3-42.4(1)#80; *2*, C42.3-42.4(1)#8.

Figure 7.–*Labyrinthosphaera* species A. C147.5(1)#52.

Figure 8.–*Labyrinthosphaera* species B. C42.3-42.4(1)#60.

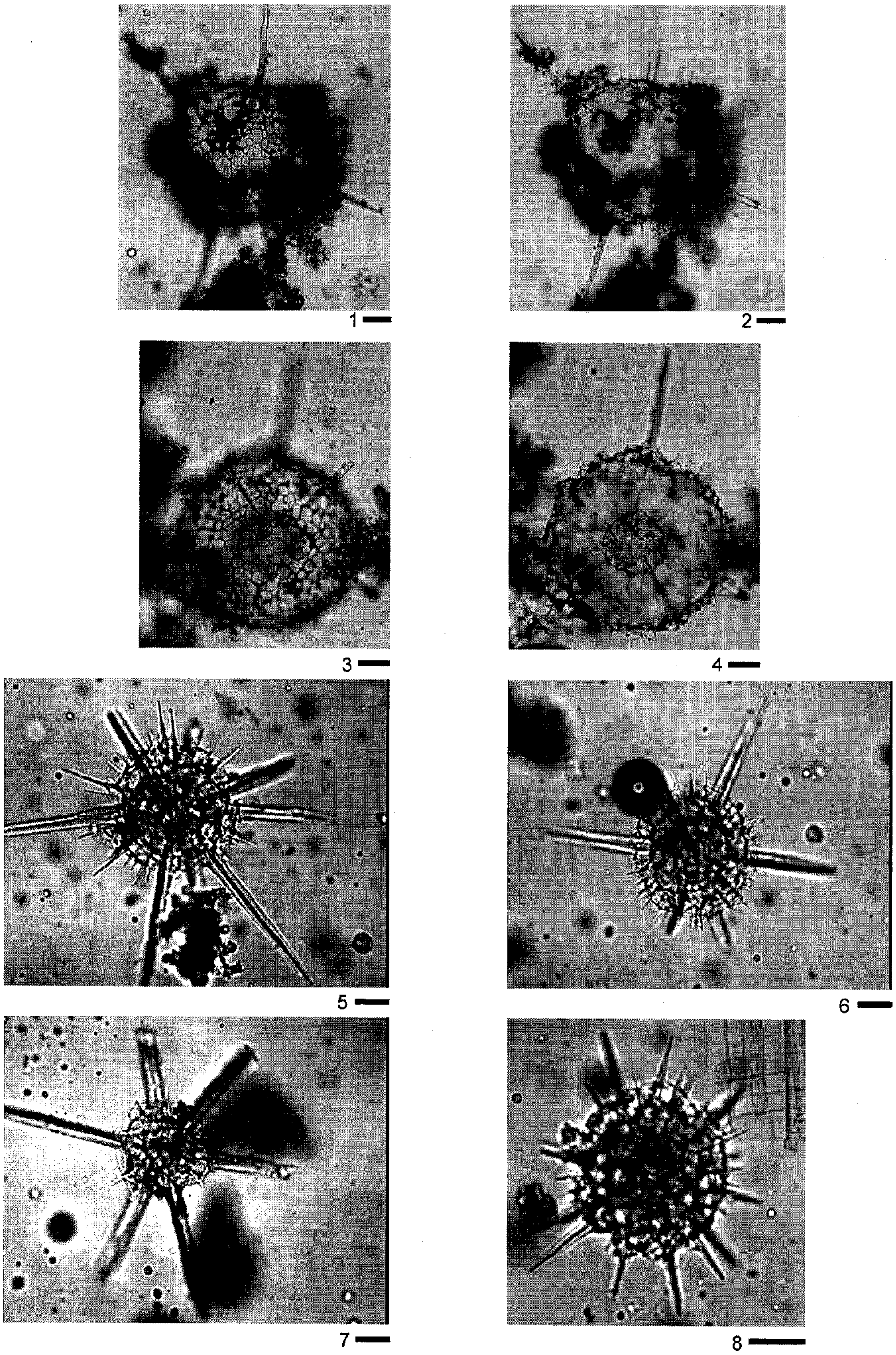

Plate 42

Plate 43

Scanning electron micrographs - *Labyrinthosphaera*

All scale bars 50 μm

Figures 1-3.–*Labyrinthosphaera macdonaldi*. *1*, C42.3-42.4#42JL9/01; *2*, C147.5#1JL4/01; *3*, C42.3-42.4#54JL9/01.

Figures 4, 5.–*Labyrinthosphaera* species A. *4*, C147.5#6JL4/01; *5*, C147.5#8JL4/01.

Figure 6.–*Labyrinthosphaera* species B. C20#51JL4/01.

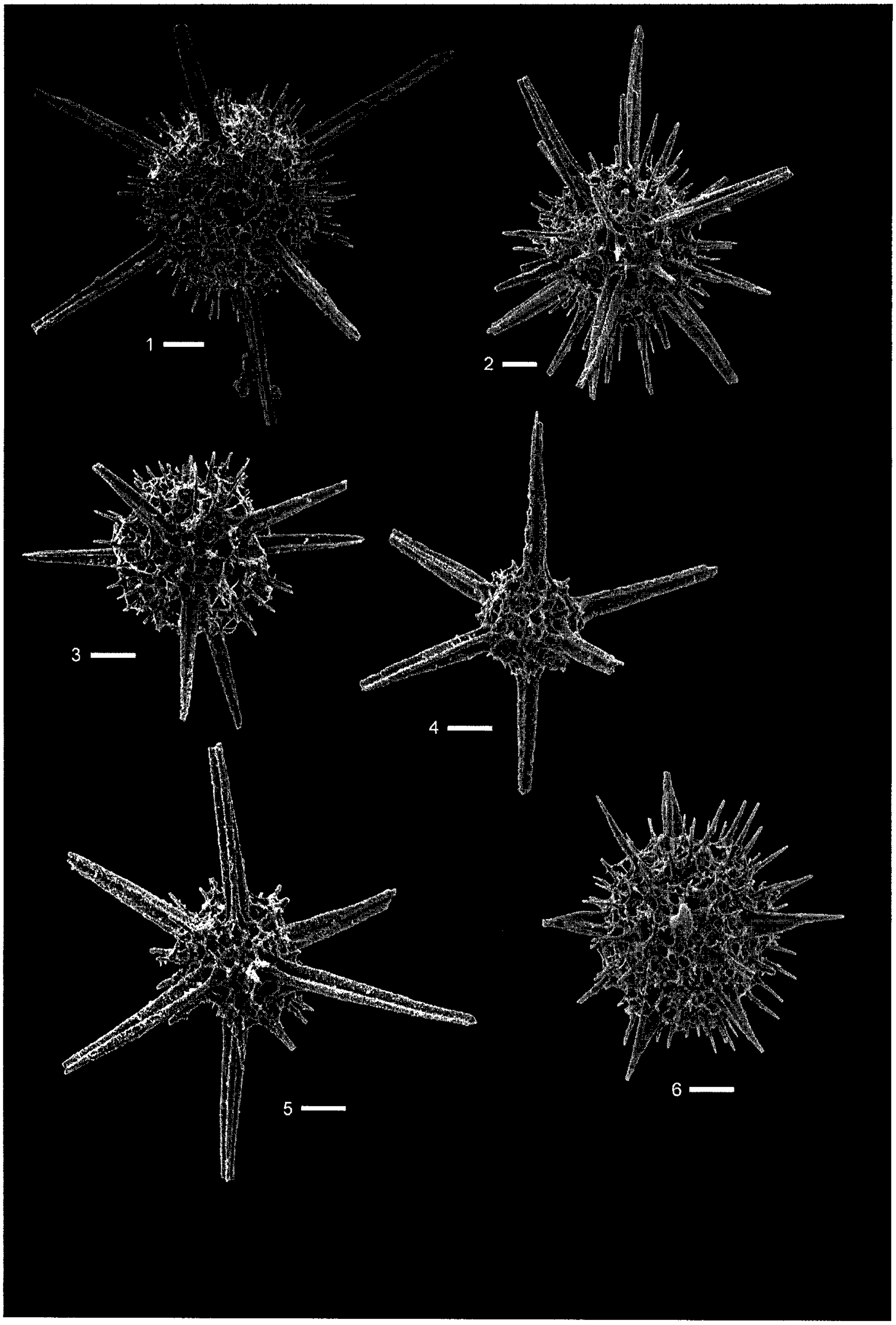

Plate 43