

**Late Neogene Radiolaria
from the East Coast Deformed Belt,
New Zealand**

by

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ABSTRACT

Within the East Coast Deformed Belt there are a number of Late Neogene sedimentary basins with relatively deep-water sediments which, at places, contain abundant radiolarian skeletons. The region was subject to relatively open ocean circulation patterns during the Neogene which, combined with the input of rhyolitic glass shards, has enhanced the siliceous microfossil preservation. A short review of the silica budget is presented and discussed in relation to the preservation of siliceous microfossils in the New Zealand sequences.

Techniques were developed to extract and quantitatively study fossil Radiolaria from some of the relatively barren shelf/slope sediments. One hundred and thirty-eight radiolarian taxa are described, most of which can be assigned at the generic level, but thirty-one of which can not be assigned specific names and may eventually prove to be new species.

The radiolarian zonation presented is based on detailed analysis of 155 samples from 26 sections and sites ranging in age from basal Tongaporutuan (early Late Miocene) to middle Nukumaruan (early Pleistocene). Sediments of the Kapitean (uppermost Miocene) were generally deposited in shallow water environments or are missing in unconformities in the East Coast Deformed Belt, consequently the radiolarian zonation is based on very poor data in this time segment. Also upper Opoitian and Waipipian (middle Pliocene) sediments, although at places deposited in relatively deep water, generally lack siliceous tuffs, and radiolarian preservation is poor. Five major radiolarian zones can be recognised: *Diartus hughesi* Zone, *Didymocyrtis* sp. A Zone, *Didymocyrtis tetrathalmus tetrathalmus* Zone, *Lamprocyrtis heteroporos* Zone, and *Lamprocyclas gamphonycha* Zone. In samples with good radiolarian preservation six subzones can be identified. The *Diartus hughesi* Zone can be divided into the *Heliodiscus umbonatum* Subzone, *Didymocyrtis laticonus* Subzone, *Heliodiscus asteriscus forma large pores* Subzone, and *Anthocyrtidium ehrenbergi pliocenica* Subzone. Additionally the *Didymocyrtis tetrathalmus tetrathalmus* Zone can be divided into the *Lychnocanium* sp. aff. *grande* Subzone and *Lamprocyrtis hannai* Subzone. The bioevents that define the zonal boundaries are discussed along with other biostratigraphically useful radiolarian datums.

These zones and subzones are correlated to the foraminiferal zonation which in turn

has been related, in part, to the paleomagnetic time scale. Correlations are then made with other radiolarian zonations in the north Pacific, tropics, and southern ocean. Points to emerge from these correlations include the apparent provincialism in the transition from *Stichocorys delmontense* to *Stichocorys peregrina* in the tropical Pacific. This transition has been reported to occur during approximately 1.5Ma but in New Zealand occurs over a time segment of at least 5.5Ma. The first appearance of *Lamprocyclas gamphonycha* appears to be an isochronous datum level in temperate radiolarian faunas of the northern and southern Pacific. The last appearance datum of *Diartus hughesi* at about 7.5Ma is in good agreement with its level in the tropics. The presence of this taxon in lower Gilbert Antarctic cores suggests either a grossly diachronous event between tropical/temperate areas and the southern ocean or, more probably, a misinterpretation of the paleomagnetic signature from key southern ocean piston cores. If the latter situation is the case then the real age estimates on the "pre middle Gilbert" southern ocean diatom and silicoflagellate stratigraphies are questionable because they are based on the same key cores.

Statistical faunal analysis shows that during the Miocene there was not much change in the radiolarian faunas with time and a major change, probably climatically controlled, took place across the Miocene/Pliocene boundary. Variability in preservation has probably affected the faunas to obscure more precise time variation although post-Miocene faunas indicate that some is present.

In conclusion, the Radiolaria, although not as common in the fossil record as the foraminifera, definitely contribute to New Zealand Late Neogene integrated stratigraphy and suggest that our knowledge could be greatly enhanced by the study of other siliceous microfossil groups.

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Chapter I

INTRODUCTION

1.1 PREAMBLE

Radiolarians are free-living, marine, pseudopod-bearing protozoans. They are exclusively holoplanktic with the exception of one benthic acantharian. Most are solitary but two families, the Collosphaeridae and Sphaerzoidae, have colonial forms. Present in all the major oceans and mediterranean seas they occupy niches from the surface to the abyss in equatorial to polar waters, being most abundant in epipelagic and upper mesopelagic depth zones (0 to 300 metres) (Petrushevskaya, 1971b). Occurring in all marine waters of normal salinity the number of large individuals is approximately equivalent to that of planktic foraminifera (Cifelli and Sachs, 1966) and the number of smaller individuals is considerably greater (Beers and Stewart, 1971).

Like most other planktic taxa, radiolarians are most abundant in regions of high biological productivity associated with the equatorial current system, eastern and western boundary currents and the east-flowing currents in latitudes higher than about 40°S (Riedel and Sanfilippo, 1977). After the diatoms, radiolarians are the second major producer of suspended amorphous silica in the oceans with variations from 16,000 individuals per cubic metre in the equatorial Pacific to tens or hundreds of individuals per cubic metre in Antarctic waters (Lisitzin, 1972).

Radiolarians are distinguished from other protists by the organisation of their cell which is divided into an inner and outer zone by a membrane. Until recently it was generally accepted that the membrane strongly controlled the shape of the skeleton, but Anderson (1976c) has reported cases in which the relationship is slight.

Geologists are mainly concerned with polycystine Radiolaria. The order Polycystina have coherent skeletons of opaline silica and are the only group with a substantial fossil record. They are divided into two suborders : the "spherical" Spumellaria and "ring or cap-shaped" Nassellaria.

The order Phaeodaria (Triplylea) occur as fossils in some Neogene sediments (Riedel, 1963; Dumitrica, 1964; Reshetnyak, 1971; Stadum and Ling, 1969), but only where the siliceous preservation is exceptionally good. Their skeletons are constructed of tubular opaline silica admixed with organic material and are readily dissolved during early

TABLE 1.1

Comparison of the characteristics of the major microfossil groups used in marine geological work

	Foraminifera	Radiolaria	Calcareous nannoplankton	Diatoms
* Taxonomy	3	1	3	1
* General diversity	2	3	1	2
* Diversity sufficiently high for polar Cenozoic paleoceanographic studies	2	3	1	3
* Diversity sufficiently high for subpolar Cenozoic paleoceanographic studies	3	3	3	3
* Biostratigraphy known	3	3	3	2
* Biological controls known	2	1	2	3
* Modern vertical and geographic distribution known	3	1	3	2
* Species and assemblage patterns match surface water masses	3	3	3	3
* Morphological variation related to environmental change	3	1	2	1
* Tests resistant to dissolution	1	3	2	2
* Census data can provide data on original assemblages	2	3	2	2
* Tests resistant to lateral displacement	3	2	1	1
* Commonly found over wide areas in Cenozoic sediments	3	3	3	2
* Relative simplicity of counting	3	3	3	3
* Tests suitable for isotopic measurements	3	1	3	2

3 = relatively high values, or well known

2 = moderately high values, or only partially known

1 = relatively low values, or poorly known

after Kennett, 1982.

diagenesis (Riedel and Sanfilippo, 1977). No tripylean Radiolaria have been found as fossils in New Zealand Upper Neogene sediments.

The Acantharia have skeletons made of celestite (strontium sulphate) and are never found as fossils (Kling, 1978). They were removed from the subclass Radiolaria by Deflandre (1952).

Radiolaria are less often preserved as fossils than the calcareous microfossils but are still useful as climatic and stratigraphic indicators (Foreman, 1981). Table 1.1 (reproduced from Kennett, 1982: p.637) compares some characteristics of the major microfossil groups used in marine geology. Radiolaria are geologically important because they are abundant and diverse in deep-sea sediments. More than 7,000 species have been described but this figure is probably inflated by excessive taxonomic splitting (Kennett, 1982: p.573).

The oldest known Radiolaria are from the early Ordovician of Spitzbergen (Fortey and Holdsworth, 1971). Possible Pre-Cambrian occurrences have been reported from France, Australia, and India but the age of the rocks is uncertain (Deflandre, 1952).

The total number of radiolarian species living at any given time in the Cenozoic was approximately 100 to 200 (Riedel and Sanfilippo, 1977). Their wide geographic distribution and rapid evolution should make them stratigraphically useful, but their stratigraphic application is inhibited by an unsatisfactory taxonomic classification, the limited number of Cenozoic radiolarian fossil localities on land, and the incomplete descriptions of most known fossil assemblages (Riedel and Sanfilippo, 1977).

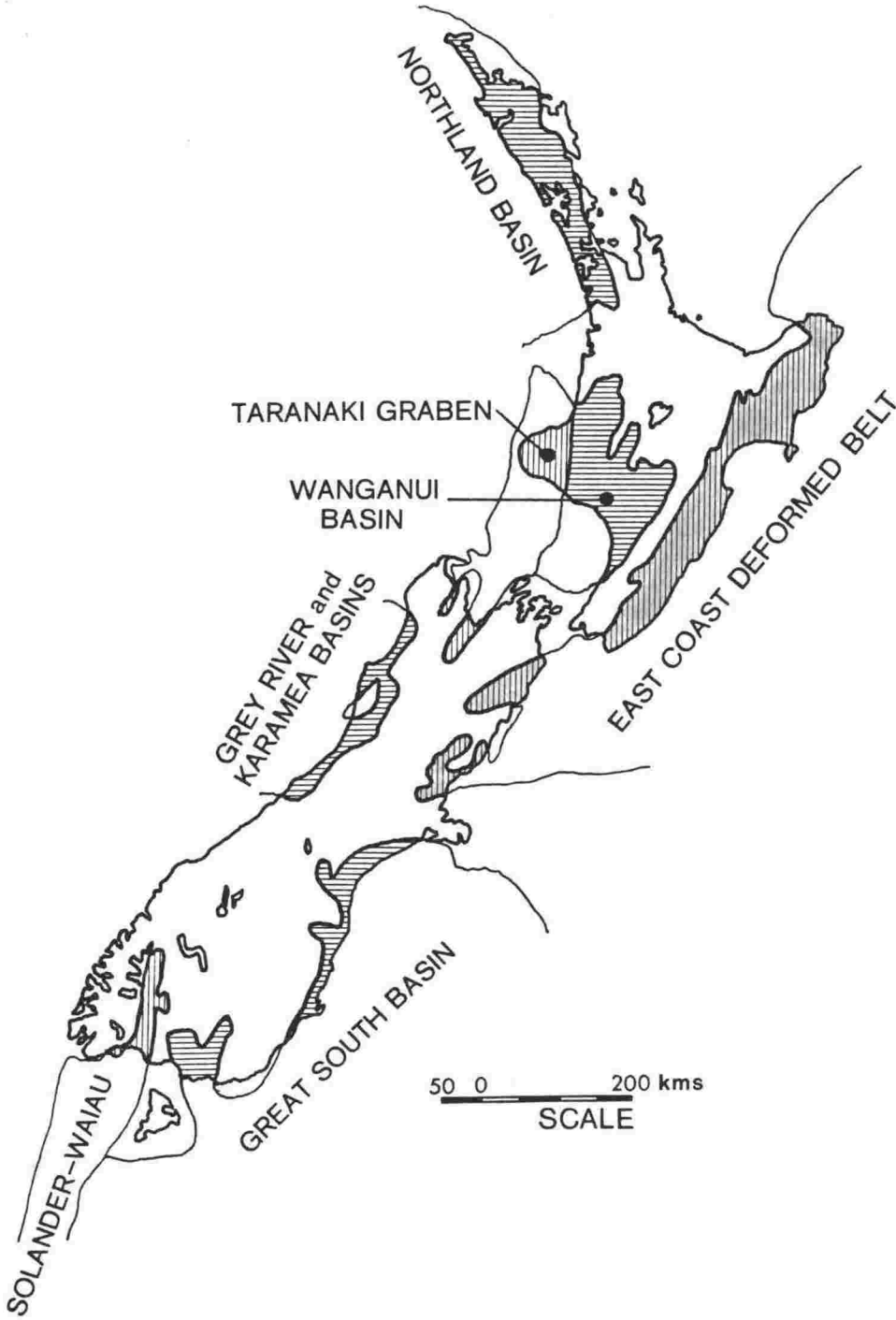
Between 400 and 500 polycystine species are living in the seas today (Casey, Gust, Leavesley *et al.*, 1979) compared with about 40 species of planktic foraminifera (P. Vella, pers. comm.) and 38 species of pteropods (Kennett, 1982: p.562). Radiolarians are more diverse because they occupy more niches.

Radiolarians are sensitive to small variations of physical and chemical conditions in the ocean. The large number of species, a tendency towards endemism, and subspecific morphological changes correlated with changes in oceanographic conditions, make the fossils fairly precise paleoceanographic indicators (Casey, 1971a). Distributional studies include Nigrini (1967), Casey (1971a), Sachs (1973), Moore (1973a), Lozano and Hays (1976), Casey (1977), Nigrini and Moore (1979), and Johnson and Nigrini (1980).

In some cases, because of the imperfect taxonomy, researchers have used ill-defined and/or inadequately illustrated, poly-specific and even poly-generic "counting groups" which

Figure 1.1

Major Neogene sedimentary basins in New Zealand. East Coast Deformed Belt (the area of study) is highlighted.



blur distributional patterns and make it hard for one researcher to duplicate or use the results of another (Nigrini and Moore, 1979).

1.2 AIM AND SCOPE

The main aim of this thesis is to set up a radiolarian biostratigraphic framework for the New Zealand Late Neogene. The term Neogene represents the interval from the base of the Miocene to the present time. The Late Neogene encompasses the interval since the beginning of the Late Miocene, about eleven million years ago (Berggren, 1972a). All the rocks studied in this thesis outcrop above sea-level and uplift rates have not been fast enough to expose any radiolarian-bearing rocks less than approximately 1.5 million years old in the study area. The rocks studied are restricted to the East Coast Deformed Belt (figure 1.1). Within that region there are a number of Late Neogene sedimentary basins with relatively deep-water mudstones which at places contain abundant radiolarian skeletons. Some of the sections studied are relatively continuous and well exposed providing ideal sites for microfossil, macrofossil, paleomagnetic, and tephrochronological studies. The East Coast Deformed Belt encompasses about a 6° paleolatitudinal spread in an area only five degrees north of the present Subtropical Convergence.

In the course of this study techniques have been developed to extract and quantitatively study fossil Radiolaria from relatively barren shelf/slope sediments, taxa described, and a local biostratigraphic zonation developed and correlated with previously described Late Neogene biostratigraphic schemes. The geological usefulness of fossil radiolarians in the study of the New Zealand Late Neogene is evaluated at the end of this thesis.

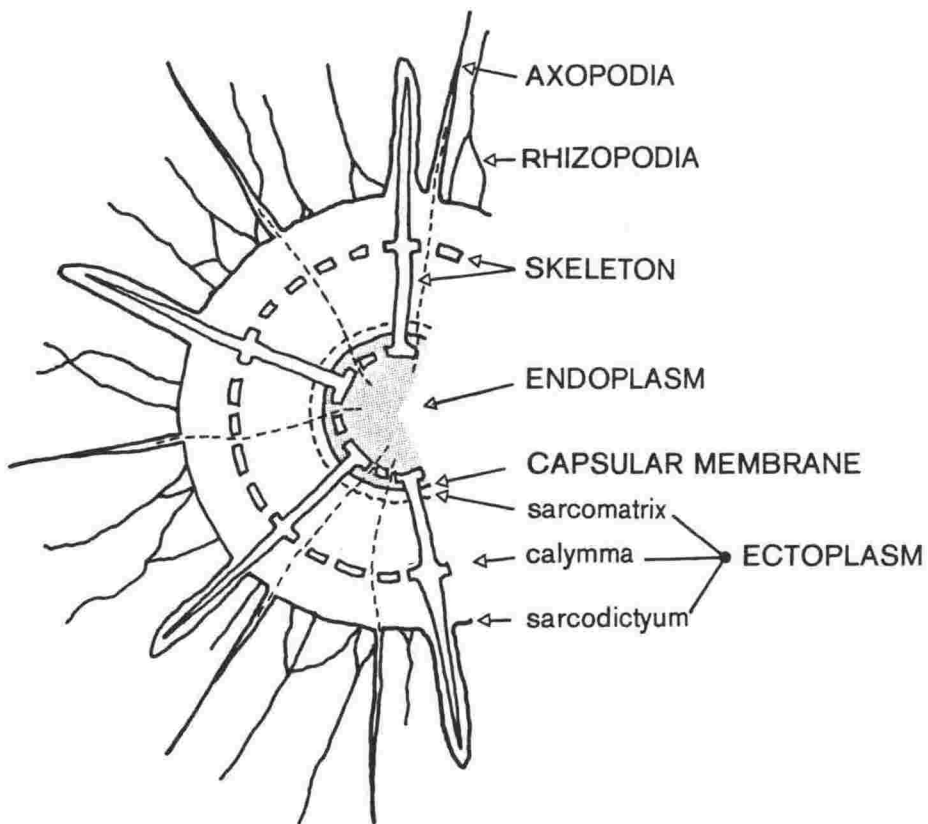
1.3 RADIOLARIAN BIOLOGY

1.3.1 Introduction

Relatively little is known about the cytoplasmic structure and life cycle of radiolarians. A serious limiting factor is the failure of nearly all attempts to keep radiolarians alive in laboratory cultures. Specimens of the colonial radiolarian, *Thalassicola nucleata*, survived three weeks in a laboratory culture but its life span is thought to be longer (Anderson, 1978a). Casey, Partridge, and Sloan (1971) reported life spans of one month for two endemic Southern Californian species. Colonial radiolarians have been studied more than solitary species because they are larger and easier to culture. In the absence of successful culturing experiments spanning the complete life cycle, interpretations of morphologic data are still a major source of life cycle information (Kling, 1971a).

Figure 1.2

Schematic cross-section of a spumellarian radiolarian showing cytoplasmic features in relation to a hypothetical spherical skeleton.



Diverse nutritional habits, highly differentiated cytoplasm and the specialised network of skeletal cytoplasmic sheaths suggest that the Radiolaria, though unicellular organisms, are highly advanced in their physiological development, which may help to explain their wide geographic distribution and relative abundance over a large geologic time span (Anderson, 1976c).

1.3.2 Cytoplasmic structure

1.3.2.1 Preamble

The following short review of radiolarian cytoplasmic structure is based on the following sources: Campbell, 1954; Pokorny, 1963; Anderson, 1976c; Riedel and Sanfilippo, 1977; Kling, 1978; Goll and Merinfeld, 1979; Kennett, 1982; and other specifically referenced papers.

Little attention has been given to radiolarian cytoplasmic morphology although it is clear that the ultimate explanation for skeletal secretion and architectural design is biological. Ultrastructural characteristics of the axopodial apparatus and the position of the nucleus varies between different radiolarian groups and should be important in radiolarian taxonomy (Petrushevskaya, 1975). Radiolarian cytoplasm can be divided into three units:

1. ectoplasm (extracapsular cytoplasm),
2. endoplasm (intracapsular cytoplasm), and
3. central capsular membrane.

The central capsule is a distinctive structure in Radiolaria and separates them from close relations such as the Heliozoa.

Figure 1.2 is a schematic cross-section of a spumellarian radiolarian showing the major cytoplasmic features in relation to a hypothetical spherical skeleton.

1.3.2.2 Ectoplasm

The ectoplasm consists of three units. The assimilative layer (sarcomatrix) lies immediately next to the central capsule and is thought to be the area where food is assimilated into the cytoplasm. Surrounding it is a frothy layer (calymma) which makes up the bulk of the ectoplasm. Its frothy appearance is due to the presence of numerous alveoli which are probably carbon dioxide saturated and aid buoyancy. Covering the protoplasm, including the distal skeletal elements, is a protoplasmic sheath (sarcodictyum) which prevents silica dissolution in the living radiolarian.

Radiolarians have two principal kinds of pseudopodia which aid in flotation, food capture, and respiration.

1. The axopodia are long, straight, radially aligned pseudopodia that are stiffened by microtubules (very fine protein rodlets) which can also be found as supporting structures in other parts of the cytoplasm. The axopodia extend through the ectoplasm and central capsular membrane to the interior of the endoplasm.
2. The rhizopodia are thin, delicate extensions of the peripheral cytoplasm and are approximately radial but may anastomose, particularly towards the base. Cytoplasmic streaming in the rhizopodia is differentiated. Prey can be carried in one direction while symbiotic zooxanthellae can be held stationary or moved in an opposite direction (Anderson, 1978a).

1.3.2.3 Endoplasm

The endoplasm contains the nucleus, or nuclei (multiple nuclei are not uncommon), of the radiolarian. Radiolarian nuclei can have large numbers of chromosomes, up to 1500 having been reported. The endoplasm also contains lipid droplets of varying composition and albumenoid spherules containing crystals presumed to be proteins and is involved in reproduction, biochemical synthesis, and energy production.

1.3.2.4 Central capsular membrane

The central capsular membrane is a single layer (double layer in the Phaeodaria) of chitinous or mucoid material between the endoplasm and ectoplasm. Its shape varies considerably from species to species and is frequently related to the shape of the skeleton. In living radiolarians the membrane is usually pigmented and easily visible. Pores in the membrane permit exchange between the endoplasm and ectoplasm and act as exits from the endoplasm for the axopodia.

1.3.3 Reproduction

The life cycle is believed to include both asexual binary fission and sexual reproduction involving flagellated gametes.

Pokorny (1963) described asexual reproduction as nuclear, central capsular, and ectoplasmic division and finally, in some forms, skeletal division. In species with complex skeletons one daughter cell retains the original skeleton while the other leaves and secretes a new one. Kling (1971a) gives examples of two spherical lattice skeletons still joined and suggests the pairs could have been secreted "accidentally", before completion of fission. This phenomenon is reported to occur in several species.

Sexual reproduction has never been fully observed. Anderson gives accounts of the cytoplasmic separation of flagellated swarmers, each with its own nucleus, lipid (food)

reserves and cytoplasm, at the periphery of two colonial radiolarians *Sphaerzoum punctatum* and *Thalassicola nucleata* (in 1976b and 1978a respectively). The swarmers did not survive in the laboratory.

1.3.4 Skeleton

Radiolarian skeletons are generally within the size range 50 to 400 microns. Members of the polycystine family Orosphaeridae (solitary) produce skeletons as large as 5mm in diameter (Friend and Riedel, 1967). Rare orosphaerid fragments are preserved in New Zealand upper Neogene sediments. By far the largest known solitary species is the phaeodarian *Coelothamnus maximus* Haeckel (1887), with a skeletal diameter of 32mm.

All polycystine radiolarians produce skeletons made of amorphous silica most of which is in the form of solid bars (attached at both ends) and spines (attached at one end). Some radiolarians produce hollow spines (Petrushevskaya, 1975). The phaeodarians utilise amorphous silica admixed with organic matter in their skeleton elements which are usually hollow. The skeleton is never in direct contact with sea water in a living radiolarian, even the extremities of long spines being encased in a layer of ectoplasm (see section 1.3.2.2).

Four basic wall structures exist:

1. Latticed wall - a network of bars forming closely spaced pores.
2. Spicule - a network of widely spaced bars.
3. Spongy wall - an intricate interlacing of relatively thin bars in a thick, seldom regular, three-dimensional network with pore patterns not well defined.
4. Perforate plate wall - a solid uniformly thin wall penetrated by widely spaced pores.

Ontogeny has seldom been observed in living radiolarians. Some closely related fossil forms may be adult, intermediate, and juvenile stages (Kling, 1978). There is some evidence of skeletal elements thickening through the life span of a radiolarian (Kennett, 1982).

Anderson (1976c) considered that skeletal architecture bears little relationship to the organisation of the cytoplasm but reported that radial spines and concentric lattice skeletal elements are foreshadowed by a similar pattern of organisation of the soft parts. The constant association of skeletal framework with a surrounding cytoplasmic sheath suggests that skeletal deposition occurs within this envelope. The presence of a silica depositing sheath (siliclemma), has been clearly established in diatoms (Reimann, 1964: after Anderson,

1976c).

The polycystine Radiolaria are divided into two groups according to skeletal morphology. The Spumellaria are basically spheres with the external skeleton called the cortical and inner/inners the medullary/medullaries. Variations on the spherical shape include ellipsoidal (one axis lengthened), discoidal (one axis shortened), and coiled. The Nassellaria have axial symmetry. It is characteristic of most radiolarians that the radial elements never meet at the centre (Kling, 1978). Silica deposition in growing spumellarians probably occurs concentrically outwards as the animal grows, with the skeleton always preceeding the central capsule (Pokorny, 1963). During development of the nassellarians the cephalis and thorax form first followed by later segments which are divided internally by fairly complete septa. On the exterior, the septa are normally marked by constrictions.

1.3.5 Nutrition

Radiolarians were originally assumed to be herbivores grazing exclusively on diatoms and other algae even though Haeckel (1887) had observed a tintinnid within the protoplasm of a radiolarian (Anderson, 1976c). Radiolarians are now known to be omnivorous, feeding on various kinds of planktic organisms including microflagellates and other protozoans, diatoms, and possibly forms as large and as active as copepods (Campbell, 1954; Kling, 1978). Anderson (1978a) studied *Thalassicolla nucleata*, a colonial radiolarian, and found it receives nutrition from diatoms, colourless flagellates, pigmented unicellular algae, and crustacea. This radiolarian has the ability to sort out its food, unwanted material being released within several minutes.

Food is captured as it floats into contact with the rhizopodia and is transported by cytoplasmic streaming into the digestive region (Anderson, 1978a; Goll and Merinfeld, 1979). Anderson (1978a) gives an account of the capture and breakdown of a crustacean. Rhizopodia quickly entangle the struggling prey which is eventually enclosed in rhizopodial envelopes. Segments of rhizopodia, in immediate contact with the surface of the prey, contain numerous microfilaments which can break open the prey's exoskeleton. Coelopods (hollow specialised extensions of the rhizopodia) penetrate and start digesting the flesh under the exoskeleton.

Anderson (1978b) presents C^{14} isotope evidence for transfer of organic substances from zooxanthellae to host in *Collosphaera globularis*, a colonial radiolarian. The predation of symbiotic zooxanthellae is also noted by Anderson (1976a, 1976c, 1977) and Casey (1977). This nutrient source may partially explain the high abundance of radiolarians in

oligotrophic regions of the oceans (Anderson, 1976c, 1978b).

1.3.6 Radiolarian mobility

Radiolarians have no method of swimming to allow for lateral movement. They can move vertically by varying their buoyancy, either by altering the carbon dioxide content of the alveoli (Campbell, 1954; Riedel and Sanfilippo, 1977; Kling, 1978), or by altering the amount of fat in globules (Riedel and Sanfilippo, 1977), or by a combination of both.

1.4 HISTORY OF STUDY

Meyen (1834) was the first to recognise radiolarians in plankton and described two species. In a series of papers from 1838 to 1875, Ehrenberg described fossil Radiolaria from Quaternary and Tertiary sediments. From the 1850's to the 1880's there were extensive descriptions of living radiolarians mainly from the Mediterranean Sea (e.g. Muller, 1858; Haeckel, 1860a, 1860b, 1862) and fossil assemblages (e.g. Ehrenberg, 1854, 1872a, 1872b, 1873, 1875; Zittel, 1876; Stohr, 1880). There were repeated attempts to form a taxonomic system capable of accommodating the rapidly increasing number of forms discovered (e.g. Muller, 1858; Haeckel, 1862, 1881; Butschli, 1882a, 1882b). Hertwig (1879) established the unicellular nature of radiolarians and divided the major radiolarian groups on the basis of the morphology of the central capsule.

The *HMS Challenger* Expedition of 1873-1876 collected large numbers of plankton and bottom sediment samples from all the world's oceans. The *Challenger* Report on the Radiolaria (Haeckel, 1887) was a monographic treatment which has remained the most important single reference on the subclass (Riedel and Sanfilippo, 1977). In it Haeckel set up an exhaustive classification but at the time virtually nothing was known about the biology, stratigraphy, or phylogeny of the group. The classification was artificial and based on morphologic subdivisions that cut across natural generic and species groupings (Kennett, 1982), and for nearly a century obscured the natural relationships of radiolarians (Kling, 1978). Oceanographic expeditions of the late 19th century and early 20th century initiated an explosion in the study of radiolarians, the main contributions being by Popofsky, Cleve, Haecker, and Dreyer.

Haeckel (1887) assumed that his bottom sediment samples were all Recent in age, but some of them are now known to be Paleocene. Consequently Haeckel, and many subsequent authors, assumed that many species have long time ranges and the Radiolaria were not regarded as useful stratigraphic indicators. A good example is an assemblage from the Indonesian island of Rotti, originally described as Pliocene (Tan Sin Hok, 1927), even

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though it is most similar to known Mesozoic assemblages. The Pliocene age was accepted because of the mistakenly presumed long time ranges. Riedel (1953) finally showed that the Rotti assemblage is Mesozoic although one sample did contain a mixture of post-upper Miocene and obviously reworked Mesozoic specimens.

In the early 1950's, Riedel began studies of deep-sea samples collected by the Swedish Deep-Sea Expedition and on-land fossil samples from tropical localities. It soon became obvious that many of the sea-floor sediments contained fossil or mixed fossil and Recent assemblages (Riedel, 1952, 1957a).

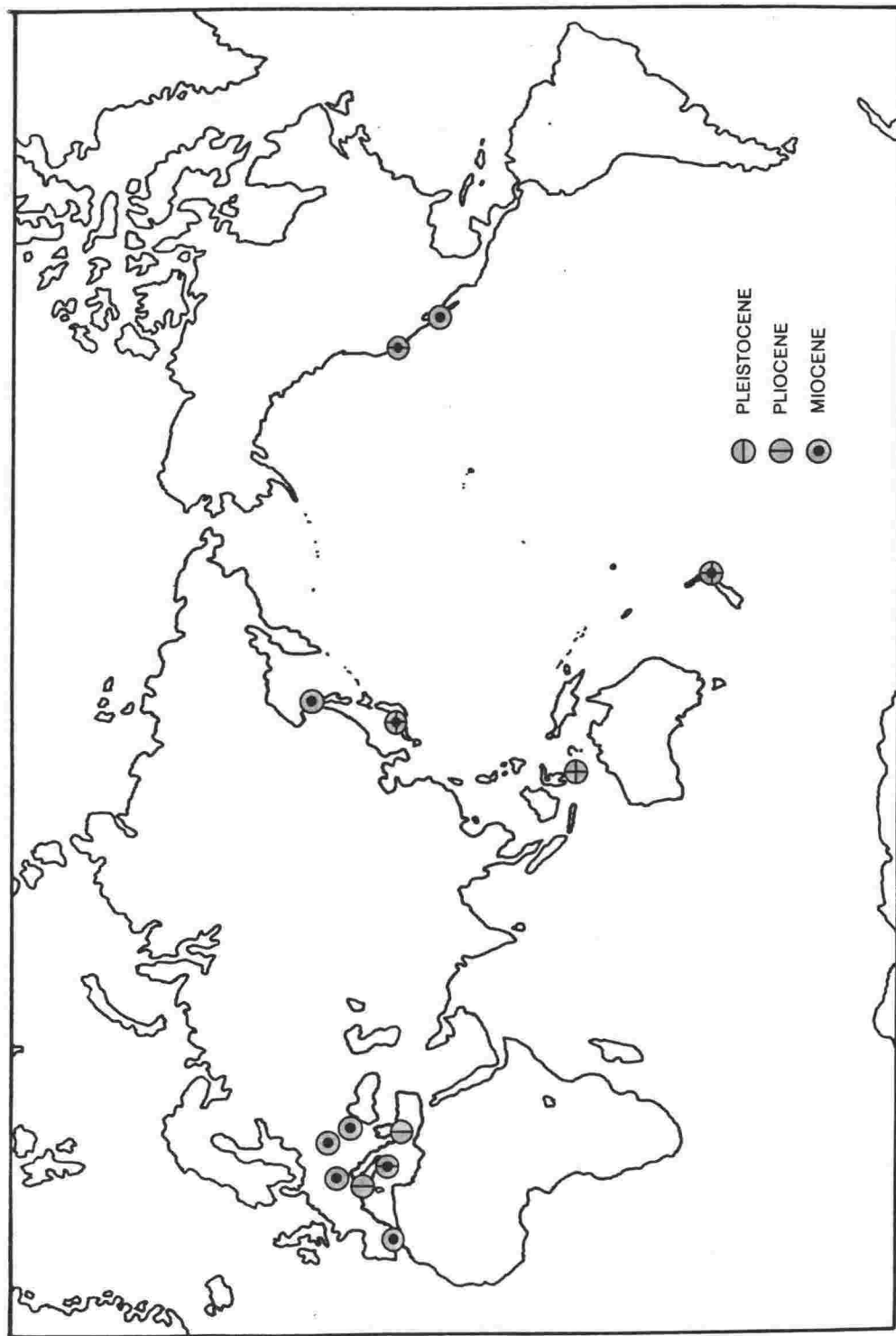
Since the early 1960's cores from the Deep Sea Drilling Project have proved the usefulness of radiolarians in biostratigraphy. The rate of evolution of Radiolaria is comparable to that of other microfossil groups. The legacy of Haeckel's classification is the a major problem in applying Radiolaria to biostratigraphy.

At present the taxonomy is being revised by Riedel, Petrushevskaya, Nigrini, Goll and others. Emphasis has been on the revision and refinement of the taxonomy of certain forms, particularly those species and evolutionary lineages which have proven to be useful in biostratigraphy (Nigrini and Moore, 1979). Petrushevskaya (1975) stressed the value of incorporating into the present classifications based on the hard parts, the recent biological investigations which have shown that radiolarians can be divided into several major groups with differing cytoplasmic characteristics, especially in connection with the form of the axopodia and the position of the nucleus.

Future studies will still require a large taxonomic component until a phylogenetic classification is achieved. Paleoecological studies will be increasingly important as the taxonomy improves. Emphasis will increase on establishing the statistical relationships between the distribution of species (or species groups) and quantitative measurement of their environmental parameters (Nigrini and Moore, 1979). Another potential area of research is the protein-containing matrix preserved in radiolarian skeletons. The protein could be used for dating by amino acid epimerisation-racemisation reactions and for the tracing of evolutionary lineages by the analysis of species specific amino acid patterns (King, 1974).

Figure 1.3

Published locations of on-land, upper Neogene, radiolarian bearing sediments in the world.



1.5 PREVIOUS WORK

1.5.1 Land-based sections

New Zealand is one of the few places in the world where upper Neogene radiolarian-bearing rocks outcrop in well exposed land based sections and is probably the only situation where Late Neogene southern temperate assemblages can be found in on-land outcrops (see Figure 1.3).

The following is a list of known upper Neogene land based radiolarian bearing localities and references.

1.5.1.1 Europe

Northern Italy

Tabianian - stratotype: Lower Pliocene
Sanfilippo 1971.
Sanfilippo, Burckle, Martini, and Riedel 1973.

Southern Italy

Calabria - Zanclean: Pliocene
Seguenza 1880.

Calabria - Tortonian: Upper Miocene
Pantanelli and Stefani 1880.

Sicily

Torrente Rossi: Upper Miocene
Sanfilippo 1971.
Sanfilippo, Burckle, Martini, and Riedel 1973.

Capodarso - 10km west of Pasquasia (location of the neostratotype Messinian). Samples from just below the Messinian evaporites - Tortonian: Upper Miocene
Sanfilippo 1971.

Capo Rossello - near Agrigento - "Trubi" marls which define the stratotype Zanclean: Pliocene
Riedel, Sanfilippo, and Cita 1974.
Riedel and Sanfilippo 1978.

Grotte - Girgenti Province - Tortonian: Upper Miocene
Stohr 1880.

Crete

Late Pliocene
Sanfilippo and Riedel 1975.

Austria

Northeast Austria - Tortonian: Upper Miocene
Bachmann 1961.

Spain

El Cuervo section, Andalusia: early Late Miocene
Berggren *et al.* 1976.

Rumania

Tortonian of the Subcarpathians - mainly Phaeodaria
described: Upper Miocene
Dumitrica 1964.

Poland

Vicinity of Krakow and Bochnia, southern Poland - central
part of the Carpathian foothills: Upper Miocene
Barwicz-Piskorz 1978.

1.5.1.2 Asia

Russia

Northern Sakhalin: Upper Miocene
Kozlova 1960.

Rotti

Near Timor: one possible Plio-Pleistocene sample
Riedel 1953.

Japan

On the west coast of Japan there are a series of Neogene
Basins. The formations listed below are defined from the
Oga Peninsula Section, Akita Sedimentary Basin (after
Nakaseko, 1959) and are typical of the lithologies
represented in many of these Neogene basins.

Shibikawa Fmn. - late Pliocene and Pleistocene
Blue coarse-medium sands, mollusca, some lignite seams.
Waikimoto Fmn. - Pliocene
Fine sands, mollusca.
Kitaura Fmn. - late Miocene to early Pliocene
Massive dark grey mudstones with sandstone and tuff
layers.
Funakawa Fmn. - late Miocene
Black mudstone with tuffs.
Onnagawa Fmn. - middle to late Miocene
Hard siliceous shales.

Fossil Radiolaria are present in all these formations
Nakaseko (1955, 1959, 1960).
Ling (1971) described some Radiolaria from the
Onnagawa Formation.

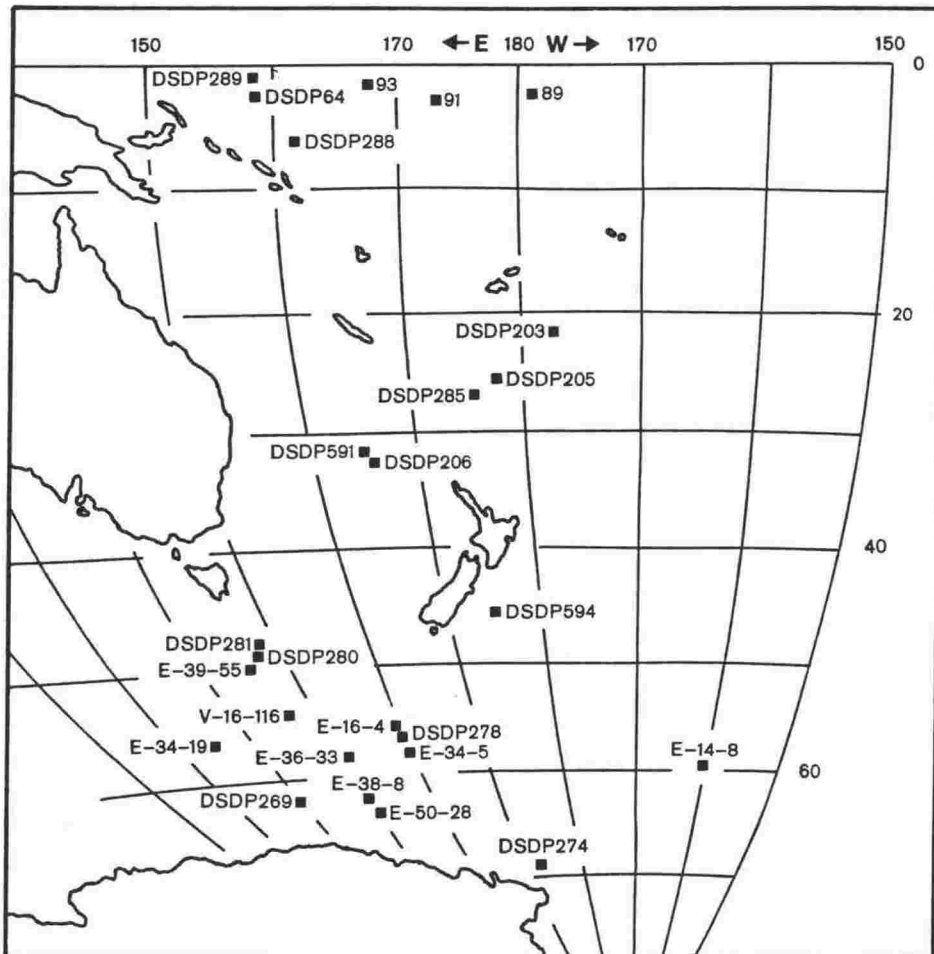
1.5.1.3 America

California

The Newport Bay area has been well studied. The
Late Neogene radiolarian-bearing rocks are the Malaga
Mudstone (late Miocene) and the Capistrano Formation
(latest Miocene and early Pliocene) where numbers are
as high as 10,000 radiolarians per gram of sediment
(Ingle and Barron, 1978). The main references are:
Campbell and Clark 1944.
Casey 1972.
Casey, Price and Swift 1972.
Ingle and Barron 1978.

Figure 1.4

Location of upper Neogene, radiolarian bearing deep-sea cores in the south-west Pacific.



The Mission Hills area has upper Miocene faunas in the Modelo Formation (late Miocene).

Barron and Ingle 1978.

The Centerville Beach section located in the Humboldt Basin along the coast of northern California.

Radiolarians present in the late Miocene-early Pliocene Pullen Formation.

Weaver, Casey, and Perez 1981.

Bahia de Asuncion, Baja California - diatomites with late Miocene radiolarians.

Weaver, Casey, and Perez 1981.

Maria Madre Islands: late Miocene.

Weaver, Casey, and Perez 1981.

1.5.2 Deep-sea cores

Most of the work on late Neogene Radiolaria has been done on deep-sea cores. The following cores in the southwest Pacific contain late Neogene Radiolaria (see figure 1.4 for locations). A biostratigraphic discussion of some of these and other deep-sea cores will be presented in Chapter Five. If any author/s worked on only a part of the radiolarian-bearing sequence from the cores the age range of the material they worked on is shown.

1.5.2.1 Deep Sea Drilling Project sites

64 Ontong-Java Plateau

Radiolarians are common and well preserved through the late Neogene. This part of the sequence appears to be uninterrupted.

Winterer, Riedel, Moberly *et al.* 1971.

Riedel and Sanfilippo 1971.

203 Lau Basin

Rare to few, well preserved in the upper Pleistocene and very rare and corroded in the lower Pleistocene.

Burns, Andrews, van der Lingen *et al.* 1973a.

Dumitrica 1973.

205 South Fiji Basin

Very rare to common, moderately well preserved late Miocene faunas. Phaeodarians present.

Burns, Andrews, van der Lingen *et al.* 1973b.

Dumitrica 1973.

206 New Caledonia Basin

Quaternary to middle Oligocene sequence. Although rare to common, radiolarians are persistent throughout and coexist with rich nannofossil and planktic foraminiferal assemblages.

Burns, Andrews, van der Lingen *et al.* 1973c.

Dumitrica 1973.

Westberg and Riedel 1978.

269 *Southeastern edge of the South Indian Abyssal Plain*

Few to common and well preserved post-Miocene specimens.
Sparse and moderately preserved in the upper Miocene.
Chen 1974.
Hayes, Frakes, Barrett *et al.* 1975a.
Chen 1975.

274 *Near the Antarctic Continental Margin*

Pleistocene - few and well preserved.
Pliocene and uppermost Miocene - common and well preserved.
Miocene - rare and moderately preserved.
Chen 1974.
Hayes, Frakes, Barrett *et al.* 1975b.
Chen 1975.

278 *South Emerald Basin*

Almost complete Pleistocene to middle Oligocene sequence.
172m of radiolarian/diatom and diatom ooze.
Late Pliocene to Recent.
214m of alternating siliceous nannofossil ooze and nannofossil rich siliceous ooze.
Earliest Miocene to early Pliocene.
Kennett, Houtz, Andrews *et al.* 1975b.
Petrushevskaya 1975.
Keany and Kennett 1975 - Plio-Pleistocene.
Weaver 1976a - late Miocene to early Pliocene.

280 *South of the South Tasman Rise*

1m of late Pleistocene overlying 5m of late Miocene to early Pliocene sediments containing radiolarians.
Kennett, Houtz, Andrews *et al.* 1975c.
Petrushevskaya 1975.

281 *South Tasman Rise*

Scattered, well preserved specimens in late Miocene to Pleistocene sediments.
Kennett, Houtz, Andrews *et al.* 1975d.
Petrushevskaya 1975.

285 *Central South Fiji Basin*

Some late Miocene faunas.
Andrews, Packham, Eade *et al.* 1975a.
Holdsworth 1975.

288 *Ontong-Java Plateau*

Few to trace in Pleistocene and late Pliocene sediments.
Andrews, Packham, Eade *et al.* 1975b.
Holdsworth 1975.

289 *Ontong-Java Plateau*

Complete Neogene sequence with radiolarians present throughout.
Andrews, Packham, Eade *et al.* 1975c.
Holdsworth 1975.
Westberg and Riedel 1978.

591 *New Caledonia Basin*

Uncommon but persistent throughout the late Neogene sequence.

J.P. Kennett (pers. comm.).

594 *Southern Chatham Rise*

Well represented faunas from middle Miocene to Holocene. From latest Miocene to Holocene there is a sequence of oscillations between dark hemipelagic and lighter pelagic biogenic sediments which are probably climatically controlled.

J.P. Kennett (pers. comm.).

1.5.2.2 **Eltanin cores**

E-14-08 *Flank of the Mid-Pacific Ridge*

Hays and Opdyke 1967 - late Miocene to Holocene.
Bandy, Casey and Wright 1971 - late Miocene to Holocene.
Hays and Donahue 1972 - late Miocene to early Pliocene.
Weaver 1976a - late Miocene to Pliocene.
Keany 1979 - early Pliocene.

E-16-04 *Emerald Basin*

Weaver 1976a - late Miocene to Pliocene.
Keany 1979 - early Pliocene.

E-34-05 *Flank of the Macquarie Ridge*

Weaver 1976a - late Miocene.
Keany 1979 - early Pliocene.

E-34-19 *South of the Indian-Antarctic Ridge*

Weaver 1976a - late Miocene to early Pliocene.
Keany 1979 - early Pliocene.

E-36-33 *Macquarie Swell*

Weaver 1976a - Pliocene.
Keany 1979 - early Pliocene.

E-38-03 *Base of the Antarctic Continental Rise*

Weaver 1976a - Pliocene.
Keany 1979 - early Pliocene.

E-39-55 *Macquarie Swell*

Weaver 1976a - Pliocene.

E-50-28 *Base of the Antarctic Continental Rise*

Weaver 1976a - Pliocene.
Keany 1979 - early Pliocene.

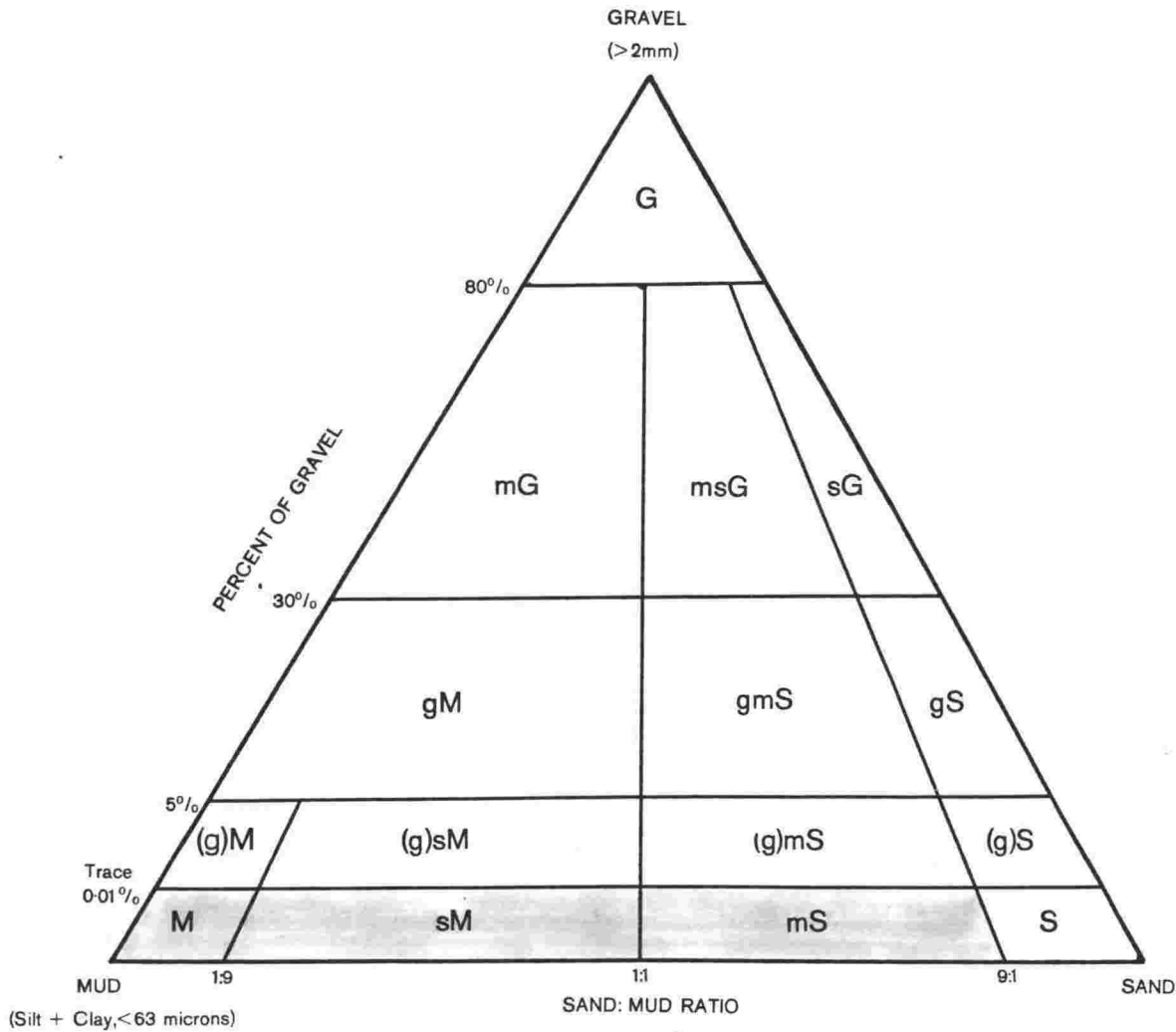
1.5.2.3 **Vema core**

V-16-116 *Flank of the Indian-Antarctic Ridge*

Hays 1965 - Pliocene to Holocene.

Figure 1.5

Size classification of sediments (after Folk, 1974). All radiolarian bearing sediments from the late Neogene of New Zealand fit into one of the three categories highlighted.



1.5.2.4 Swedish Deep Sea Expedition cores

89 *Central Pacific Basin*

Quaternary fauna (abundant and well preserved) overlying a mixture of Quaternary, middle Tertiary and late Tertiary forms.
Riedel 1957a.

91 *Gilbert Ridge*

Upper 2-3m contain an abundant, well preserved Quaternary assemblage disconformable on middle Tertiary sediments.
Riedel 1957a.

93 *Nauru Basin*

Probably entirely Quaternary containing abundant and well preserved specimens with some rare reworked early, middle and late Tertiary species.
Riedel 1957a.

1.5.3 New Zealand

Previous work on New Zealand Late Neogene Radiolaria is virtually nonexistent. Eggo (1979) attempted to determine the radiolarian biostratigraphy in the upper Mangaopari Stream section (upper Miocene to lowermost Pliocene), but was unable to define any datums because his extraction technique was not good enough to obtain sufficient well preserved specimens. Improved techniques have allowed the writer to obtain good assemblages from that section. Ashby (1978) illustrated some species from Pliocene sediments in Wairarapa. No other taxonomic or biostratigraphic work has been done on New Zealand Late Neogene Radiolaria.

The writer located radiolarian-bearing sections and samples mainly by discussion with other micropaleontologists working on New Zealand Late Neogene sediments and by sampling horizons with high preservation potential (see Chapter Three). A number of localities were gleaned from scattered references in publications, theses, and New Zealand Fossil Record Forms.

1.6 NOMENCLATURE

The following list of publications contain some important definitions used in this thesis.

1.6.1 Size classification of sediments

Reference: Folk (1974).

Figure 1.5 shows this classification where fifteen major textural groups are defined on the basis of the gravel content and sand to mud ratio. Nearly all the samples studied in this thesis contain no gravel size material and have a sand to mud ratio of less than 9:1 so the number of groups available for classification is reduced to three. For samples lacking

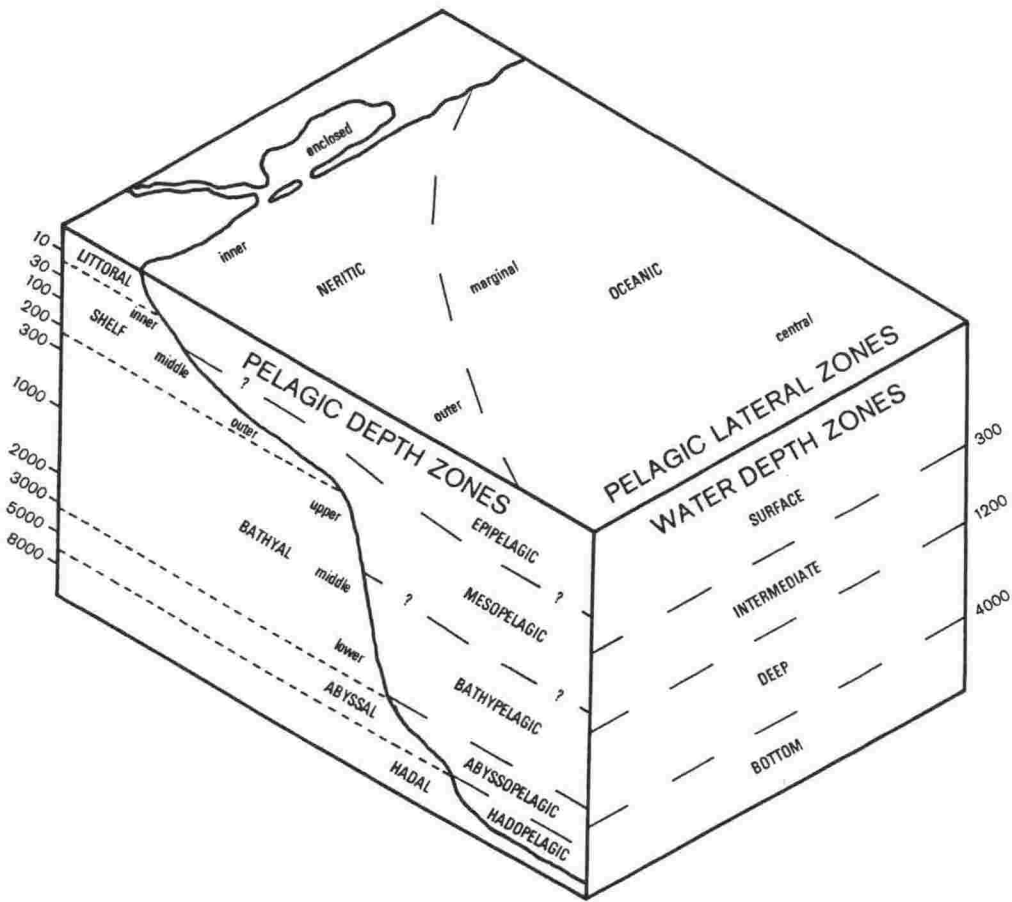
Figure 1.6

Upper Neogene section of the New Zealand Cenozoic time scale.

	SERIES	STAGE	SUBSTAGE
HOLOCENE	HAWERA		
PLEISTOCENE	WANGANUI	Castlecliffian	Wc
			Putikian Wu
			Okehuan Wk
		Nukumaruan	Wn
? — PLIOCENE	WANGANUI		Marahauan Wa
			Hautawan Wh
		Mangapanian	Wm
		Waipipian	Wp
? — MIOCENE	TARANAKI	Opoitian	Wo
		Kapitean	Tk
		Tongaporutuan	Tt
	SOUTHLAND	Waiauan	Sw

Figure 1.7

Marine ecologic zones: all depths in metres (after Edwards, 1979).



gravel, Folk defines a further ten groups based on sand percentage and clay to silt ratio. As the clay to silt ratio in the mud size fraction was not determined for the samples studied this "subclassification" can not be used.

1.6.2 Lithologic symbols and abbreviations

Reference: Andrews (1982).

1.6.3 New Zealand Cenozoic Time Scale

Reference: Hoskins (1982).

The late Neogene portion of the time scale, with the standard abbreviations used, is reproduced in figure 1.6.

1.6.4 Definition of type sections

Reference: Hoskins (1982: pp.72-73).

1.6.5 Nomenclature pertaining to type specimens

Reference: Hornibrook (1968a: p.20).

1.6.6 Ecologic zones

Reference: Edwards (1979), reproduced in Kennett (1982: p.258).

The ecologic zones are outlined in figure 1.7.

1.6.7 Biostratigraphic zones

Reference: Hedberg (1976).

The definitions of the zones are outlined in figure 1.8.

1.6.8 Paleomagnetic zones

All the paleomagnetic zones discussed in this thesis are based on the paleomagnetic time-scale whereby Anomaly 5 = Chron 9. The paleomagnetic usage of "Epoch" is retained to conform to the usage in most of the references cited.

1.6.9 Use of planktic, nektic, and benthic

Reference: Martinnsen (1975).

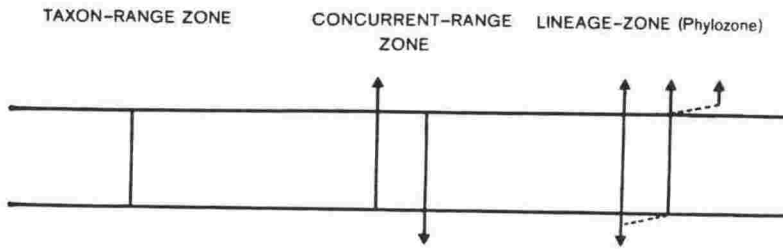
This usage is accepted.

Figure 1.8

Definitions of biostratigraphic zones (after Hedberg, 1976).

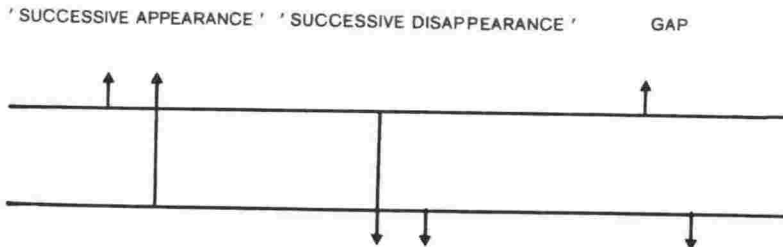
RANGE ZONES:

A group of strata representing the stratigraphic range of some selected element/s of the total assemblage of fossil forms present.



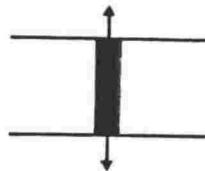
INTERVAL ZONES (Interbiohorizon Zone):

The stratigraphic interval between two biohorizons.



ACME ZONE:

A group of strata based on the abundance or development of certain forms, regardless of either association or range.

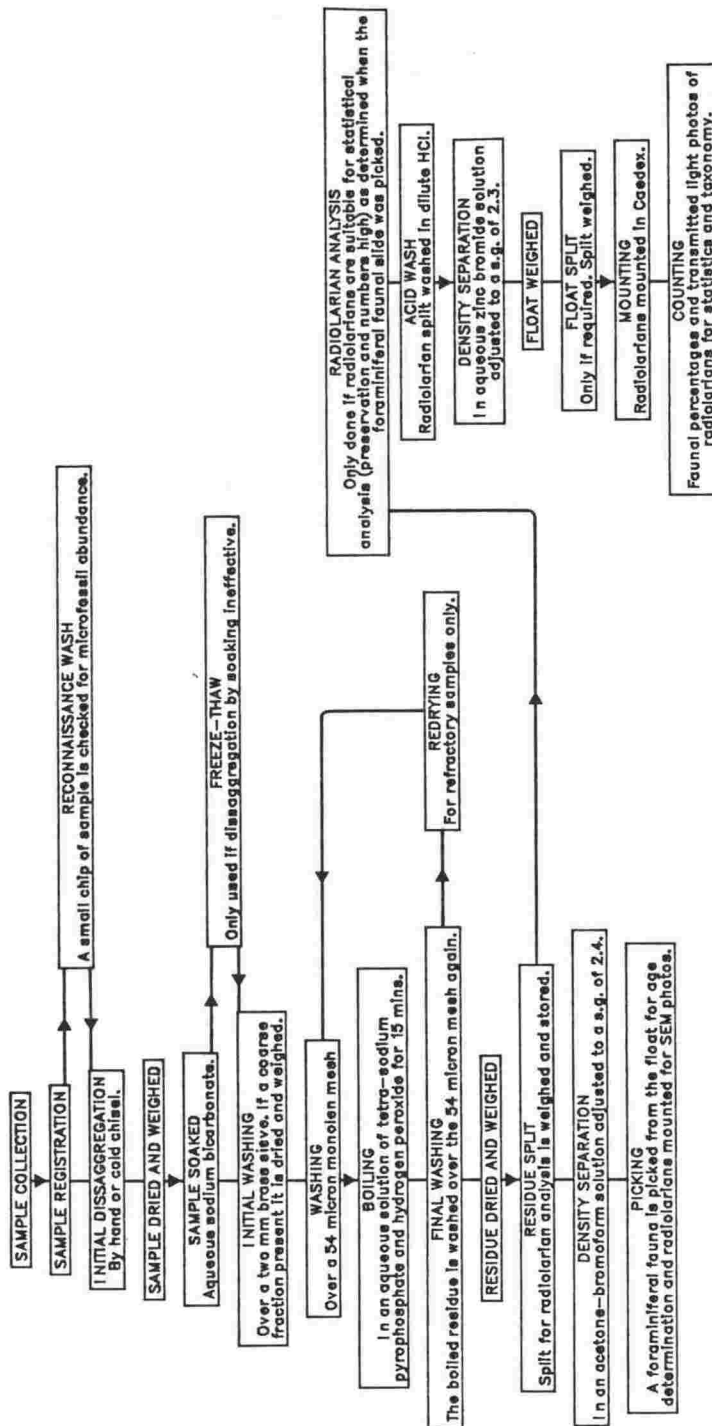


ASSEMBLAGE ZONE:

A group of strata characterised by a distinctive natural assemblage of all forms present or of the forms present of a certain kind or kinds.

Figure 2.1

Sample preparation flow chart.



Chapter II

TECHNIQUES

2.1 PREAMBLE

It was found necessary, because of the relatively low abundance of radiolarians in the samples studied, to improve upon standard techniques and develop new methods for the qualitative analysis of microfossils and the quantitative analysis of radiolarians. Some of these developments are outlined in Appendix C (Ashby, 1983) which is reproduced within appropriate sections in this chapter to enhance readability. A flow chart showing the sample procedure used in this thesis is presented in figure 2.1.

All computing was done on the IBM 4341 at the Computing Services Centre, Victoria University of Wellington. The following software packages were used during the course of this study:

SAS - both the graphics and statistical sections used.

TELAGRAF - for high quality output of graphs.

SCRIPT - word processing.

Procedures for collection do not differ substantially from those employed in collecting for other types of microfossils. Usually about 0.5kg of sample was collected and the site marked on aerial photographs. It is usually impossible to determine, by use of a hand-lens in the field, whether or not radiolarians are present in sedimentary rocks because generally they can not be distinguished on the rougher surfaces of less indurated rocks (Riedel and Sanfilippo, 1977). It soon became apparent that rhyolitic glass shards, often present in of New Zealand Upper Neogene sediments enhance the preservation potential of the radiolarian skeletons (see Chapter Three) and horizons about 0.5 to 1 metres above rhyolitic tuff beds in hemipelagic mudstones were found to be likely to contain well preserved Radiolaria. Some samples were obtained from Geological Survey and University collections.

Samples were registered in the New Zealand Fossil Record File. A small chip of sample was quickly disaggregated using an ultrasonic tank and washed over a 54 μ brass mesh to check for microfossil abundance if this was not already known.

2.2 DISAGGREGATION

2.2.1 Initial disaggregation

The sample was first broken into half centimetre pieces. Pokorny (1963) recommended wrapping the sample in several layers of paper and hammering it on a solid base. This method is not ideal as uneven crushing occurs and the microfossils contained in the dust produced by the first few blows can be damaged by later blows. Using a mortar and pestle has the same result. Less damage occurs if the rock is broken by gradual pressure from a vice (Glaessner, 1948).

It was found that a compacted mudstone can be broken easily and quickly using a cold chisel, with only a minimum of damage to the contained microfossils. Some mudstones were found to be moderately friable when damp and could be easily broken by finger pressure.

The samples were then oven dried overnight at 35°C and weighed. At higher temperatures baking inhibited disaggregation in some samples.

2.2.2 Chemical disaggregation

The chemicals most commonly recommended to enhance disaggregation by soaking include: sodium bicarbonate to enhance deflocculation (Franke, 1935), 10-15% hydrogen peroxide which requires no preliminary drying of the sample (Wick, 1947), petrol followed by water on a dry sample (Layne, 1950), sodium sulphate which disaggregates the sample by crystallisation (Pokorny, 1963), and disaggregation by acid treatment (Burma, 1965).

After weighing, the dried sample was immersed in a warm aqueous sodium bicarbonate solution and left to soak overnight. It was found that sodium bicarbonate is effective for disaggregating most New Zealand Late Neogene mudstones. Occasionally hydrogen peroxide was used.

2.2.3 Freeze-thaw disaggregation

Hanna and Church (1928) described a freeze-thaw method for breaking down samples which proved to be effective in reducing samples to approximately two millimetres. The formation of ice crystals appears to have no effect on the preservation of the foraminiferal and radiolarian specimens. This method was used only when the initial soaking had proved ineffective.

2.2.4 Initial washing

Initial washing over a two millimetre brass mesh removed lumps that were proving difficult to break down, such as cemented fossil burrows. Material that remained on this mesh was dried and its weight subtracted from the initial weight of the sample.

2.3 WET SIEVING

Separation of microfossils from sediment by the decantation method has advantages in that there is only slight breakage of specimens. However, the process is very time consuming and there is a danger that the better preserved microfossils will float away if they are filled with air. Wet sieving over brass or stainless steel meshes is preferred by most laboratories. At Scripps Institute of Oceanography the meshes are cleaned between samples by washing in strong jets of water and rubbing vigorously with a paper towel to break and dislodge any skeletons. The sieves have to be repaired fairly often (W.R. Riedel, pers. comm.).

The composition and open pore structure of many radiolarian skeletons means that the common staining techniques used to detect contamination, such as dipping the mesh in methylene blue, are ineffective.

Baker (1951) described a technique using cloth (organdie and silk) sieves for separating microfossils from muddy matrix. The cloth has a cushioning effect which reduces damage and can be cleaned easily because of its flexibility.

The writer used a monolen mesh held taut in a PVC frame. Even after repeated use the monolen still retained pore size characteristics comparable to research brass sieves used for grain size analysis in the Sedimentology Laboratory at this institution (P. Barrett, pers. comm.). Monolen is a very durable, polyester and nylon combination resistant to 40% hydrofluoric acid. To prevent contamination the mesh was immersed in 20% aqueous hydrofluoric acid after each preparation, dissolving any attached skeletons, and then neutralised in a sodium bicarbonate solution.

The sediment that passed through the 2mm brass mesh was washed over a 54μ monolen mesh which retains the smallest radiolarians and identifiable fragments. The fraction coarser than 54μ is usually not completely disaggregated at this stage. Gentle rubbing between the fingers helps to complete the disaggregation and damages the microfossils only slightly (Glaessner, 1948).

The sample may be boiled in a variety of solutions to complete disaggregation. The

procedure used by Frizzell and Middour (1951), as described by Riedel (1959), has been adopted by the writer. The sample is boiled in water and tetrasodium pyrophosphate added (three to five grams per 50ml of water), then 30% hydrogen peroxide is added by eye dropper until the boiling solution starts to foam. Boiling is continued for 15 minutes. Care must be taken at this stage because if the sample is sandy the boiling may become explosive. The boiled sample is then washed back over the 54μ mesh using a fine jet of water at low pressure. Too great a water pressure can damage the specimens (Pokorny, 1963). Some more refractory samples required redrying, resoaking, and reboiling. The residue was then washed into a bowl and left to dry. The excess water was never decanted off as many of the microfossils float, e.g. planktic foraminifera and spongodiscid radiolarians. The dried residue was then weighed. Splits for foraminiferal and radiolarian analysis were taken using a modified Otto microsplitter for large samples and a small, non-laminated sample splitter (Humphries, 1961) for small samples.

2.4 DENSITY SEPARATION

Residues of New Zealand Upper Neogene mudstones almost always contain sand sized inorganic mineral grains. In most cases the siliceous biogenic component is small, requiring concentration by density separation. If quantitative data on the radiolarians is required, the separate must be representative of the assemblage in the sample.

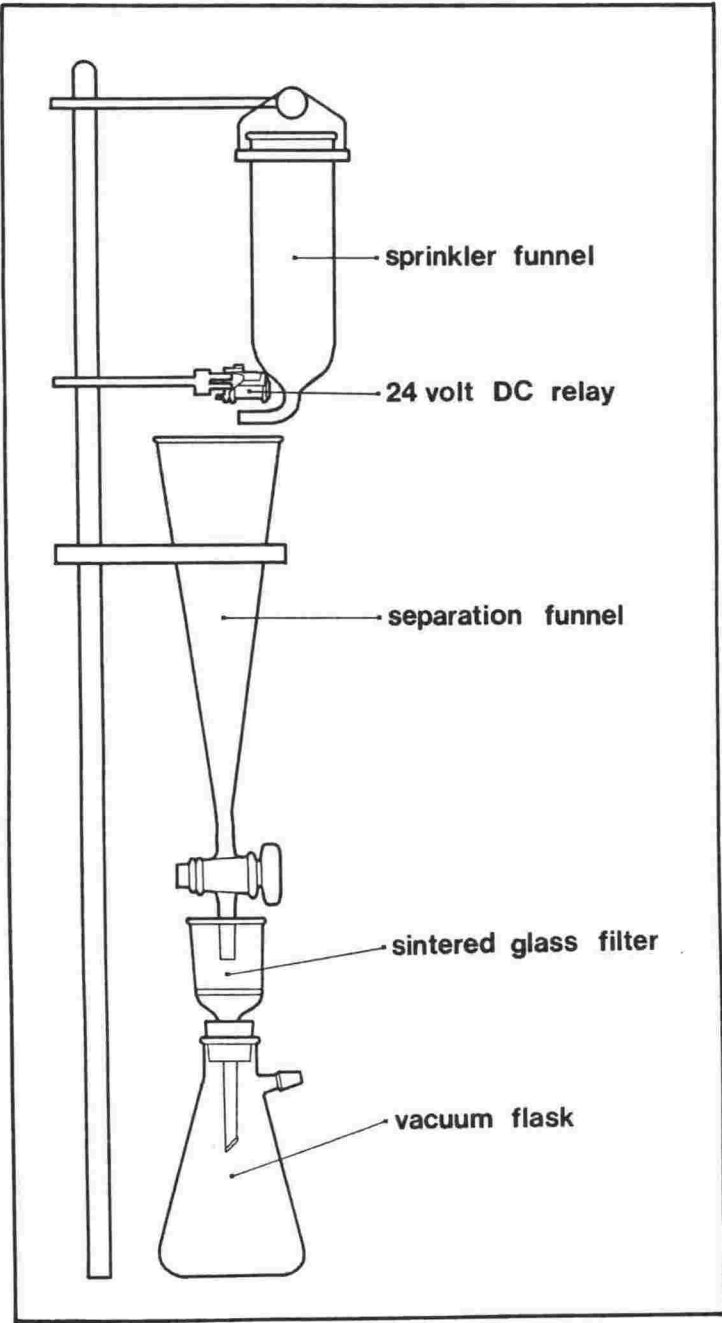
Howe (1941) described a method of separating calcareous microfossils from the residue by boiling in a soapy solution and stirring to form a froth on which the calcareous specimens float. The concentrated specimens can be decanted off. Glaessner (1948) described the technique developed by Bataafsche Petroleum Maatschappij (The Hague) which utilises hot pyridine solution to remove oily matter from sandy residues before using the soap foam flotation. This method works equally well with foraminifera and radiolarians but the separation is size selective and incomplete.

Density separations using a heavy liquid is the usual method of concentration. Carbon tetrachloride has a maximum specific gravity of 1.6 at 20°C , insufficient to give good density separations of foraminifera and radiolarian skeletons. Solutions of bromoform (tribromoethane) adjusted to a density of 2.2 - 2.4 are suitable for separating foraminiferal specimens (Gibson and Walker, 1967).

To concentrate radiolarian samples for quantitative analysis, flotation in aqueous solutions of zinc bromide has been found to be very effective. Zinc bromide solution is commonly used in palynology and Brady (1977) described its use for the flotation of

Figure 2.2

Apparatus used for density separation of radiolarian skeletons and foraminiferal tests.

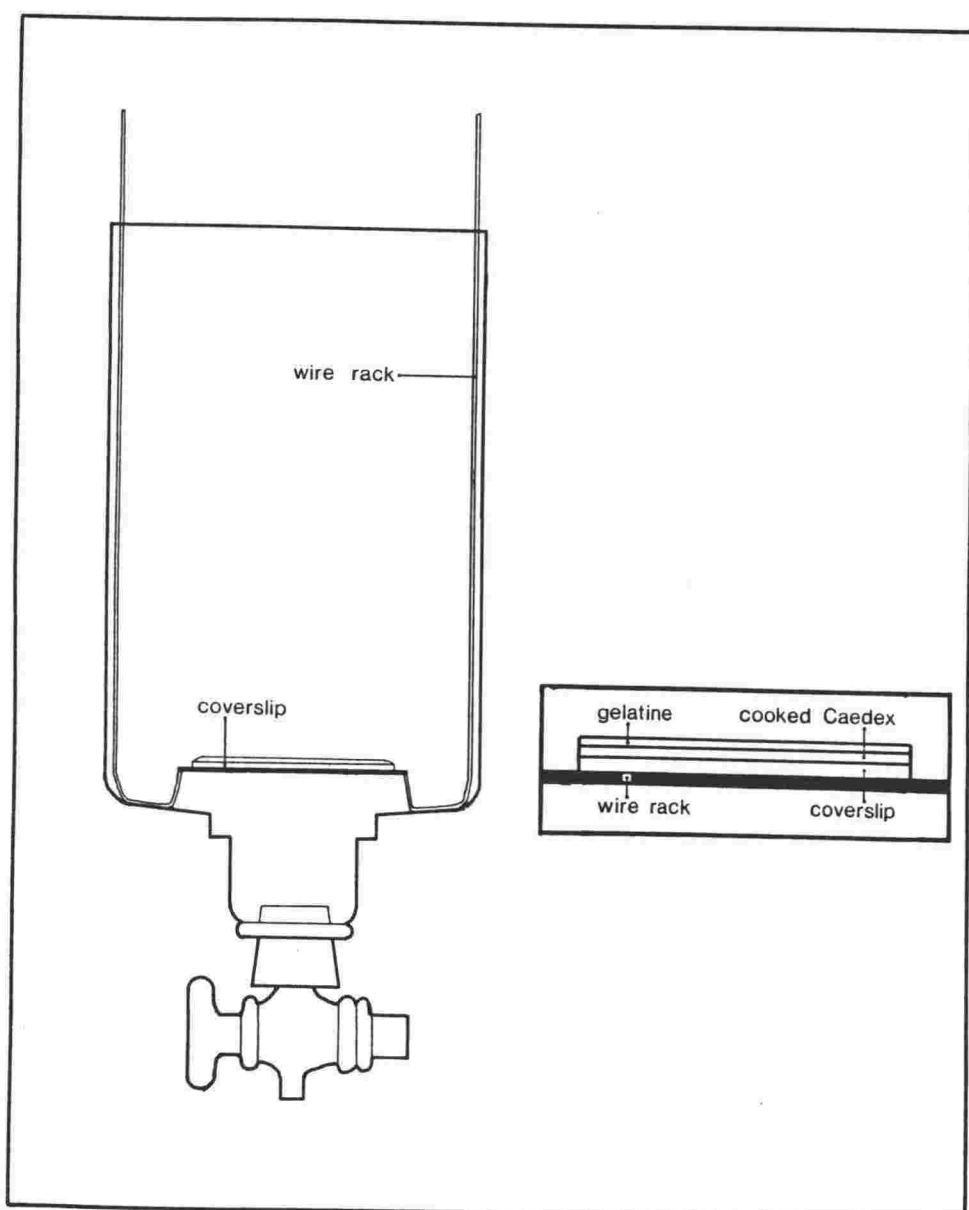


diatom frustules. The maximum density obtainable at 18°C is 2.64. Its advantages over bromoform is that it is miscible in water, is relatively non-toxic and is more viscous, allowing for slower and therefore more accurate separation. Zinc bromide solutions are made up using 10% hydrochloric acid to prevent the precipitation of zinc hydroxide, and to prevent discolouration of the solution by ferric ions from the residues. Hydrogen ions in the acid solutions reduce ferric complexes to ferrous chloride, which is almost colourless (a slight yellow tinge may develop after prolonged use). The acid in the heavy liquid makes it unusable for foraminiferal flotation. The density of the zinc bromide solution can be adjusted by evaporating or adding water.

Each split for radiolarian analysis was washed in dilute hydrochloric acid, then rinsed and dried. In the apparatus for density separation (figure 2.2), a separating funnel is used in a way similar to that described by Hecht (1933). The separating funnel is filled with zinc bromide solution (specific gravity of 2.3) and the acid washed residue sprinkled onto the surface of the liquid and stirred in. A slow-feed device similar to that described by Faul and Davis (1959) was used if there was a relatively large residue to be floated. The quantity of the residue in the heavy liquid must be low to prevent radiolarians from being trapped under inorganic grains and pushed to the bottom of the separating funnel. After separation is complete (approx. two hours) the stopcock is opened and the heavy fraction is allowed to run off into a sinter glass filter placed on top of a vacuum flask. The zinc bromide solution is then vacuumed into the flask. Next the heavy fraction is washed off the sinter glass filter with a jet of water. The filter is rinsed in acetone and dried. The light fraction, containing most of the radiolarians, is then allowed to run off on to the glass filter and the zinc bromide solution vacuumed into the flask as before. The use of the vacuum flask enables approximately 99% of the heavy liquid to be retained without change in its specific gravity. The sinter glass filter, containing most of the light fraction is then placed on a different vacuum flask and the rest of the light fraction, left clinging to the sides of the funnel, is washed through onto the filter with water from a wash bottle. The filtrant is discarded and the filtrate washed into a beaker with a jet of water. Filter paper cannot be used with zinc bromide solution because the paper fibres swell and burst. In any case, filter papers should not be used to collect radiolarian residues as the specimens tend to stick to the paper (Burma, 1965). Contamination from the sinter glass filter is eliminated by scrubbing with a stiff paintbrush and thorough rinsing after each sample treatment.

Figure 2.3

Apparatus used for the random settling of radiolarian skeletons onto a gelatine and Caedex coated coverslip.



2.5 MOUNTING METHOD

For quantitative work, radiolarian residues were mounted in Caedex. The following method works equally as well using Canada Balsam, but it is advisable to cook the balsam at a slightly lower temperature (85-90°C) than normal (100-110°C) and for a longer time. At the lower temperature the balsam remains slightly more fluid, making it easier to put on the coverslip without enclosing air bubbles.

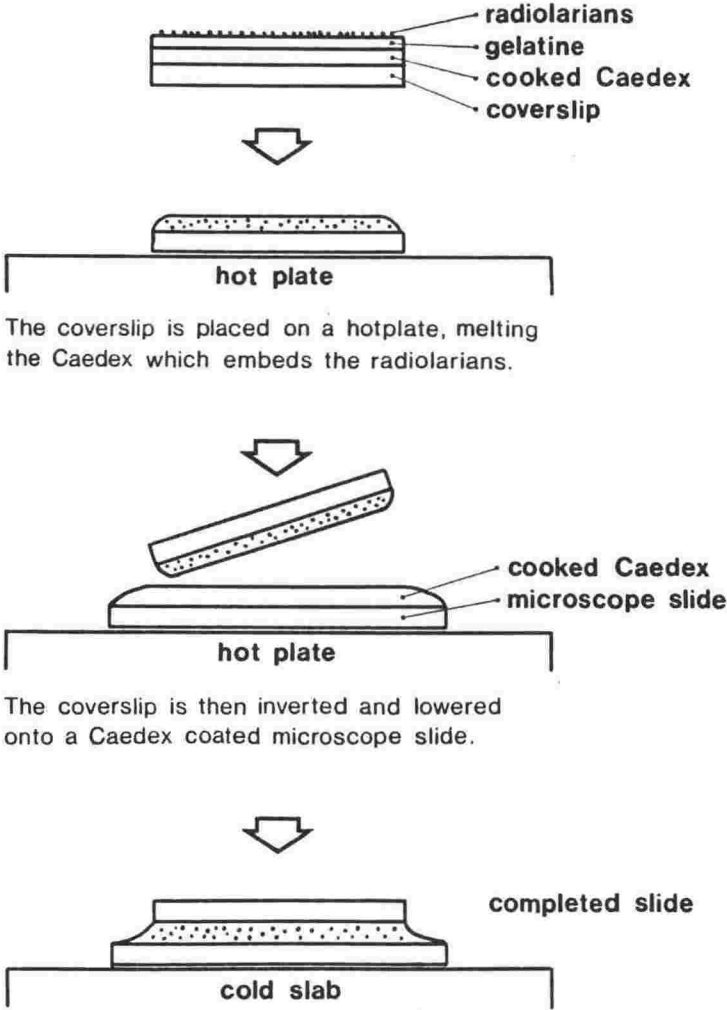
The common method of using a pipette to place a drop of radiolarian skeletons suspended in water onto a glass slide, results in the heavy skeletons sinking to the bottom of the drop and remaining at the centre of the slide, while delicate forms are carried to the sides. The distribution of skeletons on the slide cannot be randomised by stirring with a probe (Moore, 1973). Radiolarian skeletons are too large to be sprayed onto the slide like pollen grains (McIntyre *et al.*, 1967). Moore (1973) described a technique for making glass slide mounts using a random settling technique. Laws (1983) quantitatively assessed the differences in counts made from slides prepared by the pipetting technique and the random settling technique, using known mixtures of calibrated microspheres as a sample. Results indicate that slides prepared by the pipetting method yield erroneous data, whereas the random settling technique (as used by the author and outlined below) produces an accurate sample of the original material. Moore's (1973) technique utilises a gelatine coated slide placed at the bottom of a container filled with water. The residue is placed in the water which is then stirred with a vertical motion. The radiolarians are allowed to settle. Then all but 1cm of water is siphoned out of the container and the rest dried under an infra-red lamp. When the surface of the slide is dry (in about two hours), the coverslip can be mounted using the preferred medium.

The writer modified Moore's method by using a coverslip instead of a glass slide at the bottom of the settling container, by adding a thin film of cooked Caedex between the gelatine and the coverslip, by using a settling container with a stopcock at its base, and by placing the coverslip on a wire rack in the settling container. The apparatus used is shown in figure 2.3.

The coverslip is prepared by smearing about five drops of a 1:10 Caedex to Xylene mixture onto the coverslip and placing it onto a hotplate. When the Caedex is cooked and cooled the surface is scored with fine emery paper and a thin film of gelatine solution (10-20mg in 50ml of water) is brushed onto the Caedex. The gelatine solution is left to dry on the Caedex coated coverslip, then placed on the wire rack in the settling container. The container is then filled with water and the residue added. The water is stirred with a

Figure 2.4

Technique for making glass slides using the randomly coated coverslip.



vertical motion as recommended by Moore. After the specimens have settled onto the coverslip the stopcock is opened and the container emptied. Turbulence is avoided by emptying the container slowly. The stopcock is closed to a drip as the falling water level reaches the surface of the coverslip, in order to avoid runoff carrying specimens off the slide. By releasing the water in this way specimens which have not sunk due to entrapment of air are deposited randomly on the coverslip. The wire rack makes it easier to emplace and remove the coverslip.

The coverslip is then dried, the gelatine gluing the specimens to the coverslip. The coverslip is placed on a hotplate (figure 2.4) and the skeletons drop into the Caedex when it melts. The coverslip can then be inverted without losing specimens. A slide is prepared with Caedex and the inverted coverslip lowered slowly onto it. Duplicate slides can be prepared either by splitting the original radiolarian float or saving and resuspending the specimens that were not collected on the first coverslip.

2.6 STATISTICAL COUNTING

Galehouse (1971) outlined three methods for the counting of grains on a grain mount. In the first method the entire slide is counted. This is the best statistical approach for counting the assemblage but is too time consuming when the number of specimens on the slide is large (approx. 64000 specimens on slide JAA380 : sample MO13). This counting method was used if there were less than 300 specimens on a slide (6 cases).

Second is the line method where all the grains traversed by a cross-hair are counted on randomly chosen lines. With this technique a number frequency is obtained and not a number percent because larger specimens are counted preferentially. This method does not provide numbers suitable for statistical analysis and was not used by the writer.

Third is the area or "ribbon" method where every specimen within one or more specified areas of the slide is counted. Typically the slide is moved along and all individuals between two lines counted. As the specimens on the slides counted for this thesis are considered to be randomly distributed the placement of the "ribbons" was not considered to be important. If the "ribbon" width is considerably larger than the largest grain this method gives a number percent.

Using the "ribbon" counting method, the first 300 specimens encountered were recorded from each slide. Three hundred was chosen as an optimum number because below 300 the probable error in the numbers increases rapidly and above 300 it decreases slowly and therefore was considered to give the maximum accuracy for the minimum investment of

time. Only specimens with at least half of their skeleton inside the bounds of the "ribbon" were counted, and only specimens with at least half of the skeleton preserved were counted.

The great variation of preservation and abundance in New Zealand Late Neogene samples precludes the accuracy of constant numerator percentage estimates for uncommon species by the method of Riedel and Sanfilippo (1978a).

2.7 QUALITATIVE STUDIES

Foraminiferal specimens were floated from the second spilt using bromoform, adjusted to a specific gravity of 2.2 - 2.3, using the same apparatus and method as for the Radiolaria. With bromoform, acetone is used instead of water for washing the equipment, etc.. If quantitative work is required on the foraminifera the dried floated light fraction can be split down to approximately 300 specimens and the entire split counted. From this fraction, radiolarian specimens were picked and mounted on polyvinyl acetate coated stubs for scanning electron microscopy.

2.8 PHOTOGRAPHY OF RADIOLARIAN SPECIMENS

Transmitted light photographs of the radiolarians were taken on a Leitz Orthoplan microscope with an Orthomat-W fully automatic camera attachment. Positions of photographed specimens were recorded by use of an England Finder. Ilford FP4 film was used with the shutter speed adjusted to three to five seconds by the use of light filters.

All scanning electron microscope work was done in the Electron Microscope Facility, Victoria University of Wellington. Initially a Cambridge Stereoscan 600 was used, but this was later replaced by a Phillips 505. All the scanning electron microscope photographs in this thesis were taken on the latter machine at an accelerating voltage of 30.0 kv.

The heavy oil immersion technique for taking both transmitted light and scanning electron microscope (SEM) photographs of the same specimen (Empson-Morin, 1981; Boltovsky, Kotzian, and Pedrozo, 1983) was utilised in studying selected taxa.

2.9 NUMBER OF RADIOLARIANS PER GRAM OF SEDIMENT

To calculate the number of radiolarians per gram of sediment the following data was necessary.

Weight of sample	= SAM	error = 0.1%
Weight of wash	= WAS	error = 2.0%
Weight of split	= SPL	error = 0.1%
Weight of float	= FLO	error = 0.1%
Weight of float split	= FSP	error = 0.2%

Note: FSP not always required.

The errors on the above weights are variable due to variations in the weights measured and the varying precision of different balances used.

Area of settling container	= 6894.1 sq mm	error = 4.1%
Area of field of view	= 4.155 sq mm	error = 1.7%
Number of fields of view searched	= FOV	no error
Number of radiolarians counted	= NUM	error = 5%

The error in NUM is derived from problems in counting fragments and those at the edge of the field of view and also completely missing some specimens.

The following calculations can then be made:

Number of radiolarians in the container
and therefore in the float split.

$$A = \text{NUM} \times [6894.1 / (\text{FOV} \times 4.155)] \quad \text{error} = 10.8\%$$

Number of radiolarians in the float
and therefore in the initial split.

$$B = A \times [\text{FLO} / \text{FSP}] \quad \text{error} = 11.1\%$$

Number of radiolarians in the residue
and therefore in the sample.

$$C = B \times [\text{WAS} / \text{SPL}] \quad \text{error} = 13.2\%$$

Number of radiolarians per gram of sediment

$$= C / \text{SAM} \quad [\text{error} = 13.3\%]$$

The assumptions in this method are:

- (a) All radiolarians are caught on the 54 micron mesh.
- (b) All radiolarians floated in the density separation.
- (c) The radiolarians were randomly distributed in the water column and therefore on the slide.
- (d) No radiolarians were washed off the coverslip as the container emptied.

The assumptions most likely to be wrong in part are (a) and (b) and could conceivably increase the final error to 20%.

The calculated radiolarian numbers per gram of sediment are presented in Appendix E (raw statistical data).

Chapter III

RADIOLARIAN PRESERVATION

3.1 SILICA DISTRIBUTION PATTERNS

There is a strong correlation between planktic productivity and the accumulation of biogenic opal in underlying bottom sediments (Lisitzin, 1972; Heath, 1974; Riedel and Sanfilippo, 1977; Kennett, 1982: p.476). The amount of opal produced in the surface water (0-200m) is controlled by plankton productivity (Lisitzin, 1971) which is in turn controlled by the essential plant nutrients, phosphate and nitrate. High concentrations of nutrients occur in regions of upwelling and surface mixing (Heath, 1974). Renz (1976) reported a probable direct relationship between the amount of dissolved silica and the size and abundance of radiolarians in central Pacific plankton. However, it appears that the availability of silica seldom limits the growth of siliceous organisms, the only likely place where that happens being the North Atlantic where dissolved silica concentrations approach, at places, zero. The availability of nutrients favours the production of protoplasm and this in turn favours the biologic fixation of opaline silica even where dissolved silica concentration is very low (Kennett, 1982: p.474).

The calcite compensation depth, CCD, below which calcium carbonate does not accumulate on the ocean floor, is the level where the rate of solution of calcium carbonate is balanced by the rate of supply. Silica usually becomes a quantitatively important component only in sediments near or below the CCD. The depth of the CCD is known to have varied with time and consequently siliceous accumulation patterns have also varied. Reasons for the movement of the CCD are unknown but two possible mechanisms are:

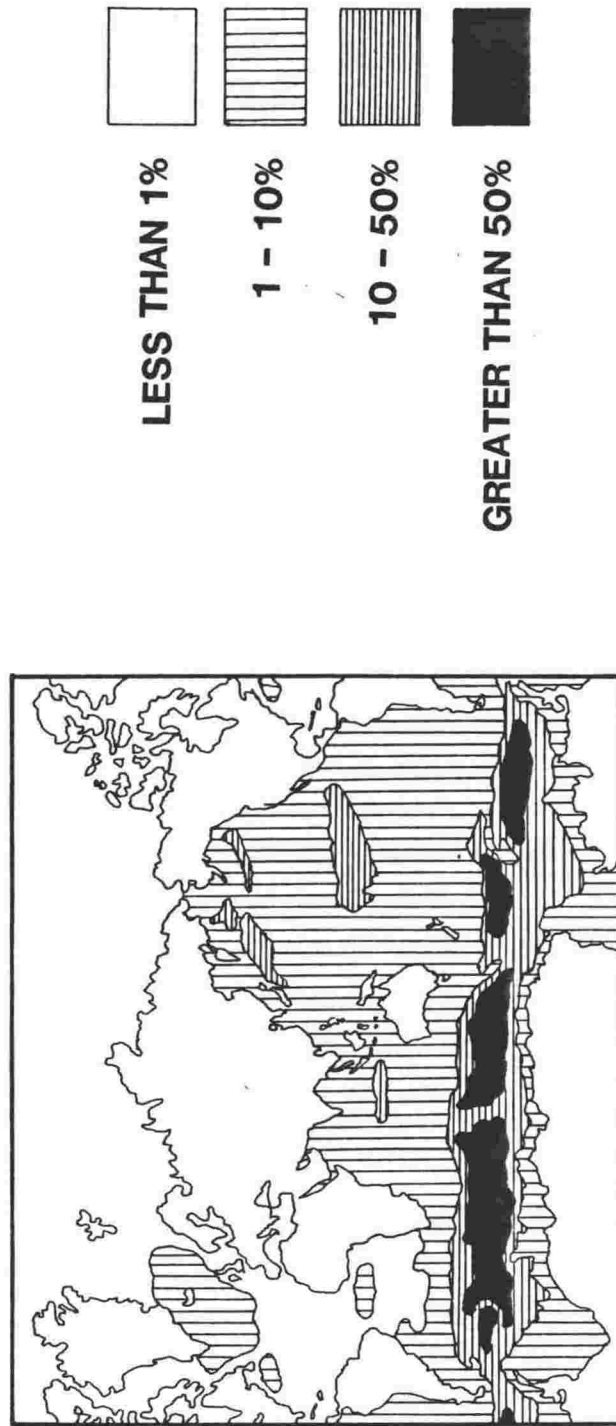
1. The spread of a particularly successful calcareous planktic organism may suddenly remove large amounts of calcium carbonate from marine waters.
2. Marine transgressions, which increase the volume of shelf-sea carbonates, also subtract calcium carbonate from the oceans.

In both cases the depletion of calcium carbonate could be balanced by a rise in the CCD causing solution of increased amounts of pelagic carbonate (Jenkyns, 1978: p.318).

Radiolarian skeletons accumulate in abundance in equatorial sediments where productivity is high in the water column above. High productivity in equatorial waters is attributed to the divergence of surface waters caused by an asymmetric pattern of surface winds about the geographic equator which create extensive upwelling bringing nutrients to

Figure 3.1

Amorphous silica distribution in the surface layer of bottom sediments expressed as a percentage of dry sediment (after Lisitzin, 1972)



the surface (Kennett, 1982: p.477). Because the productivity of all organisms is high in the equatorial upwelling belt, radiolarians are often masked in the bottom sediments by large quantities of foraminifera and calcareous nannoplankton (Kling, 1978). In equatorial regions the abundance of calcareous material depresses the CCD (Jenkyns, 1978: p.318). Siliceous sediments in equatorial regions occur in areas that are deeper than the CCD (figure 3.1) although Goll and Bjorklund (1974) found that on a calcium carbonate free basis, radiolarians are equally abundant in some calcareous oozes as they are below the lysocline. North and south of the biogenic rich equatorial belt siliceous oozes grade into brown clay (Kennett, 1982: p.478).

The main areas of siliceous deposition are below the high latitude productivity belts. In fact about 75% of all oceanic silica accumulation occurs beneath the southern belt (Lisitzin, 1972). In these areas radiolarians are normally subordinate to diatoms (Lisitzin, 1971; Lisitzin, 1972; Kling, 1978) which is the reverse of the equatorial relative abundances. The southern belt, which extends completely around the globe, is 900 to 2000 km wide, its northern boundary being the Antarctic convergence. To the south the siliceous sediments grade into glacio-marine sediments (Kennett, 1982: p.477). The northern high latitude belt is discontinuous and poorly developed (Lisitzin, 1971). Siliceous concentrations are lower in the northern belt than around Antarctica because of a greater terrigenous input (Kennett, 1982: p.476). Siliceous oozes in the high latitudes are produced mainly by high productivity but an added factor is that the CCD is relatively shallow and there is not as much masking of the siliceous component in the sediments by calcareous material. The depth of the CCD ranges from a few hundred metres in the Ross Sea to greater than five kilometres in the equatorial Pacific (Heath, 1974).

In the central parts of the oceans between the northern, equatorial, and southern high productivity belts, the rates of accumulation of the terrigenous sedimentary component are low, depths are generally below the CCD (Kling, 1978), and the water masses are stably stratified and less productive biologically (Riedel and Sanfilippo, 1977; Kling, 1978). Lengthy exposure of siliceous material at the sediment-water interface results in more complete dissolution and barren pelagic brown clays accumulate (Kling, 1978).

Radiolarians are generally rare or absent in continental margin sediments because they are diluted by large influxes of terrigenous material, which may provide a chemical sink for silica (Heath, 1974). For example, on the continental shelf off the western United States, radiolarians can be found in near surface sediments, but not in deeper sediments (Kling, 1978). Hemipelagic sediments, which are a mixture of terrigenous clays and biogenic

TABLE 3.1

Magnitudes of components of the silica cycle.

Units 10^{13} gram/year.

The number of significant figures results from material balance calculations and not from the real precision of the data.

Input components

River influx	42.7
Deuteric/hydrothermal	0.004-0.540
Halmyrolysis of basalt	8.1
Escape of interstitial silica	38-76
Oxidative dissolution	?1200-2800?
Non-oxidative dissolution	350-380
TOTAL INPUT	approx. 2500

Output components

Biologic fixation	1700-3200
Inorganic absorption	4.3
Burial of opaline skeletons	?85-123?
TOTAL OUPUT	approx. 2600

after Heath (1974)

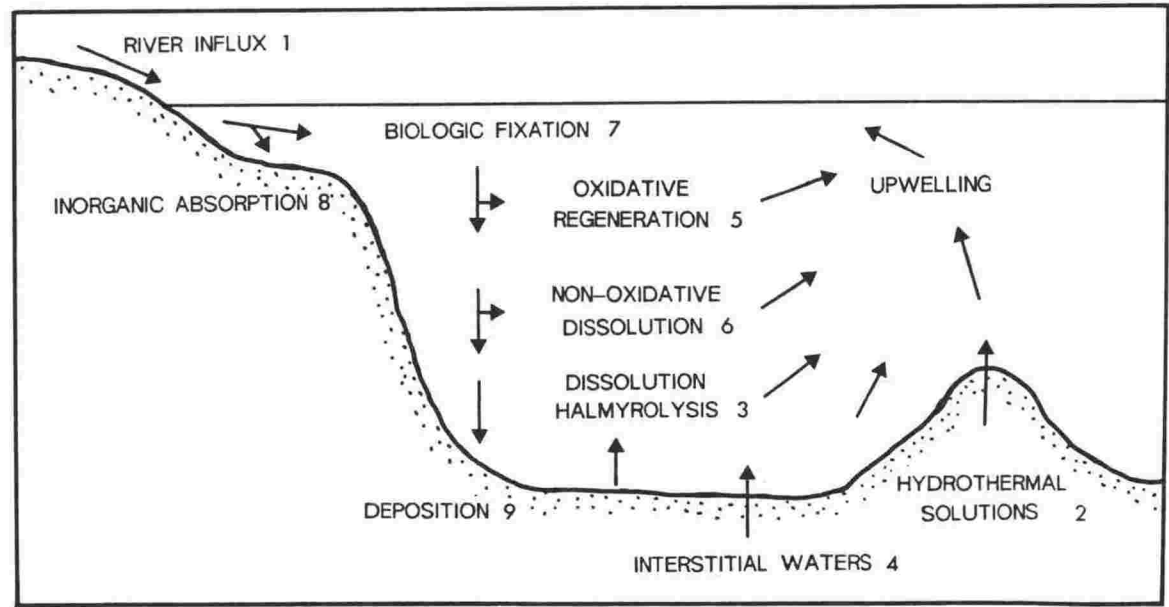


Figure 3.2

Components of the cycle of dissolved silica in the oceans. Numbers refer to text subdivisions of section 3.2 "Silica budget".

material can provide sites for the preservation of radiolarians on the slope and rise portion of the continental margin. There is also a rapid rise in the CCD towards continents. Since productivity is generally high around continents, because of upwelling and mixing processes delivering nutrients to surface waters, the rise in the CCD must be entirely due to greatly intensified carbonate dissolution, despite the increased burial rates provided by terrigenous material. This increased dissolution is probably due to the development of copious carbon dioxide from a rich supply of organic matter, which is responsible for a considerable lowering of pH. Also the activity of abundant benthic organisms stirs the sediment, preventing the interstitial waters from becoming saturated in calcium carbonate (Berger and Winterer, 1974).

High silica accumulation rates prevail at present in areas on the continental shelf and slope beneath regions of local upwelling, high nutrient input and corresponding high productivity. The Santa Barbara Basin has laminated anaerobic sediments rich in radiolarians and other siliceous microfossils accumulating in water depths of about 500 m (Kling, 1978). Similar deposits are forming in the Gulf of California (Calvert, 1966) and fiords along the coasts of western North America and Norway (Kling, 1978).

Differences in silica accumulation exist between ocean basins. The Atlantic has an equatorial siliceous belt but the accumulation rate of silica is relatively low compared to the Pacific. Berger (1970) and Berger and Winterer (1974) report that the Atlantic tends to collect "young" surface-type waters which are depleted in nutrients, relatively warm, oxygen-rich and carbon dioxide-poor. It is characterised by carbonate sedimentation and has the deepest CCD. Conversely, the Pacific has a relatively shallow CCD, its deeper water being "old", relatively cold and rich in carbon dioxide. The water mass differences are maintained by fractionation processes resulting from biological activity and from the water exchange pattern between the basins. The Pacific gains deep water from other oceans and loses surface water that has largely been stripped of silica by opal secreting plankton whereas the Atlantic loses deep water in exchange for silica poor surface water from other oceans (Heath, 1974).

3.2 SILICA BUDGET

The following text is subdivided into sections based on the silica cycle diagrammatically shown in figure 3.2. Heath's (1974) silica budget values are shown in table 3.1.

3.2.1 River input

Silica rich terrestrial rocks are the greatest source of silica. Weathering and erosion of these rocks supplies dissolved silica to rivers and consequently to the oceans (Kennett, 1982: p.478).

3.2.2 Submarine volcanic sources

Most submarine volcanic rocks are basic and they have only recently been considered a likely source of much silica. The association of bedded cherts with large masses of volcanic material in the geological record has been taken as evidence of a genetic relationship. Primary quartz is known in sediments from the crest of the East Pacific Rise (Peterson and Goldberg, 1962). Silica could be released in a volatile aqueous fraction left over after crystallisation of the basalt, or could be freed by the deuteric alteration of hot lava by seawater entering fractures resulting from thermal contraction (Heath, 1974). Edmond, Measures, McDuff *et al.* (1979) calculated that the amount of silica added from submarine sources in the Galapagos area is equal to 50% of that added by rivers. Mottl (1983), pointed out that Edmond *et al.* (1979) were dealing with an abnormally fast and hot spreading ridge and the likely input of silica from a normal spreading ridge would be about one sixth of their estimate (i.e. approximately 8% of river input). Heath (1974) estimated the total submarine volcanic input to be 1% of the river input.

3.2.3 Low temperature reactions at the sea floor

Heath (1974) divides this input into three main classes:

(i) Dissolution of opaline tests

At present, dissolution of opaline tests at the sea floor cannot be distinguished from non-oxidative dissolution within the water column (Heath, 1974) and in this discussion the two are treated together in section 3.2.6.

(ii) Low temperature alteration (halmyrolysis) of oceanic basalt.

Heath (1974) calculates an input rate 20% that of the river influx based on data of silica loss by Hart (1970) assuming that the low temperature alteration of oceanic tholeiitic basalts proceeds to a depth of only 100m and supplies silica to the ocean only in areas of thin or no sediment cover.

(iii) Halmyrolysis of detrital silicate phases

This does not appear to be a major source of silica. Keller *et al.* (1963) crushed a

number of common silicate minerals and determined the concentration of silica after equilibrium at 20°C. If temperatures are reduced to 2°C (temperature of bottom waters) it appears that only the pyroxenes among the common detrital minerals could provide much soluble silica (Heath, 1974). The persistence of pyroxenes in Tertiary deep-sea cores (Heath, 1969) suggests little alteration.

3.2.4 Release of interstitial waters

Most marine interstitial waters are richer in silica than overlying sea water. The concentration gradient across the sediment water interface must cause upward diffusion of dissolved silica. There must also be physical expulsion of interstitial water during compaction. Heath (1974) calculated a figure approximately twice as much as river input.

3.2.5 Oxidative dissolution

Most opaline skeletons are fragile and dissolve once their protective organic coating disappears. The process is referred to as oxidative dissolution because it seems to be controlled primarily by the oxidation of the protoplasm. Heath (1974) derived a value for oxidative dissolution by assuming a steady state with silica deposition rates balancing the amount of new silica entering the oceans. Although this steady state is believed to be the case for modern and late Quaternary oceans (Kennett, 1982: p.475) the depositional rate of silica (see section 3.2.9) is still poorly known and Heath's oxidative dissolution value is not reliable.

3.2.6 Non-oxidative dissolution

The silica content of deep ocean waters rises steadily with time as long as the waters remain below the biological uptake zone which approximates to the photic zone (Heath, 1974). The source of this silica is largely from dissolving opaline skeletons falling through the water column and resting on the sea floor. All deep ocean water is undersaturated relative to opal, and the dissolution must be rate limited rather than governed by chemical equilibrium. Two key factors in dissolution are the surface area of the solid phase and the movement of the water, which is required to maintain the maximum concentration gradient against the silica particles (Heath, 1974). The calculated rate of input from non-oxidative dissolution is one order of magnitude greater than river input. It was determined by subtracting volcanic input, interstitial water input and halmyrolytic input from Berger's (1970) value for the non-oxidative silica content of the deep ocean which in turn, was determined using phosphate-silica plots (Heath, 1974).

3.2.7 Biological fixation

Most of the biological fixation of silica takes place in the photic zone. Diatoms probably extract an order of magnitude more silica than radiolarians (Heath, 1974). The rate of biological fixation of silica is calculated from the known uptake of carbon in the worlds oceans and the known silica to organic carbon ratio in diatoms (2.3/1). The assumptions are that this ratio reflects the relative rates of fixation of the two components and that diatom productivity is 50 to 70% of the total primary productivity. It is calculated to be 40 to 75 times the annual river input (Heath, 1974).

3.2.8 Inorganic absorption

Bien *et al.* (1959) showed that part of the dissolved silica load of the Mississippi is lost by reaction with particulate matter as the river enters the Gulf of Mexico but did not quantitatively assess the effects of biogenic uptake on the system. Liss and Spencer (1970) reported a 10-20% abiotic loss of dissolved silica from the River Conway in Wales but Maeda (1952), Kobayashi (1967) and Fanning and Pilson (1973) show no or little abiotic loss. Heath (1974) used a value for inorganic absorption of silica of about 10% of the annual river input.

3.2.9 Deposition

Knowledge of depositional rates of biogenic opal in the deep ocean is still poor but is improving with increased paleomagnetic and biostratigraphic resolution. The lack of accurate opal determinations in dated cores makes global depositional rates hard to determine. Heath (1974) calculated a value based on the assumption of a steady state in the silica cycle.

3.3 SILICA DISSOLUTION IN THE WATER COLUMN

There is no critical depth like the CCD for silica dissolution (Lisitzin, 1972). All ocean water is undersaturated in silica (Heath, 1974; Goll and Merinfeld, 1979). It is less undersaturated in bottom waters. All exposed polycystine skeletons are subject to dissolution. The degree of undersaturation varies from essentially 100% in warm surface water because of biologic depletion to 85% in Antarctic bottom waters. Amorphous silica dissolves in either fresh or marine water to the extent of 100 to 140 ppm at ordinary temperatures. This is a true solution, not colloidal dispersion, most or all of the silica being in the form of monosilicic acid (Krauskopf, 1959).

The main factors affecting silica dissolution are:

temperature: solubility increases with temperature (Krauskopf, 1959; Hurd, 1972; Heath, 1974),

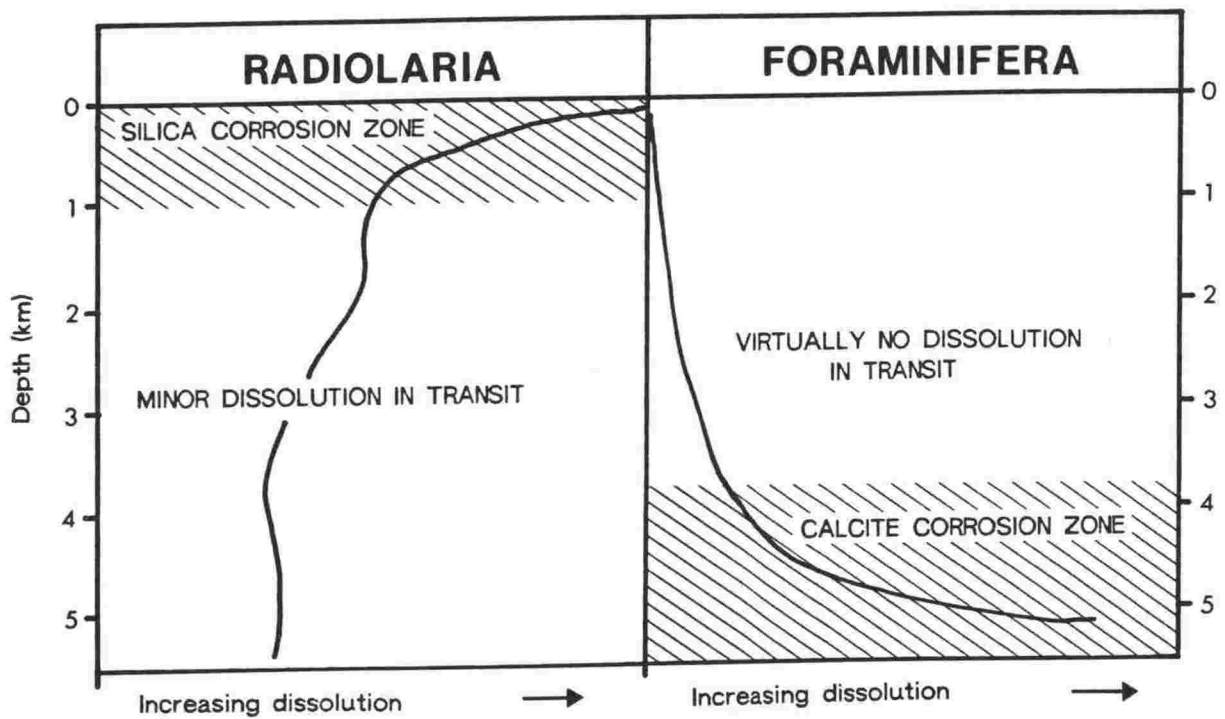


Figure 3.3

Comparison of dissolution profiles of radiolaria and planktic foraminifera based on field experiments. Most dissolution of radiolaria (and diatoms) occurs in shallow waters. In contrast, most dissolution of carbonate microfossils occurs on the sea floor at depths greater than 3.5 km (Berger, 1976).

pressure: solubility increases slightly with pressure (Heath, 1974),
degree of saturation: (Hurd, 1972),
surface area of the solid phase: (Hurd, 1972; Heath, 1974), and
agitation of the water: necessary to maintain maximum concentration gradients against silica particles (Heath, 1974).

The pH of the water, which is controlled by the carbon dioxide - carbonate system (Pytkowicz, 1967) has little affect on silica solubility in the range 0 - 9 but causes it to increase abruptly at higher values because of the ionization of monosilicic acid (Krauskopf, 1959).

The presence of metal coatings on diatom frustules is known to retard dissolution (Lewin, 1961) and electron microprobe analyses of radiolarian skeletons indicate Mg, Ca, Na, and Al as minor elements present in concentrations up to 4% by weight (Stanley, 1973). Different uptake of these elements might cause different dissolution rates from one species to another.

Variations in internal ordering and specific surface area of different forms of opaline silica cause varying solubilities (Hurd and Theyer, 1975) but silica gel (which biogenic silica resembles the most) and vitreous silica both have similar solubilities which are an order of magnitude greater than that of quartz.

Silica dissolution is usually greatest near the surface and decreases with depth (figure 3.3) in accordance with the normal bathymetric distributions of dissolved silica and temperature (Berger, 1976). Most of the siliceous skeletons dissolve rapidly in the water column and at the sea floor and only about 4% survive long enough to be buried (Heath, 1974). The bulk are returned to the water column as dissolved monosilicic acid in the upper 1000 m (Kennett, 1982: p.480). Particles with high specific surface area such as diatom frustules, are preferentially dissolved and the survival rate for radiolarians is relatively high (Lisitzin, 1971).

3.4 FAECAL PELLET DEPOSITION

Faecal pellets produced by invertebrate plankton are important in preventing dissolution before deposition of very small skeletal remains such as coccoliths and most diatom frustules (Kennett, 1982: p.483), but are thought to be unimportant for radiolarian skeletons. Settling velocity is determined mainly by particle mass, size and shape and to a minor extent by water density (Lisitzin, 1972). The average-sized coccolith would take about 100 years to fall from the photic zone to the deep sea floor (Kennett, 1982: p.483), whereas

copepod faecal pellets take only a few days or a few weeks (Smayda, 1971), and consequently the time available for solution of contained skeletons is two to three orders of magnitude shorter. Settling tube experiments (after Casey, Spaw, Kunze *et al.*, 1979) have shown that radiolarian skeletons have settling velocities similar to those of copepod faecal pellets.

The protection against dissolution given by the organic binding material of faecal pellets is uncertain. In the case of radiolarian skeletons it would probably be counterbalanced in part or entirely by fragmentation, and consequent increase in specific surface area, in the gut of the feeding invertebrate.

3.5 SILICA DISSOLUTION IN SEDIMENTS

A decrease in the number of empty skeletons with increasing depth in the water column indicates most dissolve before reaching the ocean floor (McMillen and Casey, 1978). However, dissolution does not stop below the sediment-water interface.

Dissolved silica concentrations in interstitial waters range from 3 to 81 ppm, the larger values usually occurring in diatomaceous oozes, and being close to equilibrium solubility levels at 2-3°C (Calvert, 1968). Siliceous remains may be preserved in sediments in which most of the pore water is undersaturated either by sea floor mechanical processes or as a result of localised extra dissolved silica from, for example, the devitrification of a rhyolitic tuff. The biogenic opal solution rate in near surface sediments of the central Equatorial Pacific is 3 to 8 orders of magnitude slower than in the water column (Hurd, 1973). Other important factors in dissolution within the sediments are the sedimentation rate and the degree of disturbance by infauna (Hurd, 1972). Burrowing can maintain high concentration gradients between siliceous particles and the interstitial waters but siliceous particles may also be concentrated in burrows.

Areas of high biological productivity also supply much organic matter to the sediments which can result in a pore-water chemistry that favours the preservation of biogenic silica (Kennett, 1982: p.475). Although carbonaceous fragments are common in New Zealand Upper Neogene sediments no sapropels have been detected by the writer.

Diffusive, not advective, processes are chiefly responsible for the removal of dissolved silica in sediments (Hurd, 1973) but Johnson (1976), in his study of cores in a small area of the eastern Tropical Pacific, found a down-core increase in clay (smectite) aggregates corresponding with a down-core decrease in radiolarian skeletons. Some of these clay aggregates are reported to be radiolarian casts. The transformation of less stable biogenic

silica into more stable smectitic lattices is probably important in the dissolution of siliceous skeletons at depth, e.g. 50cm in the sediment, where a strong concentration gradient with the bottom water and intense bioturbation is lacking. Only about 4% of biogenic opal particles survive water column transit and after dissolution within the sediment only 0.3% are preserved (Heath, 1974).

3.6 MECHANICAL PROCESSES AFFECTING SILICA PRESERVATION

In addition to gravity settling, bottom currents and bioturbation affect the preservation of radiolarian skeletons.

3.6.1 Bottom currents

Density driven bottom currents reflect the net northward movement of Antarctic bottom water in most of the abyssal parts of the oceans. Even at the relatively slow speeds of two to five cm/sec (Siebold, 1978) these currents can have an effect on radiolarian preservation. Huang and Watkins (1977) determined the grain size distribution of deep-sea bottom sediments and concluded that those sediments with skewness values more positive than -0.2 indicate high bottom current influence and those more negative than -0.2 indicate dominant pelagic settling. As an example of New Zealand upper Neogene sediments, samples from the Mangapoike River section are in all cases more positively skewed than -0.2 (I.C. Wright, pers. comm.) but were deposited on the outer continental shelf and slope. They have had coarse components filtered out in estuaries and on the inner shelf and are positively skewed when supplied to the pelagic environment. The relative influence of high bottom currents and pelagic sedimentation can not be determined without additional data.

Shelf and upper slope sedimentation is well above the influence of bottom water currents, but can be influenced strongly by contour currents, up to 55 cm/sec (Rupke, 1978: p.389), and tidal currents of even greater velocity.

Johnson (1976) showed that the resuspension and/or hydraulic sorting of skeletons by ocean currents can cause preferential deposition of radiolarian skeletons in topographic depressions, even where the bottom currents are quite slow, therefore increasing the net biogenic silica input into depressions relative to "highs" on the ocean floor. Benthic organisms may stir sediment particles back into suspension to be transported by weak bottom currents (Seibold, 1978). In areas of low depositional rates, bottom currents must have a greater effect because sediment is exposed to them for relatively long periods.

Plate C3.1

Centimetre-scale bioturbation in a Lower Tongaporutuan tuff exposed at Gable End Foreland, 28 kms north of Gisborne (photo: Greg Gosson).



3.6.2 Bioturbation

Various estimates have been made of the depth below the sediment-water interface, to which bioturbation has an effect on sediment.

(a) Ruddiman and Glover (1972): Based on the dispersion of ice-rafted debris from known Icelandic and Jan Meyen volcanic episodes in North Atlantic deep sea cores, 17 to 66cm.

(b) Arrhenius (1963): Up to 30cm based on mixing across unconformities. The mean mixing depth, i.e. the depth above which 50% of the extraneous material is located is about 5cm.

(c) Noshkin and Bowen (1973): Up to 12cm of mixing in the last ten years based on plutonium (fallout from the previous ten years) dispersion in six Mediterranean and Atlantic cores.

(d) Glass (1969): Based on the microtextite dispersion in deep-sea cores from the Atlantic and Indian Oceans and the Caribbean Sea, up to 90cm of a geologically mixed zone with mixing occurring up to 40cm below the surface.

The most important factors influencing the magnitude of the bioturbation effect are assumed to be the type and number of the burrowing organisms, the sediment type, and the depositional rate. Many of the samples studied for this thesis showed signs of bioturbation, usually mm-scale mottles on freshly broken surfaces of the mudstone. Some tuffaceous horizons show intense burrowing by larger organisms (cm scale) which are occasionally detectable in the encompassing mudstone (see plate C3.1).

With depositional rates of, for example, approximately 55 cm/kyr in the Mangapoike section (I.C. Wright, pers. comm.), the effect of the mixed zone is insignificant with respect to the stratigraphic sampling interval and the faunal events discussed.

Burrowing organisms can concentrate siliceous skeletons in their burrows thereby enhancing biogenic silica preservation by locally increasing the amount of silica per gram of sediment.

3.7 SELECTIVE SPECIES DISSOLUTION

As expected, the most fragile, thinly silicified radiolarians tend to disappear entirely during settling and many bottom sediment assemblages are impoverished relicts of the original surface water assemblages (Kennett, 1982: p.480). Petrushevskaya (1971a, 1971b) divided

radiolarians into three groups:

- (a) thin walled, delicate skeletons which are more abundant in plankton than sediments,
- (b) sturdier skeletons which are normally well preserved, and
- (c) sturdiest, most solution resistant which are less abundant in plankton than sediments.

Group (b) specimens are the most reliable indicators in the sediments of the ecologic conditions in the water above. Berger (1968) outlined the results of an experiment where radiolarian skeletons were placed at several depths on the taut mooring wire of a buoy in the central Pacific for four months. He found that the *Acantharia* dissolved completely at all depths, the tripyleans seemed less resistant than polycystines, and that recent radiolarian sediments dissolved at appreciable rates at depths less than 2000m. Johnson (1974) carried out a quantitative study of the dissolution of different radiolarian species and diatoms. On a scale of 0 (least resistant) to 70 (most resistant), the small diatoms ranged from 0 to 7, radiolarians from 5 to 70, and sponge spicules 58. Moore (1969) also quantitatively studied species dissolution rates by dissolving faunas of different geological ages in a standard 2N solution of sodium hydroxide. Dissolution variations between species is similar to that described for planktic foraminifera (Hecht, Eslinger and Garmon, 1975; Yamashiro, 1975) in that those that fall faster are heavier and thicker and more resistant to solution.

3.8 SILICA DIAGENESIS

In the marine environment the initial silica phase is mostly biogenic opal-A (Kastner and Gieskes, 1983). This transforms to metastable opal-CT by a solution precipitation mechanism where a magnesium hydroxide compound serves as a nucleus for opal-CT crystallisation (Kastner and Gieskes, 1983). The opal-CT is commonly massive but may occur as lepispheres (3 to 4 μ) in cavities (Kastner and Gieskes, 1983). Opal-CT orders to cristobalite during burial diagenesis. The two forms co-exist in the Neogene Monterey Shale of California (Murata and Larson, 1975; Oehler, 1975). Cristobalite will eventually recrystallise to quartzose chert (Tada and Iijima, 1983).

Under early diagenetic conditions, in the relatively cold pelagic environment, the reaction from opal-A to opal-CT is very slow and most probably quantitatively insignificant within a period of a few thousand years but will be significant in less than one million years (Kastner and Gieskes, 1983). With burial, the rate of reaction will increase. The hard "silicified" nature of some of the New Zealand Upper Neogene mudstones and tuffs is presumably due to the partial crystallisation of cristobalite from the original biogenic and volcanic opal-A.

TABLE 3.2

Averages of various components (coarser than 54 microns) in the sediment surrounding the tuff in the Palliser Bay Section

expressed in number per gram of sediment

The "above tuff" averages are divided into two sets. One set is calculated using all the "above tuff" samples and the other set deleting the first three samples immediately above the tuff where the glass shard numbers are very high and the counting accuracy of the other components was not good.

	BELOW TUFF	ABOVE TUFF	
		all samples	upper samples
	n=10	n=9	n=6
Benthic foraminifera	610	1048	1063
Planktic foraminifera	83	244	237
Sponge spicules	291	263	245
Radiolaria	763	835	968
Glass shards	627	6036	855

Raw data is presented in Appendix F.

Plate C3.2

Tuff exposed in the coastal cliffs in the Palliser Bay Section (grid. ref. S28/94317357). Note that samples taken up to 80 cm above the top of the tuff contain over 50% glass shards in the residue coarser than 54 microns. The pick head is 30 cm in length.



3.9 VOLCANIC ASSOCIATION

The input of silica from volcanic sources has been cited as an important factor in the production of siliceous organisms which subsequently contribute their remains to sediments (e.g. Taliaferro, 1933; Bramlette, 1946).

Garrison (1974) commented that the precise field relationships between eugeosynclinal bedded cherts and spatially associated igneous rocks are usually unclear. Tectonic shearing tends to be concentrated along contacts between massive igneous rocks and thinly bedded cherts thereby obliterating primary relationships, but most detailed descriptions of unsheared contacts indicate that cherts rest depositionally upon submarine extrusive rocks. Clearly some genetic relationship exists but the lack of any significant petrological differences between cherts occurring in ophiolite sequences and those in non-volcanic sections suggest that the cherts associated with volcanic rocks are not formed from local inorganic precipitation of silica.

Enrichments of dissolved silica, thermal upwelling and associated plankton blooms in the vicinity of active volcanoes have been reported but are of limited spatial and temporal extent (Kling, 1978). Volcanism may contribute to skeletal preservation by addition of silica to the interstitial environment either by direct fluid emanations or the alteration of volcanic glass (Kling, 1978).

Considering the siliceous organism's ability to develop in waters of extremely low dissolved silica concentrations, the preservation factor is probably the major influence. Volcanic ash layers create local conditions favourable to radiolarian preservation by increasing the sedimentation rate in deep-sea areas and more importantly by increasing the concentration of dissolved silica in the interstitial waters (Riedel and Sanfilippo, 1977). Free silica is derived from the devitrification of tuffaceous volcanic material (Wise, Weaver and Guven, 1973) and has been the most important factor in preservation of radiolarian skeletons in New Zealand Upper Neogene sediments. In the deep-water mudstone of the Palliser Bay section, radiolarian skeletons are present only in samples containing glass shards. The same radiolarian/glass shard correlation is true for most of the deep-water mudstone sections and samples examined by the writer.

Exceptions to this rule, are samples from the Upper Miocene Ruamahanga section which have well preserved, high diversity radiolarian assemblages but no glass shards. It is possible that these samples were deposited beneath an area of local upwelling where productivity was more important than the input of glass in preserving the skeletons.

Figure 3.4

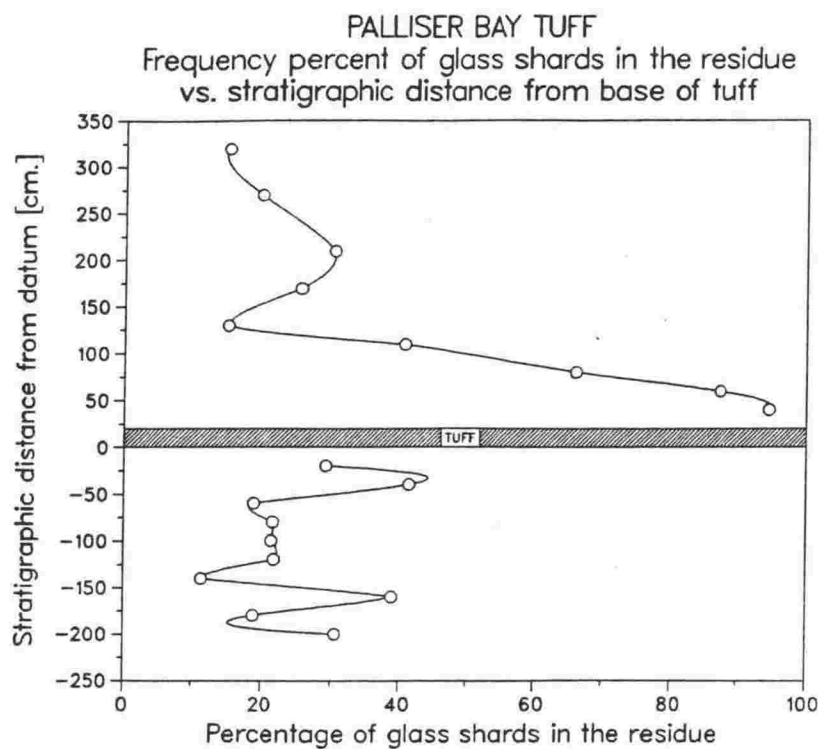
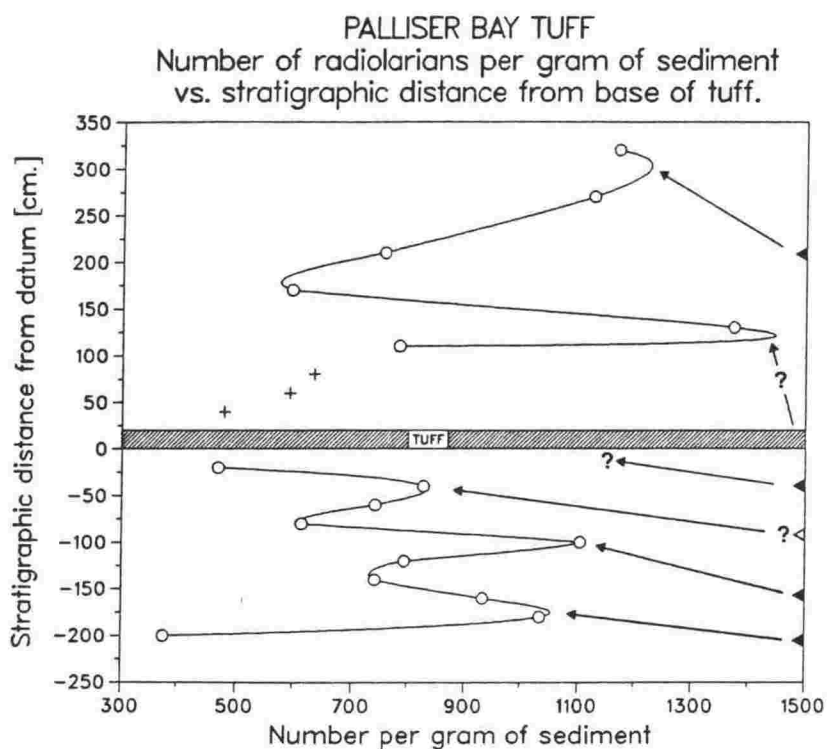


Figure 3.5



The samples marked by crosses are those with high biogenic counting errors due to large numbers of glass shards in the residue. The arrows define the correspondence between glass shard "highs" (see figure 3.4) and peaks in radiolarian numbers above.

Microfossil abundances determined in a closely sampled section through sediments enclosing a tuff in the Palliser Bay section (plate C3.2) are presented in table 3.2. Nine samples above and ten samples below the tuff were collected at about 20 - 30cm intervals and numbers for the five major components of the fraction coarser than 54μ determined. The raw counts on the planktic and benthic foraminifera, sponge spicules, radiolarian skeletons and glass shards are presented in Appendix E.5. The three samples immediately above the tuff have large errors on the biogenic component counts and have been disregarded in the calculation of one set of average numbers above the tuff. Their residues contained a large proportion of glass shards and it was impractical to count sufficient numbers of grains to make reliable estimates of the biogenic component.

Overall, the biogenic silica component in the sediment is hardly affected by the incoming of the volcanic ash, and radiolarian numbers are generally good in all the samples because the rhyolitic glass shard component is relatively high.

Figures 3.4 and 3.5 show the variation in glass shard percentage and radiolarian numbers stratigraphically away from the tuff. The peaks in radiolarian abundance are generally displaced from the glass shard "highs". The devitrification of glass shards is known to release free silica into interstitial waters (Wise, Weaver and Guven, 1973). The devitrification takes place after hydration of the glass during early stage of diagenesis (Barker, 1983: p.110). The glass shard "highs" would, therefore, be buried by the time free silica is released. The depth of burial would depend on the depositional rate and time elapsed. The dissolved silica released would tend to move upwards in the sediment due to the presence of a dissolved silica concentration gradient between sediments and the water column and also the upward physical expulsion of interstitial waters due to compaction. Any effect of relatively high dissolved silica values would tend to be displaced upwards as supported by the presence of radiolarian peaks above each glass shard "high". Sampling in other sections is needed to confirm it as a general process. Furthermore, the chemistry of the interstitial waters, is more likely to be controlled by the finer particles which will have higher specific surface areas than the $>54\mu$ particles examined. The $<54\mu$ fraction constitutes about 98% of the sediment in the samples studied from this section.

As a general rule samples were collected near tuffs to increase the chance of radiolarian preservation and if possible at least one metre above thicker tuffs to avoid the masking effects of large numbers of glass shards in the residues.

TABLE 4.1

Variations in radiolarian taxonomy

Haeckel (1883, 1887)	RADIOLARIA			
Campbell (1954)	Porulosida		Osculosida	
	Acantharia	Spumellaria	Nassellaria	Phaeodaria
Dreyer (1913)	RADIOLARIA			
	Acantharia	Polycystina		Phaeodaria
		Spumellaria	Nassellaria	
Deflandre (1952)	ACANTHARIA	RADIOLARIA		
		Spumellaria	Nassellaria	Phaeodaria
Cachon-Enjumet (1961)	ACANTHARIA	RADIOLARIA		PHAEODARIA
		Spumellaria	Nassellaria	
Riedel (1967a)	ACANTHARIA	RADIOLARIA		
	(implied)	Polycystina		Phaeodaria
		Spumellaria	Nassellaria	

after Goll and Merinfeld (1979)

Chapter IV

TAXONOMY

4.1 INTRODUCTION

The name Radiolaria was first proposed by Muller (1858) for marine Sarcodina with radial symmetry, this configuration being used to distinguish them from the foraminifera. Haeckel (1862) emended the definition to include organisms containing a central capsular membrane because many organisms included in the group do not possess radial symmetry.

The most important, comprehensive, taxonomic monograph on radiolarians is the *HMS Challenger* Report of Haeckel (1887). The taxonomic system outlined has provided the framework within which most radiolarian assemblages have since been described, despite the fact that it has long been recognised as not adequately reflecting true relationships (Riedel and Sanfilippo, 1977). Campbell (1954) re-examined the entire Haeckelian classification in order to accommodate later work and to conform to the Code of Zoological Nomenclature. Although his Treatise conveniently summarises the Haeckelian system it is flawed by innumerable errors (Riedel and Sanfilippo, 1977; Goll and Merinfeld, 1979). The main variations in radiolarian taxonomy are summarised in Table 4.1.

The taxonomic subdivision within the morphologically distinct Spumellaria and Nassellaria is still in a state of confusion. Taxonomists have attempted, since Haeckel's time, to erect classifications for the Polycystina. In recent years changes in the system have been proposed on the basis of two types of study : comparative morphology and phylogeny. Comparative morphology studies involve a re-evaluation of the significance of certain elements of skeletal structure, without regard to geologic time (Riedel and Sanfilippo, 1977) and have resulted in revisions of the classification at the family and generic levels : e.g. genera of the Orosphaeridae (Friend and Riedel, 1967) and families, subfamilies, and genera of the Nassellaria (Petrushevskaya and Kozlova, 1972: p.530). Phylogenetic studies are more firmly substantiated at the generic and species level and have become more common since deep-sea cores have been available for study. Taxonomic revisions are best based on the phylogenetic studies rather than the comparative morphologic studies because of the lack of supporting stratigraphic evidence for the latter (Riedel and Sanfilippo, 1977).

Classifications based on comparative cytoplasmic studies may foreshadow major revisions

in polycystine taxonomy and are strongly at variance with classifications based exclusively on skeletal morphology (Hollande and Enjumet, 1960). These schemes are difficult to apply because they require cytological examination of thin-sections and the number of species analysed is too small to validate the proposed classification (Goll and Merinfeld, 1979).

The first major reassessment of polycystine taxonomy is that of Riedel (1967a, 1971) and that classification and subsequent emendations (e.g. Actinommidae and Coccodiscidae by Sanfilippo and Riedel (1980) and Artostrobiidae by Foreman (1973)) is followed wherever possible in the following account.

4.2 SYSTEMATIC SECTION FORMAT

For each of the species included in the systematic section the following information is given where possible:

Name, author, and figure identification.

Synonomies of the taxa identified are not complete and are restricted to the original description, any revised concept of the species, plus easily accessible, important, modern references.

Description.

Dimensions are all in microns unless otherwise stated. If a reasonable number of well preserved specimens were available for study the dimensions were measured and are presented. If, however, the species are represented by either low numbers or are poorly preserved, previously reported dimensions are presented and referenced. Any variation in dimensions between specimens from this study and those previously reported are noted.

Remarks include notes on distinguishing characteristics and taxonomic placement.

Recorded range presents important previously reported range or time occurrence data. Ages quoted as Theyer *et al.* (1978) have been adjusted by Nigrini and Lombardi (1984) to conform to the time scale published by Ness *et al.* (1980).

Observed range was determined from this study. Presence or absence data is presented in Appendix D.

Geographic distribution for species is presented and referenced.

The format for the plate captions is

species name : magnification : sample number : reference number.

In the case of the SEM photos the reference number corresponds to the stub number (e.g. AA4) and the line number on the stub in which the specimen is located (e.g. 6). The stub number and line number are separated by a "/". With the transmitted light photos the reference number is an England Finder coordinate for the specimen on the transmitted light slide. In some cases the transmitted light sample number is followed by a "d" (e.g. HR04d) and this indicates that the specimen is on the duplicate slide for that particular sample. Also, some transmitted light photos have "RIO" as their reference number and this indicates the specimen was photographed whilst immersed in refractive index oils prior to mounting on a stub.

4.3 CHECKLIST OF SPECIES

Suborder SPUMELLARIA Ehrenberg 1875

Family OROSPHAERIDAE Haeckel 1887

Genus *Oropelex* Friend and Riedel 1967
? *Oropelex* sp.

Family COLLOSPHAERIDAE Muller 1858

Genus *Collosphaera* Muller 1855
Collosphaera cf. *polygona* Haeckel
Collosphaera sp. aff. *huxleyi* Muller
Collosphaera sp. A

Genus *Acrosphaera* Haeckel 1881
Acrosphaera spinosa echinoides (Haeckel)
Acrosphaera spinosa spinosa (Haeckel)

Genus *Siphonosphaera* Muller 1858
Siphonosphaera polysiphonia Haeckel

Genus *Otosphaera* Haeckel 1887
Otosphaera polymorpha Haeckel

Family ACTINOMMIDAE Haeckel 1862
emended Sanfilippo and Riedel 1980

Genus *Actinomma* Haeckel 1860a
Actinomma antarcticum (Haeckel)
Actinomma leptodermum (Jorgensen)
Actinomma polycanthum (Muller) group

Genus *Cladococcus* Muller 1857
Cladococcus dentata (Mast)
Cladococcus stalactites Haeckel

Genus *Cenosphaera* Ehrenberg 1854b
Cenosphaera cristata Haeckel
Cenosphaera spp.

Genus *Acanthosphaera* Ehrenberg 1858
Acanthosphaera dodecastyla Mast
Acanthosphaera sp. A
Acanthosphaera sp. B

Genus *Hexacontium* Haeckel 1881
Hexacontium enthacanthum Jorgensen
Hexacontium laevigatum Haeckel

Genus *Thecosphaera* Haeckel 1881
Thecosphaera cf. *akitaensis* Nakaseko
Thecosphaera grecoi Vinassa de Regny group

Genus *Prunulum* Haeckel 1887
Prunulum spp.

Genus *Styptosphaera* Haeckel 1881
Styptosphaera stupacea Haeckel
Styptosphaera spumacea Haeckel

Genus *Stylatractus* Haeckel 1887
"Stylatractus" *neptunus* Haeckel *forma* large pores
"Stylatractus" *universus* Hays

Genus *Sphaerostylus* Haeckel 1881
"Sphaerostylus" sp. aff. *timmsi* (Campbell and Clark)

Genus *Xiphatractus* Haeckel 1887
"Xiphatractus" sp. A

Genus *Prunopyle* Dreyer 1889
? *Prunopyle antarctica* Dreyer
Prunopyle sp. A

Genus *Spongurus* Haeckel 1860b
Spongurus pylomaticus Riedel
Spongurus sp. A

Genus *Spongocore* Haeckel 1887
Spongocore puella Haeckel
Spongocore sp. A

Family PHACODISCIDAE Haeckel 1881

Genus *Heliodiscus* Haeckel 1882
Heliodiscus asteriscus Haeckel
Heliodiscus umbonatum (Ehrenberg)

Family COCCODISCIDAE Haeckel 1862
emended Sanfilippo and Riedel 1980

Genus *Didymocyrtis* Haeckel 1860a
Didymocyrtis antepenultima (Riedel and Sanfilippo)
Didymocyrtis laticonus (Riedel)
Didymocyrtis virgineum (Haeckel)
Didymocyrtis sp. A
Didymocyrtis tetrathalmus tetrathalmus (Haeckel)

Genus *Diartus* Sanfilippo and Riedel 1980
Diartus hughesi (Campbell and Clark) group

Family **SPONGODISCIDAE** Haeckel 1862
emended Riedel 1967a

- Genus *Amphirhopalum* Haeckel 1881
Amphirhopalum cf. *ypsilon* Haeckel
- Genus *Dictyocoryne* Ehrenberg 1860
Dictyocoryne profunda Ehrenberg
- Genus *Hymeniastrum* Ehrenberg 1847b
Hymeniastrum euclidis Haeckel
- Genus *Spongaster* Ehrenberg 1860
Spongaster pentas Riedel and Sanfilippo
- Genus *Stylodictya* Ehrenberg 1847
Stylodictya validispina Jorgensen
Stylodictya cornuspira Campbell and Clark
- Genus *Porodiscus* Haeckel 1881
Porodiscus sp. A
Porodiscus sp. B
- Genus *Stylochlamyidium* Haeckel 1881
Stylochlamyidium asteriscus Haeckel
- Genus *Spongotrochus* Haeckel 1860b
Spongotrochus glacialis Popofsky

Family **PYLONIIDAE** Haeckel 1881

- Genus *Hexapyle* Haeckel 1881
Hexapyle cf. *dodecantha* Haeckel
- Genus *Tetrapyle* Muller 1858a
Tetrapyle octacantha Muller group

Family **LARNACIDAE** Haeckel 1887

- Genus *Larnacilla* Haeckel 1887
Larnacilla typus Haeckel

Family **THOLONIIDAE** Haeckel 1887

- Genus *Cubotholus* Haeckel 1887
Cubotholus rhombicus Haeckel

Family **LITHELIIDAE** Haeckel 1862

- Genus *Lithelius* Haeckel 1860b
Lithelius minor Jorgensen
Lithelius nautiloides Popofsky
Lithelius sp. A
Lithelius sp. B

- Genus *Pylospira* Haeckel 1887
Pylospira octopyle Haeckel

Suborder **NASSELLARIA** Ehrenberg 1875

Family **PLAGONIIDAE** Haeckel 1881
emended Riedel 1967a

- Genus *Antarctissa* Petrushevskaya 1967
Antarctissa antedenticulata Chen
Antarctissa conradae Chen
Antarctissa longa (Popofsky)
Antarctissa strelkovi Petrushevskaya

- Genus *Lithomelissa* Ehrenberg 1847b
(?) *Lithomelissa setosa* Jorgensen

- Genus *Lophophaena* Ehrenberg 1847b
Lophophaena macrencephala Clark and Campbell group

Family **ACANTHODESMIIDAE** Hertwig 1879

- Genus *Desmospyris* Haeckel 1881
Desmospyris rhodospyroides Petrushevskaya
Desmospyris sp. aff. *rhodospyroides* Petrushevskaya
Desmospyris (?) sp. A.

- Genus *Gorgospyris* Haeckel 1881
Gorgospyris sp. aff. *perizostra* Sanfilippo and Riedel

- Genus *Phormospyris* Haeckel 1881
Phormospyris stabilis (Goll) *antarctica* (Haecker) group
Phormospyris stabilis (Goll) *scaphipes* (Haeckel) group

Family **CARPOCANIIDAE** Haeckel 1881
emended Riedel 1967a

- Genus *Carpocanarium* Haeckel 1887
Carpocanarium papillosum (Ehrenberg)
Carpocanarium sp. A

- Genus *Carpocanistrum* Haeckel 1887
Carpocanistrum sp. A

- Genus *Cystophormis* Haeckel 1887
Cystophormis sp. A
Cystophormis sp. B

Family **THEOPERIDAE** Haeckel 1881
emended Riedel 1967a

- Genus *Cornutella* Ehrenberg 1838
Cornutella profunda Ehrenberg
- Genus *Plectopyramis* Haeckel 1881
Plectopyramis dodecomma Haeckel
- Genus *Dictyophimus* Ehrenberg 1847a
Dictyophimus hirundo (Haeckel) group
- Genus *Pseudodictyophimus* Petrushevskaya 1971c
Pseudodictyophimus gracilipes (Bailey)
- Genus *Lychnocanium* Ehrenberg 1847a
Lychnocanium sp. aff. *grande* Campbell and Clark
- Genus *Lychnocanella* Haeckel 1887
Lychnocanella conicum (Clark and Campbell)
- Genus *Archipilium* Haeckel 1881
Archipilium macropus (Haeckel)
- Genus *Cyrtocapsella* Haeckel 1887
Cyrtocapsella japonica (Nakaseko)
Cyrtocapsella tetrapera (Haeckel)
- Genus *Cyrtolagena* Haeckel 1887
Cyrtolagena laguncula (Haeckel)
- Genus *Stichophormis* Haeckel 1881
Stichophormis cornutella Haeckel
- Genus *Theocalyptra* Haeckel 1881
Theocalyptra bicornis (Popofsky)
Theocalyptra davisiana davisiana (Ehrenberg)
- Genus *Lampromitra* Haeckel 1881
Lampromitra butschlii (Haeckel)
Lampromitra erosa Cleve
Lampromitra tiara Dumitrica
- Genus *Theocampe* Haeckel 1887
? *Theocampe* cf. *mongolfieri* (Ehrenberg)
- Genus *Eucyrtidium* Ehrenberg 1847a
Eucyrtidium acuminatum (Ehrenberg)
Eucyrtidium cienkowskii Haeckel group
Eucyrtidium hexagonatum Haeckel
Eucyrtidium calvertense Martin
Eucyrtidium inflatum Kling
Eucyrtidium punctatum (Ehrenberg) group
Eucyrtidium cf. *montiparum* Ehrenberg
Eucyrtidium sp. A
Eucyrtidium vincentense (Campbell and Clark)

Genus *Stichocorys* Haeckel 1881
Stichocorys peregrina (Riedel)
Stichocorys delmontensis (Campbell and Clark)
Stichocorys sp. A

Genus *Gondwanaria* Petrushevskaya 1975
Gondwanaria dogeli (Petrushevskaya) group

Genus *Artostrobus* Haeckel 1887
"Artostrobus" (?) pretabulatus Petrushevskaya

Family **PTEROCORYTHIDAE** Haeckel 1881
emended Riedel 1967a

Genus *Anthocyrtidium* Haeckel 1881
Anthocyrtidium ehrenbergi (Stohr) *pliocenica* (Seguenza)
? *Anthocyrtidium* ? sp. A
Anthocyrtidium zanguebaricum (Ehrenberg)

Genus *Lamprocyclas* Haeckel 1881
Lamprocyclas gamphonycha (Jorgensen)
Lamprocyclas maritalis Haeckel
Lamprocyclas (?) sp. A
Lamprocyclas sp. B
Lamprocyclas sp. C
Lamprocyclas sp. D
Lamprocyclas sp. E

Genus *Lamprocyrtis* Kling 1973
Lamprocyrtis (?) *apollinis* (Haeckel)
Lamprocyrtis hannai (Campbell and Clark)
Lamprocyrtis heteroporus (Hays)
Lamprocyrtis (?) *junonis* (Haeckel)

Family **ARTOSTROBIIDAE** Riedel 1967a
emended Foreman 1973

Genus *Botryostrobos* Haeckel
Botryostrobos aquilonaris (Bailey)
Botryostrobos auritus-australis (Ehrenberg) group
Botryostrobos bramlettei (Campbell and Clark)

Genus *Phormostichoartus* Campbell 1951
Phormostichoartus fistula Nigrini
Phormostichoartus sp. A

Genus *Siphocampe* Haeckel 1881
Siphocampe arachnea (Ehrenberg) group
Siphocampe lineata (Ehrenberg) group
Siphocampe nodosaria (Haeckel)

Genus *Siphostichartus* Nigrini 1977
Siphostichartus corona (Haeckel)

Genus *Spirocyrtis* Haeckel 1881
Spirocyrtis subscalaris Nigrini

Family **CANNOBOTRYIDAE** Haeckel 1881
emended Riedel 1967a

Genus *Botryopyle* Haeckel 1881
Botryopyle dictyocephalus Haeckel group

4.4 SYSTEMATICS

Phylum Protozoa

Class Actinopoda

Subclass Radiolaria

Order Polycystina Ehrenberg 1838 emended Riedel 1967a

Radiolaria with a skeleton of opaline silica
without admixed organic compounds.

Suborder Spumellaria Ehrenberg 1875

Family Orosphaeridae Haeckel 1887

Skeleton consisting of a lattice shell, or two approximately concentric shells, and radial spines which are almost invariably circular in cross-section. In some forms a double spicule is present at or near the shell apex. The shell in some members is subspherical, but actually monaxon-allopolar in all well-known forms. Lattice is generally robust and irregular, with commonly angular or subangular pores (Friend and Riedel, 1967).

Genus *Oropelex* Friend and Riedel 1967

Orosphaeridae with a subcylindrical to conical single lattice shell with hemispherically closed upper end and ribs or bars prolonged to form spines at the lower open end. Some specimens have a latticed wall transversely subdividing the cavity.

Type-species: *Oropelex pagoda* Friend and Riedel 1967

? *Oropelex* sp.

Plate 1, figure 1

? *Oropelex pagoda* Friend and Riedel 1967 p.224, pl.2, figs.1-4.

Description: Fragments of a lattice wall with subtriangular to subquadrangular (10-80 μ) pores. At least one prominent rib usually present.

Dimensions: Fragments up to 4mm.

Remarks: These fragments appear to be related to *O. pagoda*.

Observed range: Sporadic occurrences in Miocene samples with excellent siliceous preservation (e.g. Morrisons, Ruamahanga, and Leader sections). One post-Miocene occurrence in the dextral *G. crassaformis* - *G. crassula* overlap zone at Waiatai (WA08). Too rare to be of biostratigraphic use.

Family *Collosphaeridae* Muller 1858

Colonial spumellarians with lattice and plate perforate shells and one genus without skeletal elements.

Genus *Collosphaera* Muller 1855

Collosphaeridae with simple shells, smooth on the inside and outside without any spines or tubuli.

Type-species: *Collosphaera huxleyi* Muller 1855 : designated by Campbell 1954

Collosphaera cf. *polygona* Haeckel

Plate 2, figure 1

Collosphaera polygona Haeckel 1887, p.96, pl.5, fig.13.

Description: Subspherical lattice shell, thin walled, smooth surface with approximately nine subangular pores on the half equator. Pores large (up to 25μ), variable in size, and bars approximately 7μ in width.

Remarks: The rare specimens found have pores not quite as polygonal as in Haeckel's figured specimen.

Observed range: Restricted to Miocene samples but too rare to be of use biostratigraphically.

Collosphaera sp. aff. *huxleyi* Muller

Plate 1, figures 3,4; Plate 2, figure 5

Collosphaera huxleyi Muller 1858, p.55, pl.8, fig.7.

Collosphaera huxleyi Muller: Goll 1980, p.436, pl.1, figs.16-17.

Collosphaera sp. aff. *C. huxleyi* Muller: Johnson and Nigrini 1980, p.147, pl.1, fig.6, pl.4, fig.14.

Description: Shell spherical to slightly ellipsoidal, thick-walled, smooth surface with a moderate number (6-8 on the half equator) of circular to subcircular pores irregularly scattered.

Dimensions: Based on eight specimens. Diameter 110. Pores 5-25. Bars 10-30.

Remarks: Goll (1980) notes that he has doubt about calling his specimens *C. huxleyi* as his forms (and the forms described herein) differ from Muller's figured form in having fewer pores on the half equator. Johnson and Nigrini (1980) differentiate between *C. huxleyi* and *C. sp. aff. C. huxleyi* on the lesser number of pores in the latter species. Some forms which have larger pores and thinner bars approach *C. macropora* Popofsky (1917).

Recorded range: Goll (1980) places the FAD of *Collosphaera huxleyi* at 1.8Ma in the eastern tropical Pacific.

Observed range: Apart from uncertain occurrences with *G. dehiscens* in SWR4, LT05, LT06, and RK04, there are only two positive identifications older than the LAD of *G. dehiscens* in samples KB01 and SPA1. The highest positive identification is in East Cape Section at the level of the FAD of *G. crassaformis*. Sporadic uncertain identifications as high as sample WA02 (Waiatai). A good indication of upper Miocene age if found in a sequence of samples. See *Acrosphaera spinosa echinoides*.

Geographic distribution: Johnson and Nigrini (1980) show *C. huxleyi* is present between 18°S and 37°S and *Collosphaera* sp. aff. *C. huxleyi* consistently present in samples north of about 5°N with scattered occurrences of small, impoverished forms between 0° and 10°S (western Indian Ocean).

Collosphaera sp. A

Plate 1, figure 2

Description: Shell slightly ellipsoidal, thick walled, smooth surface with 4-5 large subelliptical pores, 50 to 100 μ long with the long axis of each pore aligned subparallel to the long axis of the ellipse. Two smaller subcircular pores are present at the polar ends. Bars consistently about 12 μ broad.

Dimensions: Based on four specimens. Length of long axis 105. Breadth of ellipse 80.

Observed range: Restricted to southern Wairarapa samples with good preservation in the age range post-LAD *G. dehiscens* to slightly above the local FAD of *B. compressa sensu stricto*. Too rare to be of use biostratigraphically.

Genus *Acrosphaera* Haeckel 1881

Collosphaeridae with simple shells, the outer surface of which is covered with radial, irregularly scattered spines, but no external tubes.

Type-species: *Acrosphaera echinoides* Haeckel 1887 : designated by Bjorklund and Goll 1979

Acrosphaera spinosa echinoides (Haeckel)

Plate 1, figure 5: Plate 2, figure 3

Acrosphaera echinoides Haeckel 1887, p.100, pl.8, fig.1.

Acrosphaera spinosa echinoides Haeckel: Bjorklund and Goll 1979, p.1311, pl.1, figs.12-13, pl.4, figs.1-4,7,8 (only).

Description: Lattice shell, thick walled, approximately spherical with numerous conical wall protuberances and alternating depressions. Protuberances 15-20 μ in diameter, perforated by irregular subangular pores up to 8 μ in diameter (especially around the base). Simple spines, 5-10 μ long, project from the summit of each protuberance. Intervening depressions of lattice shell broad, sparsely perforated by small round pores.

Remarks: This subspecies shows a pronounced size decrease in the Upper Miocene (Bjorklund and Goll, 1979) and the form described here differs somewhat from Haeckel's illustrated form in being smaller and there being not so many pores in the depressions.

Recorded range: FAD in lower Miocene and persists in variable frequencies into the lower Pliocene (Bjorklund and Goll, 1979).

Observed range: Tends to be found only in samples with excellent preservation. Apart from one uncertain identification between the LAD of *G. dehiscens* and the FAD of *B. compressa* at Hangaroa (HR06) all other occurrences are above the base of the Opoitian. A moderately useful Plio-Pleistocene indicator. It appears *A. spinosa echinoides* may be a descendant of *C. sp. aff. huxleyi* and/or *A. spinosa spinosa* with the protuberances getting longer. This trend is opposite to that suggested by Bjorklund and Goll (1979).

Geographic distribution: Loads highest in subtropical areas, its present maximum abundance in the middle of the subtropical gyre (Morley, 1977, south Atlantic). Present in all samples except southernmost (48°S) and northernmost (19°N) being particularly abundant at about 20°S (Johnson and Nigrini, 1980, western Indian Ocean, *Acrosphaera spinosa*).

Acrosphaera spinosa spinosa (Haeckel)

Plate 1, figure 6

Collosphaera spinosa Haeckel 1862, p.536, pl.34, figs.12,13.

Polysolenia spinosa (Haeckel): Dumitrica 1973, pl.18, fig.2.

Polysolenia spinosa (Haeckel): Nigrini and Moore 1979, p.S19, pl.2, fig.5.

Acrosphaera spinosa spinosa (Haeckel): Bjorklund and Goll 1979, p.1308, pl.1, figs.8,9.

Description: Shell thin walled, smooth, spherical, with irregularly scattered subcircular pores of variable size, half to two times as broad as the bars. Short spines, usually mounted on conical elevations, project randomly over the shell surface. Spines usually conical but may be quite sharp.

Dimensions: Diameter of shell usually 81-128 (Nigrini, 1967).

Remarks: Differs from *A. spinosa echinoides* in having smaller pores and also the lattice protuberances are lower and spines shorter (Bjorklund and Goll, 1979).

Recorded range: First appears in the Upper Miocene *Didymocyrtis penultima* Zone (DSDP Site 77, core 12, *Ommatartus penultimus* Zone). It is assumed to have evolved from *A. spinosa echinoides* (Bjorklund and Goll, 1979). See *A. spinosa echinoides*.

Observed range: Most occurrences are limited to upper Tongaporutuan samples with only one pre-LAD *G. dehiscens* (KB01). Four positive post-Miocene identifications. Too sporadic to be of use biostratigraphically. See *Acrosphaera spinosa echinoides*.

Geographic distribution: Same as *A. spinosa echinoides*.

Genus *Siphonosphaera* Muller 1858

Collosphaeridae with simple shells, the pores of which are prolonged into external simple radial tubuli with solid wall; outer mouth of the tubuli truncated, smooth.

Type-species: *Collosphaera tubulosa* Muller 1855

Siphonosphaera polysiphonia Haeckel

Plate 2, figure 2

Siphonosphaera polysiphonia Haeckel 1887, p.106.

Siphonosphaera polysiphonia Haeckel: Dumitrica 1973, p.832, pl.18, fig.3.

Siphonosphaera polysiphonia Haeckel: Nigrini and Moore 1979, p.S21, pl.1, figs.6a,b.

Siphonosphaera polysiphonia Haeckel: Johnson and Nigrini 1980, p.119, pl.1, fig.12.

Description: Shell spherical, rather thick walled with somewhat rough or pitted surface and numerous, small, irregularly scattered, subcircular pores. Four to ten poreless tubules, thin walled, cylindrical, having no definite arrangement. Tubules usually broader than long and smoothly truncated.

Dimensions: Diameter of shell 81-119 (Nigrini, 1967).

Remarks: Tubules usually longer but poorer preservation could have reduced their length in the samples studied.

Observed range: Found in only two Pliocene samples (SWR1 and WA16).

Geographic distribution: Loads most highly in subtropical waters, absent south of 40°S (Morley, 1977, south Atlantic).

Most abundant in low latitudes (Johnson and Nigrini, 1980, western Indian Ocean).

Genus *Otosphaera* Haeckel 1887

emended Nigrini 1967

Collosphaeridae with simple shells, some of the pores of which are prolonged into simple external radial tubules with fenestrate walls; outer mouth of the tubules armed with a single tooth or spine. Emended by Nigrini (1967) to include forms having a spine on the distal end of the tubules.

Type-species: *Otosphaera polymorpha* Haeckel 1887 : designated by Campbell 1954

Otosphaera polymorpha Haeckel

Plate 2, figure 4

Otosphaera polymorpha Haeckel 1887, p.116, pl.7, fig.6.

Otosphaera polymorpha Haeckel: Renz 1974, pl.13, fig.15.

Trisolenia megalactis megalactis (Ehrenberg): Bjorklund and Goll 1979, p.1321, pl.5, figs.1-21 (in part).

Otosphaera polymorpha Haeckel: Nigrini and Moore 1979, p.S9, pl.1, fig.5.

Description: Shell smooth, thin walled, subspherical, with numerous very small pores, much smaller than the bars. Tubules, 2-4, are truncated obliquely, one side prolonged into an acute tooth.

Dimensions: Diameter of shell 100-146. Maximum length of tubules (including tooth) 18-45. Maximum breadth of tubules 27-36 (after Nigrini, 1967).

Remarks: Bjorklund and Goll (1979) defined *T. megalactis megalactis* to include a number of forms, one of which is *O. polymorpha*.

Recorded range: Quaternary (Renz, 1974). Neogene (Bjorklund and Goll, 1979)

Observed range: Found rarely in samples ranging in age from early Tongaporutuan (LT09) to middle Opoitian (SMR1).

Geographic distribution: Too rare to determine accurately (Molina-Cruz, 1975, southeast Pacific).

Family **Actinommidae** Haeckel 1862
emended Sanfilippo and Riedel 1980

Solitary spumellarians with shells spherical or ellipsoidal or modifications of those shapes, but not discoidal, nor equatorially constricted ellipsoids, usually without internal spicule and generally much smaller than the orosphaerids.

Genus **Actinomma** Haeckel 1860a
emended Bjorklund 1977

Actinommidae with three or four lattice spheres and 10-20 unbranched spines of either uniform or irregular length.

Type-species: *Haliomma trinacrium* Haeckel 1860a

Actinomma antarcticum (Haeckel)
Plate 1, figures 7-10: Plate 2, figure 6

Spongoplegma antarcticum Haeckel 1887, p.90.

Cladococcus aquaticus Popofsky 1908, p.214, pl.23, figs.3,4.

Diploplegma banzare Riedel 1958, p.223. pl.1, figs.3,4.

Spongoplegma antarcticum Haeckel: Chen 1975, p.454, pl.22, figs.3,4.

Spongoplegma sp. Chen 1975, p.454, pl.22, figs.1,2.

Spongoplegma antarcticum Haeckel: Keany 1979, p.53, pl.2, fig.1.

Actinomma antarcticum (Haeckel): Nigrini and Moore 1979, p.S25, pl.3, figs.1a,b,2a,b,3.

Actinomma antarcticum (Haeckel): Boltovskoy and Riedel 1980, p.109, pl.2, fig.2.

Description: Cortical shell large, spherical to ellipsoidal with either a rough surface; a surface covered in small thorns; a surface with very heavy short radial beams with tuberculate ends, arising from the nodes of intervening bars; or a double cortical shell. Cortical pores circular to rounded polygonal, irregular in shape and pattern but generally subequal in size, 14-26 across the half equator. Cortical shell or shells connected to a loose, subspherical, spongy medullary meshwork by numerous radial, thin, three-bladed beams. Central shell not visible. Very often medullary meshworks are preserved intact with no cortical shell attached.

Dimensions: Based on twelve specimens. Diameter of cortical shell (includes average diameter of ellipsoidal specimens) 172-292. Diameter of medullary shell (based on 16 specimens) 40-94.

Remarks: Nigrini (1967) described *A. medianum* as a species having characteristics intermediate between the cold (Antarctic) *A. antarcticum* and the warm (low latitude) *A. arcadophorum*. *A. medianum* is distinguished from *A. antarcticum* by a generally smaller size, a simply latticed cortical shell with 9-12 pores on the half equator and a more delicate medullary meshwork. Although some of the specimens described herein approach *A. medianum* (Plate 1, figure 11, Plate 2, figure 7) none could be described as *A. medianum sensu stricto*.

Recorded range: Chen (1975) believed his Miocene *Spongoplegma* sp. may be an ancestor to the Pliocene-Recent *Spongoplegma antarcticum*. Chen's two forms are herein considered conspecific.

Pliocene to Pleistocene (Keany, 1979). Miocene? to Recent (Hays, 1965).

Observed range: Normally only medullary found. Generally only lacking in those samples with poor preservation. Found throughout Late Neogene. Specimens referable to *A. cf. medianum* are found in five Miocene samples but are too rare to be of use biostratigraphically.

Geographic distribution: "One of the most abundant species in the Antarctic fauna and in several samples constitutes over 50% of the species counted."; "there seems to be a tendency for this species to reach its greatest relative abundance in the vicinity of the Polar Front" (Hays, 1965, *Spongoplegma antarcticum*, Antarctic seas).

"In the Indian Ocean it is found in some samples north of the subtropical convergence but invariably they can be interpreted as being transported by bottom currents or as intermediate forms which could be classified as *Actinomma medianum*" (Lozano, 1974).

Actinomma leptodermum (Jorgensen)

Plate 1, figures 12,13

Echinomma leptodermum Jorgensen 1900, p.57, 1905, p.116, pl.8, figs.33a-c.

non: *Echinomma leptodermum* Jorgensen: Hays 1965, p.169, pl.1, fig.2.

Echinomma leptodermum Jorgensen: Bjorklund 1976, pl.1, figs.13,14, pl.2, figs.1-6.

Actinomma leptodermum Jorgensen: Nigrini and Moore 1979, p.S35, pl.3, fig.7.

Description: Cortical shell delicate spherical to subspherical, thin walled with circular to subelliptical pores, uneven in size, 8-10 on the half equator. In some specimens the pores are infilled with a thin siliceous membrane (probably a artifact of preservation). Outer medullary subspherical to spherical connected to cortical by thin, three-bladed radial beams. Inner medullary not seen. Main spines, three-bladed, 10-15 in number; thinner shorter by-spines may also be present. Rare forms show traces of transverse processes on the main spines (especially in forms with longer spines) indicating a large outer shell may be present in living specimens.

Dimensions: Based on seven specimens. Diameter of cortical shell 88-103. Maximum length of main spines 37-80 (average = 43).

Remarks: *Echinomma antarctica* (Dreyer)? as illustrated by Dumitrica (1973, pl.20, fig.4) may be conspecific.

Observed range: The oldest sample containing positive *A. leptodermum* is MS03 (uppermost Tongaporutuan). There are sporadic occurrences in the Pliocene. Becomes more common in the Pleistocene. The form with no by-spines, tabulated under *A. cf. leptodermum*, occurs with *G. dehiscens* in sample SWR4 (Wainuioru Valley) and has a highest positive occurrence in sample WA19 (about 100m above the LAD of *C. molestus* at Waiatai). It occurs sporadically in the Miocene and maybe an environmental variant or ancestor of *A. leptodermum sensu stricto*.

Geographic distribution: There is considerable variation between authors concerning the limits of this species. Comparison of distributional data should be made with caution (Nigrini and Moore, 1979). Bjorklund (1977) concluded that *A. leptodermum* was restricted to the North Atlantic and proposed that the southern form, *A. haysi* (= *Echinomma leptodermum* of Hays, 1965) is a new species. Boltovskoy and Riedel (1980) in their study from the southwestern Atlantic Ocean did not support this view stating that "the very few specimens observed in our material were much more like *E. leptodermum* than *A. haysi*."

Actinomma polycanthum (Muller) group

Plate 2, figure 8: Plate 3, figures 1-5

Haliomma polycanthum Muller 1858, p.36, pl.1 fig.10,11.

Actinomma yosii Nakaseko 1959b, p.10, pl.2, fig.8a,b,9a,b.

Actinomma mediterranensis Hollande and Enjumet 1960, p.110, pl.54, figs.2-4.

Actinomma mediterranensis Hollande and Enjumet: Dumitrica 1973, p.832, pl.20, fig.3.

Actinomma tanyacantha Chen 1975, p.450, pl.11, figs.5,6.

Description: Three concentric lattice spheres and eight or more strong, three-bladed radial spines. The cortical shell is generally spherical, rarely ellipsoidal. Cortical pores normally circular to subcircular, subhexagonally arranged and deeply set in a relatively thick cortical wall, 11-16 on the half equator. Rare forms have a very rough, thorny surface and in these specimens the pores tend to be more irregular. Outer medullary shell spherical to rounded polygonal, 0.3 to 0.4 the cortical diameter. Inner medullary normally indistinct, subspherical, 0.15 to 0.2 the cortical diameter. Radial spines, three-bladed, strong, occasionally all intact. Rare specimens have needle-like by-spines. Most specimens have more radial spines than radial beams connecting the cortical and outer medullary shell.

Dimensions: Based on twenty specimens. Diameter of cortical shell 90-135. Length of spines 35-88.

Remarks: In sediments it is very common for the forms to have some of their spines broken. The species in the synonymy have the following number of spines according to the original description:

Haliomma polycanthum Muller - approximately 20

Actinomma tanyacantha Chen - 14

Actinomma yosii Nakaseko - 12

Actinomma mediterranensis Hollande and Enjumet - approximately 14.

It is very difficult to count the number of spines, especially in poorly preserved specimens or in those with a large number of spines so the forms were described together under the one name.

Recorded range: Chen (1975) used the first occurrence of *A. tanyacantha* to define the base of his Middle Miocene *Actinomma tanyacantha* Zone. This appears to be the oldest occurrence of members of this group. Extends up to the Recent.

Observed range: Persistent throughout the Late Neogene. Occurs in 83% of the radiolarian-bearing samples studied.

Geographic distribution: Cosmopolitan?

Genus *Cladococcus* Muller 1857

Actinommidae with a single shell: radial spines branched but the stem not forked.

Type-species: *Cladococcus arborescens* Muller 1858

Cladococcus dentata (Mast)

Plate 3, figure 6

Heteracantha dentata Mast 1910, p.37, pl.18, fig.47.

Cladococcus lychnosphaerae Hollande and Enjument 1960, p.115, pl.55, figs.1,2.

Heteracantha dentata Mast: Bjorklund 1976, pl.14, figs.10-12.

Anomalacantha dentata (Mast): Nigrini and Moore 1979, p.S37, pl.4, fig.4.

Anomalacantha dentata (Mast): Johnson and Nigrini 1980, pl.1, fig.16.

Description: Spherical lattice shell from which originate 8-12, rarely more, long broad, regularly arranged, three-bladed radial spines, each with thorns or small branches at 2-4 places. Pores circular to subcircular, of equal size, 6-7 on the half equator. Surface of shell smooth to thorny.

Dimensions: Based on 30 specimens. Diameter of shell 53-69. Length of radial spines 166-246. Breadth at their bases 6-12 (Benson, 1966).

Remarks: The forms described have a slightly larger cortical shell than those previously described. The genus *Heteracantha* (Type-species: *Heteracantha dentata* Mast 1910 : designated by Campbell 1954) has, according to Campbell (1954), two concentric lattice shells. Nigrini and Moore (1979) and herein report that *dentata* has only one lattice shell. Therefore this species should be placed in the genera *Cladococcus*. Nigrini and Moore's (1979, p.S37) description is under the generic name *Anomalacantha* proposed by Loeblich and Tappan (1961) because they found the name *Heteracantha* to be previously occupied.

Recorded range: ?Middle to late Miocene? (Bjorklund, 1976, DSDP Site 338) to Recent.

Observed range: Rare but persistent in the Miocene. Lowest occurrence in association with *G. dehiscens* at Leader River. Highest occurrence is in the middle Pliocene at Waimata.

Geographic distribution: "Belongs to a transitional assemblage derived by recurrent group analysis of North Pacific samples" (Nigrini, 1970).

"loads on the Transition (Southernmost) factor" (Sachs, 1973, subarctic Pacific).

"It is absent north of about 46°N except for rare occurrences in three samples" (Robertson, 1975, northwest Pacific).

"Bimodal distribution north of about 12°S and between about 30°S and 45°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Cladococcus stalactites Haeckel

Plate 3, figure 7

Cladococcus stalactites Haeckel 1887, p.227, pl.27, fig.4.

Cladococcus megaceros Hollande and Enjumet 1960, pl.58, fig.4.

Cladococcus sp. cf. *C. stalactites* Haeckel or *C. abietinus* Haeckel: Riedel, Sanfilippo and Cita 1974, pl.61, fig.8.

Actinommidae gen. et sp. indet. Riedel and Sanfilippo (in Berggren *et al.*, 1976) pl.12, fig.1.

Cladococcus megaceros Hollande and Enjumet: Boltovskoy and Riedel 1980, p.110, pl.2, fig.6.

Description: Spherical lattice shell, thick walled from which arise about 18 or more long, three-bladed radial spines each of which has thorns or small branches at 1-2 places. Pores very irregular in shape, subequal in size, 10-13 on the half equator.

Dimensions: Based on five specimens. Diameter of shell 92-153. Maximum length of spines 175.

Remarks: Distinguished from *C. dentata* by the larger shell and more irregular pores.

Recorded range: Riedel and Sanfilippo's (1976) form is from the early Late Miocene of Spain. Known from the Recent.

Observed range: Not found with *G. dehiscens*. Sporadic occurrences up to the Pleistocene. Too rare to be of use biostratigraphically. Generally only found in samples with excellent siliceous preservation.

Genus *Cenosphaera* Ehrenberg 1854b

Actinommidae consisting of a single, lattice, spherical shell; without spines on the shell surface.

Type-species: *Cenosphaera plutonis* Ehrenberg 1854b

Cenosphaera cristata Haeckel

Plate 3, figure 8

Cenosphaera cristata Haeckel 1887, p.66.

Cenosphaera cristata Haeckel: Riedel 1958, p.223, pl.1, figs.1,2.

Cenosphaera cristata Haeckel: Keany and Kennett 1975, pl.3, fig.9.

Cenosphaera cristata Haeckel group: Petrushevskaya 1975, p.567, pl.1, figs.3,4, pl.17, fig.2.

? *Cenosphaera cristata* Haeckel: Nigrini and Lombardi 1984, p.515, pl.2, fig.2.

Description: Shell spherical (rarely subspherical), thick walled, thorny. Pores subcircular to circular, variable in size, 10-17 on the half equator, two, rarely five, times as wide as the intervening bars. Pores surrounded by indistinct polygonal frames, bearing short thorns at the intersections of the frames.

Dimensions: Based on 32 specimens. Diameter of shell 115-230 (Riedel, 1958).

Remarks: Both Petrushevskaya (1975) and Nigrini and Lombardi (1984) have noted the presence of internal microspheres in some specimens very similar to those found in the genus *Lonchospaera*.

Recorded range: Miocene-Recent (Petrushevskaya, 1975).

Observed range: Sporadic occurrences throughout the Late Neogene.

Geographic distribution: "This species loads most heavily in factor 3 (transitional). At the present this species is most abundant in a band between about 40°N and 45°N" (Robertson, 1975, northwest Pacific).

"Present throughout the temperate Miocene sections examined, rare in the early Miocene" (Nigrini and Lombardi, 1984, CENOP Project).

Cenosphaera spp.

Description: The specimens included in this group include several forms which all have spherical shells lacking any internal structure. A variety of pore size, shape and pattern and wall thicknesses are represented. Four main forms are most common:

Cenosphaera sp. A

Plate 3, figure 10; Plate 4, figure 1

Description: Relatively small thick-walled, with small subcircular pores which approach *Cenosphaera nagatai* Nakaseko but differ in that the pores are smaller and the intervening bars broader (see Nakaseko 1959b, p.6, pl.2, figs.1a,b,2. and Hays 1965, p.165, pl.2, fig.6.)

Observed range: Sporadic occurrences throughout the Late Neogene. Rare in the Plio/Pleistocene with only three questionable identifications from Waiatai.

Cenosphaera sp. B

Plate 4, figure 2

? *Cenosphaera mellifica* Haeckel 1887, p.62, pl.12, fig.9.

Description: Moderately thick-walled with very regular circular pores and pronounced hexagonal frames.

Observed range: Sporadic occurrences in Miocene and Lower Pliocene samples. Only one higher occurrence in WA07 (Waiatai).

Cenosphaera sp. C

Plate 3, figure 9

Cenosphaera sp. Nigrini and Moore 1979, pl.4, fig.3d (only).

Description: Very distinctive, delicate, large pored forms. Pores subelliptical to circular, 9-11 on half equator.

Observed range: Rare throughout the Late Neogene.

Cenosphaera sp. D

Plate 4, figure 3

Description: Small, thorny forms with regular subcircular pores and broad intervening bars. The length of the thorns is variable and some forms with long thorns would probably be better placed in the genus *Acanthosphaera*.

Observed range: Rare but limited to Miocene and basal Opoitian strata except for one tentative occurrence in the middle Opoitian (SWM1).

Genus *Acanthosphaera* Ehrenberg 1858

Actinommidae with a single lattice shell and eight or more, normally more than twelve radial spines.

Type-species: *Acanthosphaera haliphormis* Ehrenberg 1861

Note: Haeckel (1887) differentiated between the genera *Acanthosphaera* and *Heliosphaera* on the basis of one type of spines versus the presence of two kinds of spines (main and by-spines). This separation was considered unjustified by Boltovskoy and Riedel (1980: p.107).

Acanthosphaera dodecastyla Mast

Plate 4, figure 4

Heliosphaera minuta Cleve 1900, p.8, pl.6, fig.2.

Acanthosphaera dodecastyle Mast 1910, p.16, pl.14, fig.1.

Acanthosphaera dodecastyla Mast: Boltovskoy and Riedel 1980, p.108, pl.1, fig.21.

Description: Single lattice shell, relatively thick walled. Circular to subcircular pores with very conspicuous, protruding hexagonal frames. Bars slightly narrower than pores. Six or seven pores on the half equator. At some nodal points strong, three-bladed spines of variable length project radially.

Dimensions: Based on three specimens. Diameter of shell 61-66.

Remarks: Distinguished by distinctive hexagonal frames around pores. Boltovskoy and Riedel (1980) point out that *Heliosphaera minuta* (Cleve) is a junior homonym of *H. minuta* Rust (1898).

Recorded range: Recent.

Observed range: Rare in the Late Neogene.

Geographic distribution: North, and tropical Atlantic, and tropical Indian Ocean (Boltovskoy and Riedel, 1980).

Acanthosphaera sp. A

Plate 3, figures 11,12: Plate 4, figure 5

Description: Shell spherical, latticed. Pores circular to subcircular, with no hexagonal framing, 10-12 on the half equator. From most of the nodal points arise a strong, three-bladed radial spines (some of which are slightly curved).

Dimensions: Based on six specimens. Diameter of cortical shell 96-140. Maximum length of spines (normally with broken ends) 40.

Remarks: Tabulated in two forms based on the number of spines. Generally the species has up to 25 spines (Plate 4, figure 5). Rarer specimens have spines arising from nearly all the nodal points (Plate 3, figure 11). Intermediate forms are present (Plate 3, figure 12).

Observed range: The "few spined" form is relatively common and persistent in samples from throughout the Late Neogene. The "many spined" form is found in only six Miocene samples, all post-LAD *G. dehiscens* and one Pliocene sample (TM06). Too rare to be of use biostratigraphically.

Acanthosphaera sp. B

Plate 3, figure 13: Plate 4, figure 6

Description: Shell very thick walled with very heavy three-bladed spines, the blades of which normally coalesce giving deep set subcircular to circular pores.

Dimensions: Based on four specimens. Diameter of shell 130-142. Longest spine 117.

Remarks: Superficially this form is very similar to *Haeckeliella inconstans* Dumitrica illustrated by Riedel, Sanfilippo and Cita (1974, pl.54, figs.2,3) from the Sicilian Pliocene. The forms described herein do not have the distinct, large, internal shell with hexagonal pores. There is a possibility that the delicate internal shell may have been lost due to solution although some of the specimens come from samples with excellent preservation. Some specimens have an indistinct lateral spinule near the termination of its longest spine.

Recorded range: Pliocene (Riedel, Sanfilippo and Cita, 1974) to Quaternary (Dumitrica, 1973, original definition of *H. inconstans*).

Observed range: Sporadic occurrences throughout the Late Neogene.

Genus *Hexacontium* Haeckel 1881

Actinommidae with three concentric lattice shells and six main radial spines in two planes, meeting at right angles. Main spines all similar and unbranched.

Type-species: *Hexacontium phaenaxonium* Haeckel 1887

Hexacontium enthacanthum Jorgensen

Plate 4, figure 7: Plate 5, figures 2-4,6

Hexacontium enthacanthum Jorgensen 1900, p.52, pl.2, fig.14, pl.4, fig.20.

Hexacontium pachydermum Jorgensen: Bjorklund 1976, pl.1, figs.4-9.

Hexacontium enthacanthum Jorgensen: Bjorklund 1976, pl.1, figs.1-3.

Hexacontium enthacanthum Jorgensen: Nigrini and Moore 1979, p.545, pl.5, figs.1a,b.

Description: Cortical shell generally subspherical to subquadrate, rarely spherical. Surface smooth but with tiny thorns which arise from the nodes of the intervening bars as well as along the bars. Pores generally circular to subelliptical, occasionally subpolygonal; generally irregular in size and arrangement; 8-12 on the half equator. Outer medullary shell small, 0.2 to 0.3 the diameter of cortical shell, subspherical. Inner medullary about 0.1 the diameter of cortical shell, subspherical, normally indistinct. Six, mutually perpendicular radial beams arise from the surface of the inner medullary, become relatively heavy,

three-bladed between the second and cortical shells, and pierce the cortical shell. All six spines of nearly equal length and breadth.

Dimensions: Based on twenty specimens. Diameter of cortical shell 146-194: of outer medullary shell 38-50. Length of spines 28-74.

Remarks: Nigrini and Lombardi (1984, p.519, *Hexacontium* spp.) noted that the Miocene specimens in this species group are generally larger than the Recent specimens. Robertson (1975) also notes that the inner shell was "frequently difficult to discern". Bjorklund (1976) distinguished between *H. enthacanthum* and *H. pachydermum* on thickness of shell. There is a tendency for forms with larger pores to dominate in upper Pliocene and Pleistocene faunas.

Recorded range: Present throughout the Miocene sections examined from both tropical and temperate latitudes (Nigrini and Lombardi, 1984, *Hexacontium* spp., CENOP Project).

Observed range: Tabulated in three forms. *H. enthacanthum sensu stricto* is common throughout the Late Neogene, being present in 67% of the radiolarian-bearing samples studied. Absence generally related to poor siliceous preservation. There is an apparent tendency for the cortical bars to get thinner in younger specimens. The "oval" form is found in eleven samples throughout the Late Neogene, eight of which also contain *H. enthacanthum sensu stricto*. The "quadrate" form occurs in nine Tongaporutuan samples, one of which contains *G. dehiscens* (KB01). See *H. laevigatum* for discussion of transitional forms.

Geographic distribution: "This genus (*Hexacontium* spp.) loads most heavily in factor 3 (transitional). At present its higher abundances generally occur south of 45°N" (Robertson, 1975, northwest Pacific).

Hexacontium laevigatum Haeckel

Plate 5, figures 1,5,7,8

Hexacontium laevigatum Haeckel 1887, p.193, pl.24, fig.6.

Hexacontium laevigatum Haeckel: Nigrini and Moore 1979, p.547, pl.5, figs.2a,b.

Description: Similar to *Hexacontium enthacanthum* but differs in the following respects: the cortical shell is generally more spherical, and the pores are more numerous (14-18 on the half equator), being nearly equal circular pores on the cortical shell.

Dimensions: Based on ten specimens. Diameter of cortical shell 130-170. Length of main spines 40-81.

Remarks: Some forms with very long spines differ from previously described forms. No specimens exhibited the "presence of numerous thin by-spines concentrated at one pole of the shell" reported by Benson (1966) but these may have been lost by subsequent solution. Forms transitional between *H. laevigatum* and *H. enthacanthum* are present. *Hexacontium hootsi* Campbell and Clark (1944, p.14, pl.2, fig.5) which is distinguished by deeply set, fairly well spaced pores in "thick, ridged subhexagonal meshwork with tall funnels" is probably conspecific.

Recorded range: Miocene (Campbell and Clark, 1944) to Recent.

Observed range: Tabulated in four forms. *H. laevigatum sensu stricto* occurs in 51% of the radiolarian-bearing samples throughout the Late Neogene. More common in Tongaporutuan Wairarapa sections than those of a similar age in Hawkes Bay (e.g. absent from Hangaroa). The "oval" form is found in 14 Tongaporutuan samples and two Pleistocene (WA02, WA03) and is normally associated with *H. laevigatum sensu stricto*. The "quadrate" form is restricted to late Tongaporutuan samples. The "long-spined" form has sporadic occurrences throughout the Late Neogene. The latter three forms (especially the "quadrate" and "long-spined" forms) make up higher percentages of *H. laevigatum* populations in the Tongaporutuan than in Plio/Pleistocene samples. Forms transitional between *H. laevigatum* and *H. enthacanthum* occur in 30% of the radiolarian-bearing samples studied and are normally found in association with at least one of the two species.

Genus *Thecosphaera* Haeckel 1881

Actinommidae with a cortical shell without radial spines and two medullary shells.

Type-species: *Thecosphaera tripodictyon* Haeckel 1887

Thecosphaera cf. *akitaensis* Nakaseko

Plate 5, figure 9

Thecosphaera akitaensis Nakaseko 1971, p.63, pl.1, figs.4a,b.

Description: Rare forms with three concentric lattice shells and a distinctive very thick, very rough cortical surface. Cortical pores subcircular to circular, subregularly arranged, subuniform in size. Outer medullary about one-third diameter of cortical.

Dimensions: Based on four specimens. Diameter of cortical shell 85-104.

Remarks: Tentatively placed in this species because of the smaller size of the forms studied than those described by Nakaseko (1971). Other features are very similar.

Recorded range: Middle Miocene to middle Pliocene (Nakaseko, 1971, Japan).

Observed range: Found sporadically up to the FAD of *G. crassula* at Waiatai. Too rare to be of use biostratigraphically.

Thecosphaera grecoi Vinassa de Regny group

Plate 5, figure 10: Plate 6, figure 1

Thecosphaera grecoi Vinassa de Regny 1900, p.568, pl.1, fig.8.

Thecosphaera miocenica Nakaseko 1959b, p.7, pl.2, fig.3.

Thecosphaera grecoi Vinassa de Regny: Riedel, Sanfilippo and Cita 1974, p.707, pl.56, fig.3, pl.62, figs.2-4.

Actinomma spp. Nigrini and Lombardi 1984, p.S13, pl.2, figs.1a-c (only).

Description: Shell consists of three concentric lattice shells. Cortical shell moderately thick with 15 to 20 pores on the half equator, pores circular, regular in arrangement, uniform in shape and size and sometimes with hexagonal frames. Outer medullary about one-third the

diameter of the cortical shell, subspherical, connected to cortical by 10 or more radial spines. Inner medullary, subspherical to subellipsoidal, 0.15 the diameter of the cortical shell.

Dimensions: Based on ten specimens. Diameter of cortical shell 85-150.

Remarks: This group covers all specimens with a cortical/outer medullary shell ratio of 1/0.4 or less; with cortical pores exhibiting a regular size, shape and pattern. The cortical wall may be smooth or show a distinct hexagonal frame around each pore and this feature appears to be dependent on degree of dissolution in a sample. Nakaseko (1971) described eight members of this genus. The variation and intergradation of forms seen in the samples studied indicates that *Thecosphaera dedoensis* and *T. japonica*, both described by Nakaseko (1971), would be included in this group. *Thecosphaera radians* Hollande and Enjume (as illustrated by Dumitrica, 1973, pl.5, figs.5,6, pl.6, fig.3) is also possibly conspecific.

Recorded range: Early Miocene to Pliocene (Nakaseko, 1971, Japan).

Riedel, Sanfilippo and Cita (1974) described forms from the Sicilian Lower Pliocene.

Dumitrica (1973) illustrates forms from the Quaternary.

Nakaseko and Sugano (1973) used the first occurrence of *Thecosphaera japonica* to define the base of the *Thecosphaera japonica* Zone, the youngest of four radiolarian zones established for Neogene formations in Japan. Sakai (1980) found the base of *T. japonica* occurred at the base of the *Stichocorys peregrina* Zone (DSDP Site 436).

Observed range: Present in 79% of radiolarian-bearing samples (includes a relatively high number of uncertain identifications) throughout the Late Neogene.

Genus *Prunulum* Haeckel 1887

Actinommidae with three or more ellipsoidal concentric, lattice shells without radial spines or tubules; network regular.

Type-species: *Prunulum coccymelium* Haeckel 1887 : designated by Campbell 1954

Prunulum spp.

Plate 5, figure 11: Plate 6, figures 2-4

Description: Shell consists of four concentric lattice shells, outer two ellipsoidal (rarely spherical); inner two subspherical to subellipsoidal. Outer shell generally has circular to subcircular pores in a subregular arrangement. Each concentric shell is connected by numerous radial beams; the distance between each shell being subequal. Specimens with only three concentric shells and with numerous short radial beams on the surface (commonly clustered at each pole) are common.

Dimensions: Based on ten specimens. Length of outer shell 65-150. Breadth of outer shell 54-135.

Remarks: Generally two forms are represented; a delicate form with irregular pores and a more robust form with more regular pores. Some forms included in this group may be members of the genus *Sphaeropyle* but have an indistinct pylome.

Observed range: Present in 68% of the radiolarian-bearing samples studied throughout the Late Neogene. Tends to be slightly more sporadic in the Plio-Pleistocene.

Genus *Styptosphaera* Haeckel 1881

Actinommidae with a spherical spongy framework. No medullary shell.

Type-species: *Styptosphaera spumacea* Haeckel 1887.

Styptosphaera stupacea Haeckel

Plate 5, figure 12

Styptosphaera stupacea Haeckel 1887, p.87.

Description: Spherical skeleton consisting of a loose spongy meshwork with roundish meshes, pore size up to seven times the width of the bars; bar thickness regular. Surface rough with short thornlike spines.

Dimensions: Based on two specimens. Diameter of shell 213-241.

Remarks: Differs from *S. spumacea* in its rough surface and smaller size.

Observed range: Rare throughout the Late Neogene.

Geographic distribution: South Pacific (Haeckel, 1887).

Styptosphaera spumacea Haeckel

Plate 5, figure 13

Styptosphaera spumacea Haeckel 1887, p.87.

Styptosphaera (?) *spumacea* Haeckel: Nigrini and Lombardi 1984, p.337, pl.5, fig.3.

Description: Very similar to *Styptosphaera stupacea* but differs in having a smooth surface.

Dimensions: Based on ten specimens. Diameter of shell 141-173.

Remarks: Haeckel's (1887) shell diameter is almost twice that of the specimens described herein. Nigrini (1970) described species about the same size as those found here and questionably placed her forms in this species. Nigrini and Lombardi (1984) report larger specimens in Miocene sediments, almost approaching the size of Haeckel's forms. It appears there is a considerable size variation in this species. Forms tentatively assigned to *S. spumacea* by Nigrini and Moore (1979, p.571) are a lot smaller than those described by Haeckel (1887).

Observed range: Occurs sporadically in samples younger than the LAD of *G. dehiscens*. Too rare to be of use biostratigraphically.

Geographic distribution: "belongs to a subarctic assemblage" (Nigrini, 1970, north Pacific).

"This species loads heavily in factor 3 (transitional). At present this species is most abundant in a band between 37°N and 45°N" (Robertson, 1975, northwest Pacific).

"Present in all samples between about 37°S and 46°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Notes on the Stylosphaerids

The problems with generic placement of the stylosphaerids within the Actinommidae are discussed by Nigrini and Lombardi (1984). Parts of their discussion are reproduced here to outline the problem. There are a number of described genera having the following generalised definition; up to four concentric lattice shells, either ellipsoidal or spherical. The shells are connected by radial beams which may be arranged in a set pattern or may be randomly placed. There are two opposite polar spines which may be three-bladed or cylindrical, similar or dissimilar, of equal or unequal length. The cortical shell is perforated by some number of similar or dissimilar pores and may be smooth or thorny. To accommodate species of this general form Haeckel (1887) lists a number of genera and subgenera in three different families. Riedel (1967a) and Petrushevskaya (1975) placed all the forms in one family. Petrushevskaya (1975) combined many of Haeckel's genera into three genera. While this simplification has advantages, it has the disadvantage that her generic definitions do not always conform with the illustrations of the type species of the genus. A complete taxonomic revision of these forms is apparently needed but in the absence of such a study the forms described herein all have the generic assignment placed in quotation marks indicating my uncertainty regarding the generic position of the species.

Genus *Stylatractus* Haeckel 1887

Actinommidae with an ellipsoidal lattice cortical shell and double medullary shell. Two opposite similar polar spines.

Type-species: *Stylatractus neptunus* Haeckel 1887 : designated by Campbell 1954

Note: *Amphisphaera* Haeckel (1882) has the same genotype designated by Campbell (1954) under the name *Amphisphaera neptunus* Haeckel 1887 (pl.17, fig.6).

"*Stylatractus*" *neptunus* Haeckel *forma* large pores

Plate 6, figure 6: Plate 7, figures 1-4

Stylatractus neptunus Haeckel 1887, p.328, pl.17. fig.6 (in part).

Stylatractus neptunus Haeckel: Riedel 1958, p.226, pl.1, fig.9.

Amphisphaera sp. aff. *Stylatractus neptunus* Haeckel: Petrushevskaya 1975, p.570, pl.28, fig.5 (only).

Stylatractus neptunus Haeckel: Keany 1979, p.53, pl.2, fig.2 (only).

Description: Shell consists of 3 concentric lattice shells with two polar spines. Medullary shell spherical. Inner cortical shell subspherical to subellipsoidal, with 7-8 circular pores on the half equator; connected to the medullary shell by a number of radial beams. Outermost (cortical) shell ellipsoidal, moderately thick walled, thorny with 7-8 circular to subcircular pores on the half equator, connected to the middle shell by numerous radial beams. Pores normally 2-3 times as broad as the intervening bars. Polar spines heavy, usually three-bladed. Rare teratological specimens observed with two diverging spines at one end. Polar spines normally equal in length, occasionally with the longer being 1.25 to 2 times as long as the other.

Dimensions: Based on ten specimens. Diameter of inner shell 23-28. Length of middle shell 68-81: of cortical shell 107-142: of longest spine 48-103: of shortest spine 33-65. Breadth of cortical shell 98-129.

Remarks: This form differs from that illustrated by Haeckel (1887, pl.17, fig.6) which has 12 pores on the half equator. Riedel (1958) included both forms his species definition ("7-16 pores on half equator"). Petrushevskaya (1967) suggested the pores overgrow ontogenetically. No examples of the small pored form were found in the sediments studied suggesting the two forms are in fact different species with differing ecological niches. Specimens with only two lattice shells and numerous short spines projecting from the surface are often seen. They are presumed to be representatives of this species with the cortical shell missing. This is supported by their dimensions and that the double shelled forms often exhibit small thorns on the polar spines where the cortical shell would expect to be connected.

Recorded range: Neogene (Keany, 1979). Quaternary (Petrushevskaya, 1975).

Observed range: Relatively common throughout the Late Neogene.

"Stylatractus" universus Hays

Plate 6, figure 9: Plate 7, figures 5,6

Stylosphaera angelina Campbell and Clark 1944, p.12, pl.1, figs.14-20.

Stylatractus sp. Hays 1965, p.167, pl.1, fig.6.

Stylatractus universus Hays 1970, p.215, pl.1, figs.1,2.

Axoprunum angelinum (Campbell and Clark): Kling 1973, p.634, pl.1, figs.13-16, pl.6, figs.16-17 (only).

Axoprunum angelinum (Campbell and Clark): Weaver, Casey and Perez 1981, pl.3, figs.3,4.

Stylatracta universa Hays: Keany and Kennett 1975, pl.1, fig.1.

Stylosphaera sp. Bjorklund 1976, pl.14, fig.15,16.

Axoprunum angelinum (Campbell and Clark): Sakai 1980, p.704, pl.2, figs.1a,b.

"*Stylatractus universus*" Hays: Nigrini and Lombardi 1984, p.S29, pl.4, fig.3.

Description: Skeleton consists of one subspherical cortical shell (at least three times larger than the outer medullary) and two subspherical medullary shells. Medullary shells thin walled with pores regular to irregular in size and shape. Cortical shell wall thick: pores subcircular with two types of wall found: (a) normally has 14-16 pores on a half equator, pores of equal size, hexagonally framed with small thorns projecting from the intersections of the frames and, (b) normally has 10-11 pores on a half equator, pores unequal size and not regularly patterned. Transitional forms are common. Outer medullary shell connected to cortical by stout radial beams, two lying along the major axis project through the cortical shell as stout, polar, cylindro-conical spines. Some of the other beams rarely penetrate the cortical shell and form short spines. The nearly equal polar spines are normally as long as to half as long as the major axis of cortical shell.

Dimensions: Based on 40 specimens. Diameter of innermost shell 15-20: of second shell 40-50: of cortical shell (minor axis) 103-125 (major axis) 103-131. Length of spines 86-114 (Hays, 1965).

Remarks: Nigrini and Lombardi (1984, p.27) outline the *Stylatractus universus* - *Axoprunum angelinum* problem which typifies the generic/specific definitions of many members of the stylosphaerids.

Recorded range: Morley and Shackleton (1978) find that *Stylatractus universus* becomes extinct within the transition zone between oxygen-isotope stages 12 and 11 (approximately 0.425 Ma) in two deep-sea cores in the mid- and low-latitude Atlantic. Its upper limit is used in the Antarctic to mark the boundary between the Ω and Ψ Zones. The age of this boundary is estimated to be 0.4 Ma (within the Brunhes Normal Epoch). In the North Pacific the mean age of the upper limit of this species is about 0.4 Ma. In four equatorial Pacific cores an average age for its disappearance is estimated to be 0.341 Ma (Hays, 1970).

Observed range: Tabulated in two forms. The "small pored" variety is found sporadically throughout the Late Neogene. The "large pored" form has a similar age range and is slightly more common overall. There is a tendency to the "small pored" form to be more common in the Pleistocene.

Geographic distribution: "Present throughout the Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombardi, 1984, CENOP Project).

Genus *Sphaerostylus* Haeckel 1881

Actinommidae with two concentric lattice shells and two free polar spines which are different in size and form.

Type-species: *Sphaerostylus zittelii* Rust 1885

"*Sphaerostylus*" sp. aff. *timmsi* (Campbell and Clark)

Plate 6, figures 8,10: Plate 7, figures 8-10

(?) *Lithatractus timmsi* Campbell and Clark 1944, p.18, pl.2, figs.18-19.

(?) Actinommid gen. et sp. indet. Sanfilippo and Riedel 1973. pl.25, fig.11.

(?) *Stylosphaera coronata coronata* Ehrenberg: Chen 1975, p.455, pl.5, figs.1,2. (plates under *Stylosphaera*)

non: *Stylosphaera coronata* Ehrenberg 1873, p.258: 1875, pl.25, fig.4.

Lithatractus timmsi Campbell and Clark: Weaver, Casey and Perez 1981, pl.4, figs.3,4.

Description: Shell consists of a medullary and cortical lattice shell with one major spine and a number of smaller spines clustered on the opposite half of the cortical shell. Medullary shell subspherical connected to the cortical by up to eight radial beams which pierce the cortical shell. Cortical shell thick, subcircular to slightly "balloon-shaped" with the major spine rising from the apex of the "balloon" in the latter forms. Cortical pores subcircular, usually hexagonally framed and subhexagonally arranged, 13 to 17 on the half equator. Major spine three-bladed, rarely cylindrical, 1.25 to 2 times the diameter of the cortical shell. Minor spines variable in length up to 0.5 the diameter of the cortical shell, up to eight projecting from the half of the cortical shell which is distal from the major spine. Minor spines, three-bladed commonly broken at base leaving normally 2-4. Normally one of the minor spines is directly opposite the major spine but some specimens shown no sign of one being in this position. Rare small thornlike spines may project from the cortical shell. Teratological forms with a double major spine occur rarely.

Dimensions: Based on 16 specimens. Diameter of medullary shell 20-25: of cortical shell 74-93. Length of major spine 78-125: of minor spines 25-42.

Remarks: Campbell and Clark (1944) state that in their specimen "one polar spine was broken off near the base but assumed to be a duplicate of the other". The Oligocene/Eocene forms illustrated by Riedel and Sanfilippo (1973) and Chen (1975) are slightly thicker walled and have less pores and are both related to *Stylosphaera coronata* Ehrenberg. They could be ancestors of the form described herein. Sanfilippo, Caulet and Riedel (1978, p.757, pl.1, fig.10) illustrate forms from the Middle Miocene DSDP Leg42A (Mediterranean) under the name *Stauroxiphus communis* Carnevale (1908), which differ from those described by Carnevale in having a pear-shaped medullary shell and more than three radial bars prolonged as short spines. The latter feature makes them partially synonymous with the species described herein.

Recorded range: Morphologic top of *L. timmsi* near the Epoch 6/5 boundary (Weaver, Casey and Perez, 1981, California).

Observed range: Common in Miocene samples, being more sporadic in Plio-Pleistocene samples. Highest occurrence is in sample WA03 (Waiatai). Replaced in Plio-Pleistocene sediments by a more "symmetrical" form with heavier by-spines, which is found in Cricklewood, Tahaenui-Kohukohu, Waihua, and Waiatai, with its lowest common occurrence in TK05, which contains *C. molestus* and is near the top of the Waipipian, about 50m below the FAD of dextral *G. crassaformis*. There is one identification of this "symmetrical" form in the Miocene (RM06: see Plate 7, figure 10).

Genus *Xiphatractus* Haeckel 1887
emended herein

Actinommidae with an ellipsoidal lattice cortical shell and double medullary shell; two opposite polar spines of unequal length. Emended herein to include forms with a spherical cortical shell.

Type-species: *Xiphatractus armadillo* Haeckel 1887 : designated by Campbell 1954

"Xiphatractus" sp. A
Plate 6, figures 5,7: Plate 7, figure 7

Axoprunum angelinum (Campbell and Clark): Kling 1973, p.634, pl.6, figs.14,15,18 (only).

Stylosphaera angelina Campbell and Clark: Riedel, Sanfilippo and Cita 1974, pl.56, fig.2.

Stylosphaera angelina Campbell and Clark: Riedel and Sanfilippo 1978a, p.108, pl.3, figs.1-3.

Description: Very similar to small pored forms of "*Stylatractus*" *universus*, the only difference being the length of the polar spines. In these forms the ratio of lengths of the two polar spines is 1:2 or greater. Forms with ratios less than this were placed in "*S.*" *universus*.

Dimensions: Same as "*S.*" *universus* except the ratio of lengths of the two polar spines is 1:2 or greater.

Recorded range: Probably included in populations of "*Stylatractus*" *universus* by most authors. The forms illustrated by Riedel and Sanfilippo (1978a) and Riedel, Sanfilippo and Cita (1974) are from the Sicilian Lower Pliocene.

Observed range: Sporadic throughout the Late Neogene. Similar age distribution to *S. universus* to which it is probably related.

Geographic distribution: See "*Stylatractus*" *universus*.

Genus *Prunopyle* Dreyer 1889

Actinommidae with two or more ellipsoidal lattice shells; the outermost shell at least has a large pylome.

Type-species: *Prunopyle pyriformis* Dreyer 1889 : designated by Campbell 1954

? *Prunopyle antarctica* Dreyer

Plate 9, figures 4,10

? *Prunopyle antarctica* Dreyer 1889, p.24, pl.5, fig.75.

? *Prunopyle antarctica* Dreyer: Riedel 1958, p.225, pl.1, figs.7,8.

? *Echinomma antarctica* (Dreyer)?: Dumitrica 1973, p.832, pl.21, fig.1 (only).

? *Prunopyle antarctica* Dreyer: Chen 1975, p.454, pl.23, figs.5,6.

Description: Shell ovate with small circular to subcircular subhexagonally arranged pores in a thick shell. Shell surface rough with a bunch of strong three-bladed spines surrounding a pylome and a bunch of smaller, three-bladed spines projecting from the opposite pole. Internal structure consists of a loose concentric spongy network similar to *Prunopyle* sp. A and *Spongurus* sp. A.

Dimensions: Based on three specimens. Length of cortical shell 137-144. Breadth of cortical shell 116-122. Maximum length of polar spines 29-33.

Remarks: The taxonomic relationship between forms with a bunch of spines at each pole seen under SEM imagery to those seen in transmitted light, which are similar to heavily spinose forms of *Spongurus* sp. A, is uncertain.

Recorded range: Pleistocene to Recent (Chen, 1975).

Observed range: Sporadic throughout the upper Neogene but slightly more common in Plio-Pleistocene sediments.

Geographic distribution: "No form resembling *P. antarctica* has been found in the tropical parts of the Pacific and Indian Oceans. Thus this species may possibly be restricted to high northern and southern latitudes." Riedel (1958).

Prunopyle sp. A

Plate 7, figures 11,14: Plate 8, figures 3,4

Description: All forms with a "loose" internal concentric shell layering and a distinct pylome on the outermost shell included in this species. Shell outline is commonly elliptical.

Dimensions: Based on three specimens. Length 108-125. Breadth 74-78.

Remarks: Forms intermediate between *Spongurus* sp. A and *Prunopyle* sp. A are present. The forms present here may be related to the forms assigned to *Prunopyle titan* Campbell and Clark as described by Hays (1965, p.173, pl.2, fig.4), Chen (1975, p.454, pl.23, figs.1,2), and Weaver (1976a, p.100, pl.9, fig.3) which show a loose, sometimes spiralled, internal structure. Campbell and Clark (1944) described and illustrated *P. titan* as lacking an inner concentric medullary shell.

Observed range: Found sporadically throughout the upper Neogene but slightly more common in Miocene sediments. This range pattern is the opposite of *P. antarctica*.

Genus *Spongurus* Haeckel 1860b

Actinommidae with a spongy ellipsoidal or cylindrical shell without equatorial strictures; lacking an internal latticed medullary shell; without polar spines or lattice mantle but the surface armed with radial spines.

Type-species: *Spongurus cylindricus* Haeckel 1862

Spongurus pylomaticus Riedel

Plate 9, figures 2,5

Spongurus pylomaticus Riedel 1958, p.226, pl.1, figs.10,11.

Spongurus (?) *pylomaticus* Riedel: Petrushevskaya 1975, p.577, pl.7, fig.4.

Spongurus pylomaticus Riedel: Ling *et al.* 1971, p.711, pl.1, fig.5.

Spongurus pylomaticus Riedel: Keany 1979, p.54, pl.2, fig.11.

Spongurus pylomaticus Riedel: Nigrini and Moore 1979, p.565, pl.8, figs.3a,b.

Description: Shell subcylindrical or elongate ellipsoidal, approximately twice as long as broad. An inner spongy core is surrounded by a narrow mantle of less dense meshwork which varies from being finely to sparsely perforate, the sparsely perforate forms have large pores. At one pole is a pylome surrounded by short irregular teeth and short thornlike spines are usually present at the opposite end.

Dimensions: Based on four specimens. Length of shell 136-142. Maximum breadth of shell 71-75.

Remarks: These specimens are smaller than those described by Riedel (1958) and Ling *et al.* (1971) from the Antarctic and Bering Seas respectively.

Recorded range: Neogene (Keany, 1979). Pliocene to Recent (Petrushevskaya 1975).

Observed range: Sporadic occurrences throughout Late Neogene. Not many positive identifications as a lot are specimens which tend to be variants of a more common *Spongurus* sp. A population.

Geographic distribution: "cold-water and bipolar" (Ling *et al.*, 1971).

Spongurus sp. A

Plate 8, figures 1,2: Plate 9, figures 1,3

Description: Similar to *Spongurus pylomaticus* but differs in two respects. The shell outline is definitely elliptical and the inner spongy meshwork is looser with a concentricity commonly visible in optical section.

Dimensions: Based on six specimens. Length 137-185, width 112-133.

Remarks: Similar to *Spongurus* (?) sp. A of Nigrini and Lombardi (1984, p.333) but the concentricity is a lot tighter in their figured specimens. As with their specimens it is hard to determine whether the internal structure is trizonal or concentric. The internal structure is very similar to those found in *Prunopyle* sp. A.

Observed range: Present in 62% of the radiolarian-bearing samples studied. Tends to be more common in the Miocene.

Genus *Spongocore* Haeckel 1887

emended herein

Actinommidae with an ellipsoidal or cylindrical (sometimes three jointed) shell of solid spongy framework, without internal cavity and without latticed medullary shell. Polar spines absent. An outer lattice-mantle is connected with the spongy shell by radial beams. Emended herein to include forms without the lattice-mantle preserved.

Type-species: *Spongocore velata* Haeckel 1887 : designated by Campbell 1954 (under *S. vellata*)

Spongocore puella Haeckel

Plate 8, figures 5,6: Plate 9, figures 6-8

Spongocore puella Haeckel 1887, p.347, pl.48, fig.6.

Spongocore lata Campbell and Clark 1944, p.22, pl.3, figs.5-6.

Spongocore puer Campbell and Clark 1944, p.22, pl.3, figs.7-9.

Spongurus cylindricus Haeckel: Dumitrica 1973, p.834, pl.11, fig.2 (only).

Spongocore puella Haeckel: Kling 1973, p.635, pl.7, figs.18-22.

Spongocore diplocylindrica Haeckel: Renz 1974, pl.15, fig.4.

Spongocore puella Haeckel: Nigrini and Moore, 1979, p.569, pl.8, figs.5a-c.

Spongocore puella Haeckel: Johnson and Nigrini 1980, pl.1, fig.22.

Description: Test cylindrical, opaque, spongy, with three joints separated by two constrictions. The middle joint normally 1 to 2 times the length of the terminal joints. Numerous, thin, conical, radial stubs may arise from the surface of all three joints. Rarely the middle joint and proximal halves of the terminal joints are covered by a relatively smooth, thin walled, lattice-mantle bearing small, irregularly arranged subcircular pores; mantle supported by numerous radial spines that arise from the middle joint. In some specimens the skeleton is bent at one of the constrictions.

Dimensions: Based on 30 specimens. Length of skeleton 188-363: diameter of middle joint 37-71: of terminal joints 30-68. Length of lattice mantle 123-191: of radial spines 2-25. Maximum breadth 74-111 (Benson, 1966).

Remarks: Benson (1966) and Dumitrica (1973) noted that the skeleton, although appearing spongy actually consists of closely spaced concentric shells (at least on the middle joints). Petrushevskaya (1975) synonymised *Spongocore* with *Ommatogramma* for this reason. No sign of any layering in the arms could be seen in any of the specimens studied although one specimen showed a regularity in the pore structure under SEM imagery which could indicate a regularity in chamber arrangement internally.

Recorded range: Miocene *Calocyclus* Zone (from Kling, 1973) to Recent.

Observed range: Present in 67% of the radiolarian-bearing samples studied throughout the Late Neogene.

Geographic distribution: "Belongs to a tropical assemblage derived by recurrent group analysis of North Pacific sediments, but the species ranges too far north to be useful in downcore analysis" Nigrini (1970).

Spongocore sp. A

Plate 9, figure 9

? *Spongolena* sp. Renz 1974, pl.15, fig.5.

Description: Rare specimens very similar to *Spongocore puella* with long middle joints (five times the length of the terminal joints).

Recorded range: Renz (1974) recorded her specimen from the Quaternary of DSDP Site 262.

Observed range: Very rare occurrences in Wairarapa and Leader River Tongaporutuan samples. Too rare to be of use biostratigraphically.

Family **Phacodiscidae** Haeckel 1881

Discoidal, biconvex to flat skeletons with a latticed outer shell which separates them from other discoidal families.

Genus *Heliodiscus* Haeckel 1882

emended Nigrini 1967

Phacodiscidae with a simple or double medullary shell and with numerous (7 to 20 or more) simple radial spines on the margin of the disc. Spines variable in number and irregularly disposed. The definition of the genus was emended by Nigrini (1967) to include forms having a double medullary shell and as few as seven radial spines.

Type-species: *Heliodiscus inchoatus* Rust 1885

Heliodiscus asteriscus Haeckel

Plate 8, figures 7,9; Plate 9, figures 11-13

Heliodiscus asteriscus Haeckel 1887, p.455, pl.33, fig.8.

Heliodiscus asteriscus Haeckel: Hays 1965, p.171, pl.2, fig.7.

Heliodiscus sp. A: Petrushevskaya 1975, p.576, pl.1, fig.16.

Heliodiscus asteriscus Haeckel: Weaver 1976a, p.107, pl.6, figs.9,10.

Heliodiscus asteriscus Haeckel: Nigrini and Lombardi 1984, p.339, pl.5, fig.4.

Description: Cortical shell forms a discoidal biconvex lens. Pores circular to subcircular, sometimes hexagonally framed, fairly regularly arranged over most of the smooth shell surface, more irregularly arranged near the centre of the disc; 7-12 pores on a radius. Medullary shell spherical to ellipsoidal with diameter approximately one-third that of the cortical shell, pores approximately same size as those on cortical; attached to the cortical shell by small bars. Inner medullary shell occasionally visible, always attached eccentrically to the inner wall of the outer medullary. Radial spines (10 to 16), sometimes well developed, straight, three-bladed near disc, becoming cylindrical distally, placed more or less regularly around margin of the cortical shell. Spine length up to one-third diameter of cortical shell. Usually a few short slender marginal by-spines present. No marginal girdle or by-spines on the cortical surface.

Dimensions: Based on 20 specimens. Average diameter of cortical shell 140.

Remarks: Some forms approach *H. echiniscus* Haeckel (Plate 9, figure 14), a form with numerous by-spines some of which can be present on the cortical shell near the equatorial line. *H. echiniscus* is considered by some to be a morphologic variant of *H. asteriscus* (Morley, 1977).

Recorded range: Late Miocene and Pliocene (Weaver, 1976a).

Miocene both in temperate and tropical sectors (Nigrini and Lombardi, 1984, CENOP Project). Recent (Nigrini and Moore, 1979).

Observed range: Three forms tabulated. The "large pored" form (Plate 9, figure 13) is restricted to the late Tongaporutuan, occurring in 30 upper Tongaporutuan samples in both Hawkes Bay and Wairarapa. The "small pored" form (Plate 9, figure 12) occurs in 65% of the radiolarian-bearing samples throughout the Late Neogene but is rare in Plio-Pleistocene sediments. The "long spined" form has one tentative Miocene identification in MS04, and nine positive Plio-Pleistocene identifications. Although rare, it appears to evolve from the "small pored" form in the early Pliocene. Also twelve Tongaporutuan samples contain rare forms attributed to *H. cf. echiniscus*.

Geographic distribution: Absent south of the Polar Front (Hays, 1965).

Absent south of 46°S (Morley, 1977, south Atlantic).

Heliodiscus umbonatum (Ehrenberg)

Plate 9, figure 15

Haliomma umbonatum Ehrenberg 1873, p.236: 1875, pl.27, fig.4.

Heliodiscus cingillum Haeckel 1887, p.448, pl.33, fig.7 (in part).

Periphaena decora Ehrenberg: Sanfilippo and Riedel 1973, p.523, pl.27, fig.5 (only).

Description: Same as *Heliodiscus asteriscus* but with smaller pores (12 to 16 on the cortical radius). Well developed hyaline marginal girdle from which flat triangular spines arise.

Remarks: Nigrini and Lombardi (1984, p.339) mention an early Miocene form of *H. asteriscus* similar to the form described herein.

Recorded range: Mid *Buryella clinata* Zone to near top of *Thyrsoyrtis bromia* Zone (Eocene and lowermost Oligocene) (Sanfilippo and Riedel, 1973).

Observed range: Found only in the two oldest samples studied: KB04 (Kaiti) and LT09 (Leader).

Family *Coccodiscidae* Haeckel 1862
emended Sanfilippo and Riedel 1980

Discoidal forms consisting of a lenticular cortical shell enclosing a small single or double medullary shell, and surrounded by an equatorial zone of spongy or concentrically-chambered structure, OR forms with ellipsoidal cortical shell, usually equatorially constricted, and enclosing a single or double medullary shell, the opposite poles of the shell generally bearing spongy columns and/or single or multiple latticed caps.

Genus *Didymocyrtis* Haeckel 1860a
emended herein

Coccodiscidae with an ellipsoidal cortical shell, normally equatorially constricted in all but the earliest forms. Extra-cortical caps, when present, never more than two or three on each pole. Outer medullary shell commonly lenticular (Sanfilippo and Riedel, 1980). Emended herein to include nonconstricted Late Miocene forms.

Type-species: *Haliomma didymocyrtis* Haeckel 1862 : illustrated under the invalid name *Didymocyrtis ceratospiris*.

Didymocyrtis antepenultima (Riedel and Sanfilippo)
Plate 10, figure 5

Panarium antepenultimum, conditional manuscript name proposed by Riedel and Funnell 1964, p.311.

Ommatartus antepenultimus Riedel and Sanfilippo 1970, p.521, pl.14, fig.4.

Ommatartus antepenultimus Riedel and Sanfilippo: Riedel and Sanfilippo 1971, p.1588, pl.1c, fig.11 (only).

Ommatartus antepenultimus Riedel and Sanfilippo: Westberg and Riedel 1978, pl.2, figs.4,5.

Ommatartus antepenultimus Riedel and Sanfilippo: Sakai 1980, p.708, pl.3, figs.6a-b.

Didymocyrtis antepenultima (Riedel and Sanfilippo): Nigrini and Lombardi 1984, p.555, pl.7, figs.2a,b.

Description: Cortical twin shell slightly constricted equatorially, with circular to subcircular pores. Distal chambers lenticular-hemispherical, as caps on either end of cortical twin shell. The proportion of the height of the polar cap to the length of the cortical shell is between 0.20 and 0.25 (Westberg and Riedel, 1978). Inner medullary shell

spherical and outer medullary spherical to slightly compressed.

Dimensions: Based on four specimens. Length of cortical shell 90-120. Maximum breadth of cortical shell 85-105. Breadth of outer medullary shell 27-32.

Remarks: Some of the forms included herein did not have the spongy columns on the caps preserved. The forms placed into this species adhere to the ratio of height of polar cap to length of cortical shell restriction outlined by Westberg and Riedel (1978).

Recorded range: Riedel and Sanfilippo (1970, *Ommatartus antepenultimus*) showed the evolutionary transition from *D. laticonus* to *D. antepenultima* to lie at the base of the *Didymocyrtis antepenultima* Zone and they show the evolutionary transition from *D. antepenultima* to *D. penultima* to lie within the *Didymocyrtis penultima* Zone (Late Miocene). Later (1978b), they altered the definition of this zone to the range of *Diartus hughesi* because of the problem in defining cap height, especially in poorly preserved specimens.

Reynolds (1980, *Ommatartus antepenultimus*, western North Pacific), defines the *Didymocyrtis antepenultima* Zone by the range of *D. antepenultima* subsequent to its transition from *D. laticonus* and prior to its transition to *D. penultima*.

Theyer *et al.* (1978, *Ommatartus antepenultimus*) dated the first occurrence of *D. antepenultima* at 11.4 Ma and the last occurrence at 5.7 Ma.

Observed range: Found associated with *G. dehiscens* at Kaiti, Wairarapa (SWR4, MS19), and Leader, and is found sporadically in Tongaporutuan samples. Last appearance is at the Miocene/Pliocene boundary unconformity at Mangapoike in sediments containing a tuff dated 5.80 ± 0.55 Ma, this age being supported by magnetostratigraphy (I.C. Wright, pers. comm.). Not associated with *G. sphericomiozea*. Five samples in the Wairarapa and Leader Miocene contain forms transitional between *D. laticonus* and *D. antepenultima*.

Geographic distribution: "Abundant in all tropical Late Miocene sections examined" (Nigrini and Lombari, 1984, CENOP Project).

Didymocyrtis laticonus (Riedel)

Plate 10, figure 1: Plate 11, figure 1

Cannartus laticonus Riedel 1959, p.291, pl.1, fig.5.

Cannartus laticonus Riedel: Riedel and Sanfilippo 1971, pl.1c, figs.13,14.

Cannartus laticonus Riedel: Sakai 1980, p.705, pl.3, figs.7a-b, 8a-b.

Didymocyrtis laticonus (Riedel): Sanfilippo and Riedel 1980, p.1009, text-fig.1e.

Didymocyrtis laticonus (Riedel): Nigrini and Lombari 1984, p.S53, pl.7, figs.1a-c.

Description: Cortical twin shell, with subcircular to circular pores, 10 to 15 on the half equator. On the broader parts of the shell, on either side of the equatorial constriction are moundlike protuberances, at which the shell wall is thickened. At each pole of the shell arises a broadly subconical, densely spongy column, which is almost as broad at its base as the polar surface of the twin shell. There are no pronounced caps as in *D. antepenultima* but a parallel sided clear zone is sometimes present separating the cortical shell from the columns. An extra-cortical, small pored, plate perforate wall is sometimes partially preserved.

Dimensions: Based on 20 specimens. Length of polar columns 45-70: of cortical shell 93-125. Median breadth 28-40. Maximum breadth 68-113. Breadth of outer medullary shell 30-35 (Riedel, 1959).

Remarks: Westberg and Riedel (1978: p.20, *Cannartus laticonus*) outlined that the name *D. laticonus* should only be applied to specimens "in which the height of the clear zone below the spongy column is less than 0.2 the length of the cortical shell".

Recorded range: Theyer *et al.* (1978, *Cannartus laticonus*) dated the first occurrence of *D. laticonus* at 13.5 Ma and the last occurrence at 9.6 Ma. In a study of *Didymocyrtis* spp. from DSDP Site 503A in the eastern tropical Pacific, Riedel and Westberg (1982) show that the increase in cap height during most of the upper Miocene and Pliocene is slight, if it exists at all, though above and below this interval the increase through time is pronounced.

Observed range: Found associated with *G. dehiscens* at Kaiti, Mangaopari, and Leader. The LAD of this species is a useful middle Tongaporutuan bioevent. The LAD is well defined in Upper Mangaopari Stream (at MS12) although there is one questionable occurrence in MS05.

Geographic distribution: "Common in all tropical Middle Miocene sections" (Nigrini and Lombardi, 1984, CENOP Project).

Didymocyrtis virgineum (Haeckel)

Plate 8, figure 8: Plate 11, figures 10,11,13,14

Cyphonium virgineum Haeckel 1887, p.363, pl.39, fig.12.

Cannartus sp. Riedel and Sanfilippo 1971, pl.1D, fig.1.

Ommatartus sp. Foreman 1975, pl.8, figs.17,18.

Ommatartus ? sp. Sakai 1980, pl.5, figs.3a-3b.

Description: Twin cortical shell, occasionally with a slight equatorial constriction, each side of which is subhemispherical. Pores circular in a subregular pattern. No polar caps or columns. Outer medullary shell subspherical to lenticular. Some forms have a tuberculate (knobby) surface.

Dimensions: Based on ten specimens. Length of cortical shell 110-139. Maximum breadth of cortical shell 100-114.

Remarks: Some specimens included in this taxa could be poorly preserved specimens (without polar caps or columns) of *Didymocyrtis* sp. A, *D. antepenultima*, or *D. laticonus*.

Observed range: Tabulated into three forms. The "non-constricted" form is common in the Tongaporutuan and very rare in the Plio/Pleistocene. The highest occurrence is at Cricklewood (CR03) in the dextral *G. crassaformis* - *G. crassula* overlap zone. The "constricted" form is not as common as the "non-constricted" but has a similar range, the only Plio/Pleistocene occurrence being between the LAD of *C. molestus* and the FAD of *G. crassula* at Waiatai (WA18). The "tuberculate" form is generally restricted to Miocene sediments but occurs rarely into the Pleistocene.

Didymocyrtis sp. A

Plate 10, figures 2,4; Plate 11, figures 2-9

Cannartiscus marylandicus ? Martin: Bandy, Casey, and Wright 1971, pl.1, fig.5.

Cannartus sp. D Sakai 1980, p.708, pl.5, figs.10a-b (only).

Cannartus laticonus Riedel: Sanfilippo, Burckle *et al.* 1973, pl.1, fig.6 (only).

Ommatartus antepenultimus Riedel and Sanfilippo: Sanfilippo, Burckle *et al.* 1973, pl.1, figs.13,15 (only).

Description: This form is comparable to both *D. laticonus* and *D. antepenultima*. Robust twin-cortical shell, normally without an equatorial constriction and normally with "*D. laticonus* type" clear zones between the cortical shell and spongy column.

Remarks: Sakai (1980) could not separate *Cannartus laticonus* (= *Didymocyrtis laticonus*) and *Ommatartus antepenultimus* (= *Didymocyrtis antepenultima*) stratigraphically because of their morphological continuity and the presence of transitional forms over a long stratigraphic interval. Kling (1978, p.237) also notes transitional forms are present.

Recorded range: Mid *Dorcadospyrus alata* Zone to mid *Stichocorys peregrina* Zone (Sakai, 1980, middle to late Miocene, DSDP Site 436: cores 37-29).

Bandy, Casey, and Wright (1971) have their form dying out in the middle Gilbert.

Observed range: Tabulated into four forms. The most common is the "non-constricted" form, which is persistent throughout the Tongaporutuan. Its highest occurrence is at Millers Road (SMR1) where it is associated with forms approaching *G. inflata* (middle Opoitian). It is rare in basal Opoitian sediments. The "constricted" form is not as abundant and last appears before the FAD of *G. sphericomiozea*. The "spherical" form is found only in four upper Tongaporutuan samples and is too rare to be of biostratigraphic use. The "narrow" form is only in the *Diartus hughesi* Zone.

Didymocyrtis tetralthmus tetralthmus (Haeckel)

Plate 10, figures 6,7; Plate 11, figure 12

Panartus tetralthmus Haeckel 1887, p.378, pl.40, fig.3.

Panartus tetralthmus Haeckel: Nigrini 1967, p.30, pl.2, figs.4a-d.

Ommatartus tetralthmus (Haeckel): Riedel and Sanfilippo 1971, p.1588, pl.1C, figs.5-7.

Ommatartus tetralthmus tetralthmus (Haeckel): Nigrini and Moore 1979, p.S49, pl.6, figs.1a-d.

Didymocyrtis tetralthmus (Haeckel): Sanfilippo and Riedel 1980, text-fig.1g.

Description: Cortical twin-shell, constricted equatorially, with subcircular to subangular pores having no definite arrangement. Surface usually rough, spiny. Polar caps, when present, are hemispherical to conical, approximately the same breadth as the cortical twin-shell, supported by about ten spines. Caps generally more delicate with smaller pores. No spongy columns.

Dimensions: Length of cortical twin-shell 90-136: of polar caps 36-63. Maximum breadth of cortical twin-shell 72-109 (Nigrini, 1967),

Remarks: Differentiated from *D. tetrathalmus coronatus* (Haeckel) by the absence of stout, unbranched, three-bladed spines at the distal ends of the cortical twin-shell and/or polar caps. *Didymocyrtis avitus* (Riedel) which is a transitional form between *D. tetrathalmus tetrathalmus* and *D. penultima* (Riedel) has a tuberculate (knobby) cortical shell.

Recorded range: 4 Ma to present (Casey and Reynolds, 1980).

Observed range: Oldest occurrence is in Wainuioru Valley (SWR1), basal Opoitian. Found sporadically in Plio/Pleistocene sediments.

Geographic distribution: "Abundant in low latitudes, forming up to 29% (usually 9% to 22%) of the described populations. South of 35°S only very few specimens have been observed" (Nigrini, 1967, Indian Ocean).

"absent south of 35°S" (Morley, 1977, south Atlantic).

"Present in all samples except southernmost (about 48°S), abundant in low latitudes but very rare between 37°S and 46°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Genus *Diartus* Sanfilippo and Riedel 1980

Coccodiscidae with the cortical shell generally tending to be subcylindrical, because of the concentration of protuberances in a single ring at each pole. When extra-cortical caps are present, there are often more than two or three on a pole. Outer medullary shell commonly spherical.

Type-species: *Ommatacampe hughesi* Campbell and Clark 1944

Diartus hughesi (Campbell and Clark) group

Plate 9, figures 16,17: Plate 10, figure 3

Ommatacampe hughesi Campbell and Clark 1944, p.23, pl.3, fig.12.

Ommatartus hughesi (Campbell and Clark): Riedel and Sanfilippo 1970, p.521.

Amphymenium challengerii Weaver 1976a, p.104, pl.8, figs.4,5.

Diartus hughesi (Campbell and Clark): Sanfilippo and Riedel 1980, p.1009, text-fig.1i.

Diartus hughesi (Campbell and Clark): Nigrini and Lombardi 1984, p.543, pl.6, fig.2.

Description: Shell with cylindrical centre and seven to nine chambers at each end; in most specimens the central cortical section is partially obscured by a raised patagium enveloping the central section but it appears to be about 0.2 total length; peripheral cortical shell increases in breadth distally with seven to nine chambers on each opposite pole; these chambers slightly kidney shaped especially towards distal end. Pores generally subspherical and increasing in size distally. Distal most chamber on each end has two or three projecting spines, two of which (one on either pole) appear to arise from near the central cortical section.

Dimensions: Based on four specimens. Total length 200. Maximum breadth (across peripheral arm) 51. Minimum breadth (in cortical section) 25.

Remarks: The presence of a patagium around the cortical section is atypical of *D. hughesi*. There is no problem in placing the forms in the genus *Diartus* as Sanfilippo and Riedel (1980) do not discount the presence or absence of a patagium. However, the original description of this species (Campbell and Clark, 1944) and subsequent descriptions and

It is accepted that the treatment of the two variants under the name Diartus hughesi differs from most previously published work. As both variants appear to have the same stratigraphic range in the New Zealand Late Neogene this treatment does not affect the stratigraphic comparison with previously published ranges.

illustrations show no sign of a patagium being present, except in one case (Riedel and Sanfilippo, pl.12, fig.4. in Berggren *et al.*, 1976). This feature is common in the genus *Amphymenium* Haeckel (1881) but again no mention is made of it in the original generic description. The main difference between the two genera is the make-up of the central cortical section; *Diartus* having an equatorial constriction with the cortical shell comprising two hemispherical halves and *Amphymenium* being composed of a concentrically formed central section. Unfortunately the central section is poorly defined in most specimens found in this study. Of the members of *Amphymenium*, the closest to the forms described herein would be *A. challengerii* Weaver. As it was found to be difficult to define the form of the central cortical section and the patagium was often lost due to poor preservation, all forms were lumped together in the one group even if it was clear that some specimens (e.g. Plate 9, figure 17: Plate 10, figure 3) were more related to *Amphymenium* than *Diartus*. See note on facing page.

Recorded range: Riedel and Sanfilippo (1978b, *Ommatartus hughesi*) define the lower limit of the *Didymocyrtis antepenultima* Zone by the evolutionary bottom of *D. hughesi*. The upper limit of the zone is defined by the morphotypic top of *D. hughesi* (Late Miocene). Reynold's (1980) *Diartus hughesi* Zone in the western North Pacific is defined at its base by the evolutionary transition from *D. petterssoni* to *D. hughesi*. The top of the zone is defined by the evolutionary transition from *D. laticonus* to *D. antepenultima*. According to Reynolds the zone is not reported by Riedel and Sanfilippo, because at lower latitudes the transition from *Diartus petterssoni* to *D. hughesi* and *Didymocyrtis laticonus* to *D. antepenultima* are coeval.

Theyer *et al.* (1978, *Ommatartus hughesi*) date the first occurrence of *D. hughesi* at 11.4 Ma and the last occurrence at 9.0 Ma but DSDP Leg 85 results suggest that this age should be 8.2 Ma (after Nigrini and Lombardi, 1984).

Observed range: Occurs with *G. dehiscens* at Kaiti (KB01) and Leader (LT05, LT06). Its LAD is a useful biostratigraphic event in Wairarapa, disappearing abruptly at Mangaopari (MS08). Northern samples that should contain this species are generally lacking it (e.g. TM20-23). See biostratigraphic discussion. See note on facing page.

Geographic distribution: Common to abundant in the early Late Miocene sections examined. Absent from temperate latitude sites (Nigrini and Lombardi, 1984, CENOP Project).

Family **Spongodiscidae** Haeckel 1862
emended Riedel 1967a

Discoidal, spongy or finely-chambered skeleton, with or without surficial pore-plate, often with radiating arms of marginal spines, and without a large central phacoid shell. Large, polyphyletic group, for which no satisfactory classification has been proposed.

Genus **Amphirhopalum** Haeckel 1881
emended Nigrini 1967

Spongodiscidae with a concentrically chambered central disc. Margin of disc has two radially chambered arms opposite each other in one main axis. Both arms forked (or one simple, other forked). Patagium may or may not be present.

Type-species: *Amphirrhopalum ximorphum* Haeckel 1887

Amphirrhopalum cf. *ypsilon* Haeckel

Plate 12, figure 5

Amphirrhopalum ypsilon Haeckel 1887, p.522.

Amphirrhopalum ypsilon Haeckel: Nigrini 1967, p.35, pl.3, figs.3a-d.

Amphirrhopalum ypsilon Haeckel: Casey and McMillen 1977, pl.1, fig.11.

Amphirrhopalum ypsilon Haeckel: Nigrini and Moore 1979, p.S75, pl.10, figs.1a-e.

Description: Shell with two opposite, chambered arms, one of which is forked distally, central structure appears as a concentrically annulated disc. (Central structure actually composed of two inner spherical shells and an outer oblate sphaeroidal shell (Nigrini, 1967). Arms elliptical in cross-section. Unforked arm is narrow proximally and expands distally then narrows slightly. Usually about 7-9 distinct chambers, slightly convex distally. Forked arm expands distally and branches at maximum breadth, the chamber arrangement being the same as the unforked arm.

Dimensions: Total length 236-307. Radius of simple arm 119-155: of forked arm 119-155. Maximum breadth of simple arm 63-119: of branches on forked arm 36-63 (Nigrini, 1967).

Remarks: Nigrini (1967) notes that patagium may be attached to the shell. Nigrini (1971) notes that "specimens from the upper part of the cores examined average four or five proximal chambers on the forked arm before it bifurcates. Lower down in the cores this number decreases, and forms with two or three (sometimes one) such chambers predominate". Specimens found herein appear to fork after only one or two proximal chambers so could be early members of this species. The likely ancestor to this species, *A. virchowii*, has smoother, more distinct and more rounded chambers.

Recorded range: "there is a transition from *A. virchowii* to *A. ypsilon* near the Plio-Pleistocene boundary" (Nigrini, 1974, p.1065).

Observed range: Found sporadically in Plio-Pleistocene sediments. Its lowest occurrence (tentative) is in sample SWR1 where it is associated with a basal Opoitian planktic foraminiferal fauna.

Geographic distribution: "Present in samples north of about 35°S" (Nigrini, 1967, Indian Ocean).

"Belongs to a tropical assemblage derived by recurrent group analysis of North Pacific samples, but the species does range as far north as 40°N in the western Pacific" (Nigrini, 1970).

Notes on the genera *Hymeniastrum* and *Dictyocoryne*

The taxonomic subdivision of these genera is discussed by Nigrini and Moore (1979) the main points being:

1. Development of patagium is of no consequence taxonomically.
2. All the forms of this general type possess some degree of central sphaeroidal and/or discoidal structure, but this may be obscured by spongy material. The degree of visibility may be of generic significance.

3. Some forms exhibit bilateral symmetry while others have equiangular displacement between arms and this feature may be of generic significance.

Genus *Dictyocoryne* Ehrenberg 1860
sensu Nigrini and Moore 1979

Spongodiscidae with three simple, undivided, spongy arms, with or without terminal spines, equally to bilaterally disposed. Patagium may or may not be present. Central structure often obscured by spongy meshwork, but consisting of 5 to 10 or more concentric discoidal shells.

Type-species: *Dictyocoryne profunda* Ehrenberg 1872a

Dictyocoryne profunda Ehrenberg
Plate 12, figures 1,2: Plate 13, figures 1-4

Dictyocoryne profunda Ehrenberg 1872a, p.288: 1872b, pl.7, fig.23.

Dictyocoryne profunda Ehrenberg: Ling and Anikouchine 1967, p.1489, pls.191,192, fig.6.

Rhopalastrum profunda (Ehrenberg): Petrushevskaya and Kozlova 1972, p.529, pl.17, figs.4-6, pl.20, fig.8.

Rhopalastrum profundum (Ehrenberg): Keany 1979, p.54, pl.2, figs.6,7, pl.5, fig.6.

Dictyocoryne profunda Ehrenberg: Nigrini and Moore 1979, p.887, pl.12, fig.1.

Description: Arms approximately of equal size and equidistant to bilaterally arranged, club-shaped, from 2.5 to 3 times as broad at the ends as in the narrowest part although in poorly preserved forms, arm ends not as broad. Length of arms 2.5 to 3 times the diameter of the central disc; central disc normally covered by a spongy meshwork but 5-7 concentric rings present in some specimens. Patagium may or may not be present, reaches almost to the ends of the arms in well preserved specimens, rarely showing a crude chambering.

Dimensions: Based on ten specimens. Length of arms from geometric centre to distal end 120-158. Maximum breadth of arms 60-100. Minimum breadth of arms (measurable in only three of the specimens 35-37).

Remarks: Plate 13, figs.1-4 shows the gradual loss of patagium in specimens of *D. profunda*. This supports the view proposed by Ling (1966) and Nigrini and Moore (1979) that patagium is of no generic significance. Differs from *D. truncatum* in that the arms are not as broad proximal to the centre.

Recorded range: Early Miocene to Recent (Petrushevskaya and Kozlova, 1972). Neogene (Keany, 1979).

Observed range: Found in 83% of the radiolarian-bearing samples examined. Tends to be more sporadic in Plio-Pleistocene sediments (see *H. euclidis*).

Geographic distribution: "Present in most samples north of about 25°S: very rare occurrences as far south as about 33°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Genus *Hymeniastrum* Ehrenberg 1847b

emended herein

Spongodiscidae with three simple, undivided, chambered arms, with or without terminal spines. Triangular shell, equiangular displacement between arms. Patagium may or may not be present. Central structure often obscured by spongy meshwork, but consisting of 4 to 5 concentric shells (after Nigrini and Moore, 1979). Emended herein to include forms without an equiangular displacement between arms but still possessing a bilateral symmetry. *Hymeniastrum pythagorae* Ehrenberg (1854, pl.36, fig.31), although nearly equiangular, shows bilateral symmetry, the angles between the arms being 125, 125 and 110 degrees.

Type-species: *Hymeniastrum pythagorae* Ehrenberg 1854a

Note: "It is entirely possible that *Dictocoryne* and *Hymeniastrum* are cogenetic" (Nigrini and Moore, 1979).

Hymeniastrum euclidis Haeckel

Plate 12, figures 3,4; Plate 13, figure 5

Hymeniastrum euclidis Haeckel 1887, p.531, pl.43, fig.13.

Euchitonia furcata Ehrenberg: Ling and Anikouchine 1967, p.1484, pls.189,190, figs.5,6,7 (only).

Cyclastrum ? sp. Ling and Anikouchine 1967, p.1487, pls.191,192, figs.1,2.

Hymeniastrum euclidis Haeckel: Ling and Anikouchine 1967, p.1488, pl.191,192, fig.3.

Hymeniastrum euclidis Haeckel: Nigrini and Moore 1979, p.S91, pl.12, fig.3.

Description: Discoidal skeleton with three arms of nearly equal size and similar shape. Arms chambered, chambers especially visible in area proximal to centre. Normally equiangular displacement of arms but very rare forms have one angle at about 80° but still possess bilateral symmetry. Central region circular to subtriangular in outline, consisting of 4-5 concentric discoidal latticed shells. Patagium may or may not be present.

Remarks: Some forms deviate from *H. euclidis sensu stricto* in the non-equiangular displacement of the arms. Differs from *Dictocoryne profunda* in having conspicuously chambered arms.

Recorded range: "Present throughout most of the Miocene sections examined from both tropical and temperate latitudes: rare in temperate latitudes and absent from the Early Miocene sections of DSDP Site 173. Increasingly abundant in younger sediments" (Nigrini and Lombardi, 1984, *Hymeniastrum* spp., CENOP Project).

Recent (Nigrini and Moore, 1979).

Observed range: A lot of the forms found are transitional with *D. profunda* and there are not many positive *H. euclidis sensu stricto* identifications. Tends to be more common in Plio-Pleistocene sediments where it is perhaps replacing *D. profunda*.

Geographic distribution: "Present in all samples except southernmost (about 48°S)" (Johnson and Nigrini, 1970, western Indian Ocean).

"belongs to a tropical assemblage derived by recurrent group analysis of North Pacific samples, but the species ranges too far north to be useful in down core analysis" (Nigrini, 1970)

Genus *Spongaster* Ehrenberg 1860

Spongodiscidae with flattened, obsoletely radiate-stellate shell. Median disc spongy, and the stellate radii swollen at the apex.

Type-species: *Spongaster tetras* Ehrenberg 1860

Spongaster pentas Riedel and Sanfilippo

Plate 13, figure 6

Spongaster pentas Riedel and Sanfilippo 1970: p.523, pl.15, fig.3.

Spongaster pentas Riedel and Sanfilippo: Nigrini and Lombardi 1984, p.565, pl.9, fig.2.

Description: Spongy pentagonal disc. Rays from centre to marginal angles slightly thicker. Central area (one-third of disc diameter) more dense, thicker with indefinite concentric structure.

Dimensions: Diameter 170-290 (Riedel and Sanfilippo, 1970).

Recorded range: Riedel and Sanfilippo (1978b) define the base of the *Spongaster pentas* Zone (early Pliocene) by the evolutionary transition from *Spongaster berminghani* to *S. pentas*.

First occurrence dated by Theyer *et al.* (1978) at 4.7 Ma and last occurrence at 3.7 Ma.

Casey and McMillen (1977) noted that tropical Atlantic, Gulf of Mexico and Caribbean plankton tows and Holocene sediment samples have yielded Rose Bengal stained specimens of *Spongaster pentas* and *S. berminghani*. These specimens are believed to represent a relict radiolarian fauna. This presents biostratigraphic problems with the suggestion that the occurrence of this species in the tropical Pacific late Neogene may be provincial.

Observed range: One specimen found in the upper Tongaporutuan (HR01).

Notes on the genera *Stylodictya*, *Porodiscus*
and *Stylochlamydium*.

These genera are abundant, but their identification is difficult. Their morphological characteristics are frequently gradational and incomplete specimens numerous. According to some classification schemes, rotation of the specimen is necessary to confirm the specific identification; clearly this is impossible when counting specimens in a fixed slide. Kozlova (in Petrushevskaya and Kozlova, 1972) presented a generic revision based primarily on the nature of the central structure. Unfortunately the central structure is quite often covered by a spongy meshwork. The major generic differences used herein are

Stylodictya: Concentric rings. First system clearly visible in well preserved specimens.

Porodiscus: Concentric rings. First system and proximal rings covered by a spongy meshwork and therefore opaque in well preserved specimens.

Stylochlamydium: Concentric rings normally increasing in breadth distally. Strong radial spines and an equatorial marginal girdle.

Genus *Stylodictya* Ehrenberg 1847

emended Kozlova 1972 (in Petrushevskaya and Kozlova, 1972).

Spongodiscidae with a skeleton that is flat or slightly concave with round outline; consists of equatorial and sagittal girdles (frontal girdle is not developed), wings of the rings are displaced at 45° in relation to the main axes; at their merging point they do not envelope each other and thus form girdles of regular round or scalloped form, especially distinctive in the first systems. The first system is clearly visible, cupolas do not overlap each other, and are not submerged into the skeleton; the distance between systems is greater than or equal to the diameter of the central chamber. The main and additional spines are well developed and often extend as external spines. Rim of the disc is smooth with 4, 8 or more spines.

Type-species: *Stylodictya gracilis* Ehrenberg 1854

Stylodictya validispina Jorgensen

Plate 12, figures 6,8,9: Plate 15, figure 1

Stylodictya validispina Jorgensen 1905, p.119, pl.10, fig.40.

Stylodictya validispina Jorgensen: Keany and Kennett 1975, pl.3, fig.7.

Stylodictya sp. Petrushevskaya 1975, pl.40, figs.3,4.

Stylodictya stellata Bailey group: Petrushevskaya 1975, p.576, pl.6, fig.9.

Stylodictya validispina Jorgensen: Nigrini and Moore 1979, p.S103, pl.13, figs.5a,b.

Description: Skeleton in form of a flat disc not thickened in the middle. Central chamber distinctly visible. Concentric rings of chambers disposed regularly, usually number 5-6; their width hardly increases to the periphery of the disc. Pores on the walls of chambers subregular, usually 2-2.5 pores located in the width of one ring. Pores on the peripheral rings somewhat larger than those on the central rings. Irregularly arranged radial needles extend from the margin of the disc, some appear to be extensions of faintly visible radial bars which pierce the outer 2 to 3 rings. More commonly the needles are broken off at their base. Rare forms include those with a quadrate outline and heavily spinose forms.

Dimensions: Diameter of central chamber 12-15: of disc with five rings 140 (Nigrini and Moore, 1979).

Remarks: Differs from *S. aculeata* Jorgensen by having a greater number of narrower, more regularly concentric chambers and smaller pores.

Recorded range: "Present throughout the late Early to Late Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombardi, 1984, CENOP Project). Known from the Recent.

Observed range: Tabulated into three forms. *S. validispina sensu stricto* is present in 72% of the radiolarian-bearing samples examined. Tends to be slightly more sporadic in younger sediments. The "spinose" form has a highest occurrence below the LAD of *C. molestus* at Waiatai but is too rare to be of biostratigraphic use. The "quadrate" form is found in only eleven samples from throughout the Late Neogene.

Geographic distribution: "prefers Northern (Polar factor) conditions" (Sachs, 1973, Late Pleistocene subarctic Pacific).

"this species loads most heavily in factor 3 (transitional) but also loads in factor 1 (subpolar). The greatest abundances for this species are to the north of 40°N" (Robertson, 1975, northwest Pacific).

Stylodictya cornuspira Campbell and Clark

Plate 12, figure 7

Stylodictya cornuspira Campbell and Clark 1944, p.27, pl.3, fig.22.

Description: Same as *Stylodictya validispina* except the rings form a spiral from the centre.

Observed range: Rare sporadic occurrences throughout the Late Neogene.

Genus *Porodiscus* Haeckel 1881

emended herein

Spongodiscidae with a skeleton that is flat or slightly concave in its centre, has a rounded outline, and is composed of annular equatorial rings. The first system has a central chamber and one ring, very rarely submerged in the skeleton; distance between the annular rings is less than or equal to the diameter of the initial chamber. Main spines are indistinct and as a rule cannot be distinguished from secondary spines. The rim of the skeleton is either smooth or covered by numerous spines (Kozlova, in Petrushevskaya and Kozlova, 1972). Emended herein to include only forms that have a spongy meshwork covering the central chambers and proximal rings in well preserved specimens.

Type-species: *Flustrella concentrica* Ehrenberg 1838

Porodiscus sp. A

Plate 14, figures 1,2: Plate 15, figures 2,3

Porodiscus sp. A Nigrini and Moore 1979, p.S107, pl.14, figs.1,2b (only).

Perichlamidium sp. Petrushevskaya 1975, pl.40, figs.1,2.

Description: Skeleton in form of a disc thickened in the central part and therefore opaque. Central structure obscured by spongy meshwork. Chambers normally disposed in concentric rings, rings number 7 to 9, width of chambers not increasing to periphery of disc. Rounded pores, subregularly arranged and slightly smaller in the central region.

Dimensions: Based on seven specimens. Diameter of central opaque part of shell 50-94: of shell with six rings 150-260.

Remarks: Differs slightly from Nigrini and Moore's (1979) specimens in having less number of pores per concentric ring width and being slightly larger. Some forms have smaller pores on the outer surface (from SEM studies) than others but this may be related to differing preservation. Differs from *Stylodictya validispina* in having a thickened opaque central region.

Observed range: Present in 86% of the radiolarian-bearing samples examined from throughout the Late Neogene. A "spiralling" form was found in eleven samples also throughout the time range studied.

Porodiscus sp. B

Plate 14, figures 3,4; Plate 15, figures 4-6

Porodiscus sp. A Nigrini and Moore 1979, p.107, pl.14, fig.2a (only).

Description: Skeleton slightly smaller than *Porodiscus* sp. A with more rings (approximately 10) which show less concentricity. Under SEM imagery the pores also show a tendency towards a more random distribution.

Dimensions: Based on five specimens. Diameter of central part of shell 80: of skeleton 150.

Remarks: This form with a large number of rings could be the same as those found by Petrushevskaya (1967) in the Pacific Ocean sector of the Antarctic Ocean.

Observed range: Present throughout the Late Neogene. Tends to be more abundant in Miocene sediments but is not common enough to determine accurately.

Genus *Stylochlamyidium* Haeckel 1881

emended herein after Nigrini and Moore (1979)

Spongodiscidae with skeleton that is flat or slightly concave in its centre, has a rounded outline. Central structure consists of concentric rings, often covered by a spongy meshwork. Numerous (five or more, commonly eight to twelve) solid radial spines, regularly or irregularly disposed on the margin of the circular or polygonal disc; margin of the disc surrounded by a thin, porous (but not chambered), equatorial girdle. Spines may or may not pierce the equatorial girdle.

Type-species: *Stylochlamyidium asteriscus* Haeckel 1887

Stylochlamyidium asteriscus Haeckel

Plate 14, figure 5

Stylochlamyidium asteriscus Haeckel 1887, p.514, pl.41, fig.10.

Stylochlamyidium asteriscus Haeckel: Nigrini and Moore 1979, p.113, pl.14, fig.5.

Description: Circular disc with centre somewhat thickened. Concentric rings surround a central chamber (which is often covered by a spongy meshwork). Rings increase in breadth toward shell margin. Pores are subcircular, approximately the same size and evenly spaced, 1-3 per ring. Marginal band is a thin porous, equatorial girdle (normally present). Radial needle-like spines (up to 15) extend from at or near the centre to the periphery and beyond, subdividing the concentric rings into chambers.

Dimensions: Based on 20 specimens. Diameter of central shell 10-12: of shell with five bands 94-110 (after Lombardi, in Nigrini and Lombardi, 1984). Shell with equatorial girdle 140.

Recorded range: "common to abundant throughout the Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombari, 1984, CENOP Project). Known from Recent.

Observed range: Sporadic occurrences throughout the upper Neogene.

Geographic distribution: Molina-Cruz (1975) subdivided forms under this name into three variants. One variant "has an opaque centre and is mostly abundant in the equatorial region" and is most like the forms described herein.

Genus *Spongotrochus* Haeckel 1860b

Spongodiscidae with a discoidal or lentiform, biconvex skeleton with innumerable small branches forming a dense or loose web (without concentric rings or latticed plate). With five or more marginal spines in the plane of the disc as well as spines radiating from both surfaces of the disc.

Type-species: *Spongotrochus brevispinus* Haeckel 1862

Spongotrochus glacialis Popofsky

Plate 14, figures 6-9: Plate 15, figures 7-11

Spongotrochus glacialis Popofsky 1908, p.228, pl.26, fig.8, pl.27, fig.1, pl.28, fig.2.

Spongotrochus ? *glacialis* Popofsky: Riedel 1958, p.227, pl.2, figs.1,2.

Spongotrochus glacialis Popofsky: Keany and Kennett 1975, pl.1, fig.12.

Spongotrochus glacialis Popofsky group: Petrushevskaya 1975, p.575, pl.5, fig.8, pl.35, figs.1-6.

Spongotrochus glacialis Popofsky: Keany 1979, p.54, pl.2, figs.9,10, pl.5, fig.8.

Spongotrochus glacialis Popofsky: Casey and Reynolds 1980, pl.2, fig.15.

Spongotrochus glacialis Popofsky group: Nigrini and Lombari 1984, p.S79, pl.11, fig.2.

Description: Shell biconvex-discoidal, consisting of a disc of spongy structure, thickened in its central portion (a quarter to half of its total diameter); with rarely preserved numerous acicular or acutely conical spines of different lengths around its circumference and also near the thickened central portion. Rarely an enclosing lenticular lattice shell is in contact with the disc by short bars, at or near its circumference. The lattice shell has an uneven surface with small subcircular to circular pores (smaller than the pores in the underlying spongy mass) randomly distributed over its surface. Very poorly preserved (thin) specimens shown an indefinite radial alignment of pores in the spongy network.

Dimensions: Based on 17 specimens. Average diameter of shell 211 (range 109-300).

Remarks: There is a possibility that specimens of *Spongopyle oculosa* Dreyer without its characteristic pylome tube preserved, have been included in this species. Riedel (1958) notes a wide variation in the forms he described, probably including the abundant Antarctic form which Popofsky identified as *Stylotrochus arachnius* (Haeckel) and some forms described by Popofsky (1908) as *Spongodiscus favus* Ehrenberg *maxima* which Riedel considers to be no more than incompletely developed forms of *S. glacialis*.

Recorded range: Miocene to Recent (Petrushevskaya, 1975).

Neogene (Keany, 1979).

Observed range: Present in 92% of the radiolarian-bearing samples studied. Very persistent and occurs in samples with very poor siliceous preservation.

Geographic distribution: "Present throughout the Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombardi, 1984, CENOP Project).

"Higher percentage values are generally found under subantarctic waters where, with few exceptions, it constitutes over 10% of the total Radiolaria"; "The southern boundary of the area with more than 10% *S. glacialis* being coincident with the average position of the Antarctic Polar Front. The northern limit of the area with over 10% *S. glacialis* cuts the isotherms and separates the subtropical Atlantic fauna with less than 10% *S. glacialis* from that of the subtropical Indian Ocean where it generally constitutes over 10% of the total Radiolaria" (Lozano, 1974).

Family Pyloniidae Haeckel 1881

Regular, incompletely latticed cortical shell, distinguished by two to four or more symmetrically disposed gates or large fissures remaining between one to three latticed dimensive girdles (perpendicular one to another). One, two, or three concentric systems of such girdles (each system with three girdles) may be developed.

Genus *Hexapyle* Haeckel 1881

Pyloniidae with a simple spherical central chamber surrounded by two concentric tri-radial girdles. Six gates between three double arm-chambers (three inner and three outer); no chambered marginal girdle; faces of the gates simple or in well preserved specimens barred by a latticed equatorial girdle.

Type-species: *Hexapyle triangula* Haeckel 1887

Hexapyle cf. *dodecantha* Haeckel

Plate 14, figure 11

Hexapyle dodecantha Haeckel 1887, p.569, pl.48, fig.7.

Hexapyle dodecantha Haeckel: Renz 1974, pl.13, fig.7.

Hexapyle dodecantha Haeckel: McMillen and Casey 1978, pl.2, fig.22.

cf. *Hexapyle* spp. Nigrini and Moore 1979, p.S121, pl.16, figs.1a-c.

Description: Test consisting of a double pylodiscid shell. Shell subtriangular in outline with three relatively large gates at the apex of each angle. Outer lattice has large subcircular pores and is normally thorny, the long, slender, cylindrical spines being broken off. Innermost structure within first pylodiscid shell not observed. This may consist of a central node from which radiate three radial beams (after Benson, 1966).

Dimensions: Length of base of inner triangular pylodiscid shell 18-43: of outer pylodiscid shell 80-137 (Benson, 1966).

Remarks: Completely developed shells with outer lattice covering not found. This form is only tentatively placed in this species because the inner pylodiscid shell is about twice the size of the gates whereas all the figured specimens in the synonymy have gates the same size as the inner shell. Identification of this species would depend on its orientation.

Recorded range: Renz's (1974) specimens are from Quaternary sediments.

Observed range: Only positively identified in Tongaporutuan samples although there are two tentative identifications in Opoitian samples (SWR3, SMR1). Too rare to be of use biostratigraphically.

Genus *Tetrapyle* Muller 1859

Pyloniidae with two systems of concentric girdles, medullary trizonal. Cortical shell with two perfect girdles and four simple gates.

Type-species: *Tetrapyle octacantha* Muller 1858

Tetrapyle octacantha Muller group

Plate 13, figures 9-13: Plate 14, figures 10,12

Tetrapyle octacantha Muller 1858, p.33, pl.2, figs.12,13, pl.3, figs.1-12.

Phorticium pylonium Haeckel 1887, p.709, pl.49, fig.10.

Phorticium pylonium Haeckel: Cleve 1899, p.31, pl.3, fig.2.

Tetrapylonium clevei Jorgensen 1900, p.64.

Tetrapyle (?) sp. Dumitrica 1973, pl.6, fig.5.

Phorticium clevei (Jorgensen): Bjorklund 1976, pl.4, figs.6-10.

Phorticium clevei (Jorgensen): Keany and Kennett 1975, pl.3, fig.6.

Phorticium clevei (Jorgensen) group: Petrushevskaya 1975, p.573.

Tetrapyle octacantha Muller: McMillen and Casey 1978, pl.3, figs.2a,b.

Pylonidae genn. et. spp. indet. Riedel and Sanfilippo 1978a, pl.3, figs.13-15.

Phorticium clevei (Jorgensen): Keany 1979, p.54, pl.2, fig.5.

Tetrapyle octacantha Muller: Nigrini and Moore 1979, p.5125, pl.16, figs.3a-b.

Phorticium pylonium Haeckel: Nigrini and Lombardi 1984, p.585, pl.12, figs.2a,b.

Description: Cortical shell irregular, ellipsoidal, about three times as large as the enclosed ellipsoidal to spherical inner shell. Cortical shell in various stages of development but even in the most developed forms there are still some subspherical gates present; connected to the inner shell by radial beams and irregular latticed girdles. Surface of shell spiny. One specimen has a subspherical (third girdle) preserved (Plate 14, figure 12).

Dimensions: Based on twelve specimens. Length of major axis of outermost shell 78-140: of minor axis 46-85. Length of major axis of inner shell 23-55: of minor axis 15-47.

Remarks: I have lumped together all forms with an ellipsoidal outer shell, in various stages of development, with gates and with simple or *Larnacilla*-type inner shell because of the difficulty in determining the shape of the central structure.

Recorded range: "Common to abundant in all the Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombari, 1984, CENOP Project, *P. pylonium*).

"Present throughout the Late Miocene sections examined from both tropical and temperate latitudes. Rare in material from temperate latitudes; abundant in tropical material" (Nigrini and Lombari, 1984, CENOP Project, *T. octacantha*).

Riedel and Sanfilippo's (1978a) forms are from the Sicilian Lower Pliocene.

Neogene (Keany, 1979, *P. clevei*).

Miocene to Recent (Petrushevskaya, 1975, *P. clevei* group).

Observed range: Present in 65% of the radiolarian-bearing samples examined from throughout the Late Neogene. Tends to be more sporadic in Plio-Pleistocene sediments.

Geographic distribution: Cosmopolitan.

Family *Larnacidae* Haeckel 1887

Regular, completely latticed lentelliptical cortical shell, without open gates or annular constrictions; either cortical or medullary trizonal, composed of three elliptical, latticed dimensive girdles of different sizes, perpendicular to one another.

Genus *Larnacilla* Haeckel 1887

Larnacidae with a simple lentelliptical cortical shell connected by the lateral wings of a latticed transverse girdle with the simple, spherical or lentelliptical medullary spines. Surface without radial spines.

Type-species: *Larnacilla typus* Haeckel 1887

Larnacilla typus Haeckel

Plate 13, figure 7

Larnacilla typus Haeckel 1887, p.617, pl.50, fig.1.

Description: Shell outline rounded square to parallelogram. Cortical shell smooth with subcircular to circular pores in a subhexagonal arrangement, about ten on the half equator. Gates (between transverse and lateral girdles) roundish rectangular; radial beams support side of gate. Medullary not seen but according to Haeckel is spherical, scarcely one-third as broad as the lentelliptical cortical shell.

Dimensions: Based on one specimen. Length of shell 175. Breadth of shell 154. Height of gate 18.

Remarks: Slightly larger than the specimens described by Haeckel 1887.

Observed range: Only two positive identifications in Tongaporutuan samples (PB04, LT06) the latter with *G. dehiscens* and one tentative identification in LT01 where it is associated with *Didymocyrtis tetrathalmus tetrathalmus*.

Family **Tholoniidae** Haeckel 1887

Regular, completely latticed cortical shell, which is composed of two to six or more hemispherical or cap-shaped domes (vaulted chambers or cupolas). The domes lie opposite in pairs on the poles of the three dimensive axes; are separated by annular constrictions; and surround a simple or *Larnacilla*-shaped central chamber.

Genus *Cubotholus* Haeckel 1887

Tholoniidae with simple cortical shell (without external veil), composed of six hemispherical cupolas, opposite in pairs on the poles of three axes perpendicular to one another, covering six sides of the cuboidal central chamber (with medullary shell).

Type-species: *Cubotholus regularis* Haeckel 1887 : designated by Campbell 1954

Cubotholus rhombicus Haeckel

Plate 13, figure 8

Cubotholus rhombicus Haeckel 1887, p.681.

Cubotholus sp. Dumitrica 1973, pl.7, fig.3.

Cubotholus rhombicus Haeckel: McMillen and Casey 1978, pl.3, fig.19.

Description: Distinctive four-cupola shell outline. All three fundamental axes unequal i.e. the principal cupolas are larger than the transverse cupolas, which are larger than the sagittal cupolas. Surface thorny with the bases of short, thin, cylindrical spines present. Pores subcircular generally slightly larger than the bar width. Pores in the constrictions are generally larger and more irregular, eight to twelve in the base semicircle of each cupola.

Dimensions: Based on two specimens. Length of principal axis 121-124: of transverse axis 90-94.

Remarks: These two specimens are about 25% smaller than Haeckel's (1887) forms.

Recorded range: Quaternary occurrence (Dumitrica, 1973).

McMillen and Casey's (1978) specimen is from Recent sediments.

Observed range: Found sporadically throughout the Late Neogene but tends to be more common in upper Pliocene and Pleistocene sediments.

Family **Litheliidae** Haeckel 1862

Symmetrical spiral shell, divided by the spiral plane into two symmetrical halves; all windings of the spiral lie in this plane. Primordial chamber either simple or *Larnacilla*-shaped.

Genus *Lithelius* Haeckel 1860b

Litheliidae with simple, spherical or subspherical medullary shell and lentelliptical or subspherical spirally constructed cortical shell, surface covered with numerous, simple or branched radial spines.

Type-species: *Lithelius spiralis* Haeckel 1862 : designated by Campbell 1954

Lithelius minor Jorgensen

Plate 13, figures 14,15: Plate 16, figure 5

Lithelius minor Jorgensen 1900, p.65, pl.5, fig.24.

Lithelius minor Jorgensen: Nigrini and Lombardi 1984, p.S95, pl.14, figs.1a,b.

Description: Ellipsoidal to spherical skeleton consisting of approximately five concentric shells, separated by subequal distances. In certain orientations the internal structure appears as a double spiral. Lozano (1974) notes that the single spiral position is very difficult to photograph as the shell never adopts this orientation in permanent slides. Shells supported by thin radial beams which give the outer shell a thorny appearance. Pores subcircular with a subregular arrangement, approximately 15 on the minor circumference of the outermost shell.

Dimensions: Major diameter of skeleton 79-148: minor diameter 70-132 (Benson, 1966).

Remarks: In general the specimens found to the north of the subtropical convergence have more shells, four to seven, most frequently four to five, whereas under southern subantarctic waters specimens with three to four shells are common (Lozano, 1974). Differs from *L. nautiloides* in having a tighter concentricity.

Recorded range: Common in most of the Miocene sections examined from both tropical and temperate latitudes (Nigrini and Lombardi, 1984, CENOP Project) to Recent.

Observed range: Found in 64% of the radiolarian-bearing samples examined throughout the Late Neogene.

Geographic distribution: "Generally absent south of the Antarctic Polar Front", "it is always found in samples under subantarctic and subtropical waters" (Lozano, 1974).

"This species appeared very cosmopolitan. It probably needs a taxonomic review since the specimens may represent more than one species with markedly different ecological responses" (Molina-Cruz, 1975).

Lithelius nautiloides Popofsky

Plate 16, figures 1,6

Lithelius nautiloides Popofsky 1908, p.230, pl.27, figs.2-4.

Lithelius nautiloides Popofsky: Riedel 1958, p.228, pl.2, fig.3 (only), text-fig.2.

Spirema sp. Kling 1973, p.635, pl.7, figs.23-25.

Lithelius nautiloides Popofsky: Nigrini and Lombardi 1984, p.S97, pl.14, figs.2a,b.

Description: Shell subspherical, consisting of a small, spherical medullary shell surrounded by an involute spiral of three to five whorls. The whorls of the spiral generally increase in width outward. The shell wall is of moderate thickness with rounded pores normally about 5 μ in diameter. In certain orientations a double spiral is exhibited.

Dimensions: Based on six specimens. Diameter of medullary shell 15-20: of entire shell of four whorls 96-118.

Remarks: As noted by Riedel (1958) the radial spines (extensions of radial bars penetrating through the shell surface) are mostly broken off in specimens from sediments. The bases of some of these spines are still preserved. Rare specimens show no increase in whorl width outward, like Kling's (1973, pl.7, figs.23-25, *Spirema* sp.) specimens, but no examples were found where the specimens are evolute and close up near the edge (as in *Lithelius* sp. Nigrini and Lombardi 1984, p.S99, pl.14, figs.3a-c.).

Recorded range: *Calocyclus costata* Zone (Kling, 1973) to Recent.

Observed range: Found in 50% of the radiolarian-bearing samples examined throughout the Late Neogene.

Geographic distribution: "It is always present under Antarctic waters and generally present under southern sub-antarctic waters. When found close to or north of the subtropical convergence it is generally as a product of reworking or northern transport by bottom waters" (Lozano, 1974).

Lithelius sp. A

Plate 16, figure 3

Description: Specimens of a litheliid with a double spiral of two wings as in *Larcospira* but apparently without the development of an inner trizonal shell, one of the characteristics of that genus.

Observed range: Found in only nine samples ranging from MS19 (with *G. dehiscens*) to about 40m below the FAD of *G. crassula* at Waiatai.

Lithelius sp. B

Plate 16, figure 4

Description: Specimens with a very indistinct internal spiral and subelliptical outer shell outline included in this species.

Dimensions: Length of shell 125; breadth 109.

Observed range: Found in only seven samples from just above the LAD of *G. dehiscens* at Mangaopari Stream to WA02 at Waiatai.

Genus *Pylospira* Haeckel 1887

Litheliidae with double, trizonal or *Larnacilla*-shaped medullary shell; cortical shell subspherical or lentelliptical, constructed of a single or double spiral of the lateral girdle (or second cortical girdle); the spiral lamellae revolving round the sagittal axis.

Type-species: *Pylospira octopyle* Haeckel 1887 : designated by Campbell 1954

Pylospira octopyle Haeckel

Plate 16, figure 2

Pylospira octopyle Haeckel 1887 p.698, pl.49, fig.4.

? *Pylospira octopyle* Haeckel: Nigrini and Lombardi 1984, p.S101, pl.14, fig.4.

Description: Shell elliptical to oval in outline. Composed of a series of spiralling chambers supported by numerous cylindrical radial beams which pierce the outer shell margin. Outer shell thorny with subcircular pores, irregular in size and distribution.

Dimensions: Based on ten Quaternary specimens. Length of major axis 101-122: of minor axis 79-106. Miocene forms are larger, the dimensions based on 20 specimens being, 145-220 and 105-163 respectively (Nigrini and Lombardi, 1984).

Remarks: The forms found are more similar in size to Quaternary than Miocene specimens.

Recorded range: Miocene to Recent (after Nigrini and Lombardi, 1984).

Observed range: Appears to be restricted to the Tongaporutuan. Found with *G. dehiscens* at Wainuioru (SWR4), Leader and SPA1, and Kaiti. Not found above the Tongaporutuan except for one one tentative identification at SWM1 which is well above (410m) the FAD of *G. crassaformis* at Waimata.

Suborder Nassellaria Ehrenberg 1875

Family Plagoniidae Haeckel 1881

emended Riedel 1967a

Skeleton consisting entirely of spicule with median bar, apical and dorsal spines, vertical spine, primary lateral spines and sometimes other spines; or having a lattice skeleton including a large cephalis within which this spicule is well developed. Large probably polyphyletic group subject to future subdivision (Riedel, 1967a; Kling, 1978).

Genus *Antarctissa* Petrushevskaya 1967

Plagoniidae consisting of a cephalis and thorax. Cephalis smaller than thorax, the lower part being submerged in the thorax. Thorax generally widens gradually distally although in some mature specimens it is closed. Surface rough. All internal spines well developed. No horns on cephalis. Axostyle very long, uneven. Spines Lr and Ll are arranged symmetrically to MB (contrary to *Lithomelissa*) (after Petrushevskaya, 1967).

Type-species: *Lithobotrys denticulata* Ehrenberg 1844a

Antarctissa antedenticulata Chen

Plate 16, figures 7,9,11

Antarctissa antedenticulata Chen 1975, p.456, pl.18, figs.1,2.

Description: Cephalis spherical, with randomly distributed, small subcircular pores. Collar stricture variable, depends on the thickness of shell, but generally marked by change in contour. Thorax subcylindrical or inflated cylindrical, about the same width as the cephalis or slightly wider with subcircular pores of various dimensions.

Dimensions: Based on 20 specimens. Length of cephalis 27-45: of thorax 36-54. Width of cephalis 36-45: of thorax 54-63 (Chen, 1975).

Remarks: Evolved into *A. denticulata* (Ehrenberg) in the Lower Pliocene and differs from it in having a cephalis and thorax of almost equal width and a shell of smaller dimensions (Chen, 1975).

Recorded range: Middle to Upper Miocene (Chen, 1975).

Observed range: At least one record with *G. dehiscens* (LT05) and one tentative at KB01. Found sporadically through to Waiatai Valley Pleistocene sediments.

Antarctissa conradae Chen

Plate 16, figure 8

Antarctissa conradae Chen 1975, p.457, pl.17, figs.1-5.

Botryopera deflandrei Petrushevskaya 1975, p.592, pl.11, figs.30-32.

Antarctissa deflandrei (Petrushevskaya): Nigrini and Lombardi 1984, p.N5, pl.15, figs.3a,b.

Description: Cephalis thick walled, ovate, with scattered small, subcircular pores. Thorax cylindrical, slightly tapering at base in some specimens, separated from the cephalis by a distinct collar constriction. Thoracic pores circular to elliptical, scattered, and about the same size as those of the cephalis.

Dimensions: Based on 35 specimens. Length of cephalis 27-36: of thorax 45-63. Width of cephalis 25-32: of thorax 35-54 (Chen, 1975).

Remarks: Evolved into *Antarctissa longa* (Popofsky) in the lower Pliocene and distinguished from it in arbitrary size limit of thorax i.e. specimens having a thorax less than 54μ will be assigned to *conradae* (Chen, 1975). This evolutionary sequence was not observed in the North Pacific CENOP samples where *A. longa* is present in early Middle Miocene samples but *A. deflandrei* (= *conradae*) is absent from the samples (Nigrini and Lombardi, 1984)

Recorded range: Middle to Upper Miocene (Chen, 1975).

Observed range: Found with *G. dehiscens* at Wainuioru (SWR4) and Leader River. Sporadic occurrences up to EC02 which marks the FAD of *G. crassaformis* at East Cape.

Antarctissa longa (Popofsky)

Plate 16, figure 10

Helotholus longus Popofsky 1908, p.282, pl.34, fig.2.

Antarctissa (?) *longa* (Popofsky): Petrushevskaya 1975, p.591, pl.11, figs.8-10, pl.18, fig.6.

non *Antarctissa longa* (Popofsky) Keany 1979, p.55, pl.3, figs.5,6, pl.5, fig.11.

Antarctissa longa (Popofsky): Nigrini and Lombardi 1984, p.N7, pl.15, figs.4a,b.

Description: Almost identical to *A. strelkovi* except the relation between the cephalis and thorax is different. Ratio of width of cephalis to thorax is 1:1.5 or less. Thin walls with delicate pores and some secondary thorns on the surface.

Dimensions: Length of first segment 60-70: width 70-85. Length of second segment 100-120: width 100-120. Total length 160-200 (Petrushevskaya, 1967).

Remarks: Keany's (1979) identification is considered invalid and should have been put under *A. strelkovi*. His *Antarctissa longa* Zone is an acme zone in that it is "marked by high abundances of *A. longa* and by increases in percentages of *A. strelkovi* and *A. denticulata*".

Recorded range: "Absent from most of the Miocene sections examined from both tropical and temperate latitudes. Rare in the early Miocene of DSDP Site 173; common in the late Miocene of DSDP Site 173" (Nigrini and Lombari, 1984, CENOP Project).

Pliocene to Recent (Chen, 1975).

Observed range: Sporadic occurrences throughout Late Neogene.

Antarctissa strelkovi Petrushevskaya

Antarctissa strelkovi Petrushevskaya 1967, p.89, pl.51, figs.3,4.

Antarctissa (?) *strelkovi* Petrushevskaya 1975, p.591, pl.18, fig.5.

Antarctissa longa (Popofsky): Keany 1979, pl.3, figs.5,6, pl.5, fig.11.

Antarctissa strelkovi Petrushevskaya: Nigrini and Lombari 1984, p.N9, pl.15, figs.5a-c.

Description: Cephalis subspherical to ovate, separated from thorax by a slight constriction. Ratio of cephalis width to thorax is 1:1.5-2. Pores on both segments are rounded, randomly distributed; their sizes vary greatly. Shell walls comparatively thin. Surface spines usually broken off at base.

Dimensions: Length of the first segment (externally) 45-55: width 60-65. Length of the second segment 70-90: width 70-110. Overall length of the shell is up to 150 (Petrushevskaya, 1967).

Recorded range: Mid-Thvera to at least 3 Ma (Keany, 1979).

"Common in the early and late Miocene of DSDP Site 173" (Nigrini and Lombari, 1984, CENOP Project).

Pliocene to Recent (Chen, 1975).

Miocene to Recent (Petrushevskaya, 1975).

Observed range: Sporadic occurrences above the LAD of *G. dehiscens*.

Geographic distribution: "generally restricted to south of the Polar Front" (Hays, 1965, *Helotholus histicosa*).

"between 12 to 37% of the fauna south of the Polar Front."; "Values of over 3% close to the Subtropical Convergence."; "Practically absent under waters warmer than 10°C in the Atlantic (Lozano, 1974).

"present in all samples south of about 37°S (Johnson and Nigrini, 1980, *Antarctissa* spp., western Indian Ocean).

Genus *Lithomelissa* Ehrenberg 1847b

Plagoniidae with a single stricture. Thoracic ribs prolonged as lateral wings or spines. Thorax latticed, without terminal feet. With one or more apical horns.

Type-species: *Lithomelissa microptera* Ehrenberg 1854a : by subsequent monotypy Foreman and Riedel 1972

(?) *Lithomelissa setosa* Jorgensen

Plate 18, figures 1-3

Lithomelissa setosa Jorgensen 1900, p.81.

Lithomelissa setosa Jorgensen 1905, p.135, pl.16, figs.81-83, pl.18, fig.108 (in part).

Lithomelissa setosa Jorgensen: Bjorklund 1976, pl.8, figs.1-13.

Lithomelissa sp. C Chen 1975, p.458, pl.11, figs.1,2.

Description: Cephalis globular, partially imbedded in thorax. Collar stricture distinct. Thorax subcylindrical to inflated, relatively long, approximately twice as broad as the cephalis. Dorsal and two lateral spines rarely visible. No apical spines preserved. Pores circular to subelliptical, generally irregularly sized and arranged. Termination ragged. In rare specimens the thorax ribs are prolonged as indistinct feet.

Dimensions: Based on five specimens. Breadth of cephalis 25-38. Length of cephalis 23-27. Maximum breadth of thorax 48-59. Length of thorax 59-70.

Remarks: These forms are related to *L. setosa* but do not have the delicate apical spines preserved. The dorsal or two lateral spines are rarely preserved. Distinguished from *A. strelkovi* by the distinct collar stricture. *Lithomelissa stigi* Bjorklund has a very small cephalis (one third the diameter of the thorax) and *L. hystrix* Jorgensen has a very indistinct collar stricture. The forms with indistinct feet resemble those illustrated in Berggren *et al.* (1976, Plagoniidae gen. et sp. indet., pl.13, figs.12-14) from the Late Miocene of Spain. These forms appear to be related to *L. setosa* but do not conform to the generic definition because of the feet development.

Recorded range: Early late Miocene (Berggren *et al.*, 1976) to Recent.

Observed range: Rare occurrences restricted to Tongaporutuan sediments. The "tri-legged" form is more common and has the same distribution as *L. setosa sensu stricto*.

Genus *Lophophaena* Ehrenberg 1847b

Plagoniidae with a single stricture, the last segment being a broad aperture. No spiny ribs. Cephalis separated by an external stricture (often crested). With no posterior corona of spines.

Type-species: *Lophophaena galeaorci* Ehrenberg 1854a : by subsequent monotypy Foreman and Riedel 1972

Lophophaena macrencephala Clark and Campbell group

Plate 16, figure 12

Lophophaena macrencephala Clark and Campbell 1945, p.41, pl.7, figs.6-9.

Lophophaena sp. cf. *L. macrencephala* Clark and Campbell: Petrushevskaya 1971c, fig.56/10.

Lophophaena sp. Riedel, Sanfilippo and Cita 1974, p.709, pl.59, fig.6 (only).

Peromelissa sp. McMillen and Casey 1978, pl.5, fig.3.

Description: Shell with distinct subglobular cephalis, no horns intact but bases present. Cephalic pores subcircular, increasing in size distally. Collar stricture distinct. Thorax flaring rapidly but in some forms is an inverted U-shape.

Dimensions: Based on two specimens. Length of cephalis 55. Maximum breadth of cephalis 53; of thorax 61-65.

Remarks: Petrushevskaya (1971c) gives a detailed analysis of this generic group. Clark and Campbell (1945) show a wide variation in degree of thoracic flaring and the specimens encountered in this study support this and indicate that this is a polyspecific group.

Recorded range: Clark and Campbell's (1945) form is from the Californian Eocene. The forms illustrated by Riedel, Sanfilippo and Cita (1974) and McMillen and Casey (1978) are from the Sicilian Lower Pliocene and Recent respectively.

Observed range: Relatively common throughout the late Neogene although it is only found in one sample associated with *G. dehiscens*. In Upper Mangaopari Section it suddenly appears in sample MS15, above the LAD of *G. dehiscens*.

Family Acanthodesmiidae Hertwig 1879

Nassellaria possessing a sagittal ring. Forms range from simple rings to latticed chambers consisting of lobes developed on either side of the D-ring. This family has been revised by Goll (1968, 1969) under the name Trissocyclidae.

Genus *Desmospyris* Haeckel 1881

Acanthodesmiidae with bilocular cephalis and a thorax; thorax usually narrower than cephalis, no real feet and generally no horns.

Type-species: *Desmospyris mammilata* Haeckel 1887

Desmospyris rhodospyroides Petrushevskaya

Plate 15, figure 14; Plate 18, figures 4,5

Desmospyris rhodospyroides Petrushevskaya 1975, p.593, pl.10, figs.27-29,31,32.

Description: Sagittal ring is enclosed in the cephalis with no less than 9-10 pores near the ring on one lobe of the cephalis. Sagittal constriction rarely expressed externally. Thorax and cephalis are nearly the same width. Termination usually ragged, occasionally constricted. Cephalic and thoracic pores irregular, rounded polygonal, tending to increase in size towards the sagittal ring and collar stricture. Cephalic surface is rougher than thoracic in some forms.

Dimensions: Based on three specimens. Height of sagittal ring 36-42. Breadth of thorax 68-74; of cephalis 72-84.

Remarks: Petrushevskaya's specimens have larger more closely spaced pores.

Recorded range: Antarctic Miocene (Petrushevskaya, 1975).

Observed range: Apart from two tentative identifications in the Pleistocene and uppermost Pliocene it is only found in Tongaporutuan samples, four of which also contain *G. dehiscens*.

Desmospyris sp. aff. *rhodospyroides* Petrushevskaya

Plate 15, figure 12

Description: Similar to *D. rhodospyroides* but there are four differences: (a) the thorax is always broader than the cephalis (up to twice as broad); (b) the cephalis wall is alot rougher and thicker than the thorax; (c) there is a distinct collar stricture; and (d) the thorax has smaller, more sparsely scattered pores.

Dimensions: Based on five specimens. Height of cephalis 43-54. Breadth of cephalis 67-73. Maximum breadth of thorax 95-129.

Remarks: There is an intergradation of forms between this form and *D. rhodospyroides*.

Observed range: About as common as *D. rhodospyroides* and is normally associated with it. No Plio-Pleistocene occurrences.

Desmospyris (?) sp. A

Plate 18, figures 7,8

Spyrid gen. et sp. indet. Riedel, Sanfilippo, and Cita 1974, pl.59, fig.1, pl.62, fig.5.

Spyrid gen. et sp. indet. Riedel and Sanfilippo 1978a, pl.4, fig.1.

Description: Similar to *Gorgospyris* sp. aff. *perizostra* but with a well developed apical dome and a fully developed hemispherical thorax, the shell outline being similar to *Cubotholus rhombicus*. Pores over the entire shell surface are irregular in size, distribution, and shape but generally sparse.

Dimensions: Based on six specimens. Height of apical dome 21-27: of cephalis 31-39: of thorax 31-39. Maximum breadth of apical dome 43-51: of cephalis 66-81: of thorax 47-70.

Remarks: Distinguished by the well developed apical dome and hemispherical thorax.

Recorded range: The forms illustrated by Riedel *et al.* (1974) and Riedel and Sanfilippo (1978a) are from the Sicilian lower Pliocene.

Observed range: Five occurrences (one tentative) in samples which are all from upper Tongaporutuan sediments in northern Hawkes Bay.

Genus *Gorgospyris* Haeckel 1881

Acanthodesmiidae with a bilocular cephalis, without apical cupola or dome or thorax. With seven to twelve or more basal feet. No apical horn.

Type-species: *Gorgospyris medusa* Haeckel 1887

Note: Used herein to differentiate with *Desmospyris* whose forms have a definite thorax.

Gorgospyris sp. aff. *perizostra* Sanfilippo and Riedel

Plate 15, figure 13: Plate 18, figure 6

? *Gorgospyris perizostra* Sanfilippo and Riedel 1973: in Sanfilippo, Burckle *et al.* 1973, p.218, pl.3, figs.4,5.

Description: Shell anteroposteriorly compressed, horse-shoe shaped in outline. No externally expressed sagittal constriction. On the apical surface of the shell, about three lamellar ridges run transversely to the plane of the sagittal ring and extend slightly above the space normally expressed as the sagittal constriction. Shell wall smooth, perforated by subcircular rather sparse pores. Thorax (?) consists of a band of sparsely perforated shell connected to the cephalis along the basal edge parallel to the sagittal ring.

Dimensions: Based on three specimens. Length of shell including distal band 80-90. Height of sagittal ring 39-47. Maximum breadth of shell 54-58.

Remarks: Differs from *G. perizostra* in having a weaker thoracic development.

Recorded range: *G. perizostra* occurs in the early to middle Miocene *Calocycletta costata* and *Dorcadospyrus alata* Zones. It immediately succeeds *G. schizopodia* in the Pacific sequence, and may have evolved directly from it (Sanfilippo *et al.*, 1973). The form described herein may be the Upper Miocene representative of a long lineage.

Observed range: Rare with only five positive identifications all in upper Tongaporutuan sediments near the local incoming of *B. compressa sensu stricto*. Two tentative identifications in samples with *G. dehiscens* (LT05, LT06).

Genus *Phormospyris* Haeckel 1881

Acanthodesmiidae with bilocular cephalis and sagittal constriction but without apical cupola. Thorax present. Three basal feet.

Type-species: *Phormospyris tricostata* Haeckel 1887

Phormospyris stabilis (Goll) *antarctica* (Haecker) group Plate 17, figures 1,2: Plate 18, figures 9,11

Phormospyris antarctica Haecker 1907, p.124, fig.9.

Triceraspyris antarctica (Haecker): Riedel 1958, p.230, text-figs.3-5, pl.2, figs.6,7.

Triospyris antarctica Goll and Bjorklund 1974, text-fig.8.

Triceraspyris antarctica (Haecker) group: Petrushevskaya 1975, p.593, pl.8, fig.1.

Triceraspyris antarctica (Haecker): Petrushevskaya 1975, pl.27, figs.1,2.

Tristylospyris sp. cf. *antarctica* Petrushevskaya 1975, pl.27, fig.3.

Desmospyris (?) *haysi* Petrushevskaya 1975, p.593, pl.27, figs.4-5 (only).

Phormospyris stabilis (Goll) *antarctica* (Haecker): Nigrini and Moore 1979, p.N17, pl.20, figs.1a-d.

Description: Shell heavy, nut-shaped, with unequal rounded pores, generally smooth surface, and a slight or pronounced sagittal constriction. Four large basal pores. Three basal feet, three-bladed or circular in section normally one half as long as the cephalis. Rare signs of thoracic lattice work.

Dimensions: Height of sagittal ring 63-90. Maximum breadth of bilocular cephalis 80-125 (Riedel, 1958).

Remarks: All forms with large pores (generally larger than the intervening bars on the cephalis) with three feet are placed in this subspecies. Other forms which have smaller pores (almost a plate perforate wall) on the cephalis are referred to *P. stabilis scaphipes*. Transitional forms are present.

Recorded range: Miocene to Recent (Petrushevskaya, 1975).

Observed range: Sporadic occurrences throughout Late Neogene. Tends to be more abundant in southern Miocene sections.

Geographic distribution: "exclusively southern cold-water species" (Riedel, 1958).

"It has the distribution which is characteristic of the Antarctic assemblage" (Lozano, 1974, southern Atlantic/Indian Ocean).

"This species loads highest in factor 2 (polar). At present it is most abundant under polar waters south of 45°S" (Morley, 1977, south Atlantic).

Phormospyris stabilis (Goll) *scaphipes* (Haeckel) group

Plate 18, figures 10,12

Tristyllospyris scaphipes Haeckel 1887, p.1033, pl.84, fig.13.

Tholospyris scaphipes (Haeckel): Goll 1969, p.328, pl.58, figs.1-8,13,14.

Phormospyris stabilis (Goll) *scaphipes* (Haeckel): Nigrini and Moore 1979, p.N19, pl.20, figs.2a-d.

Description: Similar to *P. stabilis antarctica* group in shell outline and size. All specimens with average bar width larger than the average pore size on the parts of the cephalic wall farthest away from the sagittal ring are referred to this subspecies.

Recorded range: Miocene (from some of the Acanthodesmiidae gen. et sp. indet. of Kling (1973)) to Recent.

Observed range: Rare occurrences throughout Miocene and Pliocene up to the LAD of *C. molestus* at Waiatai. Too rare to be of use biostratigraphically.

Geographic distribution: "is abundant north of the Antarctic Convergence and is absent north of latitude 15°N" (Goll and Bjorklund, 1971, Atlantic Ocean, *Tholospyris scaphipes*).

Family *Carpocaniidae* Haeckel 1881

emended Riedel 1967a

Cephalis small, not sharply distinguished in contour from the thorax, and tending to be reduced to a few bars within the top of the thorax.

Genus *Carpocanarium* Haeckel 1887

sensu Riedel and Sanfilippo 1971

Carpocaniidae with hemispherical cephalis, distinct collar stricture, ovate thorax with rather few, rather large pores and occasionally three short spine-like wings in its proximal half, and a poreless subcylindrical peristome which in some specimens is irregularly terminated to give the impression of a corona of teeth.

Type-species: *Carpocanium calycothes* Stohr 1880

Carpocanarium papillosum (Ehrenberg)

Plate 20, figures 1,2

Eucyrtidium papillosum Ehrenberg 1872a, p.310: 1872b, pl.7, fig.10.

Carpocanium calycothes Stohr 1880, p.96, pl.3, fig.8.

Dictyocephalus papillosus (Ehrenberg): Haeckel 1887, p.1307.

Dictyocephalus papillosus (Ehrenberg): Riedel 1958, p.236, pl.3, fig.10, text-fig.8.

Tricolocapsa papillosa (Ehrenberg) group: Petrushevskaya 1975, p.588, pl.13, fig.13.

Carpocanarium papillosum (Ehrenberg) group: Nigrini and Moore 1979, p.N27, pl.21, fig.3.

Description: Cephalis approximately hemispherical, with small scattered, subcircular pores; set off from the thorax by a change in contour. Some specimens have a small, inconspicuous lateral tubule projecting slightly from the cephalis near its junction with the thorax. Thorax ovate, usually with a rough surface, and with a conspicuous subcylindrical or flared hyaline peristome surrounding the mouth which is approximately one-half to two-thirds as broad as the thorax. Thoracic pores subcircular to circular, in a subregular hexagonal arrangement separated by rather wide, often thick, intervening bars.

Dimensions: Length of cephalis 18-25; of thorax (including peristome) 60-90. Maximum breadth of thorax 58-70 (Riedel, 1958).

Remarks: None of the specimens show signs of "three, usually conspicuous longitudinal ribs, which in many specimens terminate in three short, solid, triangular lateral wings at or above the level at which the thorax reaches its maximum breadth" (Riedel, 1958).

Recorded range: Miocene to Recent (Petrushevskaya, 1975).

Observed range: Relatively common throughout Late Neogene. More sporadic in upper Pliocene and Pleistocene samples.

Geographic distribution: "Bimodal distribution: present in most samples north of about 15°S and very rare in three samples between about 37°S and 41°S" (Johnson and Nigrini, 1980, western Indian Ocean).

"very sparsely distributed in both low and middle latitudes, never forming more than 1% of the described population" (Nigrini, 1967, Indian Ocean).

Carpocanarium sp. A

Plate 20, figure 3

Description: Rare forms very similar to *C. papillosum* but without the distinctive poreless peristome and tending to have smaller, more widely spaced, thoracic pores are referred to this species.

Observed range: Same distribution as *C. papillosum*.

Genus *Carpocanistrum* Haeckel 1887
emended herein

Carpocaniidae with a campanulate-ovate shell, without radial ribs. Cephalis entirely lost, no apical horn. Mouth with a corona of radial feet. Emended herein to include forms with very rudimentary, if any, terminal feet.

Type-species: *Carpocanistrum evacuatum* Haeckel 1887 : designated by Riedel and Sanfilippo 1971

Carpocanistrum sp. A

Plate 17, figures 3,5,8; Plate 20, figure 5

Description: Shell consisting of a cap-shaped cephalis and thorax, cephalis normally hidden at the top of the thorax. Thorax subspherical; pores subcircular, hexagonally arranged. Some forms have an indefinite longitudinal arrangement transitional with *Cystophormis* sp. A (Plate 17, figure 8). Peristome hyaline, variable from a short cylindrical tube surrounding a very constricted (10μ) mouth (Plate 17, figure 5) to a narrow band surrounding a constricted mouth (Plate 17, figure 3). Termination sometimes undulatory giving the impression of terminal teeth.

Dimensions: Based on eight specimens. Total length of shell (including peristome) 82-100. Maximum breadth 78-90.

Remarks: Distinguished by the hexagonal pore arrangement and toothless peristome. The form with a very constricted mouth is similar to *Carpocanistrum* (?) *odysseus* (Haeckel) as illustrated by Dumitrica (1973, pl.15, fig.10).

Observed range: Tabulated in three forms. The "toothless" form has sporadic occurrences throughout the Late Neogene. The "toothed" form is found in only seven samples from LT06 (with *G. dehiscens*) to WA19 (about 105m above the LAD of *C. molestus*). The form with the very constricted mouth is rarer than the "toothless" form but has a similar distribution, its highest occurrence being in the Mangapanian at Waiatai.

Genus *Cystophormis* Haeckel 1887
emended herein

Carpocaniidae with an ovate or urn-shaped to campanulate shell. Radial ribs present. Mouth constricted. Without apical horn. Emended herein to include forms with terminal teeth as well as those without teeth.

Type-species: *Cystophormis pila* Haeckel 1887 : designated by Campbell 1954

Cystophormis sp. A

Plate 17, figures 6,7,9; Plate 20, figure 4

Carpocanistrum spp. Riedel and Sanfilippo 1971, pl.1G, figs.2,8,12 (only).

Description: Shell consisting of a cap-shaped cephalis and a thorax; cephalis hidden at the top of the thorax, a few specimens show a slight change in contour on the surface at the collar stricture. Thorax generally ovate to subspherical. Thoracic pores slightly larger than

cephalic pores, elliptical to subcircular, aligned in longitudinal rows (11 to 18 rows on the half circumference) separated by prominent longitudinal ridges which are generally twice as broad as the pores. Mouth constricted, in most specimens surrounded by a hyaline peristome commonly with approximately 12, flat, sharp, triangular teeth which are slightly inwardly converging. In some specimens a smooth rounded peristome is present. In poorly preserved specimens the peristome is etched with furrows which appear to be extensions of the longitudinal ridges.

Dimensions: Based on 15 specimens. Length of shell (including peristome) 95-115. Length of cephalis approximately 10.

Remarks: Some forms with a large number of longitudinal rows approach *Carpocanistrum* (?) *azyx* Sanfilippo and Riedel 1973, p.530, pl.35, fig.9.

Recorded range: The forms figured by Riedel and Sanfilippo (1971) come from the *Didymocyrtis antepenultima* Zone, *Stichocorys peregrina* Zone and Quaternary of DSDP Site 66 (western tropical Pacific).

Observed range: Tabulated in two forms. The "toothed" form occurs rarely throughout the upper Neogene, the highest occurrence being in the Mangapanian at Waiatai. More sporadic in the Pliocene than Miocene. The "toothless" follows the distribution of the "toothed" form but is rarer and occurs in Pleistocene sediments. Too rare to be of use biostratigraphically.

Cystophormis sp. B

Plate 17, figure 4

Description: Very similar to *Cystophormis* sp. A but the thorax is divided into three longitudinal sections at the cephalic end and there are about 20 longitudinal rows of smaller pores with relatively wide intervening bars.

Remarks: Similar (in part) to Nigrini and Moore's (1979, p.N25) description of *Carpocanistrum* sp. A where "primary lateral and dorsal spines extend to the thoracic wall and draw it inwards, thus making the upper part of the shell trilobate".

Observed range: Only two positive identifications and three tentative. Specimens have probably been identified as *Cystophormis* sp. A. because the tri-lobes are hard to see under transmitted light. All occurrences are upper Tongaporutuan but too rare to be of use biostratigraphically.

Family *Theoperidae* Haeckel 1881

emended Riedel 1967a

Cephalis relatively small, approximately spherical, often poreless or sparsely perforate. The internal spicule, homologous with that of the plagoniids, is reduced to a less conspicuous structural element than in the latter group. A large, probably polyphyletic, group containing the majority of ordinary cap or helmet-shaped nassellarians (Kling 1978).

Genus *Cornutella* Ehrenberg 1838
emended Nigrini 1967

Theoperidae with conical skeleton, gradually dilated to a wide open mouth. Apex armed with a horn. Cephalis very small, rudimentary, hyaline, without distinct collar septum. Ehrenberg and Haeckel regarded members of this genus as monocyrtid. Nigrini (1967) emended the genus to be best regarded as dicyrtid.

Type-species: *Cornutella clathrata* Ehrenberg 1938

Cornutella profunda Ehrenberg

Plate 17, figures 10,11: Plate 20, figure 6

Cornutella clathrata β *profunda* Ehrenberg 1854, pl.35B/IV, fig.21.

Sethoconus profundus Haeckel 1887, p.1294.

Sethoconus woodfordi Campbell and Clark 1944, p.43, pl.6, fig.9.

Cornutella profunda Ehrenberg: Riedel 1958, p.232, pl.3, figs.1,2.

Cornutella profunda Ehrenberg: Nigrini 1967, p.60, pl.6, figs.5a-5c.

Cornutella profunda Ehrenberg: Petrushevskaya and Kozlova 1972, p.551, pl.30, figs.18-20 (figs. under *Cornutella* β *profunda* group).

Cornutella profunda Ehrenberg group: Petrushevskaya 1975, p.587, pl.13, figs.32,33.

Cornutella profunda Ehrenberg: Keany and Kennett 1975, pl.2, fig.5.

Description: Skeleton slender, conical, with smooth surface. Cephalis small, hyaline, poreless. Apical horn never preserved but there is often a small bulbous stub at the apex. Subcircular pores of the thorax are regularly arranged in alternating latitudinal rows. Aperture always broken but is reported to be irregular. Most specimens are slightly contracted at the distal end. Appears to be two distinct populations, one with three pores on the half equator and the other with six.

Dimensions: Based on ten specimens. Length of cephalis 9-12: of thorax 124-160. Maximum breadth of thorax 30-50.

Remarks: This appears to be the one common, widespread species of a probably conspecific group described by Ehrenberg and Haeckel (Riedel, 1958) and this was confirmed by Nigrini (1967) after she viewed the topotypic material. Riedel (1958) notes that some specimens appear to have a heavier wall, with wider intervening bars which are slightly contracted in the distal one third or one quarter. These specimens are the predominant form found here probably because of the increased preservation potential due to their heavier walls.

Recorded range: Miocene to Recent (Petrushevskaya and Kozlova, 1972).

Observed range: Most common form is the "six-pored" form. Found in 37% of radiolarian-bearing samples studied throughout Late Neogene. Tends to get rarer through the Upper Tongaporutuan becoming sparse in the Plio-Pleistocene. The "three-pored" form is not as common but its distribution is the same as that of the "six-pored" form.

Geographic distribution: Widespread occurrence in the Indian Ocean (Riedel, 1958; Nigrini, 1967) and localities in tropical parts of the Pacific and northern Pacific (Riedel, 1958). Appears to be cosmopolitan.

Genus *Plectopyramis* Haeckel 1881

Theoperidae with numerous straight or slightly curved radial ribs in the wall of the pyramidal thorax. Network double, the large primary meshes being fenestrated by a fine secondary network. Cephalis commonly without horn. Without outer mantle.

Type-species: *Polycystina magnifica* Haeckel 1887

Plectopyramis dodecomma Haeckel

Plate 17, figures 12,13: Plate 20, figures 7,8

Plectopyramis dodecomma Haeckel 1887, p.1258, pl.54, fig.6.

Bathropyramis woodringi Campbell and Clark 1944, p.39, pl.5, figs.21,22.

Plectopyramis dodecoma Haeckel: Keany and Kennett 1975, pl.1, fig.15.

Plectopyramis dodecomma Haeckel: Keany 1979, pl.4, fig.11.

Plectopyramis dodecomma Haeckel: Nigrini and Moore 1979, p.N31, pl.21, fig.5.

Description: Test consisting of small, sub-hemispherical, poreless cephalis, without apical spine preserved and a smooth, long, conical thorax, broad at the base, consisting of 8-11 heavy, longitudinal bars or ribs, subcircular in section and joined by transverse bars that are continuous around the circumference. Thoracic pores subrectangular, increasing in size distally; in the proximal half the pores are either infilled with silica or by a thin, reticulate, secondary meshwork. Some forms taper and others flare slightly at the distal end.

Dimensions: Based on 10 specimens. Maximum length of skeleton 310: of cephalis 10. Maximum breadth of thorax 200: of cephalis 8.

Remarks: Differs from *Peripyramis circumtexta* Haeckel in the absence of branched spines arising from the thorax and in the presence of transverse bars that are continuous around the circumference. Rare forms with transverse bars that are not continuous around the circumference (transitional with *Peripyramis circumtexta*) are referred to as *Peripyramis* cf. *circumtexta*.

Recorded range: Neogene (Keany, 1979).

Observed range: Found in 42% of the radiolarian-bearing samples studied from throughout the Late Neogene. The form transitional with *Peripyramis circumtexta* is found in five samples, four in Upper Mangaopari Section and one with *G. dehiscens* at Kaiti (KB01).

Geographic distribution: Cosmopolitan.

Genus *Dictyophimus* Ehrenberg 1847a

emended Nigrini 1967

Theoperidae with three complete thoracic ribs, prolonged into three solid divergent wings. Cephalis with an apical horn. Members of this genus are regarded as tricyrtid. Haeckel and Ehrenberg thought them to be dicyrtid.

Type-species: *Dictyophimus crisiae* Ehrenberg 1854a : designated by Nigrini 1967

Dictyophimus hirundo (Haeckel) group

Plate 19, figures 1,2: Plate 20, figures 10-12

Pterocorys hirundo Haeckel 1887, p.1318, pl.71, fig.4.

Pterocorys hirundo Haeckel: Riedel 1958, p.238, pl.3, fig.11, pl.4, fig.1.

Dictyophimus hirundo (Haeckel) group: Petrushevskaya 1975, p.583.

Dictyophimus hirundo (Haeckel) group: Nigrini and Moore 1979, p.N35, pl.22, figs.2,3a,3b,4.

Description: Cephalis subglobular, with smooth surface, and numerous small pits which are probably small pores infilled with silica. Apical horn thin, vertical, eccentrically situated, sometimes as long as the thorax but normally broken. Thorax truncate-conical to slightly campanulate with large subcircular to circular pores arranged in irregular longitudinal rows; its surface bearing short thorn-like spines. Abdomen normally only consisting of one, maybe two, rows of subcircular pores preserved in discontinuous patches below the lumbar stricture. No peristome observed. In the wall of the thorax are three weak ribs, continuous with three three-bladed, acute, divergent, straight or slightly curved feet.

Dimensions: Length of apical horn 7-36: of cephalis 16-27: of thorax 30-70: of feet 35-125. Breadth of thorax 50-90 (Riedel, 1958).

Remarks: Distinguished by its relatively large pores, truncate-conical thorax, and straight feet. *D. crisiæ* Ehrenberg has an unusually robust shell and the appendages are definitely wings, not feet and project from the thorax above the lumbar stricture.

Recorded range: Miocene to Recent (Petrushevskaya, 1975).

Observed range: Relatively common throughout the Late Neogene.

Geographic distribution: May be cosmopolitan (Riedel, 1958).

Genus *Pseudodictyophimus* Petrushevskaya 1971c

Theoperidae with three complete thoracic ribs, prolonged into three solid divergent wings. Cephalis with an apical horn. Erected by Petrushevskaya to include only two segmented forms in the one genus after Nigrini emended the genus *Dictyophimus* to include three segmented forms.

Type-species: *Dictyophimus gracilipes* Bailey 1856

Pseudodictyophimus gracilipes (Bailey)

Plate 21, figure 1

Dictyophimus gracilipes Bailey 1856, p.4, pl.1, fig.8.

Dictyophimus gracilipes Bailey: Riedel 1958, p.233, pl.3, fig.5.

Pseudodictyophimus gracilipes (Bailey): Petrushevskaya 1971c, p.93, figs.47-49.

Pseudodictyophimus gracilipes (Bailey): Riedel, Sanfilippo and Cita 1974, p.709, pl.59, fig.8.

Pseudodictyophimus gracilipes (Bailey): Bjorklund 1976, pl.9, figs.1-5, pl.11, figs.6,7.

Pseudodictyophimus sp. aff. *P. gracilipes* (Bailey): Bjorklund 1976, pl.16, figs.1-5.

Description: Two segmented shell with subglobular to cap-like cephalis, rarely thorny, with scattered relatively large circular to subcircular pores; bearing an eccentric apical spine. Thorax campanulate to truncate-conical, in some specimens constricted distally; thoracic pores subcircular to subelliptical, variable in size. In thorax wall three ribs which are prolonged to form three, divergent, three-bladed, convex outwards feet. Rare specimens have a lattice mantle covering the cephalis and thorax with no constriction.

Dimensions: Based on 8 specimens. Length of apical horn 7-55: of cephalis 13-35: of thorax 25-40: of feet 27-95. Breadth of cephalis 30-46: of thorax 48-70.

Recorded range: Bjorklund (1976) finds forms with affinities to *P. gracilipes* from the upper Oligocene to Recent (DSDP Site 338, Norwegian Sea).

Observed range: Restricted to Tongaporutuan samples.

Genus *Lychnocanium* Ehrenberg 1847a
emended herein

Theoperidae with two chambers, a transverse stricture separating the first and second segments. Open triradiate, three feet, all acute, solid, without ribs. Second segment simply latticed. Emended herein to include only those forms with a distinct collar stricture and a globe shaped thorax. Emended by Riedel (1959) to include forms with two feet.

Type-species: *Lychnocanium falciferum* Ehrenberg 1854a : designated by Campbell 1954

Lychnocanium sp. aff. *grande* Campbell and Clark
Plate 19, figures 3-5: Plate 21, figures 3,4

Lychnocanium grande Campbell and Clark 1944, p.42, pl.6, figs.3,6 (only).

Lychnocanium cf. *grande* Campbell and Clark: Nakaseko 1955, p.100, pl.8, figs.6a,6b,7.

Lychnocanium sp. aff. *L. grande* Campbell and Clark: Petrushevskaya 1975, pl.12, fig.4.

Lychnocanoma sp. Chen 1975, p.462, pl.1, figs.8,9 (plates under *Lychnocanium* sp.).

Description: Cephalis hemispherical, with small subcircular pores arranged subhexagonally (frequently infilled); bearing a stout, cylindrical, sharp, central apical horn up to three times the length of the cephalis. Collar stricture very distinct with an abrupt change in contour. Thorax hemispherical to cupola-shaped (subconical above, inflated below). Thoracic pores hexagonally arranged and framed, increasing slightly in size distally, circular, 8-10 in a vertical tier. Mouth slightly constricted surrounded by a narrow, heavy, hyaline peristome. Rarely a flat plate of pore bearing shell surrounds the peristome. Three basically thick, three bladed feet emerge from the thorax immediately below its broadest part. Feet range from being nearly straight and vertical to convex-outward curved and divergent.

Dimensions: Based on ten specimens. Length of apical horn 19-52: of cephalis 14-23: of thorax: 57-80: of feet 97-129. Maximum breadth of cephalis 32-36: of thorax 88-110.

Remarks: Differs from typical *L. grande* in that the feet are normally convexly-outward curved. In other respects very similar to the species described by Campbell and Clark (1944).

Recorded range: *L. grande sensu stricto* ranges from at least the *Calocycletta costata* Zone (Kling, 1973, *Lychnocanoma grande*). The upper limit of this species in Antarctic cores is approximately upper Gauss (Bandy, Casey, and Wright, 1971), at the same level as determined from the equatorial core V-24-59 by Casey and Reynolds (1980). However, the LAD is recorded in basal Epoch 5 in the Newport Section, California by Weaver, Casey, and Perez (1981). Kling (1973, *Lychnocanoma* sp. cf. *L. grande*, pl.4, figs.9,10) records forms from sediments younger than 0.9 Ma in the eastern North Pacific.

Observed range: Tabulated into two forms. The form with diverging feet has its highest positive occurrence in sample SMR2 which is close to the FAD of *G. inflata* (middle Opoitian). Occurs commonly below this level. One tentative occurrence at Waiatai (WA17) could be an aberrant form of *Lychnocanella conicum* which occurs in the same sample. The form with vertical feet is rarer but has a similar distribution although it never occurs above the FAD of *G. sphericomiozea*, disappearing at the Miocene/Pliocene unconformity at Mangapoike.

Geographic distribution: Cosmopolitan.

Genus *Lychnocanella* Haeckel 1887
sensu Petrushevskaya 1975

Theoperidae with two chambers, a transverse stricture separating the first and second segments. Open triradiate, three feet, all acute, solid without ribs. Second segment simply latticed. Includes only those forms with a pear-shaped thorax (after Petrushevskaya, 1975).

Type-species: *Lychnocanium lanterna* Haeckel 1887 : designated by Campbell 1954

Lychnocanella conicum (Clark and Campbell)
Plate 19, figure 6: Plate 21, figure 5

Lychnocanium conicum Clark and Campbell 1942, p.71, pl.9, fig.38.

Lychnocanella conica (Clark and Campbell): Petrushevskaya 1975, p.583, pl.12, figs.2,11-15.

Description: Similar to *Lychnocanium* sp. aff. *grande* but differs in two respects: the collar stricture is not as pronounced externally giving the thorax a pear-shaped outline, and although some forms with long feet are present, most of the specimens have short feet.

Dimensions: Based on seven specimens. Length of apical horn 19-23: of cephalis 23-32: of thorax 49-62: of feet 45-48 (atypical 125). Maximum breadth of cephalis 36-39: of thorax 100-106.

Remarks: Distinguished by the distinctive pear-shaped thorax. Similar to the genus type-species *Lychnocanium lanterna* Haeckel.

Recorded range: "Antarctic Oligocene specimens *forma typica* are larger, have a thicker skeleton, and more pores (8-10 between two feet) than smaller Miocene specimens which have only 6-7 pores" (Petrushevskaya, 1975). The forms described herein tend towards the Miocene pore number. Petrushevskaya (1975) mentions other Antarctic Miocene specimens with longer feet and more pores. These forms are "very similar to *L. grande*, but the thoracic pores are a bit larger, and the feet may be curved". This description corresponds well to the atypical "long feet" members of this species found in the samples studied.

Observed range: Found sporadically throughout the Late Neogene.

Geographic distribution: Cosmopolitan?

Genus *Archipilium* Haeckel 1881

Theoperidae with a single chamber (very small cephalis), without strictures, open triradiate; three simple lateral spines. Aperture margins smooth or truncate.

Type-species: *Archipilium orthoptermum* Haeckel 1887

Archipilium macropus (Haeckel)

Plate 21, figure 2

Sethopilium macropus Haeckel 1887, p.1203, pl.97, fig.9.

Archipilium sp. aff. *A. macropus* (Haeckel) group: Petrushevskaya 1975, p.584, pl.12, fig.9, pl.43, figs.3-5.

? *Archipilium* sp. aff. *A. macropus* (Haeckel) group: Renz 1974, p.788, pl.17, figs.11a,b.

Description: Shell has conical top and cylindrical bottom. Cephalis very small hemispherical, hidden in top of the shell. No apical horn. Thorax truncate-conical proximally and subcylindrical distally. Thoracic pores relatively large, subelliptical to subcircular in an irregular pattern which is nearly symmetrical about a line which bisects the angle made between two feet. Termination ragged. Three thoracic ribs prolonged into stout, sharp, long, cylindrical feet; thoracic ribs normally leave the shell about halfway down the shell.

Dimensions: Based on four specimens. Length of shell (cephalis and thorax) 52-67: of feet 22-79. Breadth of thorax where feet leave the shell 68-78: of thorax termination 44-52.

Remarks: "Some Miocene specimens are similar in shell outline and dimensions to *Dictyophimus archipilium*. The difference is in the absence of a distinct abdomen in *A. macropus*" (Petrushevskaya, 1975).

Recorded range: "This species-group exists from the latest Oligocene, being most numerous from the middle and late Miocene and Pliocene. In Quaternary they are rather rare" (Petrushevskaya, 1975).

Observed range: Rare occurrences (5) in the Tongaporutuan.

Genus *Cyrtocapsella* Haeckel 1887

Theoperidae with three or four segments and without radial apophyses. Very restricted mouth resembling a large terminal pore surrounded by a differentiated ring. A small apical horn is commonly present, and some specimens have an additional, usually more delicate, generally closed conical segment below the constricted one.

Type-species: *Cyrtocapsa tetrapera* Haeckel 1887 : designated by Campbell 1954

Cyrtocapsella japonica (Nakaseko)

Plate 19, figure 12: Plate 21, figures 6,8

Eusyringium japonicum Nakaseko 1963, p.193, text-figs.20-21, pl.4, figs.1-3.

Eusyringium isozakiense Nakaseko 1963, p.194, pl.4, figs.5-7,11,12.

Cyrtocapsella japonica (Nakaseko): Sanfilippo and Riedel 1970, p.452, pl.1, figs.13-15.

Cyrtocapsella japonica (Nakaseko): Nigrini and Lombardi 1984, p.N107, pl.23, figs.4a-c.

Description: Shell consisting of three segments increasing in width, with a constricted mouth. Cephalis spherical, poreless, rarely bearing a small thorn-like horn. Collar stricture indistinct because the base of the cephalis is generally enclosed in the thoracic wall. Thorax hemispherical. Abdomen slightly inflated distally, with a constricted mouth. Pores of thorax and abdomen generally similar, circular, usually closely spaced but occasionally sparser, rather regular in size and arrangement. Wall of abdomen and thorax thick, with rough surface. The lumbar stricture is not deep but is marked by a corresponding change in contour. Some specimens have an inverted truncate-conical fourth segment with thinner wall and less regular pores.

Dimensions: Based on 30 specimens. Total length (excluding horn and fourth segment) 110-135. Maximum breadth 55-100. Ratio of length of abdomen to length of thorax 1.2-3.4:1 (Sanfilippo and Riedel, 1970).

Remarks: Distinguished from *C. tetrapera* by having the aperture of the third segment constricted, rather than that of the fourth.

Recorded range: A variety of ranges have been recorded for this species (see Nigrini and Lombardi, 1984). The youngest occurrence is in the *Didymocyrtis antepenultima* Zone in the Sea of Japan (Ling, 1975).

Observed range: All positive identifications in Upper Tongaporutuan sediments but occurs tentatively in four other samples, one older (SPA1) and three younger Plio-Pleistocene samples (WA03, WA15, LT01). The form with the rounded abdomen, *C. japonica sensu stricto*, is found in only three northern Hawke's Bay samples; KB01 (with *G. dehiscens*), SMH1 (associated tuff 6.3 Ma) and HR04 (about 60m below the local FAD of *B. compressa sensu stricto*).

Cyrtocapsella tetrapera (Haeckel)

Plate 19, figures 10,13: Plate 21, figures 7,9

Cyrtocapsa tetrapera Haeckel 1887, p.1512, pl.78, fig.5.

Cyrtocapsella tetrapera Haeckel: Sanfilippo and Riedel 1970, p.453, pl.1, figs.16-18.

Cyrtocapsella tetrapera (Haeckel): Nigrini and Lombardi 1984, p.N109, pl.23, fig.5.

- see Sanfilippo and Riedel (1970) for extensive synonymy.

Description: Shell of four segments, with rounded to abruptly constricted termination. Cephalis spherical, poreless with a short eccentric apical horn (normally not preserved). Collar stricture moderately pronounced. Thorax conical to hemispherical; abdomen annular or inflated; fourth segment slightly inflated with an abrupt change in contour towards a constricted mouth. Second to fourth segments thick walled with subcircular to circular pores; rather irregular in size and arrangement. Strictures rather pronounced to indefinite. Some specimens have an inverted conical to hemispherical segment with a thinner wall and less regular pores attached to the constricted fourth segment.

Dimensions: Based on 35 specimens. Total length (excluding horn and fifth segment) 100-140. Length of thorax 25-45: of abdomen 25-40: of fourth segment 30-55. Maximum breadth 75-105 (Sanfilippo and Riedel, 1970).

Remarks: Some specimens with a moderately pronounced change in contour between the thorax and abdomen approach *C. cornuta* Haeckel. Forms with an abruptly constricted fourth segment are very similar to *Cyrtocapsa subconica* (Nakaseko 1955, p.120, pl.11, fig.9) which Sanfilippo and Riedel (1970) synonymised with *C. tetrapera*.

Recorded range: Riedel and Sanfilippo (1978b) define the lower limit of the *Cyrtocapsella tetrapera* Zone (early Miocene) by the first appearance of this species. Riedel and Sanfilippo (1971) and Holdsworth (1975, DSDP Site 289) show the last occurrence of this species to be near the top of the *Dorcadospyris alata* Zone (early middle Miocene). Theyer *et al.* (1978) date the first occurrence at 21.75Ma and the last occurrence at 11.95Ma, but DSDP Leg 85 results suggest that the latter date should be 12.4-12.7Ma (after Nigrini and Lombari, 1984). Sanfilippo and Riedel (1970, table 1) show rare occurrences up into the upper Miocene (at about the FAD of *Stichocorys peregrina*) and Holdsworth (1975) reports rare *C. tetrapera* forms higher than the top of the *Dorcadospyris alata* Zone. Kling (1973) notes the occurrence of *C. tetrapera* and *C. japonica* up into the *Didymocyrtis antepenultima* Zone (upper Miocene).

Observed range: Sporadic occurrences in Tongaporutuan. Rare in upper Tongaporutuan sediments (above the 20% five chambered *Globorotalia miotumida* level) and found in only one sample with *G. dehiscens* (LT06). This distribution pattern is especially pronounced in the Mangapoike Section. Both this species and *C. japonica* tend to be more abundant in Hawkes Bay sections.

Geographic distribution: "Common to abundant throughout the early Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombari, 1984, CENOP Project)

Genus *Cyrtolagena* Haeckel 1887 emended herein

Theoperidae with three or more strictures. Terminal mouth fenestrated. No solid lateral ribs but may have three rows of lateral spines or combs.

Type-species: *Cyrtolagena laguncula* Haeckel 1887

Note: The primary difference in the original definitions of *Cyrtolagena* and the related genera (*Stichophormis* and *Stichopera*) was the composition of the basal segment, i.e. either open or closed. It appears that there is an intergradation of forms with a wide, open mouth, a constricted mouth, and a fully closed mouth. Furthermore, specimens in sediments are often preserved with the basal segment missing, making generic placement difficult. Another important difference is in the makeup of the lateral spines, combs or ribs. Again the spines or combs are often lost in specimens from sediments. Herein the main distinguishing characteristic of this genera is the absence of the lateral ribs.

Cyrtolagena laguncula (Haeckel)

Plate 22, figure 1

Cyrtopera laguncula Haeckel 1887, p.1451, pl.75, fig.10.

Stichopera pectinata Haeckel 1887, p.1449, pl.75, fig.11.

Stichopera pectinata Haeckel group: Kling 1973, p.638, pl.3, figs.25-27, pl.10, figs.1-5.

Cyrtolagena laguncula Haeckel: Petrushevskaya 1975, p.583, pl.14, figs.3,4.

Theoperidae gen. et sp. indet. Riedel and Sanfilippo 1978a, pl.4, fig.6.

Cytopera laguncula Haeckel: Weaver, Casey and Perez 1981, pl.6, fig.6.

Description: Shell has a strongly conical outline. Cephalis subspherical with scattered small pores. Post-cephalic segments greater than nine in number, each segment of nearly equal length and very slightly inflated. Postcephalic pores circular to subcircular, arranged in a regular hexagonal pattern, two to three transverse rows per segment, increasing in size distally. Termination ragged. No lateral ribs. Very rare forms have a definite spiral structure.

Dimensions: Based on two specimens. Length of cephalis 16-17: of shell 94-130. Breadth of cephalis 15-16: of base of shell 43-55.

Remarks: In rare specimens the spiral nature of the postcephalic segments differs from the species as described by Haeckel but it appears to be so closely related in all other aspects that it is herein considered to be a variant of this species. No forms with a constricted last segment seen.

Recorded range: *Calocycletta costata* Zone to Recent (Kling, 1973, DSDP Site 173) and Miocene to Recent (Petrushevskaya, 1975). Riedel and Sanfilippo's (1978a) specimen is from the lower Pliocene of Sicily.

Observed range: Found in only four Tongaporutuan samples. The spiralling form was found in only one sample (RM07).

Geographic distribution: Cosmopolitan. Weaver, Casey and Perez (1981, p.75) regard this as a deep living species.

Genus *Stichophormis* Haeckel 1881

emended herein

Theoperidae with three or more strictures. Mouth wide open. Lateral ribs prolonged into terminal feet. Emended herein to include forms with a slightly constricted mouth.

Type-species: *Stichophormis pyramidalis* Haeckel 1887

Note: See remarks under the generic definition of *Cyrtolagena*.

Stichophormis cornutella Haeckel

Plate 19, figure 11

Stichophormis cornutella Haeckel 1887, p.1455, pl.75, fig.9.

Description: Very similar to *Cyrtolagena laguncula* but with six lateral, solid ribs projecting as cylindrical terminal feet. The feet project where the shell constricts slightly towards the mouth. All the specimens studied have more regular pore shape and pattern in the upper half of the shell. No spiralling forms seen.

Dimensions: Based on four specimens. Length of cephalis 18-19: of shell (excluding feet) 257-289: of feet about 50. Maximum breadth of shell 156-160.

Remarks: Differs from Haeckel's illustrated form in that the shell has a constricted mouth.

Observed range: Only one occurrence at Leader River (LT03).

Genus *Theocalyptra* Haeckel 1881

Theoperidae with a shell divided by two transverse strictures into cephalis, thorax, and abdomen. Abdomen discoidal, basal shell mouth open without basal apophyses. One or two apical horns.

Type-species: *Theocalyptra veneris* Haeckel 1887

Note: Nigrini and Moore (1979, p.N51) outline the problems involved with the generic placement of *bicornis* and *davisiana* into *Theocalyptra* (as opposed to the genus *Cycladophora*). Essentially the problem is related to poorly or non-illustrated type specimens.

Theocalyptra bicornis (Popofsky)

Plate 22, figure 4

Pterocorys bicornis Popofsky 1908, p.228, pl.34, figs.7,8.

Theocalyptra bicornis (Popofsky): Riedel 1958, p.240, pl.4, fig.4.

Clathrocyclas bicornis (Popofsky) group: Petrushevskaya 1975, p.586, pl.15, fig.26, pl.23, fig.2.

Theocalyptra bicornis (Popofsky): Chen 1975, p.462, pl.13, figs.1,2.

Theocalyptra bicornis (Popofsky): Keany 1979, p.56, pl.4, figs.1,2.

Theocalyptra bicornis (Popofsky): Nigrini and Lombardi 1984, p.N137, pl.26, figs.1a-c.

Description: Shell conical campanulate, consisting of two or three segments. Cephalis subglobose, with scattered small pores, bearing two three-bladed spines; approximately the same length as the cephalis. Collar stricture slight. Thorax conical proximally, campanulate distally, with subcircular to polygonal pores separated by narrow intervening bars. Pores increase in size distally, arranged in up to twelve transverse rows. Well preserved specimens have a third segment (?) marked by a flaring in the thorax wall and by an internal septal ring. This abdomen? normally consists of one transverse row of polygonal pores.

Dimensions: Based on 14 specimens. Length of cephalis 15-27: of thorax 80-97. Maximum breadth 95-120 (Riedel, 1958).

Remarks: Differs from *T. davisiana davisiana* in having lighter walls, larger thorax, and more prominent cephalic horns. Hays (1965) described a form under the name *Clathrocyclas bicornis*. Superficially it resembles *T. bicornis* but the length/width ratio of *C. bicornis* is less, it has a much thicker wall, and the internal structure differs.

Recorded range: Miocene to Recent (Petrushevskaya, 1975; Keaney, 1979). Middle Miocene to Recent (Chen, 1975)

Observed range: All positive identifications restricted to three southern Wairarapa sections: Mangaopari Stream, Morrisons and Ruamahanga sections close to the local FAD of *B. compressa*.

Geographic distribution: "seems to increase in relative abundance in a belt approximately coincident with the Antarctic Polar Front" (Lozano, 1974).

"At present it is most frequently found in samples from under the subantarctic waters" (Morley, 1977, south Atlantic).

"Present in all samples south of about 37°S. There is a similar, but diminutive, form in lower latitudes" (Johnson and Nigrini, 1980, western Indian Ocean).

Theocalyptra davisiana davisiana (Ehrenberg)

Plate 19, figure 8: Plate 22, figures 5,6

Cycladophora ? *davisiana* Ehrenberg 1861, p.297: 1873, pl.2, fig.11.

Theocalyptra davisiana (Ehrenberg): Riedel 1958, p.239, pl.4, figs.2,3, text-fig.10.

Diplocyclas (?) *davisiana* (Ehrenberg): Petrushevskaya 1975, p.587.

Cycladophora davisiana Ehrenberg: Chen 1975, p.459, pl.13, fig.3.

Cycladophora davisiana Ehrenberg: Weaver 1976a, p.117, pl.1, fig.4.

Cycladophora davisiana Ehrenberg: Keaney 1979, p.56, pl.4, figs.3,4.

Theocalyptra davisiana (Ehrenberg): Nigrini and Moore 1979, p.N57, pl.24, figs.2a,b.

Theocalyptra davisiana davisiana (Ehrenberg): Nigrini and Lombardi 1984, p.N139, pl.26, fig.2.

Description: Shell conical-campanulate of moderately heavy structure. Cephalis subglobose, with small sparse pores and bearing two short spines. Collar stricture slight. Thorax truncate-conical proximally, then flares slightly in the middle, then subcylindrical to truncate-conical distally. In some specimens an internal septal ring is present where the thorax begins to flare. Thoracic pores subcircular proximally, becoming polygonal distally, arranged in 7-8, indefinite, transverse rows. In some specimens a third? segment is present below a transverse septal ring. This abdomen? is short, truncate-conical, usually flared at a wider angle than the thorax, with one or two transverse rows of polygonal pores.

Dimensions: Based on seven specimens. Length of cephalis usually 17-25: of thorax 40-80: of abdomen: 15-35. Maximum breadth of shell 70-130 (Riedel, 1958).

Remarks: Shell is an irregular cone, made up of a cephalis with two prominent horns and a post-cephalic part with poorly defined segmentation and subcircular pores of variable size and arrangement. The subspecies *T. davisiana* (Ehrenberg) *cornutoides* Kling has a more regular conical outline.

Recorded range: Miocene to Recent (Petrushevskaya, 1975).

Pliocene to Recent (Chen, 1975; Keaney, 1979).

"Rare or absent in most of the Miocene sections examined from both tropical and temperate latitudes; common in the latest Miocene of DSDP Site 173" (Nigrini and Lombardi, 1984, CENOP Project).

Observed range: Sporadic occurrences throughout the Late Neogene.

Geographic distribution: "Its distribution does not show a preferentially latitudinal pattern but its lowest values of relative abundance occur under subtropical waters" (Lozano, 1974, Antarctic seas). Lozano also notes it is probably a deep living species.

Genus *Lampromitra* Haeckel 1881
emended herein

Theoperidae with shell divided into cephalis and thorax by a transverse stricture. Three divergent lateral ribs in wall of flat, conical, discoidal, or pyramidal thorax. With apical horn. Basal shell mouth open with a prominent spiny corona. Emended herein to include forms with the three lateral ribs absent or indefinitely expressed.

Type-species: *Lampromitra coronata* Haeckel 1887

Lampromitra butschlii (Haeckel)
Plate 22, figure 3

Dictyophimus butschlii Haeckel 1887, p.1201, pl.60, fig.2 (in part).

Dictyophimus cienkowskii Haeckel 1887, p.1200, pl.60, fig.1 (in part).

Description: Very delicate shell. Cephalis spherical with subcircular to polygonal pores, narrow intervening bars; surface rough with the bases of broken spines (?). Collar stricture very distinct, 90° change in shell contour. Thorax flatly conical with a number of radial beams connected by randomly scattered transverse and oblique beams of about the same thickness. Rare small spines arise from thoracic beams.

Dimensions: Based on one specimen. Height of cephalis 14. Breadth of cephalis 15. Length of thorax (minimum) 31. Breadth of thorax 46.

Remarks: The form described has the distinct spherical cephalis and collar stricture of *D. butschlii* and the irregular, large, polygonal pore pattern of *D. cienkowskii*.

Observed range: Rare occurrences throughout the Late Neogene.

Lampromitra erosa Cleve
Plate 22, figure 2

Lampromitra erosa Cleve 1900, p.10, pl.4, figs.2,3.

Lampromitra erosa Cleve: Dumitrica 1973, p.838, pl.24, figs.8,9.

non: *Lampromitra erosa* Cleve: Riedel, Sanfilippo and Cita 1974, pl.59, fig.13, pl.62, fig.7.

Description: Shell flatly conical. Cephalis subspherical, with collar stricture distinct. Apical horn small (if present). Cephalic pores small, irregular, subcircular. Thoracic pores irregular, circular to subelliptical, increasing in size distally. Termination ragged.

Dimensions: Based on three specimens. Length of cephalis 20-28. Breadth of cephalis 30-32: of thorax 113-142.

Remarks: *L. erosa* limited to those forms with a distinct cephalis. Forms with an indistinct cephalis are referred to *L. tiara*. Also differs from *L. tiara* in that the thoracic wall is heavier with wider intervening bars between the pores. No forms found with the distinctive double corona of downwardly and laterally directed branches around the peristome.

Recorded range: Dumitrica's (1973) specimens are from Quaternary sediments.

Observed range: Restricted to the Miocene but too rare (6 samples) to be of biostratigraphic use.

Lampromitra tiara Dumitrica

Plate 19, figure 7; Plate 20, figure 9

Lampromitra tiara Dumitrica 1973, p.838, pl.23, figs.9,10.

Lampromitra erosa Cleve: Riedel, Sanfilippo and Cita 1974, pl.59, fig.13, pl.62, fig.7.

? *Ceratocyrtis* sp. aff. *Cornutella cucullaris* Ehrenberg: Petrushevskaya 1975, p.591, pl.11, fig.2.

Description: Shell inflated conical. Cephalis subhemispherical, indistinct. Collar stricture externally expressed as only a slight change in contour. Apical horn small. Cephalic pores small, subcircular, scattered. Thoracic pores subcircular to rounded polygonal, increasing in size distally. In one specimen the thoracic pores show a fenestrated infilling with up to 13 subpores per pore (Plate 19, figure 7). Thoracic surface has common short, thornlike spines arising from the bar nodes. Termination ragged.

Dimensions: Based on one specimen. Length of shell 123. Maximum breadth of thorax (at base) 177.

Remarks: See *L. erosa*. No specimens found with peristome preserved. Petrushevskaya's (1975) specimen is narrower than typical *L. tiara*.

Recorded range: Dumitrica's (1973) specimens are from Quaternary sediments. Riedel, Sanfilippo, and Cita (1974) figure a specimen from the Sicilian lower Pliocene.

Observed range: Two forms tabulated. The "flaring" form is found sporadically throughout the Late Neogene. The "U-shaped" form is rare with one positive identification in sample WA19 (Mangapanian), all other occurrences being in the Tongaporutuan. More common in southern Wairarapa Tongaporutuan samples.

Genus *Theocampe* Haeckel 1887

emended Burma 1959

Theoperidae with shell divided by two transverse strictures into cephalis, thorax and abdomen. Without basal apophyses and basal shell mouth constricted. Swollen, ovate abdomen. No apical horn. Abdominal pores show a strong tendency to be arranged in a square horizontal and vertical grid.

Type-species: *Dictyomitra ehrenbergii* Zittel 1876 : designated by Campbell 1954

? *Theocampe* cf. *mongolfieri* (Ehrenberg)

Plate 19, figure 9

? *Eucyrtidium mongolfieri* Ehrenberg 1854a, pl.36, fig.18B.

? *Sethamphora mongolfieri* (Ehrenberg): Haeckel 1887, p.1251.

? *Sethamphora costata* Haeckel 1887, p.1251, pl.62, fig.3.

? *Sethamphora mongolfieri* (Ehrenberg): Riedel 1957, p.81, pl.1, fig.7.

? *Theocampe mongolfieri* (Ehrenberg): Sanfilippo and Riedel 1971, p.1601, pl.3E, fig.13.

Description: Cephalis and thorax merged together so as to obliterate collar stricture with scattered, subcircular to elliptical pores, irregular in size and pattern. No apical horn. Lumbar stricture indistinct. Abdomen truncate-ovate with about 12 transverse rows of subcircular pores, and also in about 11 longitudinal rows (on the half equator); separated by pronounced flat-topped ridges giving the pores a rectangular arrangement. Mouth one-third to one-half as wide as the maximum shell breadth. Termination ragged.

Dimensions: Based on one specimen. Length of cephalis and thorax 37: of abdomen 81. Maximum breadth 108.

Remarks: The outline of the shell is more similar to *Theocampe armadillo* (see Sanfilippo and Riedel 1971, p.1601, pl.3E, figs.3-6.) but is placed in *T. mongolfieri* because of the distinctive pore pattern. Differs from *T. mongolfieri sensu stricto* in having a small thorax with no externally distinct lumbar stricture. This specimen is only tentatively placed in this species due to the absence of a specimen visible under transmitted light.

Recorded range: Eocene (Riedel, 1957). The first appearance of *T. mongolfieri* marks the base of the *Theocampe mongolfieri* Zone (early Eocene) (Riedel and Sanfilippo, 1978b). Foreman (1973) has *T. mongolfieri* from early Eocene to the late Eocene *Thyrsoyrtis bromia* Zone.

Observed range: Only one specimen found in one sample, a reconnaissance sample stratigraphically very close to MS05 (Upper Mangaopari Section).

Genus *Eucyrtidium* Ehrenberg 1847a

emended Nigrini 1967

Theoperidae without radial apophyses. Ovate or spindle-shaped shell, the mouth of which is constricted and, rarely, may be prolonged into an irregular short terminal tube. Tube much less well developed than that of genus *Eusyringium*. Emended by Nigrini (1967) to include forms having a short terminal tube.

Type-species: *Lithocampe acuminata* Ehrenberg 1844a : designated by Frizzell (in Frizzell and Middour 1951)

Eucyrtidium acuminatum (Ehrenberg)

Plate 23, figures 3,7,9: Plate 26, figure 1

Lithocampe acuminatum Ehrenberg 1844a, p.84.

Eucyrtidium acuminatum (Ehrenberg): Ehrenberg 1847b, p.43.

Stichopilium annulatum Popofsky: Hays 1965, p.181, pl.3, fig.6 (in part).

Eucyrtidium acuminatum (Ehrenberg): Kling 1973, p.636, pl.4, figs.20-23.

Eucyrtidium acuminatum (Ehrenberg): Johnson 1974, p.550, pl.10, fig.15.

Eucyrtidium cienkowskii Haeckel group: Riedel, Sanfilippo and Cita 1974, p.710, pl.59, fig.11.

cf. *Eucyrtidium acuminatum* (Ehrenberg) group: Petrushevskaya 1975, p.581, pl.14, fig.28.

Eucyrtidium acuminatum (Ehrenberg): Nigrini and Moore 1979, p.N61, pl.24, figs.3a,b.

Description: Cephalis subspherical, simple, with scattered small subcircular pores. Short conical apical horn usually present. Rarely the primary lateral and dorsal spines become external, forming wings in the lower thorax, upper abdomen (see Plate 23, figure 7). Collar stricture indistinct. Thorax small, conical, sometimes very slightly inflated with scattered subcircular pores aligned more or less longitudinally. Lumbar stricture not indented externally. Abdomen and 4-5 post-abdominal segments of approximately equal length, expanding distally to a maximum breadth at about the lower second or third post-abdominal segment. Pores small, subcircular, arranged longitudinally, 4-6 per segment in a vertical row. Final segments with scattered, smaller, subcircular pores, taper abruptly to a constricted mouth with no peristome or terminal teeth, but rarely, with a short cylindrical terminal tube.

Dimensions: Total length 119-182. Diameter of cephalis 9-13. Length of thorax 9-18. Maximum breadth 63-81 (Nigrini, 1967).

Remarks: Complete specimens are rarely preserved. Distinguished by the indistinct lumbar stricture and maximum breadth at about the third post-abdominal segment.

Recorded range: Lower Pliocene to Recent (after Kling, 1973). Kling (1973, pl.10, figs.21-23) figures three specimens under *Eucyrtidium* sp. cf. *E. acuminatum*. Only the youngest one, from his unzoned interval (Upper Miocene), is considered to be like the forms described herein, the other two being referable to *E. cienkowskii*. Sanfilippo, Burckle *et al.* (1973, pl.5, fig.10) and Riedel and Sanfilippo (1978a, pl.4, fig.12) illustrate two forms from the Italian and Sicilian lower Pliocene. Both forms show no indentation at the lumbar stricture but are broadest at the first post-abdominal segment and are considered to be transitional between *E. acuminatum* and *E. cienkowskii* herein.

Observed range: Sporadic occurrences in Tongaporutuan. Only two occurrences in Plio-Pleistocene (one tentative).

Geographic distribution: "Very sparsely distributed in low latitudes, but is abundant in middle latitudes. It appears to be a reliable and potentially useful member of the middle latitude assemblage" (Nigrini, 1967, Indian Ocean).

"Patchy distribution, dominantly in Transitional waters" (Sachs, 1973, subarctic Pacific).

"It does not occur south of the Polar Front and is most abundant in the cores raised from beneath the warmest surface waters in the area." (Hays, 1965, Antarctic seas).

"Very rare in Antarctic and subantarctic Tertiary sediments" (Petrushevskaya, 1975).

Eucyrtidium cienkowskii Haeckel group

Plate 23, figures 4-6, 12; Plate 24, figures 5, 6

Eucyrtidium cienkowskii Haeckel 1887, p.1493, pl.80, fig.9.

Eucyrtidium sp. cf. *E. acuminatum*: Kling 1973, pl.10, figs.22, 23 (only).

Eucyrtidium cienkowskii Haeckel group: Sanfilippo, Burckle *et al.* 1973, p.221, pl.5, figs.9, 11 (only).

Eucyrtidium cienkowskii Haeckel group: Riedel and Sanfilippo 1978a, p.114, pl.4, fig.10 (only).

Eucyrtidium cienkowskii Haeckel group: Sakai 1980, pl.7, figs.9,10 (only).

Eucyrtidium asanoi Sakai 1980, pl.7, figs.13a,b,c,14a,b (only).

Eucyrtidium cienkowskii Haeckel group: Weaver, Casey and Perez 1981, pl.1, figs.6-8.

Eucyrtidium cienkowskii group Haeckel: Nigrini and Lombari 1984, p.N111, pl.23, fig.6.

Description: Very similar to *E. acuminatum* but with an externally distinct lumbar stricture and reaches maximum breadth at the first post-abdominal segment then tapers slightly distally.

Dimensions: Based on eight specimens. Length to end of fourth abdominal segment 148-178. Length of thorax 23-32. Maximum breadth 58-85.

Remarks: *Eucyrtidium asanoi* Sakai was separated because of the "longitudinal ridges separating pores into sets" and is considered to be partly conspecific as many forms present in the samples studied show both strongly and poorly developed longitudinal ridges and transitional forms.

Recorded range: *Dorcadospyris alata* Zone to *Didymocyrtis antepenultima* Zone (after Kling 1973).

Weaver, Casey and Perez (1981) have the morphologic top of the *E. cienkowskii* group in mid Epoch 14 from the Newport Bay Section, California.

"Common in the Early Miocene sections examined from tropical and eastern temperate latitudes. Rare in the Late Miocene sections examined from tropical and eastern temperate latitudes" (Nigrini and Lombari, 1984, CENOP Project).

Riedel and Sanfilippo (1978a) recorded *E. cienkowskii* from the Lower Pliocene of Sicily. Miocene (Petrushevskaya and Kozlova, 1972).

Observed range: Relatively common throughout Late Neogene. Sparser in the Plio-Pleistocene.

Eucyrtidium hexagonatum Haeckel

Plate 23, figure 10: Plate 26, figure 3

Eucyrtidium hexagonatum Haeckel 1887, p.1489, pl.80, fig.11.

Eucyrtidium hexagonatum Haeckel: Johnson 1974, p.551, pl.10, fig.14.

Eucyrtidium hexagonatum Haeckel: Renz 1974, pl.16, fig.3.

Eucyrtidium cienkowskii Haeckel group: Riedel and Sanfilippo 1978a, p.114, pl.4, fig.11 (only).

Eucyrtidium hexagonatum Haeckel: Nigrini and Lombari 1984, p.N115, pl.23, fig.8.

Description: Very similar to *E. acuminatum* but with an externally distinct lumbar stricture. Reaches maximum breadth at about the second or third post-abdominal segment.

Dimensions: Total length (excluding apical horn) 146-209. Diameter of cephalis 9-18. Length of thorax 9-18. Breadth of thorax 27-36: maximum breadth 72-128 (Nigrini, 1967).

Remarks: Distinguished from *E. cienkowskii* by a shorter thorax and reaching maximum breadth at the second or third post-abdominal segment. Rare forms are transitional between *E. hexagontum* and *E. cienkowskii* and between *E. hexagontum* and *E. acuminatum* but there is generally a distinctive difference between the representative populations of each species.

Recorded range: "Absent from all Early Miocene sections examined from both tropical and temperate latitudes. Usually absent in Late Miocene material examined" (Nigrini and Lombardi, 1984, CENOP Project).

Riedel and Sanfilippo (1978a) record this form from the Sicilian lower Pliocene.

Recorded from the Recent (see Nigrini and Moore, 1979, p.N63).

Johnson (1974) considers *E. hexagontum* to be related to *E. acuminatum*, the latter being the mid-latitude equivalent. They occur rarely in Pliocene and Quaternary cores. The first appearance datum of both species in the late Tertiary may prove to be useful stratigraphic datum planes but these levels were not determined for the DSDP Leg 22 cores because of the uncertain relationships of the various forms of the genus *Eucyrtidium*.

Observed range: Sparse occurrences throughout the Late Neogene. Tends to be rarer in Plio-Pleistocene.

Geographic distribution: "is rather sparsely distributed in low latitudes (1% to 4% of the described population), and is practically absent in middle latitudes. Though rather rare in Recent sediments, it appears to be a useful member of the low latitude assemblage" (Nigrini, 1967, Indian Ocean).

Eucyrtidium calvertense Martin

Plate 22, figure 10: Plate 23, figures 1,2: Plate 24, figure 1

Eucyrtidium calvertense Martin 1904, p.450, pl.130, fig.5.

Eucyrtidium calvertense Martin: Hays 1965, p.181, pl.3, fig.4.

Eucyrtidium calvertense Martin: Hays 1970, p.213, pl.1, fig.6.

Eucyrtidium calvertense Martin: Bandy, Casey and Wright 1971, pl.1, fig.1.

Eucyrtidium calvertense Martin: Kling 1973, p.636, pl.4, figs.16,18,19, pl.11, figs.1-5.

Eucyrtidium calvertense Martin: Casey and McMillen 1977, pl.2, fig.9.

Eucyrtidium calvertense Martin group: Sakai 1980, p.710, pl.7, figs.2a,b,4a-6b.

Eucyrtidium calvertense Martin: Keany 1979, p.56, pl.4, figs.7,8.

Description: Very similar to *E. inflatum* but distinguished from it by being broadest in the first post-abdominal segment. More specimens of this form are complete, tapering from the first post-abdominal segment to a subcylindrical peristome with longitudinally arranged subcircular pores but less distinct sharp-crested ridges between the pore rows.

Dimensions: Based on 65 specimens. Total length 175-220. Maximum breadth 90-110. Length of cephalis 10-17: of thorax 20-30 (Hays 1965).

Remarks: Rare forms are found with large pores in the collar stricture and with irregularly sized pores (similar to *Eucyrtidium vincentense* but with more strictures). Other rare forms are found that are transitional between these and *E. calvertense sensu stricto*. Kling (1973, p.637) shows histograms of the maximum breadth of specimens of *E. calvertense* and *E. matuyamai* (Hays), its evolutionary descendant. While absolute values are

not considered significant, there is a definite deviation from a stable average in the lineage. Kling showed the *E. calvertense* forms being narrower than approximately 109μ with *E. matuyamai* broader. Forms getting close to *E. matuyamai* occur in the youngest sediments studied.

Recorded range: The morphologic top of *E. calvertense* is at the base of the Olduvai Event (Keany, 1979, subantarctic) and mid-Olduvai in the tropics (McMillen and Casey, 1977). Bandy, Casey and Wright (1971, fig.5) show its first appearance to be middle Miocene although Riedel (in Hays, 1965) thinks this species may extend back to the Oligocene. Sakai (1980) reports its range up to the Quaternary at DSDP Site 436, but these

Upper Miocene to Lower Pliocene (Chen, 1975).

Sakai (1980) records the LAD of *E. inflatum* in the middle Miocene and Reynolds (1980) reports its disappearance before the FAD of *Diartus hughesi*.

Observed range: Highest occurrence in the lower Pliocene (Wainuioru SWR1). Rare but useful biostratigraphically. Transitional forms with *E. calvertense* have a range similar to *E. inflatum*.

Eucyrtidium punctatum (Ehrenberg) group

Plate 23, figures 11,13,14: Plate 24, figures 2-4

cf. *Lithocampe punctata* Ehrenberg 1844, p.84.

Lithocampe sp. Nakaseko 1955, p.116, pl.10, figs.6a,b.

Lithocampe heptacola Haeckel: Dumitrica 1973, p.839, pl.24, fig.10 (only).

Eucyrtidium punctatum (Ehrenberg) group: Sanfilippo, Burckle *et al.* 1973, p.221, pl.5, figs.15,16.

Eucyrtidium punctatum (Ehrenberg) group: Sanfilippo, Caulet and Riedel 1978, p.756, pl.1, fig.3.

Eucyrtidium punctatum (Ehrenberg) group: Riedel and Sanfilippo 1978a, p.114, pl.4, figs.14-16.

cf. *Lithocampe* sp. Nigrini and Moore 1979, p.N65, pl.24, figs.5a,b.

Description: Small, subspherical cephalis rarely bearing a short, stout apical horn. Collar stricture normally indistinct with the cephalis submerged into the top of the thorax. Thorax long, conical, attains the same width as the subsequent (3-5) subcylindrical segments. Lumbar stricture indistinct. Cephalic pores small, subcircular, scattered. Thoracic pores subcircular, subarranged in longitudinal rows. In rare smooth walled forms the thoracic pores are only slightly bigger than cephalic pores. Abdominal and post-abdominal pores subcircular, normally arranged either hexagonally or in slightly bifurcating longitudinal rows. Post-abdominal strictures normally indistinct, occasionally marked by a slight change in contour and/or a change in pore pattern and size. Last segment tapers abruptly to a constricted mouth (usually less than one-third of the shell diameter) surrounded by a narrow, hyaline peristome.

Dimensions: Based on ten specimens. Length of shell 137-184. Maximum breadth of shell 67-93.

Remarks: This group probably includes more than one species but is distinctive because of the long, conical thorax which attains the same width as the following subcylindrical segments. Nigrini and Moore's (1979) *Lithocampe* sp. from Recent sediments has 8 segments and could be a Recent descendant of pre-middle Pleistocene forms of *Eucyrtidium punctatum* like those described herein, those from the Miocene of Japan (Nakaseko, 1955) and similar forms from the Mediterranean early Miocene (Sanfilippo, Burckle *et al.*, 1973). Riedel and Sanfilippo (1978a) figure both five and seven segmented forms from the Lower Pliocene of Sicily. The forms with seven or more segments (e.g. Plate 24, figure 2) from the Miocene of New Zealand tend to be forms transitional with *E. cienkowskii*.

Recorded range: Lower and middle Miocene (Weaver and Dinkelman, 1978, DSDP Site 391A).

Early Miocene to Late Miocene/middle Late Pliocene? (Sanfilippo *et al.*, 1973). See Remarks.

Observed range: Present in 54% of the radiolarian-bearing samples examined from throughout the Late Neogene.

Geographic distribution: "sparsely distributed in low latitudes but is abundant (2% to 16% of the described population) south of 30°S. It appears to be a reliable and potentially useful member of the middle latitude assemblage" (Nigrini, 1967, Indian Ocean).

"belongs to a transitional assemblage derived by recurrent group analysis of North Pacific samples; has been observed rarely in a few tropical samples" (Nigrini, 1970).

"rarely found under subantarctic waters" (Lozano, 1974).

Eucyrtidium cf. *montiparum* Ehrenberg

Plate 22, figure 9: Plate 26, figure 2

(?) *Eucyrtidium montiparum* Ehrenberg 1873, p.230.; 1875, pl.9, fig.11.

(?) *Eucyrtidium* sp. aff. *E. montiparum* Ehrenberg: Petrushevskaya and Kozlova 1972, p.548, pl.26, figs.2-4.

Description: Cephalis hemispherical, poreless. Collar stricture indistinct. Thorax small, truncate-conical. Thoracic pores subcircular to circular, hexagonally arranged. Lumbar stricture distinct, step-like, with upper part of abdomen wider than lower thorax. Abdominal pores larger than thorax, less regularly arranged in upper abdomen. Post-abdominal segments subcylindrical (fourth segment may be truncate conical), occasionally inflated. Pores hexagonally arranged, subcircular to circular, 11-13 on half equator. Widest part of shell fourth or fifth segment. Strictures between abdomen and post-abdominal segments normally indistinct. Termination ragged, appears to taper inwards slightly in sixth or seventh segment.

Dimensions: Based on two specimens. Length of cephalis and thorax 22-29: of shell to end of fifth segment 125-132. Maximum breadth (fourth or fifth segment) 57-71.

Remarks: *E. montiparum sensu stricto* has more inflated segments.

Recorded range: Eocene (Petrushenskaya and Kozlova, 1972).

Observed range: Present in Tongaporutuan samples. Highest occurrence in basal Pliocene samples. Probably evolved into *Eucyrtidium* sp. A.

Eucyrtidium sp. A.

Plate 22, figure 7: Plate 25, figure 15

(?) *Eucyrtidium lagena* Haeckel 1862, p.325, pl.4, fig.11.

(?) *Stichopodium* (?) sp. group aff. *Eucyrtidium matuyamai* Hays: Petrushevskaya and Kozlova 1972, p.549, pl.26, figs.5,6.

Description: Cephalis hemispherical, bearing a very short apical horn. Collar stricture distinct. Thorax truncate-conical, slightly inflated near base; pores subcircular, hexagonally arranged. Lumbar stricture marked by slight change in contour. Abdomen truncate-conical. Abdominal and post-abdominal pores subcircular, irregular in size, subhexagonally arranged, increasing in size distally, intervening bars 0.5 to 0.1 times the large pore breadth. Post-lumbar strictures indistinct externally, sometimes oblique. Broadest part of shell in fourth segment. Post-abdominal segments subcylindrical, tapering inwards slightly. Termination ragged.

Dimensions: Length of shell to end of fourth segment 117. Maximum breadth of shell 63.

Remarks: Petrushevskaya and Kozlova (1972) synonymized their forms with *E. matuyamai* Hays (Kling, 1971, pl.1, fig.4) which has indistinct longitudinal ribbing and has a maximum breadth of 124 μ , while their form has a maximum breadth of 70-90 μ . The form described herein differs from that described by Petrushevskaya and Kozlova in that it has a relatively short abdomen. See remarks under *E. calvertense* for a more complete discussion of size ranges.

Recorded range: Pliocene (Petrushevskaya and Kozlova, 1972).

Observed range: Apart from two tentative Miocene occurrences (in samples TM20, TM21 above the local FAD of *B. compressa*), all other occurrences Plio-Pleistocene. See *E. montiparum*.

Eucyrtidium vincentense (Campbell and Clark)

Plate 22, figure 8

Eusyringium vincentense Campbell and Clark 1944, p.57, pl.7, fig.22 (plate spelling *vicentense*).

Description: Shell spindle-shaped. Cephalis hemispherical, partly hidden in thorax. Short, thorn-like apical horn. Collar stricture indistinct, marked by relatively large collar pores. Thorax truncate conical with small, scattered, circular pores. Lumbar stricture indistinct. Abdomen truncate-conical. Abdominal and post-abdominal pores subcircular, increase in size to maximum breadth of shell, subhexagonally arranged (10 on half equator), well separated, deep set. Post-lumbar stricture indistinct. Greatest breadth in middle of the shell (upper part fourth segment), above and below tapers with slight convexity. Termination an inverted truncate-conical peristome. Forms with smaller, more irregular pores referred to as *E. cf. vincentense* (Plate 25, figure 9).

Dimensions: Based on three specimens. Length of shell 145-156. Maximum breadth 70-81.

Remarks: Not a typical species of the genus.

Recorded range: Found in the Californian Miocene (Campbell and Clark, 1944).

Observed range: Both small and large pored forms found in only three Tongaporutuan samples. Too rare to be of biostratigraphic use.

Genus *Stichocorys* Haeckel 1881

Theoperidae without radial apophyses. Basal shell mouth open. Multisegmented, in which the first three or four segments constitute a conical upper portion of the shell and the subsequent segments (narrower than the greatest width of the conical portion) constitute a cylindrical lower portion. Apical horn small, simple.

Type-species: *Stichocorys wolffii* Haeckel 1887

Stichocorys peregrina (Riedel)

Plate 25, figures 2-5,7: Plate 26, figures 4,6,8

Eucyrtidium elongatum peregrinum Riedel 1953, p.812, pl.85, fig.2.

Stichocorys peregrina (Riedel): Sanfilippo and Riedel 1970, p.451, pl.1, fig.10.

Stichocorys peregrina (Riedel): Riedel and Sanfilippo 1978b, p.74, pl.9, fig.11.

Stichocorys peregrina (Riedel): Westberg and Riedel 1978, p.22, pl.3, figs.6-9.

Stichocorys peregrina (Riedel): Nigrini and Lombardi 1984, p.N133, pl.25, fig.6.

Description: Shell with seven (or more) segments distinctly separated by constrictions (commonly broken at the fifth or sixth joint). The first four segments form a conical section, the subsequent segments an approximately cylindrical section. Cephalis subspherical to spherical, with scattered small pores, and rarely bearing an eccentric straight or slightly curved horn of the same length. Thorax hemispherical having 9-11 subspherical, irregularly arranged pores on the half equator. Third segment truncate-conical to inflated, usually longer than any other. Fourth segment usually inflated. Segments subsequent to the fourth are generally shorter and narrower, subcylindrical to inflated. In well preserved specimens last segment normally subcylindrical, narrow, with scattered small subcircular pores.

Dimensions: Length of the first four segments 125-135. Greatest breadth (in the lower part of the third segment, or the middle of the fourth) 70-80. Breadth of cephalis 20: of thorax 35-40: of fifth segment 60-65. Length of cephalis 12-15: of thorax 20-25: of third segment 35-50: of fourth segment 30-40: of subsequent segments 20-45 (Riedel, 1953).

Remarks: "The upper conical part of the shell consists of three segments, and the fourth is equally robust. The third segment is long, truncate-conical and the thorax short" (Riedel and Sanfilippo, 1978b).

"The width of the top quarter of the fourth segment must be at least as great as the maximum width of the third segment" (Westberg and Riedel, 1978). The form illustrated by Sanfilippo and Riedel (1970, pl.1, fig.10) does not conform to this requirement but has the typical truncate-conical third segment of *S. peregrina*.

Kling (1973) also notes the presence of specimens with a less markedly conical third segment from DSDP Site 173 (North Pacific).

Recorded range: Riedel and Sanfilippo (1978b) define the lower limit of the *Stichocorys peregrina* Zone (Late Miocene) by the evolutionary bottom of *S. peregrina*. They define the upper limit of the *Spongaster pentas* Zone (Pliocene) by the last occurrence of *S. peregrina*.

Kling (1973) finds the extinction of *S. peregrina* at the base of the upper Pliocene *Lamprocyrtis heteroporos* (Hays, 1970) Zone with a radiometric-paleomagnetic age of 2.8 Ma.

Theyer *et al.* (1978) date the first occurrence of this species at 6.4 Ma and the last occurrence at 2.4 Ma.

Observed range: Found in 70% of the radiolarian-bearing samples examined including occurrences with *G. dehiscens* in Leader, Wainuioru, Kaiti, Ruakituri and Mangaopari samples.

Geographic distribution: "Abundant in all the Late Miocene material examined from both tropical and temperate latitudes" (Nigrini and Lombari, 1984, CENOP Project).

Stichocorys delmontensis (Campbell and Clark)

Plate 25, figures 1,6,8: Plate 26, figure 5

Eucyrtidium delmontense Campbell and Clark 1944, p.56, pl.7, figs.19,20.

Stichocorys delmontensis (Campbell and Clark): Sanfilippo and Riedel 1970, p.451, pl.1, fig.9.

Stichocorys delmontensis (Campbell and Clark): Riedel and Sanfilippo 1978b, p.74, pl.9, fig.10.

Stichocorys delmontensis (Campbell and Clark): Westberg and Riedel 1978, p.22, pl.3, figs.1-5.

Stichocorys delmontensis (Campbell and Clark): Nigrini and Lombari 1984, p.N129, pl.25, fig.4.

Description: Similar to *Stichocorys peregrina* but is distinguished from it in that the "third segment inflated-annular; rather than truncate-conical as in its direct evolutionary descendant, *S. peregrina*" (Riedel and Sanfilippo, 1978b).

Dimensions: Total length 200. Diameter of cylindrical abdomen 70 (Campbell and Clark, 1944).

Remarks: "The third segment is typically inflated annular, but specimens with conical third segments are admitted here if the fourth segment is not as wide as the third" (Westberg and Riedel, 1978).

Recorded range: Riedel and Sanfilippo (1978b) show the first occurrence of this species in the Early Miocene. The lower limit of the *Stichocorys peregrina* Zone (Late Miocene) is defined by the evolutionary transition from *S. delmontensis* to *S. peregrina*.

Theyer *et al.* (1978) date the first occurrence of this species at 20.6 Ma and the last occurrence at 6.1 Ma.

Observed range: Common in Tongaporutuan samples. Present in some lower Pliocene samples. Highest occurrence is at the LAD of *C. molestus* at Waiatai (WA23). Transitional forms mimic the distributions of both *S. peregrina* and *S. delmontensis*.

Geographic distribution: "Rare or absent throughout the Miocene sections examined from temperate latitudes. Abundant in all the Miocene sections examined from tropical latitudes" (Nigrini and Lombari, 1984, CENOP Project).

Stichocorys sp. A

Plate 26, figure 7

Description: Rare specimens of *Stichocorys* with a strange chamber arrangement in its upper portion.

Observed range: Found in only three northern Tongaporutuan samples (SCV1, RK02, RK04). Too rare to be of use biostratigraphically.

Genus *Gondwanaria* Petrushevskaya 1975

Theoperidae with a globe-shaped cephalis, settled on the "neck". Thorax cupola-shaped. Spines may form three ribs in the upper walls of the thorax. There are no real "sethoperid" plates connecting these three spines with the apical horn. Abdomen may be more or less developed (and divided from the thorax). Pores irregular or in longitudinal rows.

Type-species: *Sethoconus* (?) *dogeli* Petrushevskaya 1967

Gondwanaria dogeli (Petrushevskaya) group

Plate 26, figure 9

Sethoconus (?) *dogeli* Petrushevskaya 1967, p.95, pl.53, fig.1,2.

Lipmanella (?) *dogeli* (Petrushevskaya): Petrushevskaya and Kozlova 1972, p.542, pl.37, fig.10.

Gondwanaria dogeli (Petrushevskaya) group: Petrushevskaya 1975, p.585.

Sethoconus (?) *dogieli* (Petrushevskaya): Weaver 1976a, p.124, pl.1, fig.7.

Description: Cephalis subspherical, with three-bladed apical horn and scattered small pores. Collar stricture is a distinct "neck". Thorax cupola-shaped (conical above, inflated below) with normally at least one horizontal short three-bladed spine visible just above the broadest point. Lumbar stricture marked by a slight change in contour. Thoracic and abdominal pores large, subelliptical to circular, in a subregular pattern increasing in size distally. Termination ragged.

Dimensions: Average of three specimens. Length of cephalis and neck 40: of thorax 57: of shell 164. Maximum breadth 92.

Remarks: Differs from the other members of this genus by its overall campanulate shell outline, the indistinct subdivision into thorax and abdomen, and its large pores.

Very similar to *Lithomelissa campanulaeformis* Campbell and Clark (1944, p.41, pl.6, fig.1) but differs in being smaller (Campbell and Clark's form has thorax length 180, maximum breadth 180).

Recorded range: "This species appears in the Antarctic early Miocene in an atypical form, and is known to exist up to Recent" (Petrushevskaya, 1975).

Pliocene (Weaver, 1976a).

Pliocene to Quaternary (Petrushevskaya and Kozlova, 1972).

Observed range: Occurs in nine samples from throughout the Late Neogene.

Genus *Artostrobos* Haeckel 1887

sensu Petrushevskaya 1975

Theoperidae with a small cigar-shaped, not conical shell outline. No separation into a thorax and abdomen (two-segments). Included in the theoperids to accomodate *A. pretabulatus* which lacks the transverse pore alignment characteristic of the artostrobiids.

Type-species: *Cornutella annulata* Bailey 1856

"Artostrobos" pretabulatus Petrushevskaya

Plate 30, figure 15

Artostrobos (?) *pretabulatus* Petrushevskaya 1975, p.580, pl.10, figs.2,3.

Description: Skeleton cylindrical, two segments. Cephalis subspherical, small. Collar stricture indistinct with no change of contour in the shell outline. Thorax cylindrical, tapering very slightly distally. Thoracic wall slightly thicker than cephalic. Pores subelliptical to subcircular, increasing in size towards the broadest part of the thorax and then decreasing slightly in size distally. Long axis of subelliptical pores arranged horizontally. Pores also arranged in longitudinal rows; about five on a half equator. Termination ragged.

Dimensions: Based on three specimens. Shell length 100-112: width of broadest part of thorax 36-41.

Remarks: Similar in shell outline to *Tricolocampe sanpedroana* Campbell and Clark (1944, p.50, pl.7, fig.5) which has very small abdominal pores in transverse rows with a subvertical wrinkle associated with every pore. Differs from *A. annulatus* (Bailey) in having a longitudinal pore arrangement rather than a transverse arrangement. This species is best placed among the theoperids as it lacks the transverse pore alignment characteristic of the artostrobiids.

Recorded range: Oligocene to Miocene (Petrushevskaya, 1975).

Observed range: Four occurrences, two of which are in samples with *G. dehiscens* at Kaiti and Leader. Other two occurrences are from the upper Tongaporutuan in Wairarapa.

Family **Pterocorythidae** Haeckel 1881

emended Riedel 1967a

Cephalis subdivided into three lobes by two obliquely downward directed lateral furrows arising from the apical spine in the manner described for *Anthocyrtidium cineraria* Haeckel and *Calocyclella virginis* Haeckel by Riedel (1957).

Genus *Anthocyrtidium* Haeckel 1881

Pterocorythidae with two segments. The second segment is ovate and the aperture constricted. A subterminal corona of spines above the apertural margin which itself is provided with a corona of teeth.

Type-species: *Anthocyrtidium cineraria* Haeckel 1887

Anthocyrtidium ehrenbergi (Stohr) *pliocenica* (Seguenza)

Plate 25, figure 12: Plate 26, figure 10

Anthocyrtis ehrenbergii Stohr *pliocenica* Seguenza 1880, p.232.

Anthocyrtium ehrenbergii (Stohr) *pliocenica* (Seguenza): Riedel 1957, p.84, pl.2, figs.4,5.

Anthocyrtidium ehrenbergi (Stohr) *pliocenica* (Seguenza): Nigrini and Lombardi 1984, p.N149, pl.27, figs.2a,b.

Description: Cephalis elongate, ovate-subcylindrical, with scattered subcircular to circular pores, bearing an eccentrically positioned three-bladed apical horn approximately the same length as the cephalis. Thorax usually with flat surface, campanulate, inflated with constricted mouth, having circular to subcircular pores hexagonally arranged. Nearly equally well developed peristomal and subterminal teeth. Up to 16 moderately well-developed, sharp, diverging subterminal teeth. Surrounding the constricted mouth is a hyaline peristome which usually bears 10-14 well-developed, flat, triangular, converging to vertical terminal teeth.

Dimensions: Length of apical horn 32-60: of cephalis 35-40: of thorax 90-115: of terminal teeth 5-20. Breadth of cephalis 25-32: of thorax 90-120 (Riedel, 1957).

Remarks: These rare forms are distinguished from *A. ehrenbergi ehrenbergi* by the subterminal and terminal teeth development. Nigrini and Lombardi (1984, p.N148) indicate that it seems likely *A. ehrenbergi ehrenbergi*, *A. ehrenbergi pliocenica* and *A. ophirensis* constitute an evolutionary sequence ranging from the late Miocene to the Recent. The details of such a sequence have not been well documented.

Recorded range: "may be restricted to the upper Tertiary" (Riedel, 1957).

Miocene to Lower Pliocene (Keany, 1979, *Anthocyrtidium ehrenbergi*).

Weaver, Casey and Perez (1981) show the morphotypic top of *A. ehrenbergi* in mid Epoch 5 from the Newport Bay Section.

Observed range: In Upper Mangaopari Section the abundance gradually increases until it becomes quite abundant at about the local FAD of *B. compressa*. This occurrence pattern is supported by data from Mangapoike, Morrisons, Palliser and perhaps Ruakituri. Not found with *G. dehiscens*. Highest occurrence in basal Opoitian apart from two tentative occurrences in Waiatai (WA03, WA17).

Anthocyrtidium (?) sp. A

Plate 25, figures 10,11: Plate 26, figure 11

Description: Cephalis elongate, ovate-cylindrical, with scattered subcircular to circular pores bearing a three-bladed apical horn usually of the same length or shorter than the cephalis. Thorax campanulate to inflated, with a constricted mouth. Thoracic pores circular, usually hexagonally arranged, often with a strong longitudinal ribbing developed on the surface of the thorax, which in some specimens extends onto the cephalic surface. Most specimens have moderate to well-developed subterminal teeth (14-16) projecting downwards. Surrounding the constricted mouth is a hyaline peristome which usually bears 6-8,

well-developed, flat, triangular, terminal teeth either projecting vertically or slightly converging.

Dimensions: Based on twelve specimens. Length of apical horn 18-34: of cephalis 22-56: of thorax 59-93. Breadth of cephalis 24-31: of thorax 88-118.

Remarks: This species differs from the *Anthocyrtidium ehrenbergi* (Stohr) group in having longitudinally aligned thoracic ribs. Variations in the development of the subterminal and terminal teeth indicate that subspeciation may be possible. Tentatively placed in the genus because of different definitions; i.e., Haeckel (1881) makes no mention of the presence or absence of ribbing, allowing entry of this form into the genus on all counts, but in Haeckel (1887) the definition states "no ribs on thorax" which would exclude this form. The type-species has no thoracic ribbing.

Observed range: Restricted to Tongaporutuan samples.

Anthocyrtidium zanguebaricum (Ehrenberg)

Plate 25, figures 13,14

Anthocyrtis zanguebarica Ehrenberg 1872a, p.301.

Sethocorys sp. Kling 1973, pl.12, fig.15.

Anthocyrtidium zanguebaricum (Ehrenberg): Johnson and Nigrini 1980, pl.3, fig.19.

Anthocyrtidium zanguebaricum (Ehrenberg): Nigrini and Moore 1979, p.N69, pl.25, fig.2.

Description: Similar to *A. ehrenbergi pliocenica* but with a less campanulate, more cylindrical thorax with poorly developed subterminal teeth and terminal teeth either absent, or in the form of small triangular teeth directed inwards. Thoracic pores may be hexagonally framed.

Dimensions: Length of apical horn 18-36: of cephalis 27-36: of thorax 63-90. Maximum breadth of cephalis 18-27: of thorax 63-81 (Nigrini, 1967).

Recorded range: Kling's (1973) figured form of *Sethocorys* sp. is from his Upper Miocene Zone. Known from the Recent.

Observed range: Rarer than the other members of this genus. Thirty-one occurrences are all in Tongaporutuan samples.

Geographic distribution: "Present in most samples north of about 45°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Genus *Lamprocyclas* Haeckel 1881

emended Nigrini 1979 (in Nigrini and Moore, 1979)

Pterocorythidae with a double corona of solid terminal teeth around the mouth. Thoracic ribs present. The distal projections of members of this genus are regarded as teeth rather than radial apophyses.

Type-species: *Lamprocyclas nuptialis* Haeckel 1887

Note: Within this genus there are a number of forms recognised, some of which are intergradational. Some do not strictly adhere to the generic description but the presence of transitional forms indicates some relationship to forms that can be confidently placed within the genus. More detailed work on the phylogeny of the group would be needed to confirm or deny the following morphologic speciation.

Lamprocyclas gamphonycha (Jorgensen)

Plate 27, figure 1

Pterocorys gamphonyxos Jorgensen 1900, p.86.

Androcyclas gamphonycha (Jorgensen) 1905, p.139, pl.18, figs.92,93.

Androcyclas gamphonycha (Jorgensen): Hays 1965, p.178, pl.3, fig.2.

Description: Test campanulate to subcylindrical, with three (?) segments and a heavy three-bladed apical horn. Cephalis elongate, merges with thorax without any definite stricture. Cephalic pores arranged in subparallel rows. Thorax campanulate, pores becoming more hexagonally arranged, and increasing in size distally. Very slight change in contour at lumbar stricture, sometimes with internal septal ring. Abdomen cylindrical to conical, with larger pores (8-10 on half equator), irregular to subregular in size and shape, 5-8 times the width of bars. Subterminal teeth short, divergent, around broadest part of abdomen. Mouth constricted about three-quarters the diameter of the broadest part of abdomen, with 9-11 short, sharp, vertical teeth.

Dimensions: Based on 25 specimens. Length of apical horn 30-60: of cephalis 18-30: of thorax 25-45: of abdomen 25-100. Maximum breadth 90-130 (Hays, 1965).

Remarks: Placed in this genus due to presence of the double corona of teeth. Differs from *Lamprocyrtilis heteroporos* (Hays) in tooth development and a more gradual change in pore size across the lumbar stricture. Appears to have evolved from *L. heteroporos*.

Kling (1973) documents *L. heteroporos* evolving into *L. neoheteroporos*. *Lamprocyclas gamphonycha* differs from *L. neoheteroporos* in having more regularly arranged pores and stronger tooth development. *L. neoheteroporos* also lacks a septal ring, similar to some of the forms described herein. There appears to be a relationship between the two taxa and they may even be ecologic variants of the same morphotype.

Recorded range: Found above Φ zone of Hays (1965) (base of Olduvai Event to Recent: after Keany and Kennett, 1975).

Observed range: Only two positive occurrences in Waiatai (WA03, WA07). A tentative occurrence in WA15 is midway between the LAD of *C. molestus* and FAD of *G. crassula*.

Geographic distribution: "Observed only in sediment samples taken north of the Polar Front" (Hays, 1965)

"Present in most samples between about 30°S and 46°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Lamprocyclas maritalis Haeckel

Plate 27, figure 3

Lamprocyclas maritalis Haeckel 1887, p.1390, pl.74, figs.13,14.

Lamprocyclas maritilis Haeckel: Hays 1965, p.180, pl.3, fig.11.

Lamprocyclas maritilis (Haeckel) *polypora* Nigrini 1967, p.76, pl.7, fig.6.

Lamprocyclas maritilis Haeckel group: Petrushevskaya and Kozlova 1972, pl.36, fig.13.

Lamprocyclas maritilis Haeckel: Casey, Price and Swift 1972, pl.2, fig.17.

Lamprocyclas aegles (Ehrenberg): Dumitrica 1973, pl.14, fig.1, pl.26, fig.8 (only).

Lamprocyclas maritilis (Haeckel) *polypora* Nigrini: Johnson 1974, pl.10, fig.12.

Lamprocyclas maritilis Haeckel group (in part): Nigrini and Lombardi 1984, p.N163, pl.30, figs.1a,b.

Description: Cephalis elongate, trilocular, with scattered subcircular pores sometimes arranged in longitudinal rows, bearing a strong three-bladed apical spine. Collar stricture indistinct. Thorax cupola-shaped (conical above, inflated below) with hexagonally framed circular to subcircular pores, sometimes arranged in longitudinal rows, increasing slightly in size distally. Lumbar stricture distinct. Abdomen inflated, a lot broader than thorax with circular to subcircular pores arranged hexagonally, sometimes in longitudinal rows. Outer teeth on abdomen just above peristome, well developed, conical, horn-like, divergent to vertical. Peristome hyaline, with occasionally well-developed, sharp, conical, vertical to convergent teeth.

Dimensions: Based on 6 specimens. Length of horn 54-73: of cephalis 33-38: of thorax 34-45: of abdomen 46-63. Maximum breadth of thorax 89-96: of abdomen 115-137.

Remarks: Distinguished by the difference in abdominal and thoracic breadth and well developed subterminal teeth.

Recorded range: Absent in Early Miocene tropical and temperate cores, rare in most Late Miocene sections (after Nigrini and Lombardi, 1984).

Pliocene to Quaternary (Petrushevskaya and Kozlova, 1972).

Observed range: *L. maritilis sensu stricto* positively found in only one sample (WA17) midway between the LAD of *C. molestus* and FAD of *G. crassula*. Forms herein referred to as *L. cf. maritilis* (Plate 27, figure 2) are sparse in the Miocene with 68% of the 19 samples containing this form from Plio-Pleistocene sediments.

Geographic distribution: "It is thus cosmopolitan in modern seas but has not been observed south of the South Polar Front" (Hays, 1965).

Lamprocyclas (?) sp. A

Plate 27, figures 4,8

Description: Cephalis elongate, trilocular, subcircular pores in longitudinal rows, 4-6 pores per row, bearing a strong, slightly eccentric, cylindrical apical horn. Collar stricture distinct. Thorax cupola-shaped (conical above, inflated below). Thoracic pores subcircular, 12-14 on half equator, hexagonally arranged, bars 1-2 times width of pores. Some forms show increasing irregularity in pore shape distally (some pores approach kidney-shaped: see Plate 27, figure 8) Lumbar stricture distinct. Abdomen short, cylindrical, slightly narrower than thorax, tapering abruptly at the mouth. Abdominal pores normally subcircular and rarely subelliptical with an indistinct hexagonal arrangement. Abdomen has scattered small conical, divergent spines normally clustered in a ring (approximately 16) just above the peristome. Heavy, hyaline, smooth, narrow peristome surrounds mouth. Mouth constricted to two-thirds

the width of the abdomen.

Dimensions: Based on 5 specimens. Length of apical horn 60-67: of cephalis 33-42: of thorax 55-69: of abdomen 33-50. Maximum breadth of thorax 111-128: of abdomen 103-126.

Remarks: Placed tentatively in this genus because the forms have only no terminal teeth. This form could have its ancestry in the *Calocycletta* lineage (Moore 1972). Distinguished by its cylindrical, narrower abdomen.

Observed range: Not common. Restricted to Tongaporutuan.

Lamprocyclas sp. B

Plate 27, figures 5,6

Description: Cephalis elongate to conical, trilocular, with scattered small subcircular pores sometimes arranged in longitudinal rows, bearing a strong, cylindrical to three-bladed apical horn. Collar stricture indistinct. Thorax subconical to slightly campanulate with hexagonally to longitudinally arranged subcircular pores. Lumbar stricture indistinct. Abdomen subcylindrical to inflated with hexagonally to longitudinally arranged subcircular pores which are slightly bigger than thoracic pores. Abdomen tapers towards mouth which is three-quarters to two-thirds the breadth of the abdomen. Outer teeth moderately to well developed, divergent, short, heavy, conical projections. Mouth surrounded by heavy, hyaline peristome which occasionally has up to 8 poorly developed vertical teeth.

Dimensions: Based on 6 specimens. Length of apical horn 63-91: of cephalis 28-45: of thorax 37-50: of abdomen 50-62. Maximum breadth of thorax 83-96: of abdomen 104-125.

Remarks: Distinguished by indistinct collar and lumbar strictures and better developed outer teeth.

Observed range: Not common. Restricted to the Tongaporutuan except tentative identifications at Waiatai.

Lamprocyclas sp. C

Plate 28, figures 1-7: Plate 30, figure 2

non: *Podocyrthis aegles* Ehrenberg 1854a, pl.35/B.4, fig.18.: 1854b, p.245.

Lamprocyclas aegles (Ehrenberg): Dumitrica 1973, pl.15, figs.3,4, pl.26, fig.7 (only).

Lamprocyclas aegles (Ehrenberg) group: Petrushevskaya 1975, p.584, pl.16, figs.2-4 (only).

Lamprocyclas aegles (Ehrenberg) group: Weaver 1976a, p.123, pl.6, figs.4-6.

Description: Cephalis elongate, trilocular, scattered subcircular pores, bearing a strong, slightly eccentric, initially three-bladed, cylindrical, apical horn. Collar stricture indistinct. Thorax inflated, normally conical above the broadest part with subcircular, hexagonally arranged pores which tend to increase in size distally. Occasional forms bear a thoracic wing just below the cephalis. Lumbar stricture very distinct (deep furrow on the outer surface). Abdomen inflated, normally only slightly broader and longer than the thorax. Abdominal pores subcircular, hexagonally arranged, about the same size as largest on thorax. Outer teeth divergent, poorly to well developed, approximately 12, just below broadest part of abdomen. Mouth constricted to half the diameter of the maximum breadth of abdomen.

Peristome hyaline, heavy; bearing 7-9 well developed sharp, conical, vertical teeth.

Dimensions: Based on 20 specimens. Length of apical horn 38-61: of cephalis 30-36: of thorax 38-62: of abdomen 51-75. Maximum breadth of thorax 90-103: of abdomen 103-117.

Remarks: Distinguished by similar size of thorax and abdomen and well developed terminal teeth.

Recorded range: Pliocene (?) to Quaternary (Petrushevskaya, 1975).

Late Miocene and Pliocene (Weaver, 1976a).

Observed range: Found in 58% of the radiolarian-bearing samples examined. Quite common in the lower Pliocene and Miocene, very rare in the upper Pliocene and Pleistocene. Highest occurrence is in sample WA03. The distribution of transitional forms with *Lamprocyclas* sp. D generally mimics the distribution pattern of *Lamprocyclas* sp. C and *Lamprocyclas* sp. D.

Lamprocyclas sp. D

Plate 27, figures 12,14

Theocorythium ex. gr. *amicae* (Haeckel): Dumitrica 1973, pl.26, fig.5 (only).

Description: Cephalis elongate, trilocular, with scattered subcircular pores, bearing a strong, slightly eccentric, cylindrical apical horn. Collar stricture distinct. Thorax campanulate with hexagonally arranged subcircular pores which tend to increase in size distally. Lumbar stricture pronounced to indistinct. Abdomen slightly inflated, not much broader than thorax, tapering abruptly to mouth. Abdominal pores subcircular, hexagonally arranged, same size as largest on thorax. Outer teeth divergent, conical, poorly developed in a ring just above the peristome. Terminal teeth, if present, are small, triangular, convergent extensions of a hyaline peristome (6 in a ring). Mouth constricted to between two-thirds and one-half the maximum breadth of the abdomen.

Dimensions: Based on 5 specimens. Length of apical horn 36-65: of cephalis 30-40: of thorax 37-65: of abdomen 35-65. Maximum breadth of thorax 89-120: of abdomen 100-135.

Remarks: As with *Lamprocyclas* sp. C this form is distinguished by similar size of abdomen and thorax. Differs from the former in having poorly developed teeth.

Observed range: Found in 26% of the radiolarian-bearing samples examined. Distribution pattern mimics that of *Lamprocyclas* sp. C.

Lamprocyclas sp. E

Plate 27, figure 7: Plate 30, figure 1

? *Calocyclas margatensis* Campbell and Clark: Riedel 1953, p.811, pl.85, fig.8.

Description: Very similar to *Lamprocyclas* sp. B but with a slightly more pronounced lumbar stricture and larger abdomen. Peristomal region heavily silicified with well developed, vertical, subterminal and terminal teeth joined by heavy hyaline "ridges".

Dimensions: Based on four specimens. Length of apical horn 61-80: of cephalis 36-39: of thorax 37-41: of abdomen 72-92. Maximum breadth of thorax 88-92: of abdomen 120-128.

Remarks: Easily distinguished by the heavy hyaline ridges in the terminal area.

Observed range: Restricted to Tongaporutuan samples apart from one positive identification in SWR2.

Genus *Lamprocyrtis* Kling 1973

This genus was erected by Kling (1973) to accomodate the lineage from *Lamprocyrtis heteroporos* through *L. haysi*, with *L. (?) hannai* a possible ancestor of the lineage. It is difficult to characterise because of rather marked differences between initial and latest members of the lineage. Included are two- (later) and three- (earlier) segmented forms with a usually open, indistinctly three-lobed cephalis, bearing one stout, three-bladed apical horn. Post-cephalic pores increase in size distally with earlier species displaying a distinctive discontinuity in pore size. The shells terminate in a single, irregular row of teeth which sometimes occupy a weakly developed peristome. Teeth occasionally occur outside the terminal row, but do not constitute a distinct second row as in *Lamprocyclas*.

Type-species: *Lamprocyclas heteroporos* Hays 1965

Lamprocyrtis (?) apollinis (Haeckel)

Plate 27, figure 11

Theocorys apollinis Haeckel 1887, p.1418, pl.69, fig.3.

Description: Cephalis hemispherical to elongate, trilocular with a heavy three-bladed apical horn. Collar stricture indistinct. Thorax campanulate with subcircular pores arranged in longitudinal rows, 5-6 pores per row, bars as wide as pores. Lumbar stricture not pronounced. Abdomen inflated, broadest at about two-thirds down from the lumbar stricture. Pores slightly larger than thorax, increasing slightly in size distally but decreasing in size abruptly before mouth. Pores 1-2 times wider than bars, with less pronounced longitudinal alignment. Mouth constricted, about two-thirds diameter of the broadest part of abdomen, weak hyaline peristome.

Dimensions: Based on three specimens (average). Length of cephalis 23: of thorax 40: of abdomen 70. Maximum breadth of abdomen 94.

Remarks: Tentatively placed in this genus due to slight increase in pore size distally and weak peristome.

Observed range: Rare upper Tongaporutuan occurrences in Wairarapa and the Leader Tributary Section samples. One tentative identification in the Pleistocene (WA03).

Lamprocyrtis hannai (Campbell and Clark)

Plate 27, figure 10

Calocyclas hannai Campbell and Clark 1944, p.48, pl.6, figs.21,22.

Calocyclas margatensis Campbell and Clark: Casey, Price and Swift 1972, pl.3, figs.16,18, 19,21,22 (only).

Lamprocyrtis (?) *hannai* (Campbell and Clark): Kling 1973, p.638, pl.5, figs.12-14, pl.12, figs.10-14.

Lamprocyrtis hannai Campbell and Clark: Foreman 1975, p.620, pl.9, figs.17-19.

Lamprocyrtis (?) *hannai* Campbell and Clark: Nigrini and Moore 1979, p.N83, pl.25, fig.8.

Description: Cephalis elongate, trilocular with subcircular pores and strong, eccentric, three-bladed apical horn. Cephalis open apically. Collar stricture indistinct. Thorax campanulate with circular pores increasing in size distally. Lumbar stricture not pronounced. Abdomen slightly inflated with circular to subcircular pores increasing in size distally. Smallest pore on abdomen approximately equal in size to largest on thorax. Ten pores on abdominal half equator. Peristome not preserved.

Dimensions: Based on 20 specimens. Length of cephalis 20-45: of thorax 30-70: of abdomen 25-162. Maximum breadth of thorax 75-100: of abdomen 90-152 (Nigrini in Nigrini and Moore, 1979).

Remarks: This form was only tentatively placed in this genus by Kling (1973) as he was unsure of its position in the *L. heteroporos* - *L. haysi* lineage. On the basis of morphology it is considered to be part of the genus herein. This species is distinguished from its probable descendant *L. heteroporos* by a slightly more inflated abdomen and more gradational change in pore size across the lumbar stricture.

Recorded range: *Calocyclella costata* Zone to Recent (Kling, 1973, DSDP Site 173).

Stichocorys peregrina Zone to Recent (Foreman, 1975, DSDP Site 310).

Evolved into *L. heteroporos* at about the Miocene/Pliocene boundary in southern California (Casey, Price and Swift, 1972).

Observed range: Sporadic Miocene occurrences concentrated in Wairarapa sections. Only one other occurrence (WA19), is at the level where it appears to have evolved into *L. heteroporos*.

Geographic distribution: "Consistently present in samples north of about 10°S with scattered occurrences as far south as 30°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Lamprocyrtis heteroporos (Hays)

Lamprocyclas heteroporos Hays 1965, p.179, pl.3, fig.1.

Lamprocyrtis heteroporos (Hays): Kling 1973, p.639, pl.5, figs.19-21.

Lamprocyrtis heteroporos (Hays): Foreman 1975, p.620, pl.9, fig.20.

Description: Shell campanulate with indistinct collar stricture but distinct lumbar stricture. Cephalis hemispherical bearing a long three-bladed apical horn, as long as or up to three times as long as the cephalis. Thorax campanulate with pore size similar to cephalis and pores arranged in irregular longitudinal rows and increasing in size distally. Abdomen cylindrical to slightly conical with maximum diameter just above the mouth. Pores large, irregular in size and shape and separated by thick bars. Abdominal pores 2-3 times the size of thoracic. Aperture slightly constricted, 3-5 poorly developed short teeth extend downward from a thick peristomal ring.

Dimensions: Length of apical horn 22-60: of cephalis 15-25: of thorax 48-65: of abdomen 55-70. Maximum width of shell 88-100.

Remarks: As with Foreman (1975) this species is interpreted rather strictly as described by Hays. The pores of the abdomen must be large as well as regular.

Recorded range: Lower Pliocene to mid-Pleistocene (Foreman, 1975).

Hays (1970) defined the *Lamprocyclas heteroporos* Zone as the range of *L. heteroporos* subsequent to the extinction of *Eucyrtidium elongatum peregrinum* (= *Stichocorys peregrina*) and dated this zone as 2.8 to 2.0 Ma with *L. heteroporos* becoming extinct near the base of the Olduvai. He also suggested that *L. heteroporos* evolved into *Androcyclas gamphonycha* and also concluded that *L. heteroporos* seems to have disappeared from Antarctic sediments 0.5 Ma before its final occurrence in North Pacific sediments.

Kling (1973, DSDP Site 173) shows the LAD of *L. heteroporos* at approximately 1.3 Ma.

Observed range: Restricted to Waiatai and Waihua. Highest positive occurrence at WA07 at the top of the dextral *G. crassaformis* - *G. crassula* overlap zone. Tentative identifications in sample WA03 associated with a population of *Lamprocyclas gamphonycha*. See *L. hannai*.

Geographic distribution: Occurrences "suggest that it was a warm water species, not tolerant of colder waters that lay to the south (of the Polar Front)" (Hays, 1965).

Lamprocyrtis (?) *junonis* (Haeckel)

Plate 27, figures 9,13

Theoconus junonis Haeckel 1887, p.1401, pl.69, fig.7.

Lamprocyclas junonis (Haeckel) group: Petrushevskaya and Kozlova 1972, p.545, pl.36, fig.8.

Description: Cephalis hemispherical to elongate, trilocular with subcircular pores and a short, eccentric, three-bladed apical horn. Collar stricture indistinct. Thorax truncate-conical to campanulate with subcircular pores increasing slightly in size distally. Lumbar stricture not pronounced. Abdomen inflated, narrowing sharply at the distal end. Abdominal pores subcircular, irregular in size and pattern but tending to increase in size towards the broadest part of the abdomen, then decrease in size distally. Peristome distinct, hyaline, with about twelve very poorly developed teeth.

Dimensions: Based on two specimens (average). Length of cephalis 19: of thorax 41: of abdomen 85. Maximum breadth of abdomen 95: of mouth 65.

Remarks: The peristomal development in the form described is perhaps too great to place it in this genus. Differs from *L. hannai* in its more irregular pore pattern, greater peristomal development, and generally shorter horn. Some forms with an "up-ended-cupola" shaped (expanded above, conical below) abdomen are referred to as *L. cf. junonis*.

Recorded range: Pliocene to Quaternary (Petrushevskaya and Kozlova, 1972).

Observed range: Restricted to nine Wairarapa upper Miocene samples from Morrisons, Ruamahanga and Mangaopari and one Mangapoike sample. The form *L. cf. junonis* appears to be also restricted to the Miocene except for one positive identification in sample WA16 (Mangapanian).

Family *Artostrobiidae* Riedel 1967a
emended Foreman 1973

Radiolarians with six collar pores, a well-developed vertical tube, no appendages, and the pores of at least one major segment arranged in transverse rows. They may have a smooth or ridged surface, and the last segment is not flared.

Genus *Botryostrobus* Haeckel
emended Nigrini 1977

Artostrobiidae having more than four segments, separated by rounded constrictions and having numerous rows of pores on each post-thoracic segment; cephalis bearing both an apical horn and a cylindrical vertical tube.

Type-species: *Lithostrobus botryocyrtis* Haeckel 1887 : designated by Campbell 1954

Botryostrobus aquilonaris (Bailey)

Plate 29, figure 3

Eucyrtidium aquilonaris Bailey 1856, p.4, pl.1, fig.9.

- see Nigrini 1977, p.246, for extensive synonymy.

Description: Shell heavy, thick-walled. Constrictions unevenly spaced and usually obscure externally. Shell spindle-shaped with four to five post-cephalic segments, the fourth being widest. Cephalis hemispherical with small irregular pores; vertical tube robust, cylindrical, directed obliquely upwards at about 45°. Apical horn rarely preserved, short, thorn-like. Thorax inflated with two or three transverse rows of large subcircular pores. Subsequent segments with three to six (usually four) transverse rows of closely spaced circular pores. Shell narrows distally, terminating in a smooth peristome, which may have a single row of pores. Termination smooth or undulating.

Dimensions: Based on 20 specimens. Total length 110-155. Maximum breadth 60-90 (Nigrini, 1977).

Remarks: The name is used only for heavy, thick-walled forms.

Recorded range: *Stichocorys peregrina* Zone to Recent (Nigrini, 1977).

Observed range: Occurs sporadically throughout the upper Neogene.

Geographic distribution: "Bimodal distribution: consistently present between about 35°S and 46°S, scattered occurrences between about 0° and 20°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Botryostrobus auritus-australis (Ehrenberg) group

Plate 29, figure 9: Plate 30, figure 4

Lithocampe aurita Ehrenberg 1844a, p.84.

Lithocampe australe Ehrenberg 1844b, p.187.

- see Nigrini 1977, p.246, for extensive synonymy.

Description: Shell approximately cylindrical. Cephalis hemispherical with a few subcircular pores, small thorn-like apical horn, and well developed vertical tube directed obliquely upward at about 45°. Collar stricture indistinct. Thorax inflated with 3 to 4 transverse rows of subcircular pores. Lumbar stricture distinct and marked, as are subsequent strictures by a poreless band. Three or more post-thoracic segments of more or less uniform size with four or five transverse rows of subcircular pores per segment. Termination ragged.

Dimensions: Based on 20 specimens. Total length 123-195. Maximum breadth 53-70 (Nigrini, 1977).

Remarks: Petrushevskaya (1975) attempted to distinguish individuals which were widest at the fourth segment (*B. australis*). Too many specimens are nearly cylindrical to make this distinction with certainty (Nigrini, 1977). In younger sediments (Pliocene-Recent) specimens tend to be more conical, and there is also a tendency for there to be more individuals with a smaller number of pore rows per segment (Nigrini, 1977).

Recorded range: *Cannartus* (?) *petterssoni* Zone (upper to middle Miocene) to Recent (Nigrini, 1977).

Observed range: Two positive identifications in samples with *G. dehiscens* (SWR4, LT05). Ranges into Pleistocene generally getting more abundant in younger samples. Opposite of *B. bramlettei* which it appears to replace in younger samples.

Geographic distribution: "Present in all samples" (Johnson and Nigrini, 1977, western Indian Ocean).

Botryostrobus bramlettei (Campbell and Clark)

Plate 29, figure 6: Plate 30, figures 3,5

Lithomitra bramlettei Campbell and Clark 1944, p.53, pl.7, figs.10-14.

- see Nigrini 1977, p.248, for extensive synonymy.

Description: Shell usually thick-walled, surface rough. Cephalis hemispherical with a few subcircular pores and well developed vertical tube. Rarely a thorn-like apical horn present. Collar stricture indistinct. Thorax inflated, bearing three transverse rows of subcircular pores. Lumbar stricture apparent. Abdomen and first post-abdominal segment similar in shape to thorax but somewhat larger, fourth segment being the largest in both length and breadth. Four transverse rows of subcircular pores on abdomen; three to six on fourth segment. First four segments form a cone; shell then narrows sharply to an approximately cylindrical segment. Termination may be poreless band with or without small terminal teeth.

Dimensions: Based on 15 specimens. Total length 105-130. Maximum breadth 60-65 (Nigrini, 1977).

Remarks: Distinguished from *B. aquilonaris* by its more pronounced strictures and the characteristic change in shape from conical to cylindrical and from *B. auritus-australis* group by the latter's more overall cylindrical shape.

Recorded range: *Cannartus* (?) *petterssoni* Zone to *Stichocorys peregrina* Zone (Nigrini, 1977).

Observed range: A positive identification in WA01, but generally more abundant in Miocene samples. See *B. auritus-australis*.

Geographic Distribution: Absent from the Late Miocene of the central temperate Pacific; rare in the Late Miocene of the western and central tropical Pacific; common in the Late Miocene of the eastern tropical and eastern temperate Pacific (Nigrini and Lombardi, 1984, CENOP Project).

Genus *Phormostichoartus* Campbell 1951
emended Nigrini 1977

Artostrobiidae having four segments, shell cylindrical. Mouth slightly constricted with well developed peristome. Vertical tube well developed, cylindrical, lying along the thorax. No apical horn.

Type-species: *Cyrtophormis cylindrica* Haeckel 1887 : designated by Campbell 1954

Phormostichoartus fistula Nigrini
Plate 29, figure 4

Phormostichoartus fistula Nigrini 1977, p.253, pl.1, figs.11-13.

Description: Shell thick-walled, smooth, subcylindrical, consisting of four segments. Cephalis hemispherical with a well developed, poreless vertical tube, few subcircular pores, no apical horn. Collar stricture indistinct. Thorax short, truncate-conical with two to three transverse rows of relatively large subcircular pores. Lumbar and post-lumbar strictures not pronounced. Abdomen subcylindrical elongate with five to seven closely spaced transverse rows of subcircular pores. Fourth segment approximately the same width or narrower than abdomen; pores similar in size and shape to those on the abdomen, usually in three or four transverse rows. Segment narrowing to poreless peristome, sometimes with small, poorly developed terminal teeth.

Dimensions: Based on 15 specimens. Total length 110-190. Length of cephalis and thorax 35-40: of abdomen 35-53: of fourth segment 35-70. Maximum breadth 65-83 (Nigrini, 1977).

Remarks: May be an ancestor of *Phormostichoartus corbula* (Nigrini, 1977).

Recorded range: *Thyrsocyrtis bromia* Zone to *Spongaster pentas* Zone (Nigrini, 1977).

Observed range: Sporadic throughout Late Neogene. Rare in Plio-Pleistocene samples.

Phormostichoartus sp. A
Plate 29, figures 1,2: Plate 30, figure 7

Description: Similar to *Phormostichoartus fistula* but slightly smaller with an inflated fourth segment, smaller pores, longitudinal ridges on the thorax and abdomen, and a narrower mouth.

Remarks: Rare forms exhibit a very narrow, slightly inflated fifth segment forming just before the peristome.

Dimensions: Based on seven specimens. Length of shell 87-137. Maximum breadth of shell 53-77.

Observed range: Restricted to Miocene samples. Relatively common in the Wairarapa Miocene.

Genus *Siphocampe* Haeckel 1881
emended Nigrini 1977

Artostrobiidae having three segments, the third of which is more or less cylindrical and may develop a series of rounded constrictions alternating with transverse rows of pores; vertical tube short, cylindrical. No apical horn.

Type-species: *Siphocampe annulosa* Haeckel 1887 : designated by Strelkov and Lipman 1959

Siphocampe arachnea (Ehrenberg) group
Plate 28, figure 12: Plate 30, figure 9

Lithocampe lineata Ehrenberg 1838, p.130 (in part).

Eucyrtidium lineatum arachneum Ehrenberg 1861, p.299 (in part).

- see Nigrini 1977, p.255, for extensive synonymy.

Description: Shell small, bullet-shaped, consisting of cephalis, thorax and abdomen; abdomen usually marked by a series of five or six rounded constrictions alternating with one transverse row of small subcircular pores. There is a well developed surface network of both longitudinal and transverse ridges. Cephalis subspherical with a few irregularly scattered pores; no apical horn; vertical tube short. Collar stricture indistinct. Thorax slightly inflated with two transverse rows of indistinct subcircular pores. Lumbar stricture not well developed. Post-thoracic segments usually marked by indentations, more pronounced proximally than distally, between pore rows. Termination ragged.

Dimensions: Based on 17 specimens. Total length 110-160. Maximum breadth 47-60 (Nigrini, 1977).

Remarks: The most distinctive feature of the species is the network of longitudinal and transverse ridges on the shell surface. Possibly a descendant of *S. nodosaria* (Nigrini, 1977).

Recorded range: *Stichocorys wolffii* Zone to Recent (Nigrini, 1977).

Observed range: Sporadic occurrences restricted to the Tongaporutuan.

Geographic distribution: Caulet (in Nigrini, 1977) has observed that cool-water forms of *S. arachnea* have one pore row per segment, whereas warm-water forms have two pore rows per segment. The forms found in New Zealand normally have one pore row per segment.

Siphocampe lineata (Ehrenberg) group

Plate 28, figures 9-11: Plate 30, figure 10

Lithocampe lineata Ehrenberg 1838, p.130 (in part).

- see Nigrini 1977, p.256 for synonymy.

Description: Shell smooth, consisting of a cephalis, thorax and a cylindrical to somewhat inflated abdomen. Cephalis spherical with a few irregularly scattered pores. Vertical tube well developed. Collar stricture indistinct. Thorax slightly inflated with two or three transverse rows of subcircular pores. Lumbar stricture indistinct to distinct, very pronounced in a lot of specimens. Abdomen usually smooth without indentations, bearing seven to nine rather regularly spaced transverse rows of subcircular pores. Considerable variation in pore size and distance between pore rows is allowed within the species group. Specimens with longitudinal striations are more common than not. Termination normally ragged, rarely smooth.

Dimensions: Based on 20 specimens. Total length 120-160. Maximum breadth 45-70 (Nigrini, 1977).

Remarks: Specimens with a very inflated thorax and very pronounced lumbar stricture (e.g. Plate 28, figure 10) are common in the samples studied.

Recorded range: *Thyrocyrtis bromia* Zone (possibly earlier) to Recent (Nigrini, 1977).

Observed range: Two forms tabulated. The form with the distinct lumbar stricture is more common (occurs in 46% of samples studied) than the smooth form (33%). Distribution patterns generally mimic one another. Found throughout the upper Neogene but definitely rarer in the upper Pliocene and Pleistocene.

Geographic distribution: "Present in most samples north of about 15°S, scattered occurrences between about 15°S and 26°S and very rare occurrences between about 37°S and 46°S" (Johnson and Nigrini, 1980, western Indian Ocean).

Siphocampe nodosaria (Haeckel)

Plate 28, figure 8: Plate 30, figure 8

Lithomitra nodosaria Haeckel 1887, p.1484, pl.79, fig.1.

- see Nigrini 1977, p.256 for synonymy.

Description: Similar to *S. arachnea* but with more pronounced abdominal indentations. There may be one or two transverse rows of pores between each indentation. Between pore rows there are prominent longitudinal ridges, but no cross bars between ridges as in *S. arachnea*. Termination ragged. Shell generally larger than other species of *Siphocampe*.

Dimensions: Based on 17 specimens. Total length 130-177. Maximum breadth 53-75 (Nigrini, 1977).

Recorded range: *Thyrsocyrtis triacantha* Zone (middle Eocene) to Recent (Nigrini, 1977).

Observed range: As with other members of this genus, mainly found in Miocene sediments. Only two upper Pliocene - Pleistocene occurrences (WA15, WA26).

Genus *Siphostichartus* Nigrini 1977

Artostrobiidae having four segments, ovate to spindle-shaped; mouth constricted, no terminal feet; vertical tube flared; apical horn present.

Type-species: *Cyrtophormis corona* Haeckel 1887

Siphostichartus corona (Haeckel)

Plate 29, figure 5: Plate 30, figure 6

Cyrtophormis corona Haeckel 1887, p.1462, pl.77, fig.15.

- see Nigrini 1977, p.257, for synonymy.

Description: Shell smooth, hyaline, conical, compressed laterally. Cephalis hemispherical with a few circular pores, base of a well developed three-bladed apical horn sometimes present. Prominent "duck-billed" vertical tube. Thorax inflated, slightly heavier than the rest of the shell with two or three transverse rows of small circular pores. Abdomen inflated with four to six transverse rows of small circular pores. Fourth segment considerably larger than the others, usually contracting distally without a differentiated peristome; seven or more transverse rows of small circular pores. Termination ragged. Intersegmental strictures curved, poreless.

Dimensions: Based on 20 specimens. Total length (excluding apical horn) 135-190. Length of abdomen 30-40; of fourth segment 70-105. Maximum breadth (across fourth segment) 70-95 (Nigrini, 1977).

Remarks: Appears to have developed from *S. praecorona* in which the third segment has only two rows of pores and a less prominent apical horn and vertical tube (Nigrini, 1977).

Recorded range: *Stichocorys wolffii* Zone to last rare occurrences in the *Stichocorys peregrina* Zone (Nigrini, 1977).

Observed range: Sporadic occurrences in Miocene. Only two tentative Plio-Pleistocene occurrences at Waiatai.

Geographic distribution: "Rare in all Late Miocene sections examined from both tropical and temperate latitudes" (Nigrini and Lombardi, 1984, CENOP Project).

Genus *Spirocyrtis* Haeckel 1881

emended Nigrini 1977

Artostrobiidae with more than four segments, expanding distally; intersegmental constrictions sharply rounded to angular; vertical tube flared; apical horn or tube present.

Type-species: *Spirocyrtis scalaris* Haeckel 1887 : designated by Campbell 1954

Spirocyrtis subscalaris Nigrini

Plate 29, figures 7,8: Plate 30, figure 11

Spirocyrtis subscalaris Nigrini 1977, p.259, pl.3, figs.1,2.

- see Nigrini 1977 for synonymy.

Description: Shell conical, smooth with four to six post-cephalic segments. Cephalis hemispherical with a few subcircular pores, a strong apical horn nearly as long as the cephalis, and a well developed, flared vertical tube. Collar stricture indistinct. Thorax inflated with three or four transverse rows of subcircular pores. Thorax surface normally rougher than the rest of the shell. Lumbar and post-lumbar strictures clearly visible and often marked by a poreless band. Abdomen and post-abdominal segments inflated, normally increasing in size distally, rare specimens taper slightly after the fourth segment. Each segment bears four to six transverse rows of subcircular pores of variable size. Termination usually ragged, with occasionally a short poreless peristome present.

Dimensions: Based on 15 specimens. Total length (excluding apical horn) 123-165. Maximum breadth 65-83 (Nigrini, 1977).

Remarks: Distinguished from *S. gyroscalaris*, which has more segments and is wider, *S. scalaris* which has angular segments, and *S. subtilis* which is narrower. The specimens which are broadest at the fourth and fifth segment are very similar to Kling's (1973) *Spirocyrtis* sp. aff. *S. scalaris*, which he figures (pl.5, figs.24,25,26) from the lower Pliocene to Recent. Specimens studied herein support the view that there is a tendency towards distally contracting forms in the Pliocene and Pleistocene.

Recorded range: *Calocycletta costata* Zone to Recent (Nigrini, 1977).

Observed range: Present throughout Late Neogene. Unlike most of the other Artostrobiids, shows no decrease in abundance in the Plio-Pleistocene.

Family **Cannobotryidae** Haeckel 1881

emended Riedel 1967a

Cephalis consisting of two or more unpaired lobes, only one of which is homologous with the cephalis of the theoperids.

Genus **Botryopyle** Haeckel 1881

Cannobotryidae with cephalis and thorax. Lacks cephalic tubules. Thorax open.

Type-species: *Botryopyle sethocorys* Haeckel 1887

Botryopyle dictyocephalus Haeckel group

Plate 30, figures 12-14

Botryopyle dictyocephalus Haeckel 1887, p.1113, pl.96, fig.6.

Botryocella multicellaris Haeckel 1887, p.1117, pl.96, fig.12.

Botryopyle dictyocephalus Haeckel group: Riedel and Sanfilippo 1971, p.1602, pl.1J, figs.21-26, pl.2J, figs.16-18, pl.3F, figs.9-12.

Botryopyle sp. A Petrushevskaya 1975, p.589, pl.13, fig.22.

Description: Group includes all forms with a large antecephalic chamber, small to large post-cephalic chamber, and a subcylindrical thorax, and without prominent cephalic tubes. The shell wall is variable, some are densely porous and others only very sparsely perforate, the pores being subcircular, small, irregular in size.

Dimensions: Based on eight specimens. Length of antecephalic chamber 35-44: of post-cephalic chamber 19-31: of thorax 43-66. Maximum breadth of thorax 43-55.

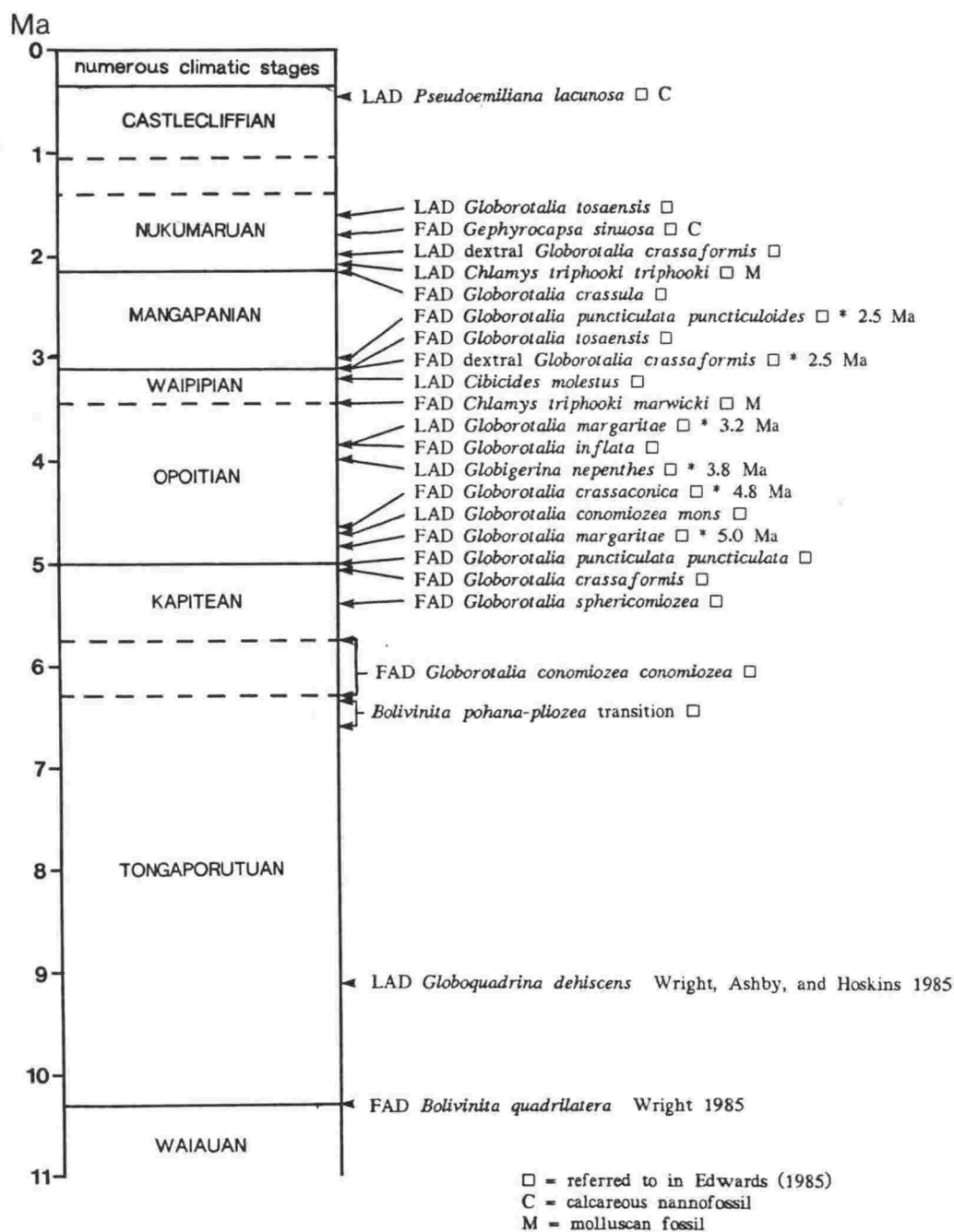
Remarks: A moderately variable group in terms of shell wall and thorax dimensions.

Recorded range: Riedel and Sanfilippo (1971) figure specimens from the Late Eocene *Thyrsoyrtis bromia* Zone to Quaternary. Petrushevskaya's (1975) *Botryopyle* sp. A, which has a large eucephalic lobe is noted by her as being a Late Miocene form and is comparable to a few of the specimens found in this study.

Observed range: Present throughout the Late Neogene although abundance slightly less in Plio-Pleistocene samples. The "normal" form is found in 35% of the radiolarian-bearing samples examined. The "large lobed" form is present in 19% of the samples occurring in only one upper Pliocene sample WA15, the rest being Miocene occurrences.

Figure 5.1

List of the main calcareous bioevents used in correlating sections in the New Zealand Late Neogene and correlations with the New Zealand Stages. All events are foraminiferal except two calcareous nannofossil (C) and two molluscan (M). Sources of information are predominantly from Edwards 1985 (□) with alternative ages from the differing paleomagnetic interpretation of Hornibrook 1981a (*).



Chapter V

BIOSTRATIGRAPHY

5.1 PALEONTOLOGICAL CRITERIA FOR DEFINING NEW ZEALAND LATE NEOGENE STAGES

5.1.1 Introduction

Finlay and Marwick (1940, 1947), whose pioneering work on defining the New Zealand stages helped in local correlations, did not always adhere to strict type-locality definitions. New Zealand stages are largely based on changes in lithofacies, facies controlled mollusca and shallow water benthic foraminifera. The stages as defined here are only approximations of the original stage definitions and are based predominantly on deeper water benthic foraminifera and open ocean planktic foraminifera and form the basis of the stage usage discussed in this thesis. The datums are summarised in figure 5.1.

Hornibrook (1958) recognised an increasing trend towards biogeographic provincialism in New Zealand during the late Tertiary, which was probably climatically controlled. As a result few of the fossils are useful for world-wide correlation. Global markers, such as magnetostratigraphic datums have improved correlation, but reliable paleontological datums are still scarce even for correlation within New Zealand. Foraminiferal datums used in this thesis are outlined in this section.

5.1.2 Waiauan Stage

Top : FAD of *Bolivinita quadrilatera*

Base : FAD of *Globigerina nepenthes*

The Waiauan was originally defined by Finlay and Marwick (1947) as "that part of the section marked by the presence of *Loxostomum truncatum* Finlay. The lower limit is marked also by the lowest occurrence of *Cibicides deliquatus* Finlay"; the holostratotype being at Clifden, Southland. *C. deliquatus* is now known down to upper Altonian (Hoskins, 1978). At many places *L. truncatum* occurs with *Bolivinita quadrilatera* (Schwager), the basal Tongaporutuan marker. The only useful planktic foraminiferal datum is the first appearance of *Globigerina nepenthes* Todd at the base of the Waiauan. The moderately shallow water benthic foraminiferal species *L. truncatum*, *Anomalina spherica*, and *Euvigenerina rodleyi rodleyi* all appear at the base of the Waiauan.

5.1.3 Tongaporutuan Stage

Top : FAD of *Globorotalia conomiozea conomiozea*

Base : FAD of *Bolivinita quadrilatera*

The name Tongaporutuan was first used, without definition, by Marwick (1924a) although it was thought to represent the Tongaporutuan Beds of Grange (1927) in northern Taranaki (Hornibrook, in Fleming, 1959). Allan (1933) proposed the Taranakian System to include both the Tongaporutuan and Urenui Stages. Finlay and Marwick (1940) adopted the name as Taranaki Series, including in it the Tongaporutuan Stage represented by the Tongaporutuan Formation (= Mt. Messenger Sandstone of Hay, 1967) exposed on the North Taranaki coast between the underlying Mohakatino Formation and the overlying Urenui Siltstone. By 1947, Finlay and Marwick included the Urenui Siltstone in the upper Tongaporutuan. The choice of the North Taranaki coastal section as the holostatotype was unfortunate because fossil mollusca are not abundant and foraminifera only fair to poor, a fact recognised by Finlay and Marwick in 1940.

A tripartate subdivision of the Tongaporutuan based on *Bolivinita* of the *quadrilatera* lineage was founded by Vella (1954) on the successive appearance of *B. quadrilatera*, *B. pohana*, and *B. compressa*, corresponding to the lower, middle, and upper Tongaporutuan respectively. Although these subdivisions are workable in many local basins, they are imprecise for regional correlation due to a complex history of gradual morphological changes associated with both facies variation and speciation.

The Tongaporutuan is characterised by populations of the planktic species *Globorotalia miotumida* Jenkins. A reliable foraminiferal datum within the Tongaporutuan is the sudden disappearance of *Globoquadrina dehiscens* (Chapman, Parr and Collins) which in the East Coast Deformed Belt occurs below the FAD of *B. compressa*, except in two Gisborne sections, Caves Road and Kaiti Beach where *G. dehiscens* and *B. compressa* occur at the same horizon. An age of 9.2 Ma for this Tongaporutuan bioevent has been paleomagnetically derived in the Mangapoike River Section (Wright, Ashby, and Hoskins, 1985). The recorded younger occurrences of *G. dehiscens* in the New Zealand region (Hornibrook, 1961; Collen and Vella, 1973) could be due to reworking but are more likely to be warm water re-entrants as first suggested by Collen and Vella.

A useful datum in the uppermost Tongaporutuan is the level at which five-chambered members of the *Globorotalia miotumida* - *G. conomiozea conomiozea* transition make up less than twenty percent of the transitional population. As definition of this datum requires a

reasonable population of *G. miotumida* morphotypes it is not entirely satisfactory but it has been found by the author to be as recognisable as the FAD of *G. conomiozea conomiozea sensu stricto*. Malmgren and Kennett (1981) showed that members of the *Globorotalia miotumida* - *conomiozea* - *sphericomiozea* - *puncticulata* - *inflata* lineage in DSDP Site 284 can be distinguished on the basis of the mean number of chambers in the final whorl, with only two out of 72 samples being misclassified. At the base of the Kapitean the mean number of chambers is 4.4 (Malmgren and Kennett, 1981: figure 2), which closely approximates the level at which less than 20% five chambered forms dominate.

5.1.4 Kapitean Stage

Top : FAD of *Globorotalia crassaformis*

Base : FAD of *Globorotalia conomiozea conomiozea*

As defined by Finlay and Marwick (1947) the Kapitean holostatotype at Kapitea Creek, Westland is marked by the FAD's of the mollusca *Sectipecten wollastoni* (Finlay) and *Austrofusus coerulescens* (Finlay) (= *tuberculatus* Marwick) which also range up to the incoming of the Opoitian foraminifera identified by Finlay as *Globorotalia "inflata"* and *Globorotalia "crassula"* but now known to be *Globorotalia puncticulata puncticulata* (Deshayes) and *Globorotalia crassaformis* (Galloway and Wissler), respectively (Hornibrook, 1982). The original definition of the base of the Kapitean has caused trouble in identification for two reasons; the use of the FAD of a facies controlled molluscan species and the existence of a greensand, representing a period of slow deposition, in the lowest part of the holostatotype.

Kennett (1966a) suggested the planktic foraminiferal change to *Globorotalia conomiozea conomiozea*, a strongly conical member of the upper Miocene *Globorotalia miotumida* lineage, may be useful in defining the same stratigraphic interval as the range of *Sectipecten wollastoni*. Even in sections where there is no unconformity the FAD of *Globorotalia conomiozea conomiozea* is a relatively unsatisfactory datum because of the intergradation of populations and low frequency of occurrence (see section 5.1.3). Some interregional correlations probably have been based on forms incorrectly identified as *G. conomiozea conomiozea* (Scott, 1976a, 1980b). Differing interpretations of *G. conomiozea conomiozea* at Blind River (Kennett, 1966b; Kennett and Watkins, 1974; Scott, 1979a; Loutit, 1981) make its quantitative age range difficult to use in correlation.

Walters (1965) proposed *Globorotalia miozea sphericomiozea* (= *Globorotalia sphericomiozea*) for a transitional form between the upper Miocene - Pliocene representatives

of the *G. miotumida* - *inflata* lineage. Jenkins (1967) equated the first appearance of this taxon with the base of the Kapitean. Scott (1982b) suggested a number of reasons for making the first appearance of *G. sphericomiozea* as a datum to define the top of the Kapitean.

1. It is recognised relatively precisely.
2. It is identifiable in New Zealand and in adjacent deep-sea cores.
3. It corresponds closely with the highest occurrence of the Kapitean mollusca cited originally by Finlay and Marwick (1947).
4. It occurs near the base of the Gilbert. Cita and Gartner (1973) and Ryan *et al.* (1974) considered that the base of the Zanclean stratotype (Capo Rossello, Sicily) lies very close to the Epoch 5/Gilbert boundary so a change in definition for the top of the Kapitean would align the Kapitean/Opoitian boundary with the international Miocene/Pliocene boundary.

Hornibrook (1984a) accepts the FAD of *G. sphericomiozea* as the Miocene/Pliocene boundary in New Zealand with no discussion as to the position of the Kapitean/Opoitian boundary. The proposal of Scott (1982b) would place the Kapitean/Opoitian boundary significantly below the previously accepted level and would make the base of the Opoitian at its lectostratotype locality, Mangapoike River, an unconformity.

The FAD of *G. sphericomiozea* is herein considered to be a reliable datum within the Kapitean which approximates the Miocene/Pliocene boundary.

5.1.5 Opoitian Stage

Top : Hard to determine using foraminiferal data

Base : FAD of *Globorotalia crassaformis*

Finlay (1939) first proposed the Opoitian for the interval of time represented by deposition of the beds described by Ongley (1930) as between the Mapiri "Series" (Formation) and the Waitotaran i.e. the Opoiti "Series" (Formation), lying within the Opoiti Survey District in the Wairoa Syncline. No particular stratotype was designated and the only microfossil index suggested for the base of the Opoitian was the FAD of *Globorotalia "inflata"*, now recognised as *Globorotalia puncticulata puncticulata* (Deshayes), the four chambered ancestor of *G. inflata* d'Orbigny.

Finlay and Marwick (1940, 1947) added the first appearance of "modern Globigerinidae including *Globigerinoides rubra* (d'Orbigny) and *G. sacculifer* (Brady), *Globorotalia crassula* Cushman and Stewart and *G. truncatulinoides* (d'Orbigny)". Their *G. crassula* is now

known to be *G. crassaformis* (Galloway and Wissler). Their *G. truncatulinoides*, whose FAD of typical populations in New Zealand is now dated at 2.9 Ma (Hornibrook, 1981a), was probably a misidentification of *Globorotalia conomiozea mons* Hornibrook, a basal Opoitian morphologic offshoot of *Globorotalia conomiozea conomiozea*.

Jenkins (1971) did not devise a workable zonation for the Pliocene and erected a single *Globorotalia inflata* Zone for the whole Pliocene and Quaternary with several subzones based on reversals in the coiling sense of *Neogloboquadrina pachyderma* (Ehrenberg).

The joint FAD's of *G. puncticulata puncticulata* and *G. crassaformis* is a reliable datum level for defining the base of the Opoitian although the former taxon is sometimes difficult to determine as it arises from the *G. miotumida* - *conomiozea* - *sphericomiozea* complex. Both taxa are widely distributed in Lower Pliocene strata beyond the tropics in both hemispheres and commonly have very close first appearance datums (Scott, 1982b). This dual FAD is significantly above the highest Kapitean Mollusca and does not coincide with any key molluscan or floral event (Scott, 1982b). The joint occurrence of *G. puncticulata* and *G. crassaformis* was used by Keller (1979) to identify the N18/N19 boundary in mid-latitude sequences in the North Pacific.

The FAD of typical *G. inflata* populations is a reliable datum in the upper Opoitian. Other datums defined by Hornibrook (1981a), e.g. the FAD of *Globorotalia crassaconica* Hornibrook and the FAD of *Globorotalia margaritae* Bolli and Bermudez in the lower Opoitian and the LAD of *Globigerina nepenthes* Todd in the upper Opoitian, have limited usefulness.

5.1.6 Waipipian Stage

Top : FAD of dextral *Globorotalia crassaformis*

Base : Hard to determine using foraminiferal data

Fleming (1953) comprehensively described the lithostratigraphy and macrofossil biostratigraphy in the Wanganui area, on which New Zealand Late Pliocene and Quaternary stages are based. The shallow water foraminiferal assemblages contain sparse planktic assemblages and are of limited use for correlation (Collen, 1972b), and do not enable direct correlation with East Coast sequences (Hornibrook, 1981b).

The Waitotaran Stage was originally proposed by Thomson (1916). Morgan in Withers (1924), on the basis of molluscan faunas, identified an Upper and Lower Waitotaran. Fleming (1953) formally defined these as the Waipipian and Mangapanian substages.

Fleming followed a policy of defining stratotypes only in the middle of his biostratigraphic units and the Middle Waipipi Shellbed on the coast south of Waverley was nominated. The top of the Waipipian is marked by the LAD of the bivalve *Mesopeplum crawfordi* Hutton.

The planktic foraminifera differ little from those in the Opoitian and Mollusca are still the best criteria for definition (Hornibrook, 1981b). The pectinid *Chlamys* (*Phialopecten*) *triphooki marwicki* Beu has been used with success in defining the Waipipian in the Te Aute Limestone facies of Hawke Bay (Beu, Grant-Taylor and Hornibrook, 1980).

On micropaleontological grounds the Opoitian/Waipipian boundary is very poorly defined being above the FAD of *G. inflata* in the Mangapoike River Section and below the LAD of *G. margaritae* in the northern part of the East Coast Deformed Belt (Hornibrook, 1982). A species of *Hyalinea* close to *H. balthica* (Schroeter), which is considered to be a cool water species and a marker for the base of the Pleistocene in the Mediterranean, occurs at several Waipipian localities in Wanganui (Collen, 1974) and the Waipipian of Hawkes Bay (Hornibrook, 1981b).

5.1.7 Mangapanian Stage

Top : FAD of *Globorotalia crassula*

Base : FAD of dextral *Globorotalia crassaformis*

Fleming (1953) established the Mangapanian to include beds with faunas like those at Mangapani and Wilkies Bluff, in the Waitotara River Valley, the Mangapani Shell Conglomerate being designated the type formation. Being based on mollusca it is difficult to determine away from the type section although species of the gastropod *Pellicaria* have been used in southern Wairarapa for recognising Mangapanian strata (Vella, 1953) and *Chlamys* (*Phialopecten*) *triphooki triphooki* (Zittel) is a key species used in the Te Aute Limestone facies in Hawke Bay (Beu, Grant-Taylor and Hornibrook, 1980).

Cibicides molestus Hornibrook, a benthic foraminifer, is common in bathyal to mid-shelf facies and usually accompanies *Mesopeplum crawfordi*, the Waipipian marker, and their extinctions, plus the FAD of *Globorotalia tosaensis* (and rare forms resembling *G. truncatulinoides*), and the FAD of dextral *G. crassaformis* occur at the same level in the Raukawa Range section (Hornibrook, 1981b). The subspecies *Globorotalia puncticulata puncticuloides* Hornibrook also appears at about this level.

The extinction of *C. molestus* and a change from predominantly sinistral or random to predominantly dextral populations of *G. crassaformis*, correlate from the East Coast to the Wanganui Basin and defines a good datum level at the base of the Mangapanian.

5.1.8 Nukumaruan Stage

Top : Hard to determine using micropaleontological data

Base : FAD of *Globorotalia crassula*

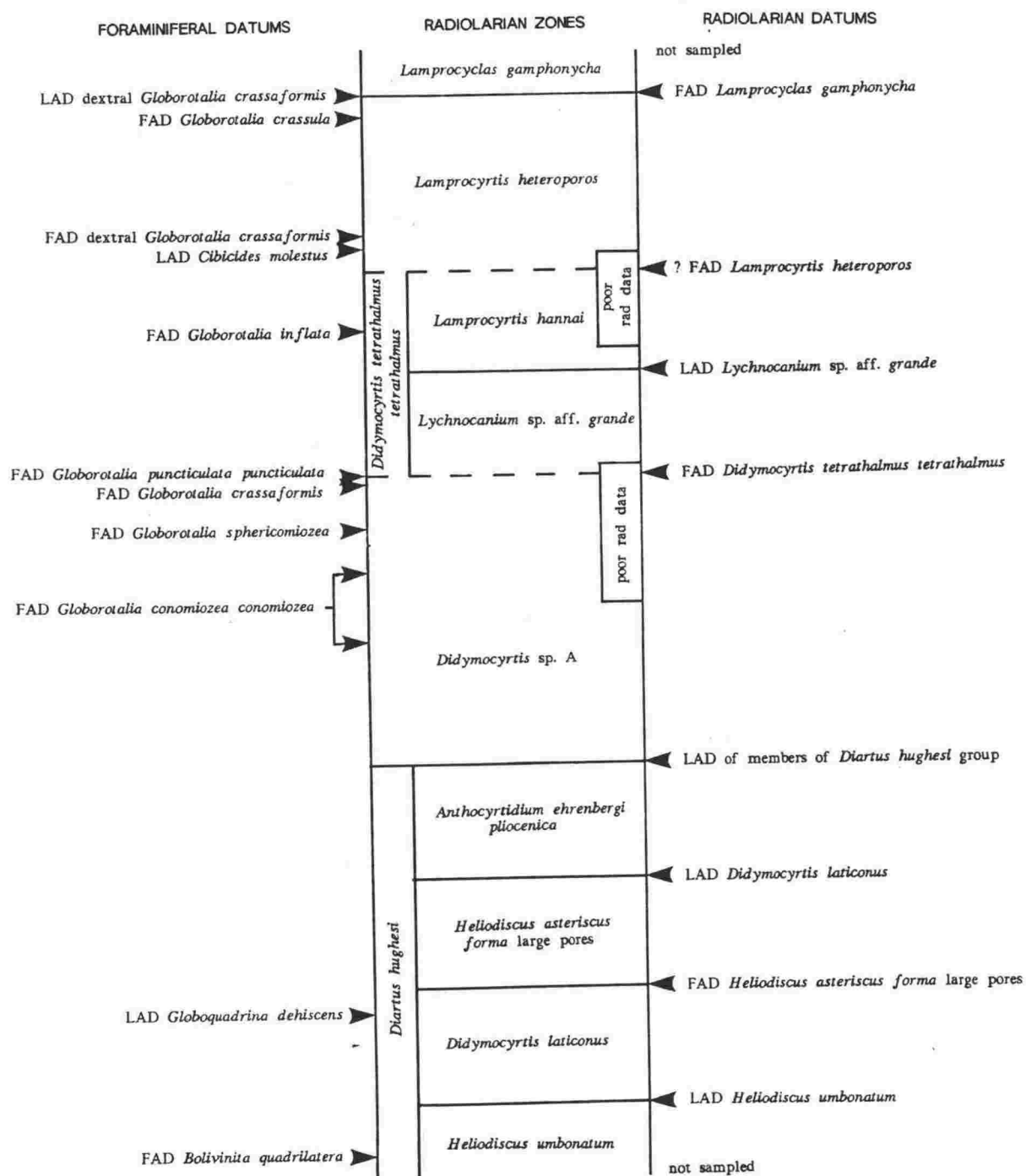
The Nukumaruan was introduced by Marwick (1924b), its name being emended to the present spelling by Marwick (1931). This stage filled in the gap between Thomson's (1916) Waitotaran and Castlecliffian. The type designated by Fleming (1953) is the Nukumaruan Brown Sand, but the stage includes a much greater thickness of strata outcropping between Okehu and Waitotara River. The Hautawa Shellbed, at the base of the Nukumaruan, was designated the type of the Hautawan substage by Fleming (1953) and it is generally accepted that it represents a major cool episode, although there has been debate about its usefulness for correlation using the subantarctic pectinid, *Chlamys delicatula* (Hutton) (see Beu, 1969; Vella and Nicol, 1970).

The FAD of the planktic foraminifer *Globorotalia crassula* Cushman and Stewart has proved useful in East Coast deeper water sequences (Hornibrook, 1980, 1981b, 1982) for identifying the base of the Nukumaruan. It is extremely rare in the type section but there appears to be correlation with East Coast sequences (Hornibrook, 1981b). The basal part of the range of *G. crassula* overlaps with dextral *G. crassaformis* which in the East Coast Basin becomes sinistral and very rare within the lower Nukumaruan. The overlap also contains *Chlamys delicatula*. The earliest appearance of *G. truncatulinoides* within the Nukumaruan is not useful because of the gradual replacement of *G. tosaensis* (Hornibrook, 1976b). The FAD of the calcareous nannofossil *Geophyrocapsa sensu stricto* (= *G. sinuosa*) in the middle Nukumaruan Waipuru Shellbed, in the Rangitikei River, is a reliable datum and permits correlation between Wanganui and the East Coast Basin (Edwards, 1976).

The marked enrichment of O^{18} between 60 and 50 metres in DSDP Site 284, which Shackleton and Kennett (1975b) considered represents the accumulation of Northern Hemisphere Ice, is within the dextral *G. crassaformis* - *G. crassula* overlap zone (Hornibrook, 1981b). Fleming (1953) placed the Pliocene/Pleistocene boundary at the base of the Nukumaruan because of the evidence of the marked cold marine climatic episode but the position of the boundary is now slightly higher (middle Nukumaruan) to allow correlation with the Vrica Section, Italy (Beu and Edwards, 1984).

Figure 5.2

Correlation of foraminiferal bioevents to the New Zealand radiolarian zones and a listing of the radiolarian events defining the zones.



5.1.9 Castlecliffian Stage

Note: Boundaries hard to determine using micropaleontological data

Thomson (1916) based the Castlecliffian on the fossiliferous beds at Castlecliff, Wanganui. Benthic foraminiferal datums mentioned in Fleming (1959) are of limited usefulness. The only planktic foraminiferal datum (also of very limited value) is the LAD of *G. tosaensis* which occurs within the lower Castlecliffian (Hornibrook, 1982). The LAD of the calcareous nannofossil *Pseudoemiliana lacunosa* in the Upper Kai-Iwi Siltstone on the Castlecliff Coast has been used by Beu and Edwards (1984) to correlate with isotope stage 12 in deep-sea cores, near the top of the Castlecliffian.

5.2 RADIOLARIAN ZONATION

5.2.1 Introduction

Five major radiolarian biostratigraphic zones can be recognised in the upper Neogene of New Zealand with six subzones identifiable in samples with good preservation. The correlation between New Zealand Late Neogene foraminiferal and radiolarian bioevents is shown in figure 5.2. Figure 5.3 shows the ranges of some of the radiolarians studied.

5.2.2 *Diartus hughesi* Zone

Top : LAD of members of the *Diartus hughesi* group

Base : Evolutionary base of *Diartus hughesi* (not sampled)

This major taxon-range zone encompasses most of the Tongaporutuan Stage in New Zealand. The base of the zone was not sampled and it is highly probable that the zone extends down into the Waiauian. The top of the zone is well defined in Wairarapa sections but is not well defined in northern sections due to either a paleoceanographic exclusion of the taxon from the northern area or some diachroneity in the LAD of members of the *Diartus hughesi* group within New Zealand. These possibilities are further discussed in section 5.3.3.

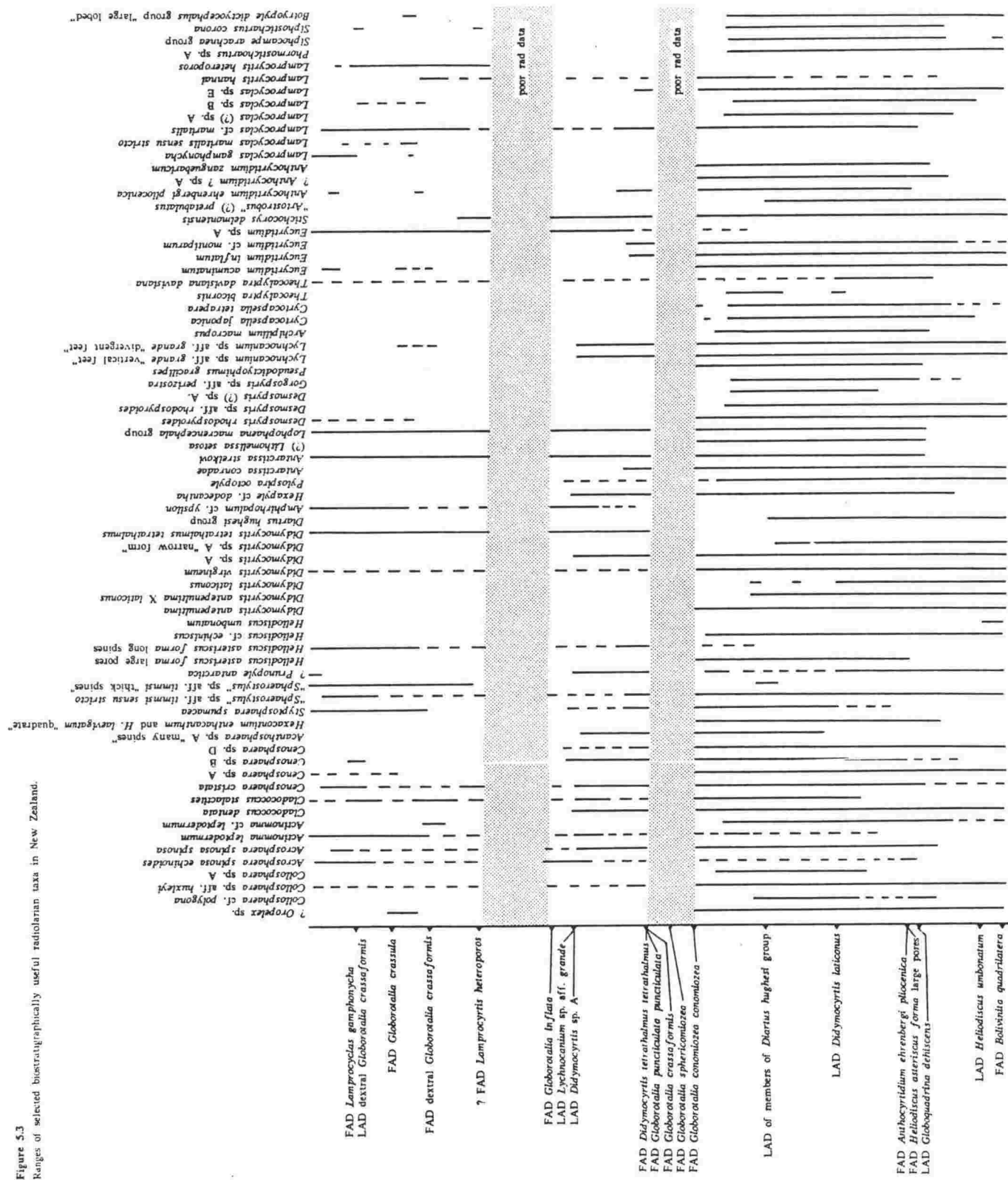
This zone is equivalent to the *Didymocyrtis antepenultima* (= *Ommatartus antepenultimus*) Zone as defined by Riedel and Sanfilippo (1978b) and in New Zealand can be divided into the following four subzones.

5.2.2.1 *Heliodiscus umbonatum* Subzone

Top : LAD of *Heliodiscus umbonatum*

Base : Evolutionary base of *Diartus hughesi* (not sampled)

Figure S.3



This is the oldest subzone and is probably a concurrent-range zone with *H. umbonatum* being very similar to an Early Miocene form of *Heliodiscus asteriscus* reported by Nigrini and Lombardi (1984, p.339). The zone occurs only in Leader River Section (northern Canterbury) and Kaiti Beach Section (Gisborne) in basal Tongaporutuan strata and is definable in only two samples (LT09 and KB04). Consequently its faunal makeup can not be fully assessed.

5.2.2.2 *Didymocyrtis laticonus* Subzone

Top : FAD of *Heliodiscus asteriscus forma large pores*

Base : LAD of *Heliodiscus umbonatum*

The FAD of *Heliodiscus asteriscus forma large pores*, normally occurring just above the LAD of *Globoquadrina dehiscens*, defines the top of this gap zone in the Tongaporutuan. The FAD of *Anthocyrtidium ehrenbergi pliocenica* is not as well defined but occurs at nearly the same level. Both *Didymocyrtis antepenultima* and *D. laticonus* occur in this subzone. Within this subzone, the FAD of quadrate forms of *Hexacanthium enthacanthum* and *H. laevigatum* occurs below the LAD of *Globoquadrina dehiscens*. Other useful radiolarian bioevents that occur within this subzone include; the FAD's of *Antarctissa strelkovi*, *Lithomelissa setosa*, *Lophophaena macrencephala*, and of rare *Pseudodictyophimus gracilipes*, *Archipilium macropus*, and *Hexapyle dodecantha*, all at about the same level as the LAD of *Globoquadrina dehiscens*. *Theocalyptra davisiana davisiana*, *Anthocyrtidium* sp. A, *Anthocyrtidium zanguebaricum*, *Lamprocyclas* sp. A, and *Siphostichartus corona* all first appear within the top half of this subzone with *Lamprocyclas* sp. B first appearing in the bottom half. The first patchy records of *Collosphaera polygona*, *Cenosphaera* sp. B, and *Gorgospyris* sp. aff. *perizostra* occur in this subzone. The large number of radiolarian bioevents at or near the LAD of *Globoquadrina dehiscens* adds support to the suggestion of Wright, Ashby and Hoskins (1985) that the sudden disappearance of *Globoquadrina dehiscens* in the Mangapoike Section is in response to a period of cooling, with the associated paleoceanographic change affecting a number of radiolarian species.

5.2.2.3 *Heliodiscus asteriscus forma large pores* Subzone

Top : LAD of *Didymocyrtis laticonus*

Base : FAD of *Heliodiscus asteriscus forma large pores*

The LAD of *Didymocyrtis laticonus* is a moderately well defined datum and provides a useful bioevent to define the top of this concurrent-range zone. The zone is marked by a

relatively stable radiolarian fauna. The few radiolarian bioevents that occur within the subzone include the FAD of *Desmospyris* sp. A in northern sections and the FAD of rare *Collosphaera* sp. A. Also present are the first patchy records of *Actinomma leptodermum* and *Styptosphaera spumacea*.

5.2.2.4 *Anthocyrtidium ehrenbergi pliocenica* Subzone

Top : LAD of members of the *Diartus hughesi* group

Base : LAD of *Didymocyrtis laticonus*

This is the youngest subzone in the *Diartus hughesi* Zone, consequently both the zone and the subzone have the same top. Radiolarian bioevents that occur within this successive disappearance subzone include the FAD of rare *Acanthosphaera* sp. A, the LAD of the "narrow" variety of *Didymocyrtis* sp. A, and of rare "*Artostrobus*" *pretabulatus*, and the first relatively common appearance of *Theocalyptra bicornis* in Wairarapa.

5.2.3 *Didymocyrtis* sp. A Zone

Top : FAD of *Didymocyrtis tetrathalmus tetrathalmus*

Base : LAD of members of the *Diartus hughesi* group

The upper half of this gap zone is poorly defined by radiolarians as they are generally lacking in the shallow water sediments typical of the uppermost Miocene (Kapitean) in New Zealand. Consequently there is a gap in the radiolarian fossil record between the FAD of *Globorotalia conomiozea conomiozea* and the joint FAD's of *Globorotalia crassaformis* and *G. puncticulata puncticulata*. The *Bolivinita pohana* - *pliozea* transition occurs in the bottom half of this zone. A number of radiolarian last appearance datums occur in the middle, being grouped at the base of the sampling gap. The grouping is most likely related to the lack of preservation in the Kapitean rather than a "mass" extinction level at the base of the Kapitean. The bioevents include the LAD of rare *Collosphaera* cf. *polygona* and *Collosphaera* sp. A, the last common *Actinomma* cf. *leptodermum* (there are some late Pliocene occurrences), last positive *Cenosphaera* sp. A (some tentative records in the late Pliocene and Pleistocene), the LAD of quadrate forms of *Hexacontium laevigatum* and *H. enthacanthum*, the LAD of *Heliodiscus asteriscus forma* large pores and the first tentative records of *H. asteriscus forma* long spines, the LAD of *Heliodiscus* cf. *echiniscus* and *Didymocyrtis antepenultima*, the last positive occurrence of *Pylospira octopyle* (one tentative identification in the basal Pliocene), the LAD of *Lithomelissa* sp. aff. *setosa*, the last positive identification of *Desmospyris rhodospyroides*, the LAD of *Desmospyris* sp. aff.

rhodospyroides, the LAD of rare *Desmospyris* sp. A (restricted to northern Hawkes Bay), the LAD of *Gorgospyris* sp. aff. *perizostra* and rare *Pseudodictyophimus gracilipes*, the LAD of rare *Archipilium macropus*, the last positive occurrence of *Cyrtocapsella japonica* (some tentative Plio/Pleistocene records), the LAD of *Cyrtocapsella tetrapera*, the LAD of *Theocalyptra bicornis* in Wairarapa, the LAD of *Eucyrtidium acuminatum*, the first tentative records of *Eucyrtidium* sp. A, the LAD of *Anthocyrtidium* sp. A and *Anthocyrtidium zanguebaricum*, the LAD of *Lamprocyclas* sp. A and the last positive occurrence of *Lamprocyclas* sp. B, the LAD of both *Phormostichartus* sp. A and rare *Siphocampe arachnea*, the last positive occurrence of *Siphostichartus corona*, and the last common occurrence of the large lobed form of *Botryopyle dictyocephalus*.

5.2.4 *Didymocyrtis tetralthmus tetralthmus* Zone

Top : ? FAD of *Lamprocyrts heteroporos*

Base : FAD of *Didymocyrtis tetralthmus tetralthmus*

This successive appearance zone is relatively poorly defined in New Zealand because a large gap occurs in the radiolarian fossil record in the upper half of this zone. The didymocyrtids are relatively poorly preserved in the uppermost Miocene and lower Pliocene part of the New Zealand sequence and there is a possibility that forms transitional between *D. tetralthmus tetralthmus* and *D. antepenultima*, such as *D. avitus* and *D. penultima* have been included in forms described as *D. tetralthmus tetralthmus* because the polar caps are often not preserved. *D. tetralthmus tetralthmus* first occurs near the level of the joint FAD's of *Globorotalia crassaformis* and *G. puncticulata puncticulata* in basal Opoitian sediments, immediately just above the Kapitean interval lacking radiolarians.

The questionable top of this zone is the FAD of *Lamprocyrts heteroporos*. This taxon is assumed to have evolved from *Lamprocyrts hannai*, which is present in the *Lamprocyrts hannai* Subzone and older sediments. The *Didymocyrtis tetralthmus tetralthmus* Zone can be divided into two subzones.

5.2.4.1 *Lychnocanium* sp. aff. *grande* Subzone

Top : LAD of *Lychnocanium* sp. aff. *grande*

Base : FAD of *Didymocyrtis tetralthmus tetralthmus*

This concurrent range zone is reasonably well represented by samples from Wairarapa but is poorly represented in northern samples. The LAD of *Didymocyrtis* sp. A occurs at about the same level as the LAD of *Lychnocanium* sp. aff. *grande* and is very useful in

co-defining the top of the subzone.

The subzone marks the first relatively common appearance of *Acrosphaera spinosa echinoides* and apart from two occurrences in the Pleistocene at Waiatai the last appearance of *Acrosphaera spinosa spinosa*. The first relatively common *Actinomma leptodermum sensu stricto* occurs in the upper half of the subzone.

Other radiolarian bioevents occurring in the subzone include the LAD of *Cladococcus dentata*, last common *Cenosphaera* sp. B, the LAD of rare *Acanthosphaera* sp. A and *Hexapyle dodecantha*, the last positive occurrence of *Collosphaera* sp. aff. *huxleyi* and *Cenosphaera* sp. D near the base of the subzone, the FAD of *Amphirhopalum* cf. *ypsilon*, the LAD of *Antarctissa conradae* and *Eucyrtidium inflatum*, the transition from *Eucyrtidium* cf. *montiparum* to *Eucyrtidium* sp. A, the last positive occurrence of *Anthocyrtidium ehrenbergi pliocenica* and the LAD of *Lamprocyclas* sp. E.

5.2.4.2 *Lamprocyrtis hannai* Subzone

Top : ? FAD of *Lamprocyrtis heteroporos*

Base : LAD of *Lychnocanium* sp. aff. *grande*

This gap zone is very poorly defined in New Zealand, the number of samples from it being only two; SWM1 near the base and LT01 from about the middle. The oldest sample from Waiatai (WA26) is placed just above the top. Intrazonal radiolarian bioevents could not be determined but the FAD of *Globorotalia inflata* occurs within the lower half of the subzone.

5.2.5 *Lamprocyrtis heteroporos* Zone

Top : FAD of *Lamprocyclas gamphonycha*

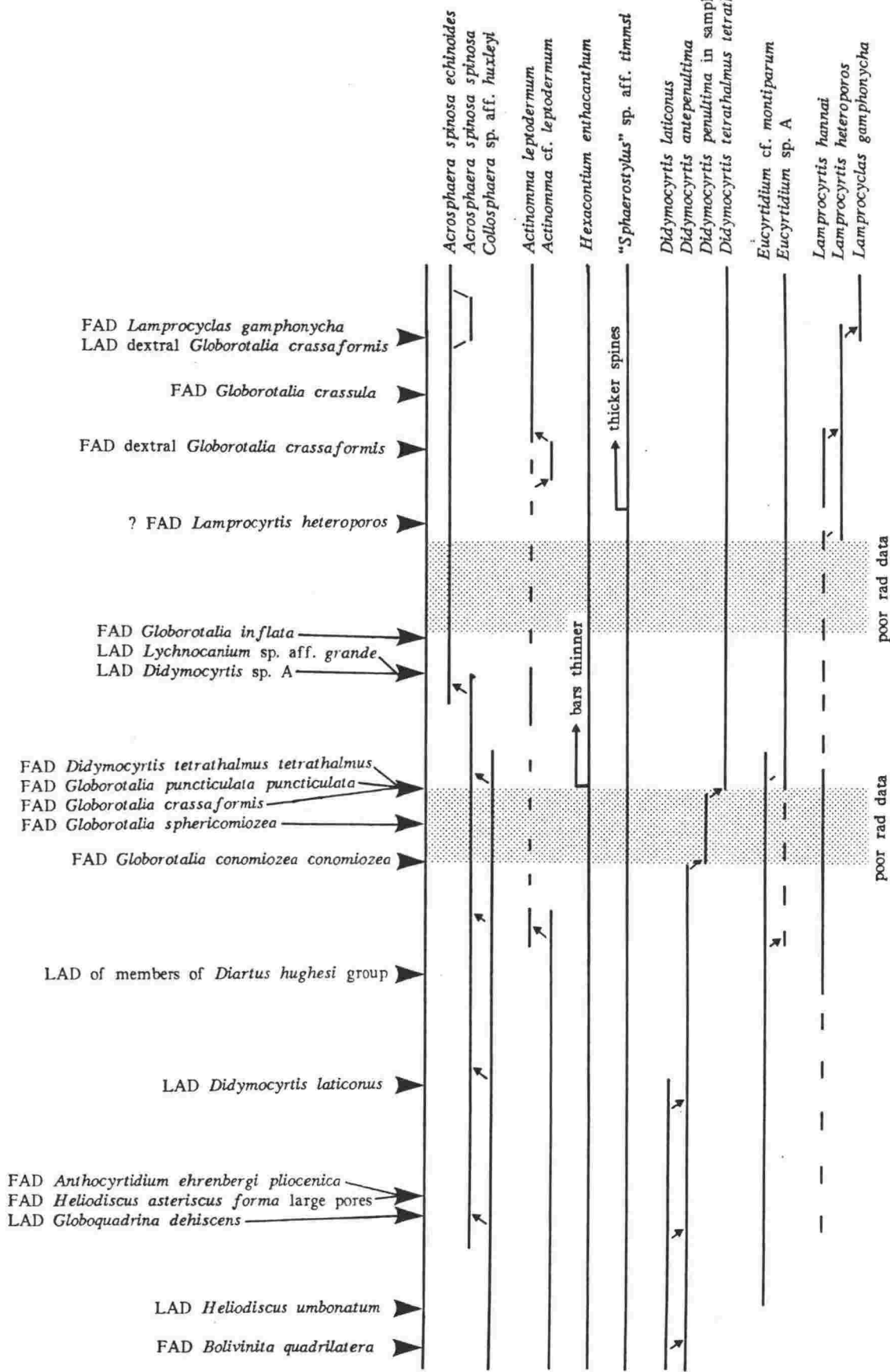
Base : ? FAD of *Lamprocyrtis heteroporos*

This successive appearance zone is well defined in northern Hawkes Bay sections, but the transition from *Lamprocyrtis hannai* to *L. heteroporos* at the base is defined by only two samples from the base of the Waiatai Valley Section. The dextral *Globorotalia crassaformis* - *G. crassula* overlap Zone occurs near the top.

Radiolarian bioevents occurring within the zone include the last positive occurrence of *Actinomma* cf. *leptodermum* which is replaced by *Actinomma leptodermum* in the Pliocene, the FAD of the thicker spined form of "*Sphaerostylus*" sp. aff. *timmsi* (apart from one specimen from the Miocene), the FAD of *Heliodiscus astericus forma* long spines and the

Figure 5.4

Generalised summary of the main radiolarian lineages and morphologic trends present in the New Zealand sequences.



last positive occurrence of *Stichocorys delmontensis*. The *Lamprocyclas* fauna is dominated by *Lamprocyclas* cf. *maritalis*.

Hays (1970) defined the zone as the range of *L. heteroporos* subsequent to the extinction of *Eucyrtidium elongatum peregrinum* (= *Stichocorys peregrina*). *Stichocorys peregrina* (a tropical radiolarian) has a higher stratigraphic range in New Zealand (into the *Lamprocyclas gamphonycha* Zone) than in the north Pacific and Hay's (1970) definition is unusable in New Zealand.

5.2.6 *Lamprocyclas gamphonycha* Zone

Top : undefined in New Zealand

Base : FAD of *Lamprocyclas gamphonycha*

This range (?) zone is marked at the base by the evolutionary transition from *Lamprocyrtis heteroporos* to *Lamprocyclas gamphonycha* and is well defined in Waiatai Valley Section. The transition in that section corresponds with the change from dextral to rare sinistral *Globorotalia crassaformis* at the top of the dextral *Globorotalia crassaformis* - *G. crassula* overlap zone.

5.2.7 Radiolarian lineages

There are a number of possible radiolarian lineages present in the New Zealand Late Neogene. The following text outlines some of the more useful biostratigraphic transitions that help in determining ages at an "epoch" level.

Acrosphaera spinosa spinosa is replaced by *Acrosphaera spinosa echinoides* in the lower Pliocene, although there are two positive occurrences of the former taxon in the Pleistocene at Waiatai. The trend is opposite to that proposed by Bjorklund and Goll (1979) for Atlantic specimens. The trend involves a gradual increase in protuberance height and is supported by the restriction of positive occurrences of the smooth outlined *Collosphaera* sp. aff. *huxleyi* (which is probably related to *Acrosphaera spinosa*) to Miocene and basal Pliocene sediments. The appearance of *Collosphaera* sp. aff. *huxleyi* in Recent sediments in the Indian Ocean (Johnson and Nigrini, 1980) and the fact that this trend is opposite to that observed by Bjorklund and Goll indicates that the biostratigraphic transition may be an expression of differing ecological responses of two species with differing niches.

The *Didymocyrtis* lineage (*laticonus* - *antepenultima* - *tetrathalmus*) is well represented in the late Miocene and basal Pliocene in New Zealand although there is an abrupt change

from *antepenultima* to *tetrathalmus* which may be related to very poor faunal preservation in the uppermost Miocene (see section 5.7.9).

Actinomma cf. *leptodermum* appears to evolve into the post-Miocene *Actinomma leptodermum* but there is one positive identification of the former taxon in the uppermost Pliocene.

The by-spines on "*Sphaerostylus*" sp. aff. *timmsi* become thicker, longer and more symmetrically disposed from the middle Pliocene onwards but there is one identification of the thicker spined form in the Miocene (RM07).

The opposing range patterns of *Prunopyle* sp. A (more common in the Miocene) and *Prunopyle antarctica* (more common post-Miocene) indicates a gradual morphologic change in this genus.

Although rare, the "long-spined" form of *Heliodiscus asteriscus* appears to have evolved, in the late Pliocene, from the more common "small pored" form.

Hexacantium enthacanthum has a tendency for the bars to get thinner in the Pliocene and Pleistocene.

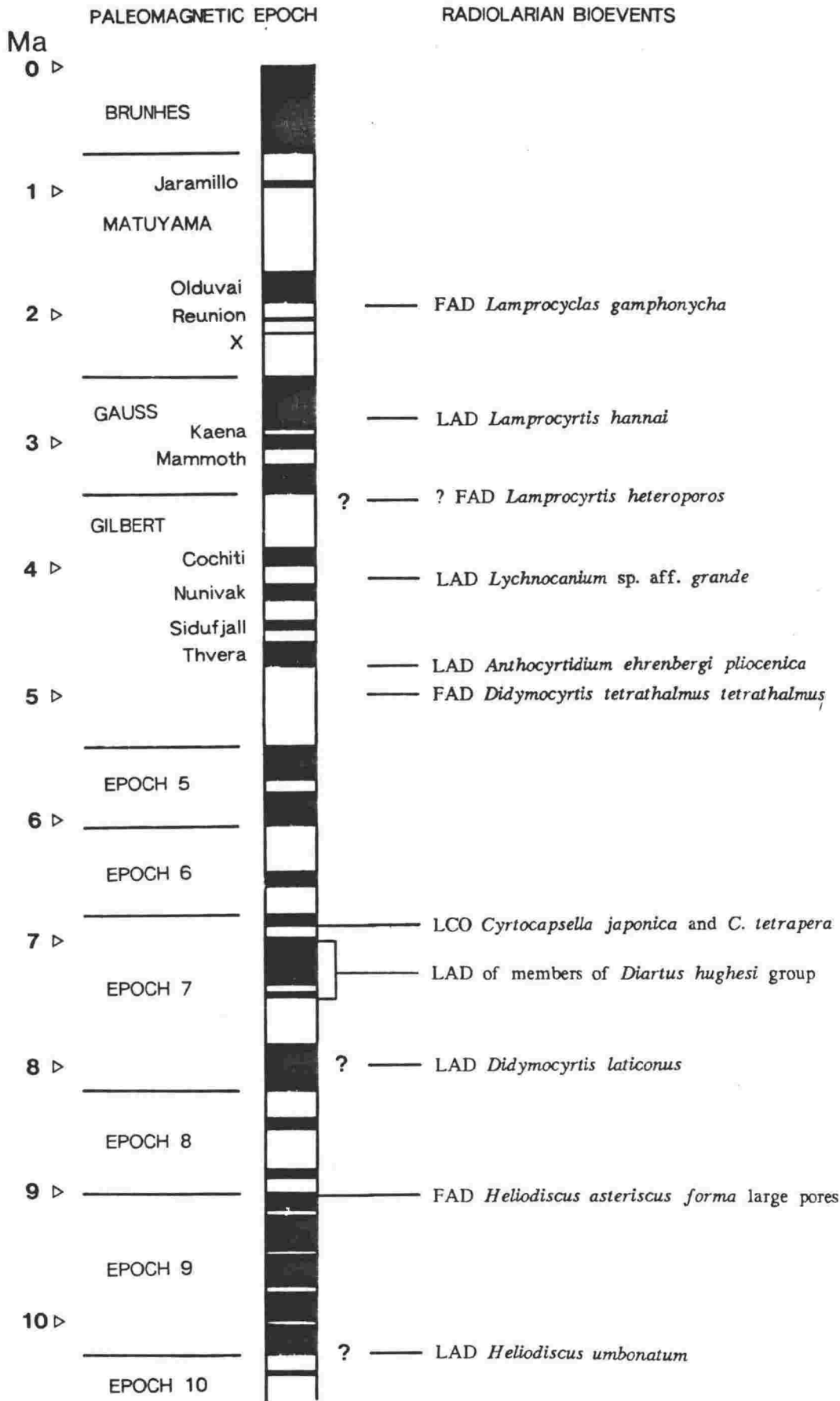
There is also an apparent partial replacement of *Dictyocoryne profunda* in the Plio-Pleistocene with the arms becoming more conspicuously chambered (cf. *Hymeniastrum euclidis*). The apparent trend of the three-rayed spongodiscids becoming more conspicuously chambered in the Pliocene is supported by the appearance of well-chambered *Amphirhopalum* cf. *ypsilon* in Plio-Pleistocene samples. The reported transition from *Amphirhopalum virchowii* to *A. ypsilon* near the Plio-Pleistocene boundary (Nigrini, 1974) is not substantiated by this study. Samples lacking *A. virchowii* but containing *A. cf. ypsilon* occur in the lower Pliocene.

The opposing range patterns of members of the *Botryostrobus auritus-australis* group (more prominent post-Miocene) and *B. bramlettei* (Miocene) indicate the same gradual evolutionary transition that was reported Reynolds (1980).

A number of forms including *Stylodictya validispina*, the *Tetrapyle octacantha* group, the carpocaniids, *Cornutella profunda*, *Eucyrtidium acuminatum*, *E. cienkowskii*, and *E. hexagonatum*, members of the genus *Lamprocyclas*, and *Siphocampe lineata* and *S. nodosaria* tend to be found in a smaller percentage of younger samples.

Figure 5.5

Correlation of radiolarian bioevents to the paleomagnetic time-scale with the age estimates from Ness *et al.* (1980). More recent age estimates on the paleomagnetic time-scale are presented in Berggren *et al.* (1985).



5.3 REAL AGE ESTIMATES OF RADIOLARIAN ZONAL BOUNDARIES

5.3.1 Radiometric ages

Radiometric dates for strata from the New Zealand Neogene are few in number. Two K/Ar dates from the Chatham Islands (Hornibrook, 1984a) are particularly relevant to this study. At Momoe-a-toa, a basalt dated at 5.2 ± 0.2 Ma appears to be interbedded with tuffaceous sediments containing rare *Globorotalia crassaformis*, rare *G. pliozea*, *G. puncticulata puncticulata* and *G. conomiozea mons* (basal Opoitian). At the other locality, Maunganui Bluff, a basalt dated at 5.33 ± 0.2 Ma overlies a thin calcareous sand containing a similar basal Opoitian planktic foraminiferal fauna. Problems with the magnetic polarity of the basalt need to be resolved (Hornibrook, 1984a).

Some fission track dating of volcanic tuffs from the upper Neogene marine sequences is available (e.g. Seward, 1974, pers. comm.; Hornibrook, 1984a). Originally, fission track ages were determined from volcanic glass (Seward, 1974) but track annealing has affected the resultant ages. Three fission track ages based on zircon crystals have particular relevance to this study. A thin tuff bed below an upper Miocene unconformity in the road cut exposure at Mangapoike River (see figure A.17) has been dated at 5.80 ± 0.55 Ma by Dr.D. Seward (in Hornibrook, 1984a). This tuff is in strata associated with predominantly four-chambered *Globorotalia miotumida* and is approximately 150m above the *Bolivinita pohana-pliozea* transition as defined by Scott (1978b). Radiolaria from the sediments encompassing the tuff (below the unconformity) are from the *Didymocyrtis* sp. A Zone and *Didymocyrtis antepenultima* is also present. At Mahia Peninsula, sample SMH1 from the *Didymocyrtis* sp. A Zone was collected 3m below a tuff (Hornibrook FT37) dated at 6.39 ± 1.14 Ma (Dr.D. Seward, pers. comm.). The foraminiferal fauna of this sample contains a *Globorotalia miotumida* population with 50% five chambered forms, and *Bolivinita pohana*. At Palliser Bay a tuff (see Plate C3.2) from within the *Anthocyrtidium ehrenbergi pliocenica* Subzone has been dated at 7.27 ± 1.28 Ma (Dr.D. Seward, pers. comm.). The FAD of *Bolivinita pliozea* occurs 36m above this tuff.

5.3.2 Paleomagnetic ages

Previous paleomagnetic studies include analyses of four Late Neogene sections in New Zealand:

- (a) Blind River: Kennett and Watkins (1974)
- (b) Hinakura-Hikawera: Lienert, Christoffel and Vella (1972)
- (c) Lower Mangaopari: Kennett, Watkins and Vella (1971)

(d) Mangapoike: Kennett and Watkins (1974), Wright (1985, in prep.)

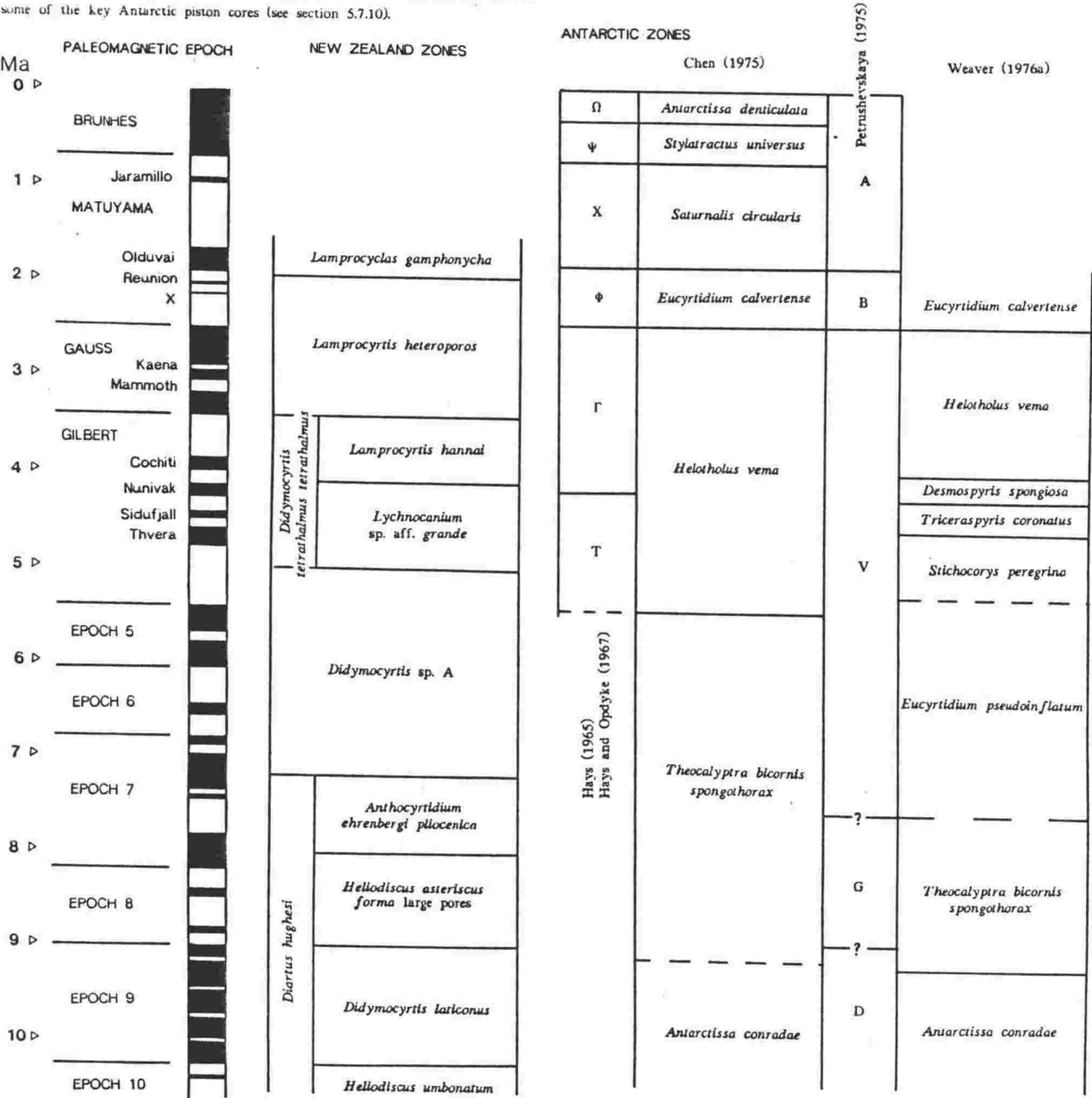
The first three sections are not helpful in determining ages of radiolarian zonal boundaries as radiolarians are either lacking or very poorly represented. The radiolarian bearing zone in the Mangapoike River Section (*Didymocyrtis* sp. A Zone) encompasses the time interval of 7.7 to 6.0 Ma. Within this interval Wright (1985) has inferred a disconformity accounting for the time interval 6.86 to 6.42 Ma. It is at this disconformity that the last positive occurrence of *Cyrtocapsella japonica* and the last common occurrence of *Cyrtocapsella tetrapera* are located.

5.3.3 Summary

Edwards (1985) has integrated the wealth of biostratigraphic, lithostratigraphic, magnetostratigraphic, radiometric and stable isotope data from the uppermost Miocene to Pleistocene into a coherent model. Radiolarian datums can be correlated with this model by tying the radiolarian bioevents to foraminiferal bioevents. The integration of these events is outlined in figure 5.5. Tongaporutuan bioevents are not as well integrated into the radiometric time scale because of a paucity of paleomagnetic and radiometric age determinations, but empirical data suggest some complications in bioevent age determinations.

The LAD of members of the *Diartus hughesi* group in the Palliser Bay Section (see figure A.36) occurs above the FAD of *Bolivinita pliozea*, about midway between the FAD of *G. conomiozea conomiozea* and the Palliser Bay tuff dated at 7.27 ± 1.28 Ma. If the sudden disappearance of *Globoquadrina dehiscens* (9.2 Ma in Mangapoike River: Wright, Ashby and Hoskins, 1985) is accepted as an isochronous event in New Zealand Tongaporutuan strata, an interpolated age for the LAD of members of the *Diartus hughesi* group in the Upper Mangaopari Stream Section (see figure A.34) would be 7.0 to 7.5 Ma. *Diartus hughesi* is absent from strata younger than 7.7 Ma (date from I.C. Wright, 1985 and pers. comm.) in Mangapoike River Section. Sediments older than this from Mangapoike River do not contain radiolarian skeletons. Two tentative identifications of *D. hughesi* from Hangaroa in sediments also containing *Didymocyrtis laticonus* are the only occurrences, post-LAD of *Globoquadrina dehiscens*, in northern Hawkes Bay. It appears that either paleoceanographic conditions excluded *D. hughesi* from northern Hawkes Bay or there is some diachroneity of its disappearance datum between northern Hawkes Bay and southern Wairarapa. The foraminiferal fauna from Mangapoike River Section indicates restricted oceanic circulation (Dr.B. Hoskins, pers. comm.) and the configuration of the Wairoa Syncline (plunging to the south) could easily accomodate basinal closure to the north in the

Figure 5.6
Correlation of the main Antarctic radiolarian zonations to New Zealand radiolarian zonations. The 'pre middle Gilbert' correlation of the Antarctic zones is in question as there appears to be substantial disconformities at the bases of some of the key Antarctic piston cores (see section 5.7.10).



Miocene. Until more radiometric and paleomagnetic dating becomes available, the former hypothesis is preferred.

5.4 ANTARCTIC ZONATIONS

The correlation of the following Antarctic zones to New Zealand zones is outlined in figure 5.6.

Hays (1965) was the first to develop an Antarctic radiolarian biostratigraphic zonation. Utilising data from 65 piston cores (only 19 of which reached sediments containing species not living in Antarctic waters today) he established four radiolarian zones based on the upward sequential disappearance of several radiolarian species. Of the four zones, the youngest, Omega (Ω), consists of only Recent species and the older three zones, Psi (Ψ), Chi (χ), and Phi (ϕ), are defined by fifteen indicator species. The boundary between the χ and ϕ zones, placed at the last common occurrence of *Eucyrtidium calvertense* in the Antarctic region, was tentatively correlated with the Pliocene/Pleistocene boundary. Opdyke *et al.* (1966) placed Hays' four zones into a time stratigraphic framework using magnetostratigraphy. They placed the boundary between the χ and ϕ zones just below the base of the Olduvai event which is in close approximation to the Pliocene/Pleistocene boundary as recognised by Ryan *et al.* (1974) and Berggren (1984). Hays and Opdyke (1967) extended Hays' initial zonation to include lower Pliocene sediments utilising the data from three long piston cores (E-13-17, E-14-8, E-13-3) and introduced two older radiolarian zones; the Upsilon (Υ), and Tau (T) zones, the base of the latter not being defined. Bandy, Casey and Wright (1971) attempted to increase the resolution of the six-fold zonation by dividing the Ω zone into two subzones, the Υ zone into four subzones and the T zone into two subzones. Regional implementation of their subzonation throughout the Southern Ocean has proven unsuccessful (Weaver, 1976a), probably because the Pliocene radiolarian zonations are essentially based on data from one of the cores (E-14-8) whose paleomagnetic signature has been interpreted differently (e.g. Weaver, 1976a and Keany, 1979).

Theyer (1972) proposed a zonal scheme for the Antarctic and subantarctic region in the late Neogene which utilised some elements of Riedel and Sanfilippo's (1970) tropical zonation. Legs 28 and 29 of the Deep Sea Drilling Project provided the first opportunity to examine radiolarians in a nearly complete Neogene sequence from the Southern Ocean. Two radiolarian zonations were developed from the cores by Chen (1974, 1975: Leg 28) and Petrushevskaya (1975: Leg 29). Chen's zonation is essentially based on two sites (265 and 266) and he defined 13 radiolarian zones for the Neogene, the upper seven of which

correspond to the range studied in New Zealand. The upper five zones of Chen's have been correlated with Hays and Opdyke's (1967) zones and have improved the usage of the latter by employing fewer index species and using only first and last occurrences rather than the last common occurrence in defining zonal boundaries.

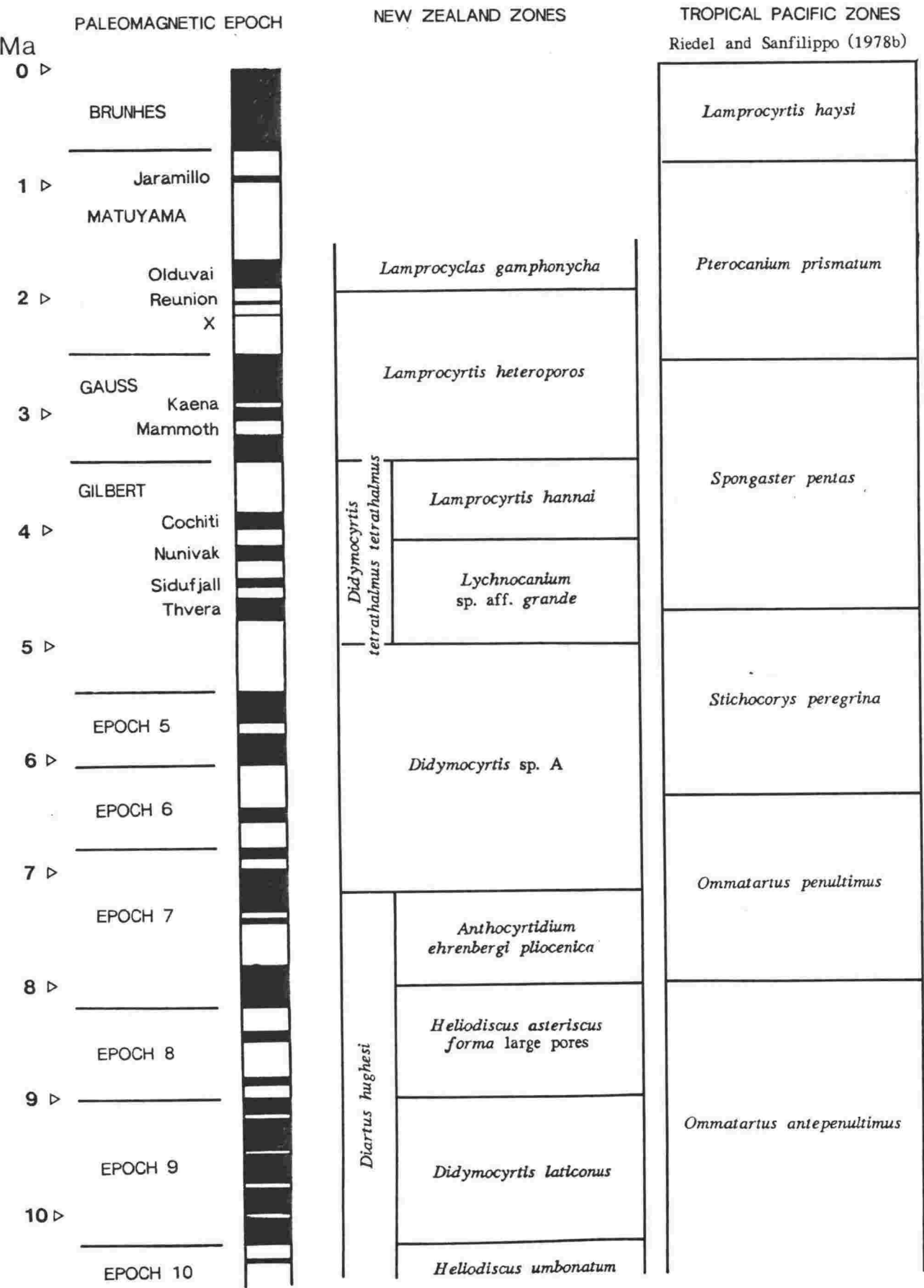
Petrushevskaya (1975) established a different tentative zonation. The Miocene portion is based primarily on Site 278. Recognising that the number of sections studied in the Antarctic is small and there are difficulties in deciding how synchronous the established periods of change in the radiolarian fauna are and also in what geographical ranges they occur. She defined a number of "biozones" using a large number of bioevents (the V/G and G/D boundaries essentially undefined). Both Petrushevskaya's and Chen's zonations have been hard to define regionally within the Southern Ocean due to the apparent diachroneity of certain biostratigraphic datums and the absence of several index species locally (Weaver 1976a), although Weaver (1976b) used Chen's zonation in defining the biostratigraphy of Leg 35 cores.

Weaver (1976a) developed a more detailed radiolarian biostratigraphy for the late Miocene-Pliocene of the subantarctic and Antarctic region in order to examine regional radiolarian paleobiogeography and Neogene paleoclimatology. This zonation utilised high resolution silicoflagellate and diatom Neogene biostratigraphies in conjunction with paleomagnetic stratigraphy to correlate cores.

Keany (1979) essentially used three Eltanin piston cores (E-14-8, E-16-4 and E-34-19) and DSDP Sites 265 and 266 to establish a detailed radiolarian zonation for the Gilbert, establishing five new partial-range zones.

Hiatuses, mixings and short-lived polarity events which do not correlate with the established paleomagnetic time-scale complicate most polarity logs and have resulted in differing paleomagnetic interpretations for Eltanin core E-14-8, one of the key Antarctic cores, (see Weaver 1976a and Keany 1979). The discovery of a substantial hiatus at 167.5m in DSDP Site 278 (Keany and Kennett, 1975) and the apparent disconformity between the *Helotholus vema* Zone and *Theocalyptra bicornis spongothorax* Zone in DSDP Site 266 (Keany 1979) indicates that as the stratigraphy gets more refined more hiatuses will be discovered and could account for the present inability to apply the zonations published.

Figure 5.7
 Correlation of Riedel and Sanfilippo's (1978b) tropical Pacific radiolarian zonation to the New Zealand zonation.



5.5 TROPICAL ZONATIONS

The correlation of Riedel and Sanfilippo's (1978b) tropical zones to New Zealand zones is outlined in figure 5.7.

Riedel and Sanfilippo (1970) established a tropical zonation for the Cenozoic utilising data from the cores obtained on Leg 4 of the Deep Sea Drilling Project (eastern tropical Atlantic) and it was on this framework that much of the following tropical radiolarian work was based. This zonation left the portion younger than the LAD of *Pterocanium prismatum* unzoned. Nigrini (1971) filled in the unzoned "Quaternary" portion of Riedel and Sanfilippo's (1970) zonation utilising data from 17 piston cores from the equatorial Pacific. These zones were correlated to the paleomagnetic sequence by Johnson and Knoll (1975).

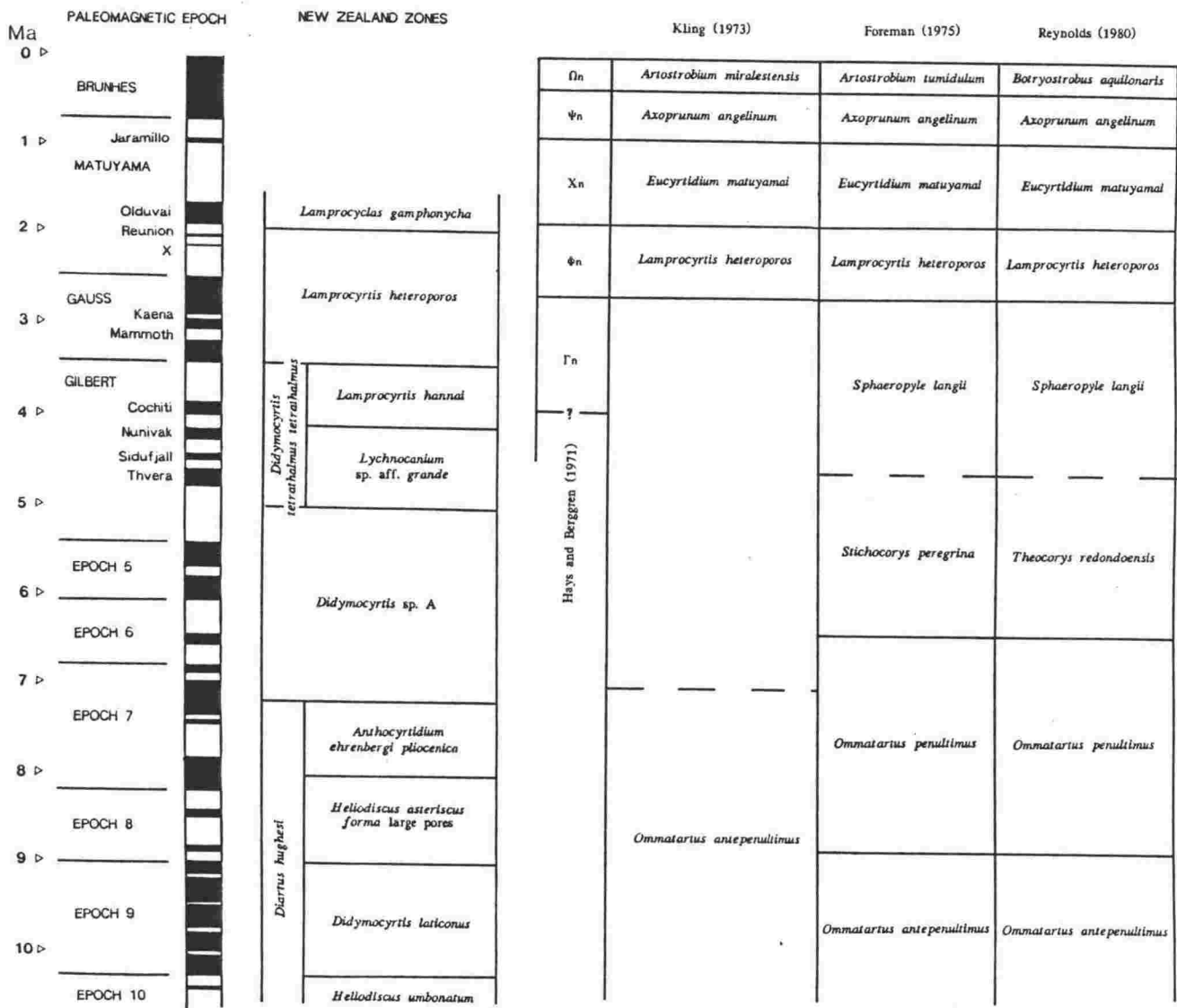
Goll (1972b) introduced a new Quaternary zone (the *Tholospyrus devexa devexa* Zone) to replace Riedel and Sanfilippo's (1970) unzoned interval and partially replace the *Pterocanium prismatum* Zone after Goll (1972a) concluded that the top of the latter zone is diachronous, being older in the eastern equatorial Pacific.

Riedel and Sanfilippo (1978b) altered the definition of some of their 1970 zones as more continuous sequences became available for study. Theyer and Hammond (1974) tied the zonal boundaries to the magnetostratigraphy and later extended the age control by correlating a number of extra radiolarian bioevents to the magnetic stratigraphy (Theyer, Mato and Hammond, 1974). Goll (1980) recognised a gap between the *Lamprocyrtis haysi* Zone and the *Pterocanium prismatum* Zone in DSDP Hole 420 on the East Pacific Rise and defined another zonal stratigraphy for the Pleistocene.

5.6 NORTH PACIFIC ZONATIONS

Hays (1970) was the first to develop a radiolarian stratigraphy for Plio-Pleistocene sediments in the North Pacific. Hays and Berggren (1971) named these zones the Ω_n , Ψ_n , X_n , Φ_n , Γ_n , and T_n zones, subscripting them with an "n" to signify that the zones are restricted to the northern hemisphere, are based on different species than the Antarctic zones of Hays (1965) and do not necessarily represent the same period of time as the Antarctic zone with the same Greek letter designation. Foreman (1975) in DSDP Leg 32 in the northern Pacific between Japan and Hawaii recognised the late Miocene zones of Riedel and Sanfilippo (1970) but could not determine their post-Miocene zones. Also Nigrini's (1971) Quaternary zones were not usable so she introduced the *Sphaeropyge langii* Zone to accommodate the

Figure 5.8
Correlation of north Pacific radiolarian zonations to New Zealand radiolarian zonations.



interval between the late Miocene and early Pliocene. This zone approximates the range of the *Spongaster pentas* Zone used in more southern tropical latitudes and underlies the *Lamprocyrtis heteroporos* Zone of Hays (1970). Kling (1973) in his study of the eastern north Pacific (especially Site 173) found, like Foreman, mixtures of equatorial and high latitude assemblages and applied both Hays' (1970) and Riedel and Sanfilippo's (1970) zonations with some emendations, especially changes of the zone names to conform to changes in the names of the taxa concerned. He also recorded an unzoned interval in the lower Pliocene and upper Miocene between the *Lamprocyrtis heteroporos* Zone and the *Ommatartus antepenultimus* (= *Didymocyrtis antepenultima*) Zone. Reynolds (1980) working on sediments from the western north Pacific used Kling's emendations to Hays' (1970) zones and also introduced some new late Miocene Zones. Other Late Neogene radiolarian zonations have been erected to cover local conditions; e.g. that for the Norwegian Sea (Bjorklund, 1976). Both the tropical and the North Pacific zonations have been applied to the on-land sequences in California (e.g. Casey, Price and Swift, 1972). Nakaseko and Sugano (1973) produced a very broadly defined zonal scheme for the late Neogene of Japan with two zones represented. The *Thecosphaera japonica* Zone essentially covers Pliocene and Pleistocene sediments and the *Lychnocanium nipponicum* Zone the upper Miocene. These two zones have been correlated to Foreman's (1975) zones by Sakai (1980: DSDP Leg 56).

5.7 CORRELATION OF NEW ZEALAND RADIOLARIAN OCCURRENCES TO INTERNATIONAL RANGES

5.7.1 LAD's of *Cyrtocapsella japonica* and *C. tetrapera*

Cyrtocapsella japonica and *C. tetrapera* have a well defined last appearance datum in the Mangapoike River Section in sample TM20. The datum falls immediately below a paleomagnetically inferred disconformity (6.86 to 6.42Ma) (Wright, 1985). Some other sections support this datum level in the upper Tongaporutuan although there are three tentative younger records of *C. japonica* in other sections with one as young as Pleistocene. These younger records could be variants of *Stichocorys* populations.

Riedel and Sanfilippo (1970) show the LAD of *C. japonica* to be synchronous with the LAD of *Didymocyrtis laticonus* within the *Didymocyrtis antepenultima* Zone. Casey (1972) shows the LAD of *C. japonica* to be in the middle Upper Miocene and the LAD of *C. tetrapera* within the Pliocene *Spongaster pentas* Zone in Mohole Samples. Casey, Price and Swift (1972) have the FAD's of *Didymocyrtis laticonus*, *C. japonica* and *C. tetrapera* together in Malaga Core samples whereas Reynolds (1980) show their LAD's to be just

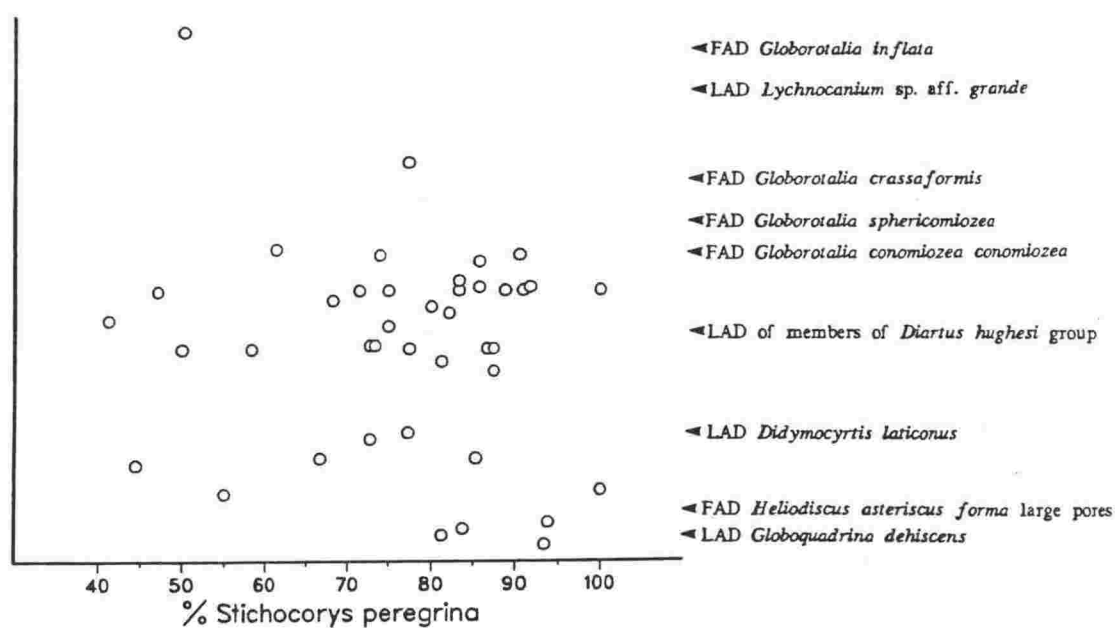


Figure 5.9

Variability in the percentage of *Stichocorys peregrina* in populations of 10 or more *Stichocorys delmontensis* - *peregrina* morphotypes (in 41 samples) from the LAD of *Globoquadrina dehiscens* (mid Tongaporutuan) to the FAD of *Globorotalia inflata* (mid Opoitian). The vertical axis is not scaled against time but the approximate position of a number of bioevents is indicated. It is apparent that there is no clear domination of one morphotype for a large time span in the New Zealand upper Miocene and lower Pliocene.

before the LAD of *Didymocyrtis laticonus* in the western North Pacific. Kling (1973) shows *C. japonica* and *C. tetrapera* to die out half way through the range of *Diartus hughesi* and considers this to be a higher occurrence than recorded in the tropics. Chen (1975) notes the disappearance of *C. tetrapera* in the Antarctic upper Miocene. Sakai (1980, northwest Pacific) records the LAD of *C. tetrapera* in the mid-Miocene with *C. japonica* dying out higher in the mid-Miocene. Weaver (1976a) reports *Cyrtocapsella subconica* (= *tetrapera*) in earliest Pliocene age sediments in E-14-08 and Kennett (1980) tabulates the top of *C. tetrapera* in subantarctic/Antarctic cores in the Cochiti Event (Kennett, 1980, table 5) and in the late Miocene (Kennett, 1980, table 7, under *Cyrtocapsella*). Casey and Reynolds (1980) show the LAD of *C. tetrapera* in the Cochiti Event (they included *Cyrtocapsella cornuta* in their counts). Weaver, Casey and Perez (1981) show the top of *C. tetrapera* to be in the top of Epoch 11 and the LAD of *C. japonica* in mid Epoch 10 at Newport Bay. In the equatorial Pacific, Johnson and Wick (1982) show the top of *C. tetrapera* to be within Epoch 11 and Epoch 12 and the LAD of *C. japonica* in the mid-top Epoch 11.

The LAD of these two species occurs later in New Zealand than in the tropics but appears to be younger than Antarctic occurrences. Substantial time missing in key Antarctic piston cores (see section 5.7.10) could make the Antarctic occurrences much older than reported and provide good correlation.

5.7.2 Transition from *Stichocorys delmontensis* to *S. peregrina*

Many authors have quoted the evolutionary transition from *Stichocorys delmontensis* to *Stichocorys peregrina* in middle Epoch 6. The lower limit of the *Stichocorys peregrina* Zone is defined as the evolutionary base of *Stichocorys peregrina* and the upper limit of the *Spongaster pentas* Zone as the last appearance of *S. peregrina* (Riedel and Sanfilippo, 1978b). Although the LAD of *S. peregrina* is considered isochronous in the tropical Pacific (Hays, 1970) the datum has been reported to occur at horizons ranging from the top of the Kaena Event (Ishida, 1978) to the top of the Olduvai Event (Ryan *et al.*, 1974). Theyer, Mato and Hammond (1978) dated the first occurrence in the basal third of Epoch 6 and the last occurrence in latest Gauss. Weaver, Casey and Perez (1981) report the base of *S. peregrina* in mid Epoch 7 and the top of the taxon in the Sidufjall Event with the *S. delmontensis* - *peregrina* transition occurring during upper Epoch 6 and the last *S. delmontensis* in basal Epoch 5. Kling (1973) in the eastern North Pacific found *S. delmontensis* morphotypes well above the FAD of *S. peregrina* with the overlap covering a considerable stratigraphic interval with no distinct change in the dominance of one

morphotype to another. Reynolds (1980) notes a long overlap zone from the upper Middle Miocene to Middle Pliocene in the western North Pacific.

In New Zealand, *S. peregrina* morphotypes occur with *Globoquadrina dehiscens* in basal Tongaporutuan strata and *S. delmontensis* morphotypes occur as high as the LAD of *Cibicides molestus*, indicating a very long overlap zone. *S. peregrina* is found in the youngest samples studied. Forty-one samples from the New Zealand upper Neogene contain more than ten specimens of either or both morphotypes in the statistical counts made of 300 specimens in 97 samples. The percentage of *S. peregrina* in the *S. peregrina* - *deltmontensis* population is shown in figure 5.15 and indicates a considerable variation in the numbers of each morphotype with no clear dominance of one morphotype over another from at least the LAD of *Globoquadrina dehiscens* to the FAD of *Globorotalia inflata* (a period of 5.5Ma). The range of *S. peregrina* in New Zealand is at least 10Ma to 2Ma. This indicates some provincialism for the tropical radiolarian zonation with supporting evidence from North Pacific cores. Antarctic cores generally lack members of this warm-water genus.

5.7.3 LAD of *Lychnocanium* sp. aff. *grande*

Lychnocanium grande has an LAD reported at middle or basal Gauss (Bandy, Casey and Wright, 1971; Casey, Price and Swift, 1972; Casey and McMillen, 1977; Kennett, 1980; Casey and Reynolds, 1980), although both Reynolds (1980) and Kling (1973) record specimens from Quaternary sediments in the North Pacific. Keany (1975) records the LAD of the subspecies *Lychnocanium grande rugosum* in the Thvera Event and Weaver, Casey and Perez (1981) report the LAD of *Lychnocanium grande* as low as Epoch 5 in Newport Bay Section.

The LAD in New Zealand is just below the FAD of *Globorotalia inflata* which has been dated as occurring in the Cochiti Event during the Gilbert by Edwards (1985). This level is lower than those previously reported. This discrepancy could be related to the poor preservation of radiolarian faunas between the FAD of *G. inflata* and the incoming of dextral *Globorotalia crassaformis* in middle Gauss.

5.7.4 LAD of *Anthocyrtidium ehrenbergi pliocenica*

The LAD of *Anthocyrtidium ehrenbergi pliocenica* has been reported in the Antarctic Lower Pliocene (Keany, 1975, *A. ehrenbergi*) and in mid Epoch 5 (Weaver, Casey and Perez, 1981, Newport Section). The LAD of this species in basal Opoitian strata (basal Gilbert) in New

Zealand indicates that it may be a useful datum level for basal Pliocene correlations.

5.7.5 Range of *Spongaster pentas*

Riedel and Sanfilippo (1978b) defined the base of the *Spongaster pentas* Zone (early Pliocene) by the evolutionary transition from *Spongaster berminghami* to *S. pentas*. Theyer, Mato and Hammond (1978) dated its range in the equatorial Pacific from early to latest Gilbert and Berggren *et al.* (1985) record its FAD at the top of the Sidufjall Event within the Gilbert.

The occurrence of a single specimen in the upper Tongaporutuan supports the view of Casey and McMillen (1977) that the tropical zone is provincial as they found living specimens of *S. berminghami* and *S. pentas* in the tropical Atlantic, Gulf of Mexico, and Caribbean. Riedel and Sanfilippo (1978b) showed pentagonal forms of *Spongaster* occurring in sediments older than the early Pliocene at DSDP Site 77B.

5.7.6 Members of the genus *Eucyrtidium*

Within the genus *Eucyrtidium* there are a number of species which appear to be biostratigraphically useful.

In the *Eucyrtidium cienkowski*, *E. hexagonatum* and *E. acuminatum* group there are varying interpretations of the species due to the transitional forms that sometimes exist, consequently there are variations in the recorded ranges. All three morphotypes occur throughout the Late Neogene in New Zealand but are rarer in post-Miocene sediments.

Various ages for the LAD of *Eucyrtidium inflatum* have been reported ranging from within Epoch 11 to the lower Pliocene (see taxonomic discussion). In New Zealand, the form is rare in the late Miocene but its highest occurrence is in basal Opoitian (basal Gilbert) strata. It appears as though *E. inflatum* evolved from *E. calvertense* and then died out in the basal Pliocene, the various levels reported for the LAD of *E. inflatum* being due to morphotypes being included in *E. calvertense* populations.

Eucyrtidium calvertense also evolved into *E. matuyamai* at the start of, or within the Olduvai Event. In some cases this has been recorded as an extinction of *E. calvertense* (especially in Antarctic populations) and in other cases as a morphologic offshoot of *E. calvertense* populations. The youngest samples studied in New Zealand contain *E. calvertense* populations with some forms approaching *E. matuyamai* but no true *E. matuyamai* morphotypes. As the LAD of *E. calvertense* and/or FAD of *E. matuyamai*

appears to be a reliable isochronous radiolarian datum in the world's oceans, this indicates the youngest samples studied herein are only slightly older than basal Olduvai.

5.7.7 Members of the genus *Antarctissa*

Chen (1975) reported that *Antarctissa antedenticulata* and *Antarctissa conradae* evolved into *Antarctissa denticulata* and *Antarctissa longa* respectively, in the early Pliocene. Keany (1975) recorded the FAD of both *A. denticulata* and *A. strelkovi* in the Thvera Event of the Gilbert. Weaver, Casey and Perez (1981) record the LAD of *A. conradae* in mid Epoch 9 at Newport Bay Section. In Pacific CENOP samples *A. longa* is present in early Middle Miocene samples but *A. conradae* is absent and common *A. strelkovi* occurs in the early and late Miocene of DSDP Site 173 (Nigrini and Lombardi, 1984).

In the New Zealand upper Neogene four members of the genus are found: *A. antedenticulata*, *A. longa*, *A. conradae* and *A. strelkovi*, with only the last two having restricted ranges. *A. conradae* is not found in sediments above the basal Opoitian (basal Gilbert) strata and *A. strelkovi* is not found below the LAD of *Globoquadrina dehiscens*. Keany (1973, 1978) and Keany and Kennett (1971, 1975) show the usefulness of members of this genus for paleoclimatic studies in Antarctic deep-sea cores. The climatic influence on the geographic presence of some of the species and a certain amount of taxonomic confusion in the genus accounts for the varying ages recorded.

5.7.8 Upper Pliocene to Pleistocene transition from *Lamprocyrtis* spp. to *Lamprocyclas gamphonycha*

Jorgensen (1900) originally defined *Lamprocyclas gamphonycha* (under *Pterocorys gamphonyxos*) from off the coast of Norway and suggested it to be a temperate oceanic form. This is supported by its absence in equatorial regions and areas south of the Polar Front (Hays, 1965). Johnson and Nigrini (1980) found it present in most samples between 30°S and 46°S in the western Indian Ocean.

Hays (1970) concluded that *Lamprocyrtis heteroporos* evolved into *L. gamphonycha* with the former taxon becoming extinct near the base of the Olduvai. This level has since been supported by evidence from the Malaga Core Section (Casey, Price and Swift, 1972) and the southern Ocean (Kennett, 1980). Weaver, Casey and Perez (1981) show the top of *L. heteroporos* to be near the top of the Olduvai Event at Newport Bay and within the Olduvai at Centreville Beach Section.

The base of *L. heteroporos* is not as well defined, various levels having been reported. Casey, Price and Swift (1972) place its first occurrence at the top of the Kaena Event in Malaga Core Section. Casey and McMillen (1977) report its FAD in a primitive form in the Gilbert from Atlantic sediments. Sakai (1980) records the FAD at the same level as the FAD of *Didymocyrtis tetrathalmus tetrathalmus*. Casey and Reynolds (1980) put the FAD of true *L. heteroporos* at about middle Gauss but report morphotypes in the middle Gilbert. Weaver, Casey and Perez (1981) place the base of *L. heteroporos* at the base of the Gilbert before the Thvera Event. The widely varying levels are probably due to taxonomic confusion caused by the gradual evolution of *L. heteroporos* from *Lamprocyrtis hannai*. This transition was first suggested by Kling (1973) and although data are scarce its existence is supported herein. The LAD of *L. hannai* occurs in sample WA19 (Waiatai Valley Section) which also contains *L. heteroporos*. This level is immediately below the LAD of dextral *Globorotalia crassaformis*, which occurs at the top of the Mammoth Event (Edwards, 1985). The evolution of *Lamprocyrtis gamphonycha* is well defined in the Waiatai Valley Section and occurs very near the top of the *Globorotalia crassaformis* - dextral *Globorotalia crassaformis* overlap zone. This level occurs between the Olduvai and Reunion Events (Edwards, 1985). The transition from *L. heteroporos* to *L. gamphonycha* appears to be an isochronous datum level in temperate radiolarian faunas of the northern and southern Pacific.

5.7.9 The *Didymocyrtis* lineage

The evolutionary lineage *Didymocyrtis laticonus* - *antepenultima* - *penultima* - *tetrathalmus* has been recognised previously as a biostratigraphically useful Miocene to Pliocene radiolarian lineage. The morphologic expression of this lineage is an increase in cap height with time (see Westberg and Riedel, 1978). Riedel and Sanfilippo (1970) used this lineage as the basis of part of their tropical Neogene radiolarian zonation. As with most zonal boundaries based on gradual evolutionary trends, the position of the last or first appearance of a particular morphotype is sometimes hard to determine. Consequently, the zonal definition was changed by Riedel and Sanfilippo (1978b) to counteract the problems in determining cap height level.

The oldest member of the lineage, *Didymocyrtis laticonus*, first appeared in latest Epoch 15 (Theyer, Mato, and Hammond, 1978). The morphotypic top of this species has been reported as isochronous with the base of *Diartus hughesi* (Kling, 1973) in middle Epoch 9 (Theyer, Mato and Hammond, 1978), and synchronous with the earliest *Didymocyrtis antepenultima* (its evolutionary descendent) (Riedel and Sanfilippo, 1970). Sakai (1980)

could not detect the *laticonus* to *antepenultima* transition because of morphologic continuity and a similar problem exists in New Zealand. Events that appear to have been abrupt in deep-sea sequences can be represented by thick stratigraphic intervals in rapidly deposited shelf/slope sequences as already shown with the *Globorotalia tosaensis* - *truncatulinoides* transition in northern Hawke's Bay (Hornibrook, 1976b). The LAD of *D. laticonus* is well defined in Upper Mangaopari Section, occurring approximately midway between the LAD of *Globoquadrina dehiscens* and the LAD of members of the *Diartus hughesi* group.

Didymocyrtis antepenultima morphotypes are found with *Globoquadrina dehiscens* in a number of samples, indicating a long overlap range with *D. laticonus* in New Zealand. The FAD of *D. antepenultima* has been placed in latest Epoch 11 (Ryan *et al.*, 1974; Theyer, Mato and Hammond, 1978; Johnson and Wick, 1982) which is in agreement with it being found in the oldest samples studied in New Zealand. Definition of the transition from *D. antepenultima* to *D. penultima* it is generally accepted as occurring above the LAD of *Diartus hughesi* (Riedel and Sanfilippo, 1971; Riedel and Sanfilippo, 1978b) although Reynolds (1980) shows the transition to be below the LAD of *D. hughesi*. This transition is not documented in New Zealand as it falls within the preservation gap at the top of the Miocene (Kapitean) above the LAD of *D. hughesi*. *D. penultima* is lacking below this gap but *D. antepenultima* is present in samples below it. The base of the preservation gap is at approximately 5.5 to 6.0Ma.

Above the sampling gap *Didymocyrtis tetralthmus tetralthmus* occurs in basal Opoitian strata. There is a possibility that poorly preserved *D. antepenultima/penultima* morphotypes have been included in the *D. tetralthmus tetralthmus* populations. The FAD of *D. tetralthmus tetralthmus* occurs in strata dated as basal Gilbert (below the Thvera Event) by Edwards (1985). This is slightly lower than previously reported levels within the Nunivak and Cochiti Events (Ishida, 1978), at middle Gilbert (Theyer, Mato and Hammond, 1978), and at the base of Gilbert "b" Event (Casey and Reynolds, 1980) and could be explained by the poor preservation of specimens.

5.7.10 The LAD of members of the *Diartus hughesi* group

Riedel and Sanfilippo (1978b) redefined the *Didymocyrtis antepenultima* Zone to be the range of *Diartus hughesi* because of the inability to accurately define the cap height trend in the *D. laticonus* - *antepenultima* - *penultima* lineage. Reynolds (1980) introduced the *Diartus hughesi* Zone in the western north Pacific, defining the base as the evolutionary transition from *Diartus petterssoni* to *Diartus hughesi* and the top of the zone as the

evolutionary transition from *Didymocyrtis laticonus* to *D. antepenultima*. Reynolds considered that this zone was not recorded by Riedel and Sanfilippo (1978b) because at lower latitudes the transition from *D. petterssoni* to *D. hughesi* and *D. laticonus* to *D. antepenultima* are coeval.

The LAD of *Diartus hughesi* is generally accepted as falling near the base of Epoch 7 (Opdyke, 1972; Ryan *et al.*, 1974; Vincent, Killingley and Berger, 1980) although Berggren *et al.*, (1985) show it to be slightly higher. Theyer, Mato and Hammond (1978) report its LAD in latest Epoch 9 although DSDP Leg 85 results suggest that this age should be at the Epoch 7/8 boundary (after Nigrini and Lombardi, 1984). In New Zealand the LAD of members of the *D. hughesi* group occurs within Epoch 7 (see section 5.3.3).

Substantially younger LAD's have been reported. Casey and Reynolds (1980) report *D. hughesi* into middle Gilbert (Nunivak) sediments in equatorial core V-24-59. At about this level in that core are a number of datums with the LAD of *D. hughesi* nearly at the same level as the FAD of *Didymocyrtis tetrathalmus tetrathalmus* and a slight overlap with the range of *Lamprocyrtis heteroporos*. This indicates a probable disconformity at the level of the LAD of *D. hughesi* which could make the normal event identified as Nunivak significantly older.

Bandy, Casey and Wright (1971) report *Ommatocampe hughesi* (= *Diartus hughesi*) from Gilbert age sediments in Eltanin Core E-14-08 (at 1750cm). Weaver (1976a) reports the presence of *Amphymenium challengerii*, a probably related form, at the same level. Casey (1972) suggested that the radiolarians at 1750cm in E-14-08 could be as old as *Diartus petterssoni* Zone. This part of the core was designated the T (Tau) "b" subzone by Bandy, Casey and Wright (1971). The substantial diachroneity required in the LAD of *D. hughesi* between tropical/temperate areas and the Antarctic sediments to account for this difference is probably too great (middle Gilbert to basal Epoch 7). A more valid explanation is that the paleomagnetic interpretation for the lower part of E-14-08 is wrong and there is a substantial time break in that core. This time break could easily be placed at 1500cm where there is a large shift in the paleotemperature curve (see Bandy, Casey and Wright, 1971, figure 6). This also explains the joint LAD's of *Cannartiscus marylandicus* (= *Didymocyrtis* sp. A) and *D. hughesi*. Additionally, in the other core on which the T "b" Subzone was based (E-13-17), there is a similar shift in the paleotemperature curve at 1930cm (Bandy, Casey and Wright, 1971, figure 9) suggesting a substantial time break as well. Thus the T "b" subzone is herein considered to be older than previously thought, but the amount of time missing is hard to determine.

Table 5.1

The left hand column is a list of the 59 counting groups originally used. The right hand column indicates the groupings made to reduce the data set to 30 variables. Of these 30 variables only 13 (those marked with an asterisk) consistently make up more than 2% of the radiolarian population. It was these 13 groups that were statistically manipulated.

<i>Collosphaera</i> spp.	Collosphaeridae
<i>Acrosphaera</i> spp.	
<i>Actinomma antarcticum</i>	<i>Actinomma</i> spp. *
<i>Actinomma leptodermum</i>	
<i>Actinomma polycanthum</i> group	
<i>Cladococcus</i> spp.	<i>Cladococcus</i> and <i>Acanthosphaera</i> spp.
<i>Acanthosphaera</i> spp.	
<i>Cenosphaera</i> spp.	<i>Cenosphaera</i> spp. *
<i>Hexacantium enthacanthum</i>	<i>Hexacantium</i> spp. *
<i>Hexacantium laevigatum</i>	
<i>Thecosphaera</i> spp.	<i>Thecosphaera</i> spp. *
<i>Prunulum</i> spp.	<i>Prunulum</i> spp. *
" <i>Stylatractus</i> " spp.	Stylosphaerids *
" <i>Sphaerostylus</i> " sp. aff. <i>timmsi</i>	
<i>Prunopyle</i> and <i>Spongurus</i> spp.	<i>Prunopyle</i> and <i>Spongurus</i> spp.
<i>Spongocore puella</i>	<i>Spongocore puella</i>
<i>Heliodiscus</i> spp.	<i>Heliodiscus</i> spp.
<i>Didymocyrtis antepenultima</i>	Coccodiscidae
<i>Didymocyrtis laticonus</i>	
<i>Didymocyrtis virgineum</i>	
<i>Didymocyrtis</i> sp. A	
<i>Didymocyrtis tetrathalmus tetrathalmus</i>	
<i>Diartus hughesi</i> group	
<i>Dictyocoryne</i> and <i>Hymeniastrum</i> spp.	<i>Dictyocoryne</i> and <i>Hymeniastrum</i> spp. *
<i>Stylodictya</i> spp.	<i>Stylodictya</i> spp. *
<i>Porodiscus</i> spp.	<i>Porodiscus</i> spp. *
<i>Spongotrochus glacialis</i>	<i>Spongotrochus glacialis</i> *
<i>Tetrapyle octacantha</i> group	Pyloniidae and Tholoniidae
<i>Cubotholus rhombicus</i>	
<i>Lithelius minor</i>	<i>Lithelius</i> spp.
<i>Lithelius nautiloides</i>	
other Spumellarians	other Spumellarians
<i>Styptosphaera</i> spp.	
<i>Antarctissa</i> and <i>Lithomelissa</i> spp.	Plagoniidae
<i>Lophophaena</i> spp.	
<i>Desmospyris</i> and <i>Gorgospyris</i> spp.	Acanthodesmiidae
<i>Phormospyris</i> spp.	
Carpocaniidae	Carpocaniidae *
<i>Cornutella profunda</i>	<i>Cornutella</i> and <i>Plectopyramis</i> spp.
<i>Plectopyramis dodecomma</i>	
<i>Dictyophimus hirundo</i> group	<i>Dictyophimus</i> , <i>Lychnocanium</i> and <i>Lychnocanella</i> spp.
<i>Lychnocanium</i> and <i>Lychnocanella</i> spp.	
<i>Theocalyptra</i> spp.	<i>Theocalyptra</i> and <i>Lampromitra</i> spp.
<i>Lampromitra</i> spp.	
<i>E. acuminatum</i> , <i>E. cienkowskii</i> group, and <i>E. hexagonatum</i>	<i>Eucyrtidium</i> spp.
<i>E. calvertense</i> and <i>E. inflatum</i>	
<i>Eucyrtidium punctatum</i> group	
<i>Eucyrtidium</i> sp. A and <i>E. montiparum</i>	
<i>Cyrtocapsella japonica</i>	<i>Cyrtocapsella</i> and <i>Stichocorys</i> spp. *
<i>Cyrtocapsella tetrapera</i>	
<i>Stichocorys peregrina</i>	
<i>Stichocorys delmoniensis</i>	
<i>Stichocorys</i> spp. (transitionals)	
<i>Anthocyrtidium</i> spp.	<i>Anthocyrtidium</i> , <i>Lamprocyclas</i> and <i>Lamprocyrtis</i> spp.
<i>Lamprocyclas</i> and <i>Lamprocyrtis</i> spp.	
<i>Botryostrobus</i> spp.	Artostrobiidae *
<i>Siphocampe</i> spp.	
<i>Spirocorytis subscalaris</i>	
<i>Botryopyle dictyocephalus</i> group	<i>Botryopyle dictyocephalus</i> group

As more unconformities in southern ocean deep-sea cores are discovered (e.g. Watkins and Kennett, 1972; Keany and Kennett, 1975; Kennett and Watkins, 1976; Ledbetter *et al.*, 1983) the continuity of a number of the deep-sea reference cores must be questioned. The older paleomagnetic correlation postulated in this case has serious implications for the "pre-upper Gilbert" paleomagnetically determined real age estimates for the southern ocean diatom stratigraphy (McCollum, 1975) and silicoflagellate stratigraphy (Ciesielski, 1975) as they are essentially based on the paleomagnetic interpretation of E-14-08 and E-13-17. These stratigraphies have been utilised in discussions on early Pliocene Antarctic temperature changes (Ciesielski and Weaver, 1974) and used to date formations and drill core from the Antarctic continent (Webb *et al.*, 1984; Barrett *et al.*, 1985).

If the disconformities represent time intervals of similar magnitude to periods between polarity changes then they could explain the apparent correlation of radiolarian extinctions to paleomagnetic changes (Hays and Opdyke, 1967; Hays, 1971).

5.8 STATISTICAL ANALYSIS

5.8.1 Introduction

Transmitted light slides of the radiolarian faunas from 97 samples were made using the technique described by Ashby (1983). Counts of up to about 300 specimens or the total slide (whichever came first) were made using the "ribbon" method (see Section 2.6 for details of statistical counting). The specimens encountered were placed into one of 59 counting groups. These counting groups are of various types, ranging from specific, poly-specific, generic, polygeneric to, in one instance, family. The groups used are listed in table 5.1. It was soon evident that these "counting" groups were too precise considering the differing preservation in the samples studied. The value of N listed in Appendix E.3 gives an idea of the preservation of radiolarians in the samples as it is a measure of the number of counting groups filled. With high preservation the N value increases because more delicate forms are preserved. Low N values indicate that only the more robust species are preserved in samples with low preservation. The N values for the samples counted vary from 14 (TK05) to 44 (HR04). The 59 counting groups were reduced to 30 by combining either similar looking forms that could have been misclassified or rare forms that could be genetically related. The new groupings are outlined in table 5.1. Of the 30 variables all with a percentage consistently less than 2% were removed. These rarer groups were removed because, as counts were made to about 300 the percentage error involved in

Figure 5.10

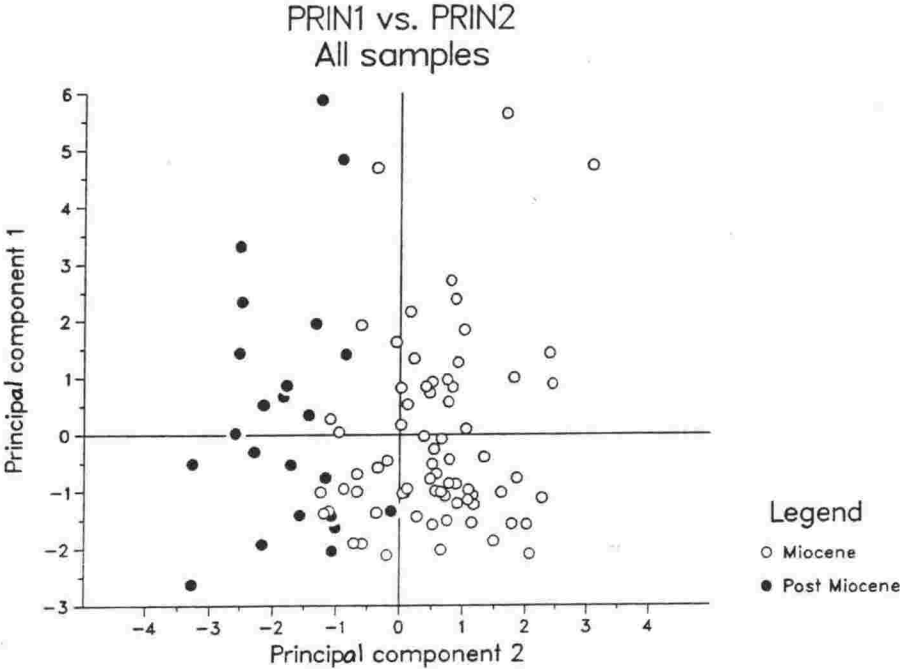


Table 5.2

Full radiolarian data set (94 samples) : eigenvalues for the twelve principal components in 13 dimensional space.

	Eigenvalue	Proportion	Cumulative
PRIN1	3.11	23.94	23.94
PRIN2	1.82	14.01	37.95
PRIN3	1.76	13.55	51.50
PRIN4	1.30	10.01	61.51
PRIN5	1.01	7.78	69.29
PRIN6	0.88	6.77	76.06
PRIN7	0.74	5.70	81.76
PRIN8	0.65	5.00	86.76
PRIN9	0.58	4.46	91.22
PRIN10	0.44	3.39	94.61
PRIN11	0.41	3.16	97.77
PRIN12	0.29	2.23	100.00

Table 5.3

Full radiolarian data set (94 samples) : values of the first four principle components for each of the variables in the data set.

	PRIN1	PRIN2	PRIN3	PRIN4
ACTINS	0.33	-0.29	-0.33	-0.10
HEXACO	0.35	0.14	-0.14	0.47
THECOS	0.24	0.00	0.35	-0.19
CENOSP	0.39	0.04	0.29	-0.10
PRUNUM	0.13	0.05	0.47	-0.15
STYLOS	0.38	-0.13	-0.29	-0.12
PROFUN	-0.31	-0.32	-0.04	0.12
VALIDI	-0.18	-0.07	0.20	0.65
PORODI	-0.40	0.12	0.02	-0.24
SGLACI	-0.18	-0.46	0.19	0.06
CARPOS	0.05	0.54	0.28	0.20
STICHS	-0.25	0.41	-0.24	-0.31
ARTOST	-0.01	0.30	-0.39	0.23

ACTINS	= <i>Actinomma</i> spp.
HEXACO	= <i>Hexacantium</i> spp.
THECOS	= <i>Thecosphaera</i> spp.
CENOSP	= <i>Cenosphaera</i> spp.
PRUNUM	= <i>Prunulum</i> spp.
STYLOS	= Stylosphaerids
PROFUN	= <i>Dictyocoryne</i> and <i>Hymenlastrum</i> spp.
VALIDI	= <i>Stylodictya</i> spp.
PORODI	= <i>Porodiscus</i> spp.
SGLACI	= <i>Spongotrochus glacialis</i>
CARPOS	= Carpacaniidae
STICHS	= <i>Cyrtocapsella</i> and <i>Stichocorys</i> spp.
ARTOST	= Artostrobiidae

miscounting a specimen at the 2% level is too large (an extra one specimen at this level introduces a 17% change in that variables abundance). This reduced the data set to 13 variables. The main aim of the statistical work was to look for any sample variation using the 13 major faunal elements. Three samples were removed from the data set because radiolarian biozones could not initially be determined for the samples. Since the statistical work was completed one sample (SMA3) has been re-examined and assigned to the *Didymocyrtis* sp. A Zone.

5.8.2 Principal components

Principal components is a multivariate statistical technique which examines the relationships within a multidimensional set of data, the purpose being to derive a small number of linear combinations (principal components) that retain as much of the information in the original variables as possible. With a data "cloud" in n-dimensional space the best position axes for that "cloud" are obtained by computing the characteristic values (eigenvalues) and vectors (eigenvectors) of a covariance matrix or a correlation matrix from the data set. In this investigation the latter matrix was used. The first principal component corresponds to the axis with the largest amount of variance, and the remaining are ranked in order of decreasing values. In this form of analysis the principal components are always orthogonal. This analysis on the reduced data set defined a distinct difference between Miocene and post-Miocene faunas. The relatively low percentage of variance taken up by the first principal component (23.9%) (see table 5.2) and the first three eigenvalues only absorbing 51% of the total variance indicates that the data "cloud" is quite "spherical" (in 13-dimensional space). From the graph of principal component 1 (PRIN1) versus principal component 2 (PRIN2) (see figure 5.10) it is obvious that the value of PRIN2 is "doing the work" in separating the data set and PRIN1 appears to reflect the general relationships among the variables with relatively high variation ($>\pm 0.3$) for six of the variables (see table 5.3). PRIN2 has high variation for four variables: *Dictyocoryne* and *Hymeniastrum* spp., *Stichocorys* and *Cyrtocapsella* spp., *Spongostrochus glacialis*, and the Carpacaniidae. It is interesting to note that of these four the first two have definite warm-water affinities and the third a definite cold water. It appears, therefore, as though climatic difference is the major factor in controlling the faunal change. The data set was then split into two, Miocene and post-Miocene, and each had principal components run separately. Within each "epoch" principal component analysis could not distinguish differences in faunal makeup between each radiolarian biozone (see figures 5.11 and 5.12).

Figure 5.11

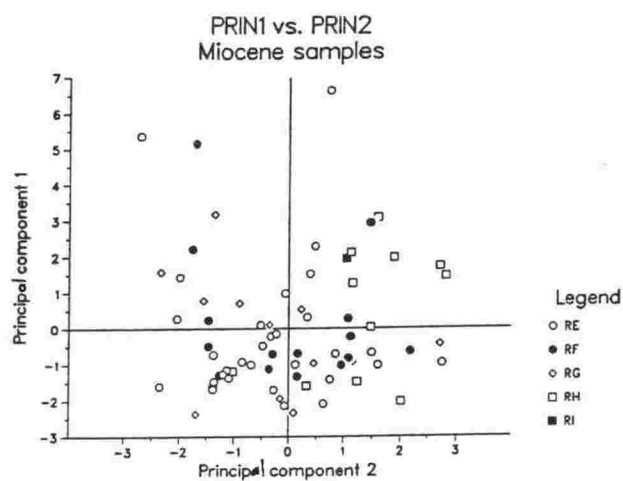


Figure 5.12

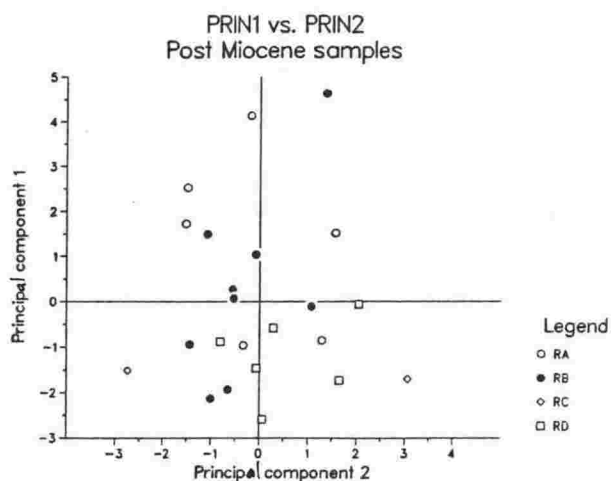


Figure 5.13

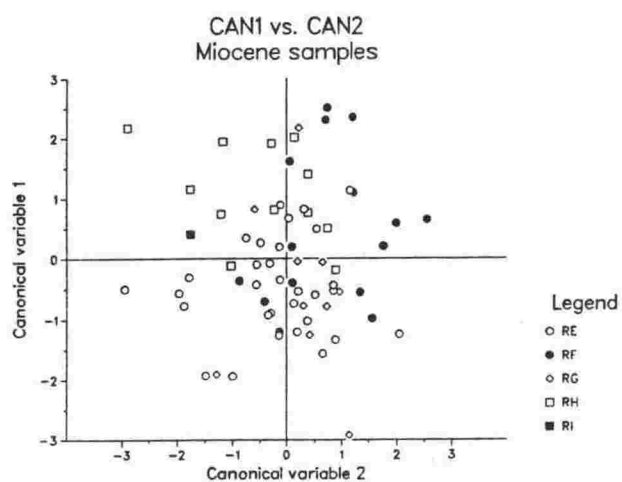
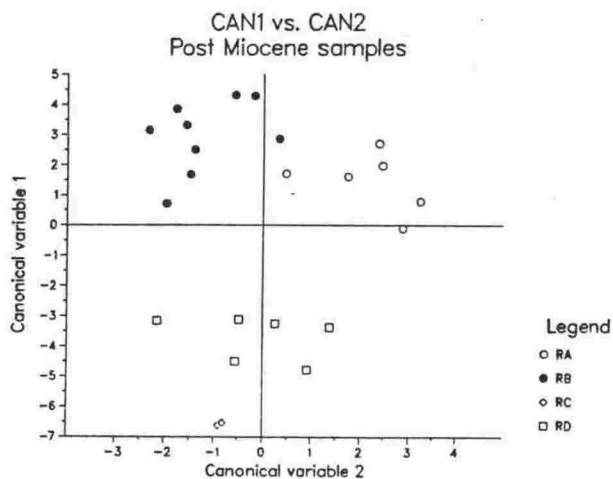


Figure 5.14



RA = *Lamprocyclus gamphonycha* Zone

RB = *Lamprocyrtis heteroporus* Zone

RC = *Lamprocyrtis hannai* Subzone

RD = *Lychnocanium* sp. aff. *grande* Subzone

MIOCENE/PLIOCENE BOUNDARY

RE = *Didymocyrtis* sp. A Zone

RF = *Anthocyrtidium ehrenbergi pliocenica* Subzone

RG = *Heliodiscus asteriscus forma large pores* Subzone

RH = *Didymocyrtis laticonus* Subzone

RI = *Heliodiscus umbonatum* Subzone

5.8.3 Canonical discriminants

Canonical discriminant analysis was run on each of the two "epoch" data sets to see if it could distinguish any differences between the biozones. Canonical discriminant is another dimension reduction technique which finds a small number of linear combinations from each set of variables that have the highest possible between-set correlation. These canonical variables would best summarise the differences (if any) between the radiolarian biozones in much the same way as principal components summarise the total variation. These canonical variables are not necessarily orthogonal. This analysis failed to separate the biozones from within the Miocene (figure 5.13) but separated the post-Miocene biozones (figure 5.14) very well. With the post-Miocene samples the *Lamprocyclas gamphonycha* and *Lamprocyrtis heteroporos* Zones were separated from the *Didymocyrtis tetrathalmus tetrathalmus* Zone. This separation was caused by high variance for CAN1 ($>\pm 0.5$) in the total canonical structure (see table 5.4) for *Actinomma* spp., *Stylodictya* spp., and *Stichocorys* and *Cyrtocapsella* spp., while the first two zones were separated by high variance in CAN2 for the Stylophaerids (+ 0.53) and the variance on the *Dictyocoryne* and *Hymeniastrum* spp. group (- 0.49) would have had a marked effect.

5.8.4 Graphical technique

The previously mentioned variance is well shown graphically by a simple bar chart (figure 5.15) noting the variance in the mean for each radiolarian biozone from a "standard" fauna (in this case an average Miocene fauna). Obvious changes in faunal makeup take place between the *Lychnocanium* sp. aff. *grande* Subzone (basal Pliocene) and the *Didymocyrtis* sp. A Zone (upper Miocene). The variance between the *Didymocyrtis laticonus* Subzone and the *Heliodiscus umbonatum* Subzone is artificial as the mean of the *Heliodiscus umbonatum* Subzone is based on only one sample and is not statistically comparable.

5.8.5 Discriminant analysis

Discriminant function analysis is made whereby an observation is classified assuming a multivariate normal distribution within each class (in this case radiolarian biozone) by computing linear or quadratic functions for classifying the observations into groups. Each observation can then be placed into the class from which it has the smallest generalised squared distance. Of the 94 samples studied only six were misclassified across the Miocene/Pliocene boundary (see table 5.5). Misclassification was common in Miocene samples but with post-Miocene samples only four of the 23 were misclassified indicating the time variance in the radiolarian faunas as previously shown.

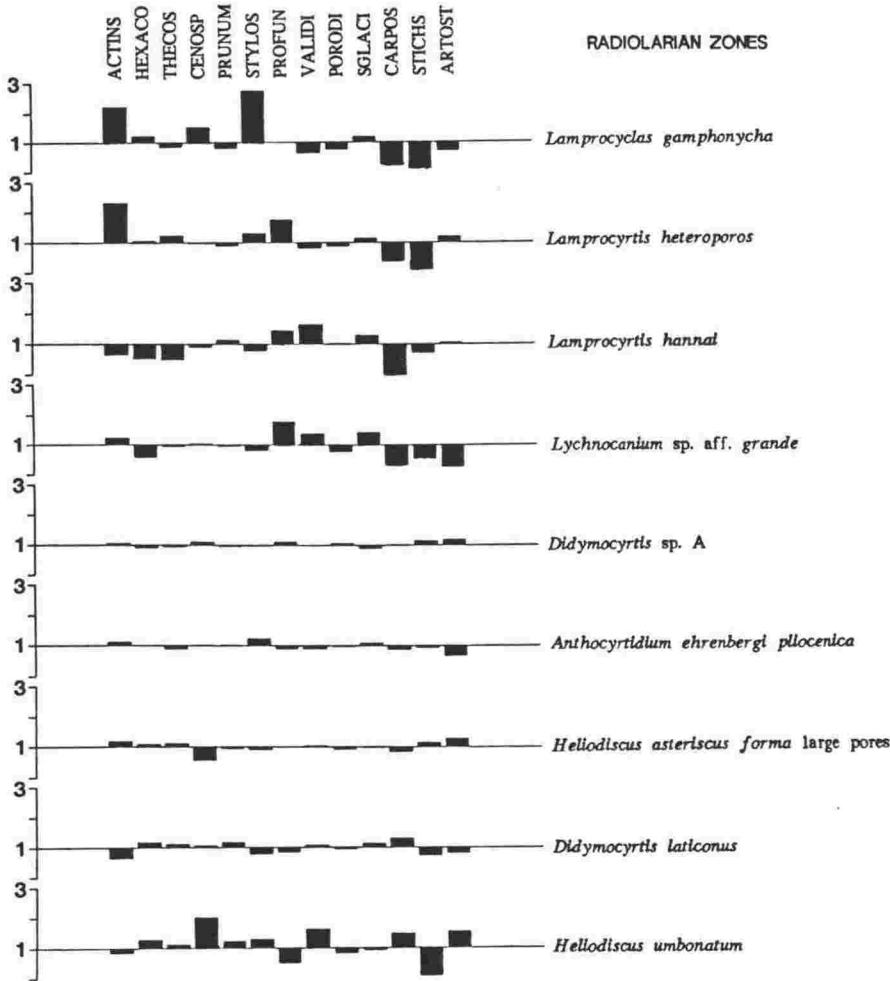
Table 5.4

Post-Miocene data set (23 samples) : values of the first three canonical variables for each of the variables in the data set.

	CAN1	CAN2	CAN3		
ACTINS	0.55	0.06	0.01	ACTINS	= <i>Actinomma</i> spp.
HEXACO	0.36	0.18	-0.10	HEXACO	= <i>Hexacantium</i> spp.
THECOS	0.31	-0.25	0.28	THECOS	= <i>Thecosphaera</i> spp.
CENOSP	0.10	0.39	-0.04	CENOSP	= <i>Cenosphaera</i> spp.
PRUNUM	-0.18	-0.14	-0.07	PRUNUM	= <i>Prunulum</i> spp.
STYLOS	0.28	0.53	-0.18	STYLOS	= Stylosphaerids
PROFUN	-0.07	-0.49	0.29	PROFUN	= <i>Dictyocoryne</i> and <i>Hymeniastrum</i> spp.
VALIDI	-0.56	-0.26	0.06	VALIDI	= <i>Stylodictya</i> spp.
PORODI	-0.04	-0.17	-0.21	PORODI	= <i>Porodiscus</i> spp.
SGLACI	-0.33	0.03	0.27	SGLACI	= <i>Spongostrochus glacialis</i>
CARPOS	0.34	-0.18	0.51	CARPOS	= Carpacaniidae
STICHS	-0.56	-0.12	0.03	STICHS	= <i>Cyrtocapsella</i> and <i>Stichocorys</i> spp.
ARTOST	0.34	-0.31	-0.49	ARTOST	= Artostrobiidae

Figure 5.15

Bar chart indicating the variance in the 13 major radiolarian faunal elements between each radiolarian biozone. The variance shown is the ratio of the mean fauna for each radiolarian biozone against a standard fauna (in this case the mean Miocene fauna). As the ratio approaches 1 (the horizontal line), less variation is indicated.



5.8.6 Statistical summary

In conclusion, statistical faunal analysis shows that during the Miocene there was not much change in the radiolarian faunas with time and a major change, probably climatically controlled, took place across the Miocene/Pliocene boundary. Variability in preservation has probably affected the faunas to obscure more precise time variation although post-Miocene faunas indicate that some is present.

Table 5.5

Full radiolarian data set (94 samples) : Discriminant analysis.

Classification of samples into radiolarian biozones from the biozones determined using presence or absence data.

		To rad biozone										
		RA	RB	RC	RD	RE	RF	RG	RH	RI	TOTAL	
From rad biozone	RA	5	1	.	.	.	.	.	.	.	6
	RB	.	9	.	.	.	.	.	.	.	9
	RC	.	.	1	1	.	.	.	.	.	2
	RD	.	.	1	4	1	.	.	.	.	6
	RE	.	.	1	.	16	4	7	3	.	31	
	RF	.	.	.	1	4	7	1	2	.	15	
	RG	.	2	.	.	1	1	7	1	.	12	
	RH	.	.	1	.	2	3	1	5	.	12	
	RI	.	.	.	.	.	.	.	1	.	1
94												

RA = *Lamprocyclas gamphonycha* Zone

RB = *Lamprocyrtis heteroporos* Zone

RC = *Lamprocyrtis hannai* Subzone

RD = *Lychnocanium* sp. aff. *grande* Subzone

MIOCENE/PLIOCENE BOUNDARY

RE = *Didymocyrtis* sp. A Zone

RF = *Anthocyrtidium ehrenbergi pliocenica* Subzone

RG = *Heliodiscus asteriscus forma large pores* Subzone

RH = *Didymocyrtis laticonus* Subzone

RI = *Heliodiscus umbonatum* Subzone

Chapter VI

CONCLUSION AND DIRECTION FOR FUTURE STUDIES

This chapter contains a summary of the principal findings of this thesis in regard to the presence, taxonomy, and biostratigraphy of radiolarians from the New Zealand Late Neogene. These points are examined briefly and guidelines for future research are outlined.

6.1 SUMMARY OF MAIN POINTS

1. Preservation of radiolarian skeletons requires the interstitial waters in marine sediments to become close to or completely saturated in silica. This is achieved by the buffering of the interstitial waters by partial dissolution of the accumulating siliceous mass. Silica can be provided by the high input of siliceous skeletons beneath high productivity belts or an influx of abiotic silica. It is the latter factor that has enhanced the preservation of radiolarian skeletons in the East Coast Deformed Belt, the silica being deposited in the form of rhyolitic glass shards. The presence of, in places, numerous volcanic tuffs in relatively deep-water basins away from the dilutory effects of terrigenous material in shallow water sequences makes the East Coast Deformed Belt the best area in New Zealand for Late Neogene radiolarian studies.

2. Relatively high uplift rates have allowed deep-water, relatively continuous, Late Neogene sequences to be exposed at many places from East Cape to northern Canterbury. At some places, the sediments are radiolarian bearing and are ideal for integrated magnetostratigraphic, paleontologic, and tephrostratigraphic analysis. In terms of global radiolarian biostratigraphy these sections are very important as they are the only known on-land sections containing southern temperate, Late Neogene, radiolarian faunas.

3. Most of the 138 taxa described can be identified at generic level, but 31 morphotypes can not be assigned specific names and may eventually prove to be new species. The classification is still mainly based on the Haeckelian morphologic system although some groups are more phylogenetically assigned.

4. Five major radiolarian zones can be recognised in the New Zealand Late Neogene with six subzones identifiable in samples with good preservation. The radiolarian zonation presented is based on detailed analysis of 155 samples from 26 sections and sites ranging in age from basal Tongaporutuan (early Late Miocene) to middle Nukumaruan (early Pleistocene). Sediments of the Kapitean (uppermost Miocene) were generally deposited in shallow water environments or are missing in unconformities in the East Coast Deformed Belt, and consequently the radiolarian zonation is based on very poor data in this time segment. Also upper Opoitian and Waipipian (middle Pliocene) sediments, although in places deposited in relatively deep water, generally lack siliceous tuffs so that radiolarian preservation is poor. The zones are well correlated to the detailed planktic foraminiferal biostratigraphy and real ages can be estimated for the zone boundaries.

5. The correlation to radiolarian zonations from other parts of the globe raises a number of interesting points:

a. In New Zealand, *S. peregrina* morphotypes occur with *Globoquadrina dehiscens* in basal Tongaporutuan (basal upper Miocene) strata and *S. delmontense* morphotypes occur as high as the LAD of *Cibicides molestus* (middle Pliocene), indicating a very long overlap zone. *S. peregrina* is found in the youngest samples studied (lower Pleistocene). There is no clear dominance of one morphotype over another from at least the LAD of *Globoquadrina dehiscens* to the FAD of *Globorotalia inflata* (a period of 5.5Ma). The range of *S. peregrina* in New Zealand is at least 10Ma to 2Ma. This indicates, along with the presence of a single specimen of *Spongaster pentas* in upper Tongaporutuan (late upper Miocene) sediments, some provincialism in the tropical radiolarian zonation.

b. The evolution of *Lamprocyclus gamphonycha* from *Lamprocyrtis heteroporos* is well defined in the Waiatai Valley Section and occurs very near the top of the *Globorotalia crassula* - dextral *Globorotalia crassaformis* overlap zone which is dated at 2.0Ma (Edwards, 1985). The transition to *L. gamphonycha* appears to be an isochronous datum level in temperate radiolarian faunas in the northern and the southern Pacific.

c. In New Zealand the LAD of members of the *Diartus hughesi* group falls within Epoch 7. This is in good agreement with levels determined in tropical Pacific cores. However, the Antarctic T "b" Subzone of Bandy, Casey, and Wright (1971) is defined

SAMPLE SUMMARY

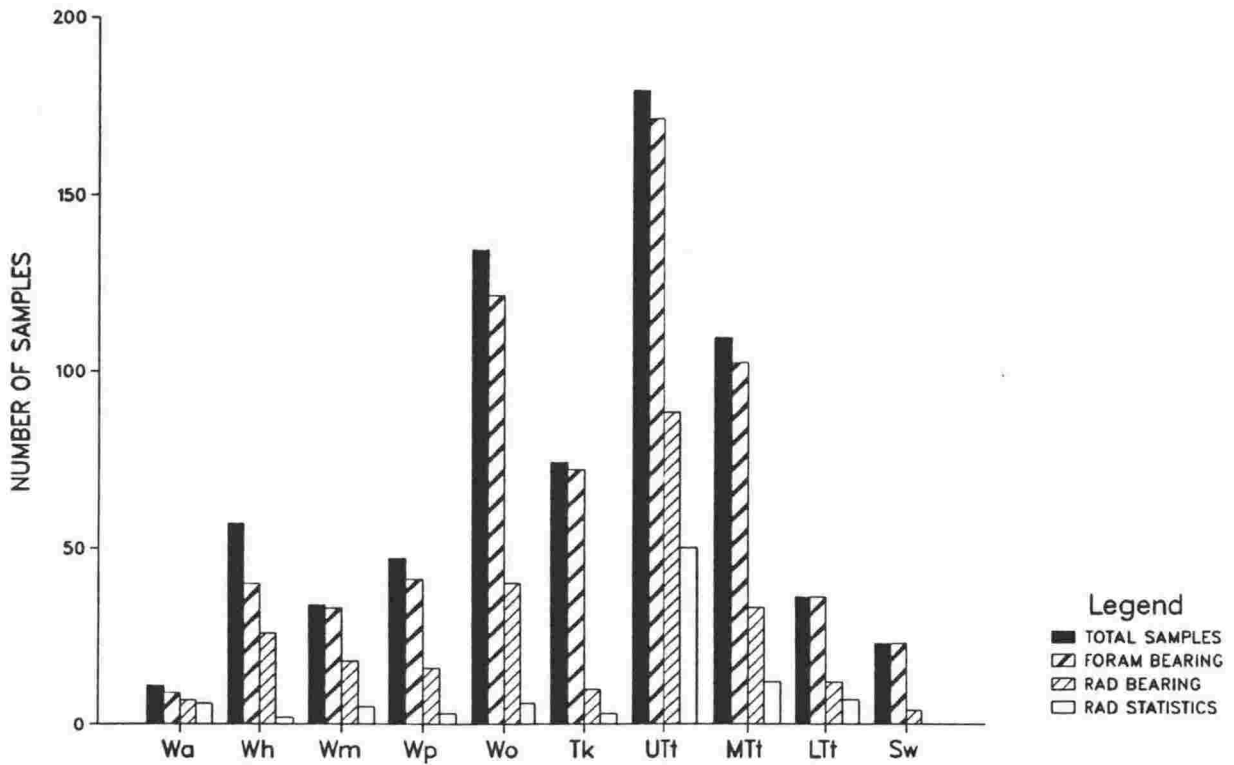


Figure 6.1

Bar chart indicating the number of possible radiolarian bearing samples looked at for each of the time intervals covered in this study. Of the samples, normally 90-100% contain foraminifera but generally only 50% contain Radiolaria. Of the radiolarian bearing samples only a small proportion of the faunas are well enough preserved for statistical analysis.

by the presence of this taxon and was paleomagnetically dated at middle Gilbert. The implied magnitude of the diachroneity in the LAD of *D. hughesi* between tropical/temperate and Antarctic sediments is unacceptably large. A more likely explanation is that the paleomagnetic interpretation for the lower parts of E-14-08 and E-13-17 (on which the subzone is based) is wrong and there is a substantial time break in both cores. There is other evidence to suggest that that is the case. Thus the T "b" Subzone is herein suggested to be significantly older than previously thought, but the amount of time missing is hard to determine. As more unconformities in southern ocean deep-sea cores are discovered (e.g. Watkins and Kennett, 1972; Keany and Kennett, 1975; Kennett and Watkins, 1976; Ledbetter *et al.*, 1983) the continuity of a number of the deep-sea reference cores must be questioned. The older paleomagnetic correlation postulated in this case has serious implications for the "pre-upper Gilbert" paleomagnetically determined real age estimates for the southern ocean diatom stratigraphy (McCollum, 1975) and silicoflagellate stratigraphy (Ciesielski, 1975) as they are essentially based on the paleomagnetic interpretation of E-14-08 and E-13-17.

7. Statistical faunal analysis shows that during the Miocene there was not much change in the radiolarian faunas with time and a major change, probably climatically controlled, took place across the Miocene/Pliocene boundary. Variability in preservation has probably affected the faunas to obscure smaller variations with time, but post-Miocene faunas indicate that some variation is present.

8. The Radiolaria, although not as common in the fossil record as the foraminifera (see figure 6.1), definitely contribute to New Zealand Late Neogene integrated stratigraphy and suggest that our knowledge could be further enhanced by the study of other siliceous microfossil groups.

6.2 DIRECTIONS FOR FUTURE RESEARCH

I conclude this thesis in the hope that the data presented here may act as a stimulus to future radiolarian biostratigraphic research, particularly in an integrated system using the many paleontologic, isotopic, radiometric, and paleomagnetic techniques now available. The first approach would best be the analysis of the diatom stratigraphy from the sequences

studied. Large members of this fossil group were encountered in many of the samples studied and assuming that smaller forms are also preserved, a wealth of biostratigraphic information is present. Analysis of this group in the New Zealand sequences now seems essential to try to check the real age estimates of the Antarctic zonation which appear to be wrong. The information to be gained from this exercise could be comparable to that obtained from additional piston cores in the southern ocean. Secondly, enhancement of the zonation presented could be made in two ways : by extending the zonation into older (and if possible younger) on-land sequences and by better defining the zonal boundaries and other radiolarian bioevents. The integrated stratigraphic approach that must be made in all these suggestions can not be stressed enough.

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Appendix A SECTION AND SITE DESCRIPTIONS

A.1 INTRODUCTION

This appendix outlines all the stratigraphic sections and sites examined during the course of this study. Descriptions of non-radiolarian bearing sections and sites are also presented as this information will be invaluable to future workers wishing to locate likely samples with good siliceous preservation. Descriptions of sections examined from outside the East Coast Deformed Belt are also presented. Figures A.1 and A.2 are summary location maps for the radiolarian-bearing sections and sites respectively.

Detailed descriptions of the radiolarian bearing samples examined in this thesis are presented in Appendix B. Presence and absence data for the radiolarian faunas is presented in Appendix D. Counts on the radiolarian faunas are presented in Appendix E.

Within this appendix when a sample is said to be barren this only applies to the absence of radiolarian skeletons, unless otherwise qualified. Some of the numbers mentioned in the text are referenced by the following abbreviations:

NG = number of radiolarians per gram of sediment in the sample

N = the number of counting groups filled after counting approximately 300 radiolarian specimens in a sample. This gives a measure of the preservation of the fauna because as dissolution increases the number of counting groups filled will decrease as more delicate forms get depleted from the sample. Numbers range from 0 (nil preservation) to 44 (highest preservation in sample HR04). As the samples chosen for statistical work are normally considered to have moderate or better preservation the range of N quoted in this appendix is 23 to 44.

Q = diversity index. This index, as outlined in Appendix E, gives an indication of diversity of the fauna independent of the degree of preservation. Values quoted range from 3.71 (low diversity in sample SWR1) to 17.29 (high diversity in sample RM07).

The stratigraphic columns represented in this appendix generally follow the following format. The left hand column defines the bioevents located in the section. The next column is a graphic log then the lithological log. On the right hand side of the lithologic log, the position of samples studied are shown as short lines. Samples containing Radiolaria are depicted as lines with solid circles attached and those referred to in the thesis have designated numbers. The right hand column gives a brief description of the lithology.

Figure A.1

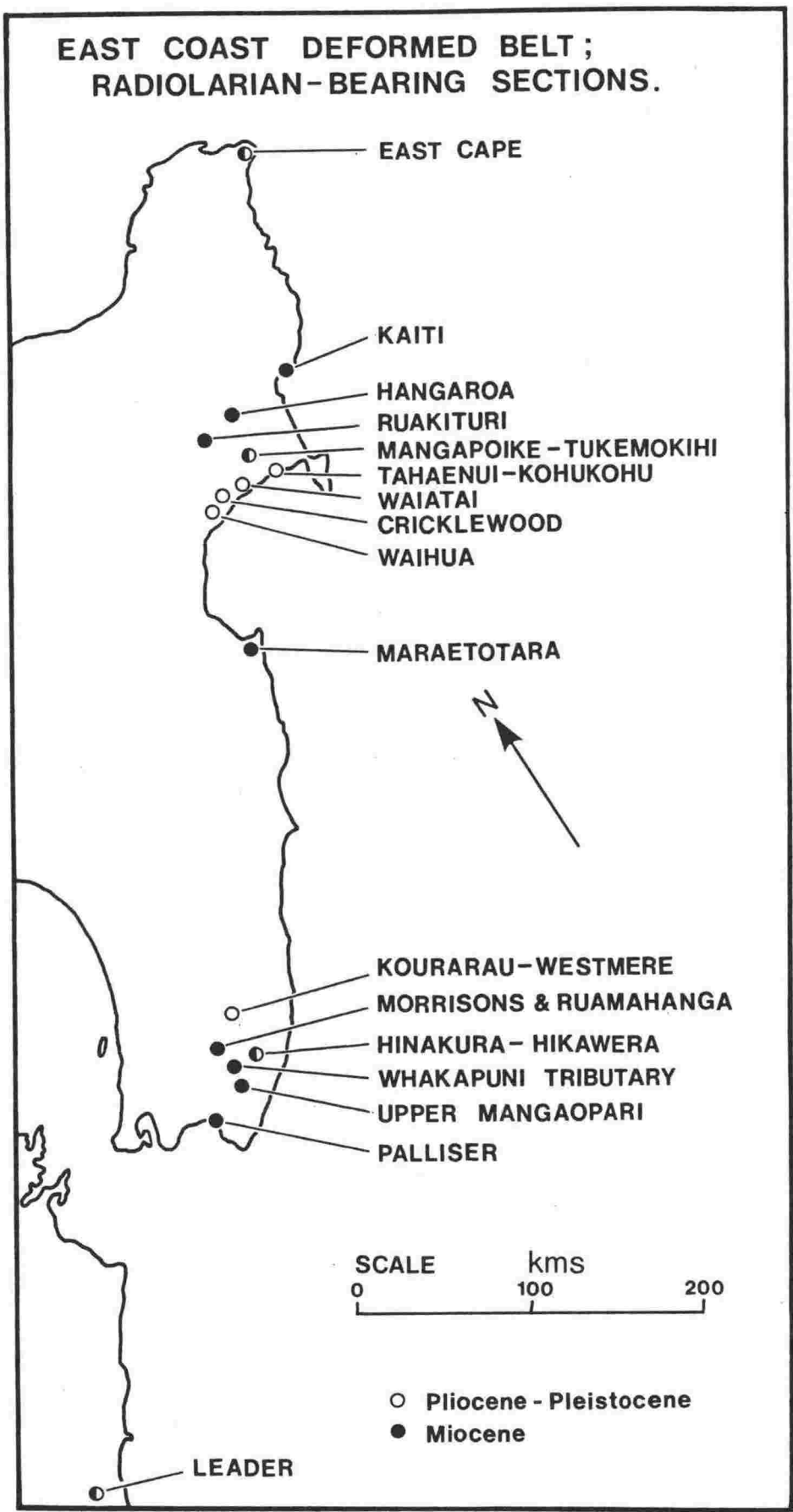


Figure A.2

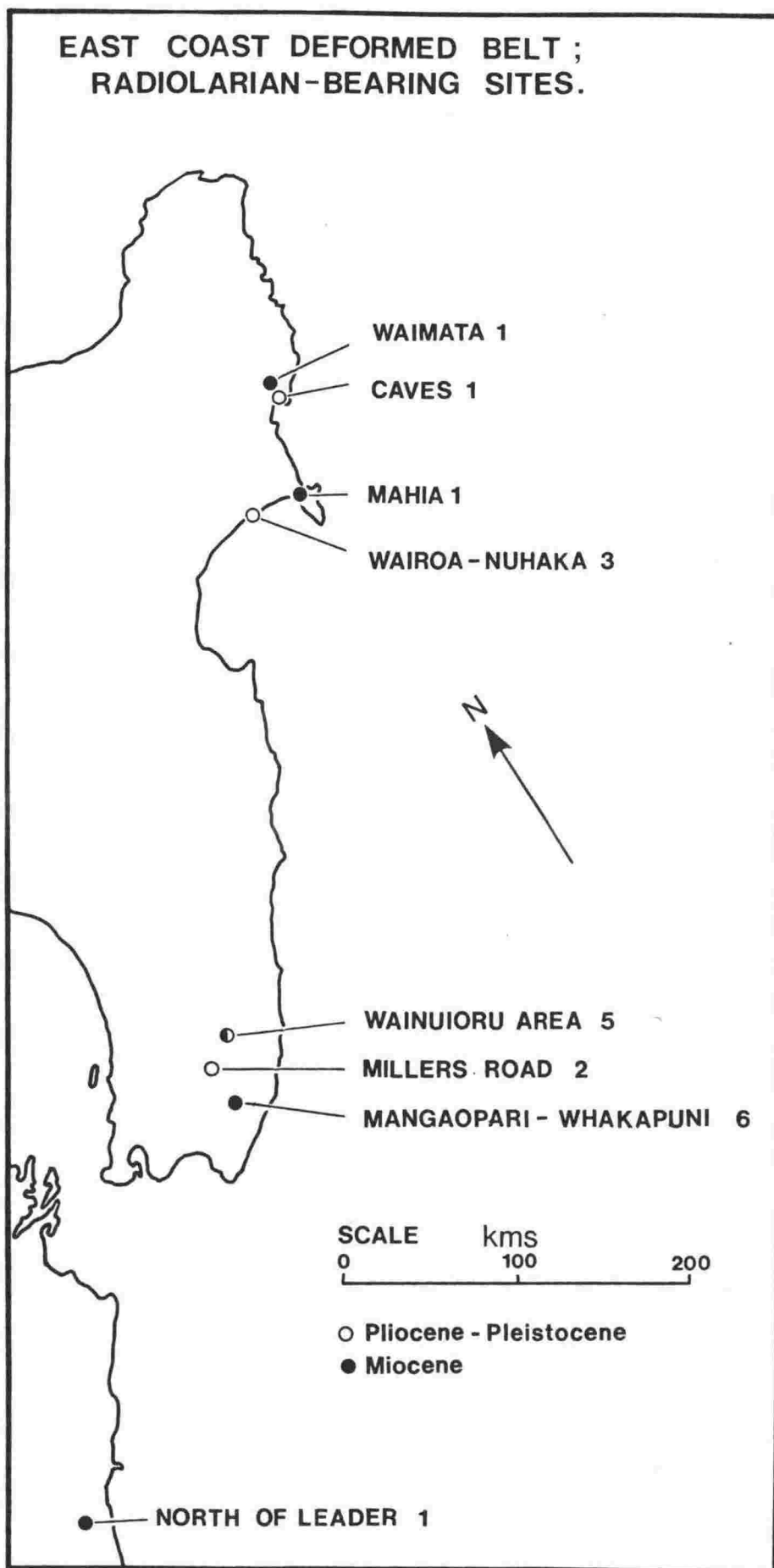


FIGURE A4 EAST CAPE SECTION

Location: Figure A3

FORAMINIFERAL & RADIOLARIAN DATUMS

- FAD *G. inflata*
- FAD *G. crassaformis*
- FAD *G. puncticulata* s.l.
- FAD *D. tetrathalmus*
tetrathalmus (=)

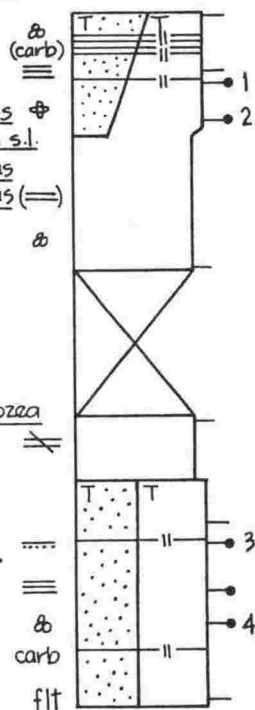
- FAD *G. sphericomiozea*

- 150 • *G. conomiozea*
- 100 • *conomiozea* s.l.

VERTICAL SCALE
(metres)

- 50
- 0

EC SAMPLES



SANDSTONE / MUDSTONE : bedding generally 40cm,
more mass near base, more tuffs towards top

gradational

SILTSTONE : generally massive, some faint
bedding, no tuffs

SANDSTONE / MUDSTONE : bedding generally 1-0.1m,
common 10-20 cm tuff beds, more mass near base

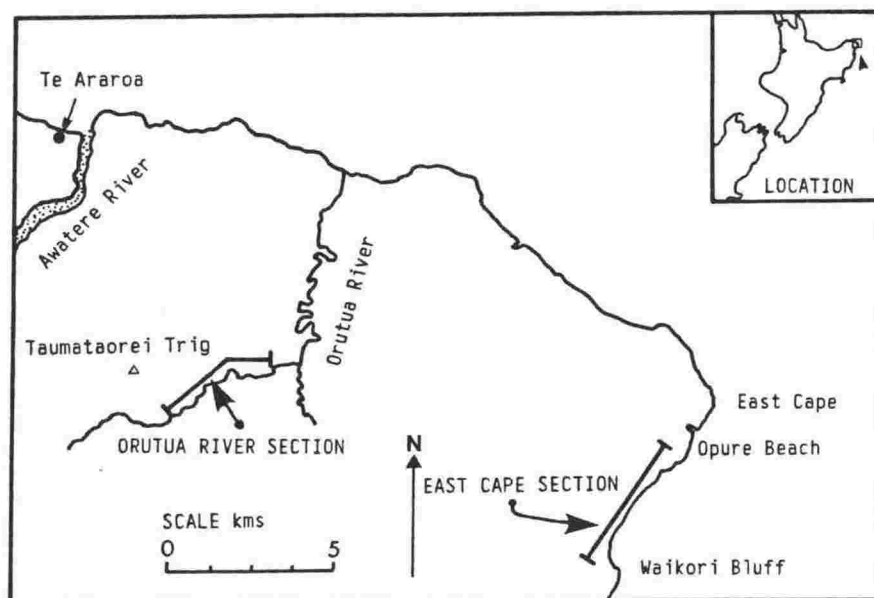


Figure A.3

Location of sections : East Cape region.

A.2 EAST CAPE SECTION

Location: Coastal cliffs from the bluffs at the south end of Opure Beach to Waikori Bluff (from 1.5 to 5.0km southwest of East Cape). See figure A.3.

Stratigraphic column: Figure A.4.

Lithology and Age: The basal unit comprises at least 190m of interbedded fine sandstone and mudstone (more massive near the base) with common tuff beds. The foraminiferal faunas include predominantly 4/4.5 chambered *Globorotalia miotumida* with some forms approaching *G. conomiozea conomiozea*.

Next is a 280m, massive to weakly bedded, slightly sandy mudstone unit with 130m of nil exposure in the middle. The FAD of *G. sphericomiozea* is recorded about 43m above the base of this unit (Z14/f43).

Overlying is at least 110m of interbedded mudstone and fine sandstone, and tuffs which becomes more massive towards the base and the tuffs more common towards the top. Planktic foraminiferal faunas from two samples in the lower half of the unit (Z14/f46, f38A) include *Globorotalia conomiozea mons*, *G. crassaformis*, common *G. pliozea*, *G. cf. puncticulata*, and mostly unkeeled *G. sphericomiozea* indicating a basal Opoitian age. The FAD of *G. inflata* is recorded 60m from the base of this unit (Z14/f47).

Samples: Eleven samples from regular intervals throughout the section were examined. Three of five samples examined from the lower unit contain Radiolaria, two of which are studied in this thesis (EC03, EC04). In the middle unit the two samples examined are barren, and in the upper unit the lower two of four samples contained Radiolaria and are used in this thesis (EC01, EC02).

Radiolaria: Of the four samples examined, two samples (EC01 and EC03) contain very poor faunas comprising only resistant members of the Spongodiscidae, some stylosphaerids, and some members of the genus *Thecosphaera*. In the other two samples (EC02 and EC04) preservation is relatively low ($N = 27$ in both cases) and diversity is also low ($Q = 6.68$ and 5.66 respectively) although for the former sample these values are reasonably typical for the lower Pliocene. Sample EC02 marks the FAD of *Didymocyrtis tetralthalmus tetralthalmus* in this section and although preservation is poor, the older age of sample EC04 is considered to be the main factor in determining the absence of this species from EC04.

References: P. Moore, NZ Geological Survey (map and column), Gosson (in prep.).

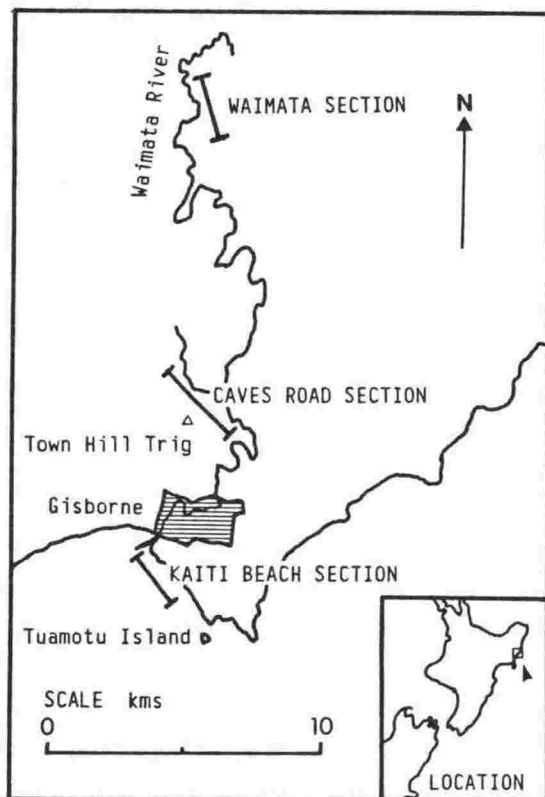


Figure A.5

Location of sections : Gisborne region.

A.3 ORUTUA RIVER SECTION

Location: In the Orutua River Valley from 4km due east to 1.5km due southeast of Taumataorei Trig. About 11km due east of the East Cape Section. See figure A.3.

Lithology and Age: The section comprises 1050m of massive mudstones, weakly bedded in places and sandier in the basal third, with common tuff beds. The age of the strata extends from lower Lillburnian (Z14/f74) to upper Tongaporutuan - middle Kapitean (Z14/f84).

Samples: Nine samples at regular intervals from throughout the section were examined and all are barren.

References: Gosson (in prep.), P. Moore, NZ Geological Survey (map).

A.4 WAIMATA RIVER SECTION

Location: Along the Waimata River from 11 to 14.5km north of Gisborne. Samples from river banks and road cuts. Poorly exposed. See figure A.5.

Lithology and Samples: The basal unit consists of at least 500m of sandy mudstone with rare Mollusca and occasional sandy layers. Two tuffs are exposed near the base. The oldest sample examined (Y17/f5) is very close to Kennett's (N98/f525) which marks the LAD of *Globoquadrina dehiscens* in this section. This sample and one other (Y17/f6) from this unit are barren.

The next unit is a 350m weakly bedded fine to medium sandstone which corresponds very closely to the *Globovalia conomiozea conomiozea* Zone. Two samples from this unit (Y17/f7, f8) are barren.

Overlying is a 630m massive sandy mudstone, sandier at the base, with occasional concretionary layers. The FAD of *G. crassaformis* is in the basal 100m of this unit. Eight samples from the lower half of this unit (Y17/f10-17) were examined and all were barren. One sample from near the top of the unit (SWM1) contains Radiolaria and is used in this thesis.

Radiolaria: The Radiolaria in SWM1 are reasonably well preserved and diverse (NG = 310, N = 30, Q = 8.93). The tentative identification of *Didymocyrtis tetralthalmus* indicates a post-Miocene age and the tentative identification of *Didymocyrtis* sp. A and no apparent *Lychnocanium* sp. aff. *grande* indicates an upper Opoitian age very near the boundary between the *Lychnocanium* sp. aff. *grande* Subzone and the *Lamprocyrtis hanna* Subzone, the latter zone being more likely. This age is supported by the sample being nearly 400m above the FAD of *Globovalia crassaformis* in strata comprising mainly massive light blue-grey mudstone.

References: Ridd (1964), Kennett (1966e).

FIGURE AG KAITI BEACH SECTION

Location: Figure A5

FORAMINIFERAL AND RADIOLARIAN DATUMS

D. laticonus
• G. dehiscens present
G. miotumida 37%
five chambered

• B. compressa s.l.

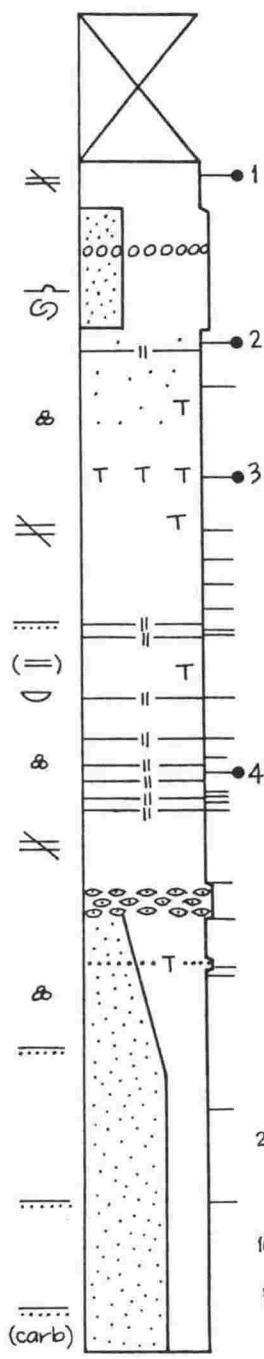
• LAD H. umbonatum

• possibly Waiauan

• Lillburnian

KB SAMPLES

BREAKWATER



SILTSTONE: mass

SANDSTONE/MUDSTONE: ibdd,
occ cgl beds (0.2-0.3m), slumped &
contorted layers in places

SILTSTONE: mass, cem in places, weakly
bdd, comm tfc beds, sandier towards
top.

"Cyclammina" Tuff

concretionary horizon

SANDSTONE/MUDSTONE: ibdd, complete
Bouma sequences at base (0.2 to 1.0m thick)
sst units less frequent towards top.

200
100
50
0 • VERTICAL SCALE (metres)

A.5 CAVES ROAD SECTION

Location: Caves Road Valley and in part of the Waimata River Valley from where the "Caves Road" Stream meets the Waimata River, downstream to Goodwin Road. From 1.5km north to 2km west of Town Hill Trig in the hills behind Gisborne. See figure A.5.

Lithology and Age: An approximately 1000m thick sequence of very poorly exposed silty mudstone was examined. Sample Y18/f171, 324m from the base of the section marks the LAD of *Globoquadrina dehiscens* which also occurs with *Bolivinita compressa* 142m below (Y18/f172). The FAD of *Globorotalia sphericomiozea* is 43m below the top of the section (Y18/f179).

Samples: Eleven samples were examined from regular intervals throughout the section. Sample Y18/f180, 74m below the FAD of *G. sphericomiozea* contained rare Radiolaria but was not used in this thesis. Sample SCV1, 265m above the LAD of *G. dehiscens* contains common Radiolaria and is used in this thesis. Of the twelve specimens of *Globorotalia miotumida* from this sample, 42% are five chambered forms.

Radiolaria: This sample, although lacking *Anthocyrtidium ehrenbergi pliocenica* contains the large pored form of *Heliodiscus asteriscus* and tentatively contains *Didymocyrtis laticonus* so is placed in the *Heliodiscus asteriscus* forma large pores Subzone. This is supported by the sample coming from strata between the LAD of *Globoquadrina dehiscens* and the FAD of *Globorotalia sphericomiozea*. Although the sample has a relatively high NG (596) the preservation and diversity ($N = 39$, $Q = 8.93$) are only slightly above normal for this radiolarian subzone (35.75 and 8.82 respectively). No member of the *Diartus hughesi* group is present in the sample.

Reference: G. Scott, NZ Geological Survey (pers. comm.).

A.6 KAITI BEACH SECTION

Location: Well exposed section on the wave cut platform from the breakwater to a point halfway between the breakwater and Tuamotu Island to the southeast, at Kaiti Beach, Gisborne. See figure A.5.

Stratigraphic column: Figure A.6.

Lithology, Age, and Samples: The basal unit comprises 440m of interbedded sandstones and mudstones, some being complete Bouma sequences, up to 1m thick. The sandstone beds become less frequent and thinner towards the top. Sediments at the base are Lillburnian (Ghent and Henderson, 1966) and are possibly Waiauan at the top of this unit. Six samples from this unit were examined and are barren.

Next in the sequence is a 22m concretionary horizon.

Overlying is a 540m massive siltstone with common tuff beds and occasional sandstone beds which increase in frequency towards the top. The basal part of this unit may be Waiauan. Eighteen samples were examined from this unit and three contained Radiolaria and are used in this thesis (KB02-04). The oldest radiolarian bearing sample (KB04) has *Globoquadrina dehiscens*, a very poor population of *Globorotalia miotumida*, and no *Bolivinita quadrilatera*. The upper two radiolarian bearing samples from this unit (KB02,

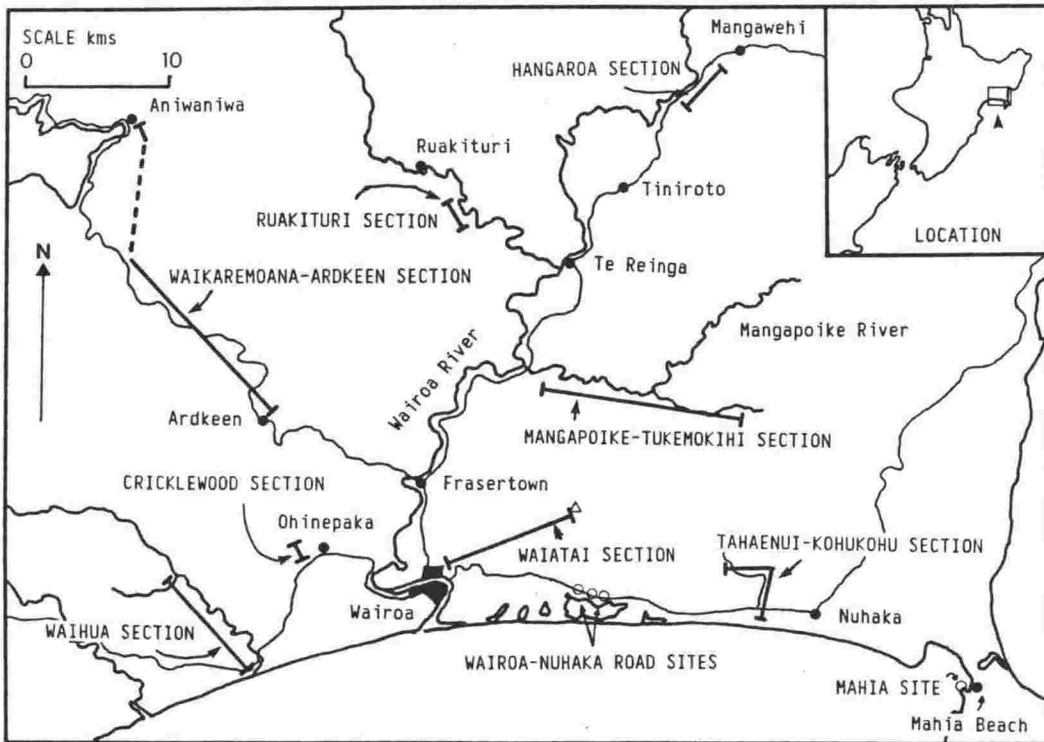


Figure A.7

Location of sections and sites : Northern Hawke's Bay.

KB03) contain *G. dehiscens*, moderate populations of *G. miotumida* (27-50% five chambered forms), and forms close to *B. compressa*.

Above this unit is a 112m interbedded sandstone and mudstone unit with some conglomeratic and very shelly beds. The basal 68m of this unit shows signs of soft-sediment deformation with many convoluted beds.

Overlying is at least 40m of massive sandy mudstone but no exposure between the top of this unit and the breakwater. One sample (KB01) yielded *G. dehiscens*, *G. panda*, a good population of *G. miotumida* (37% five chambered forms), and *Bolivinita pohana*. This sample also contained Radiolaria and is used in this thesis.

Radiolaria: Of the four samples studied the oldest three have very poor preservation with very few nassellarians preserved and faunas dominated by resistant forms such as the spongodiscids. The oldest sample (KB04) is important in that it contains *Heliodiscus umbonatum* which is restricted to the oldest material studied in this thesis. The youngest sample in the section (KB01) has a relatively high abundance (NG = 568, N = 37) and high diversity (Q = 15.91) and contains both *Didymocyrtis laticonus* and members of the *Diartus hughesi* group but lacks *Heliodiscus umbonatum*, *Anthocyrtidium ehrenbergi pliocenica*, and the large pored form of *Heliodiscus asteriscus*. This indicates an age from within the *Didymocyrtis laticonus* Subzone. This lower Tongaporutuan age is supported by the presence of *Globoquadrina dehiscens* in this sample.

References: Ghent and Henderson (1966), NZGS Micropaleontology Section unpublished stratigraphic column.

FIGURE A8 HANGAROA SECTION

Location: Figure A7

FORAMINIFERAL

DATUMS:

- FAD *B. pliozea*
- FAD *B. compressa* s.s.

- FAD *B. compressa* sl. glc

- LAD *G. dehiscens*

- *B. quadrilatera* FAD

- *G. mayeri*, *L. truncatum*
no *Bolivinita*

HR SAMPLES:

LIMESTONE: (s), lt wh-br, hd, shelly, sft s at base

MUDSTONE: mass, tfc bands common, indistinctly bdd in top 200m, lt gy-gn, (carb)

SEE FIGURE A.9 FOR DETAIL OF THE HR Ø1 to HR Ø7 PART OF THE SECTION

gradational

SANDSTONE/MUDSTONE: bedding generally 30-40cm, sst up to 1.5m, mst up to 3m.

← pumiceous fine sand

?

MUDSTONE: mass, some indistinct bedding, tfc

?

SANDSTONE/MUDSTONE: bedding generally 10-40cm, sst up to 1m, mst up to 40cm.

1000

500

400

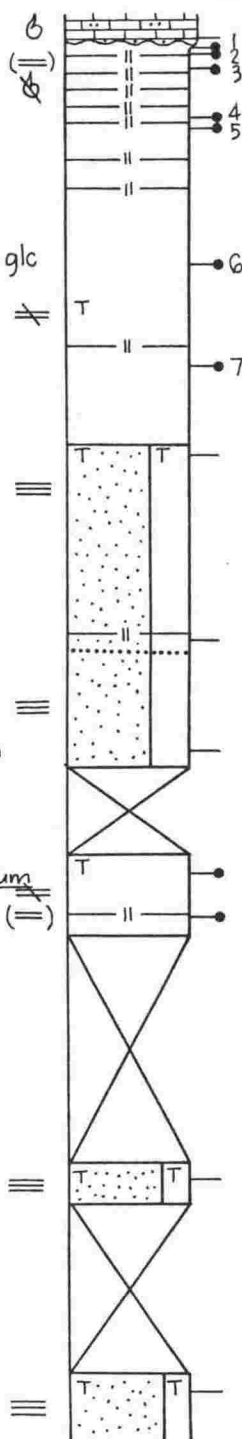
300

200

100

0

VERTICAL SCALE
(metres)



A.7 HANGAROA RIVER SECTION

Location: Mainly roadcut and some river samples along the Hangaroa River Valley from approximately 8.5km northeast of Tiniroto to about 1km west of Mangawehi, on the inland Gisborne-Wairoa Highway. See figure A.7.

Stratigraphic columns: Figures A.8 and A.9.

Lithology and Samples: The basal half of the section (1570m) is very poorly exposed with three short portions outcropping in roadcuts. The lower two portions expose interbedded sandstones and mudstones and are probably Southland Series in age. Two samples examined were barren of Radiolaria. The upper exposure contains a 2.5m tuff. Two samples (111m above and 2m below the tuff) both contain rare recrystallised Radiolaria in Waiauan mudstone (*Globorotalia mayeri*, *Loxostomum truncatum*, and no *Bolivinita*).

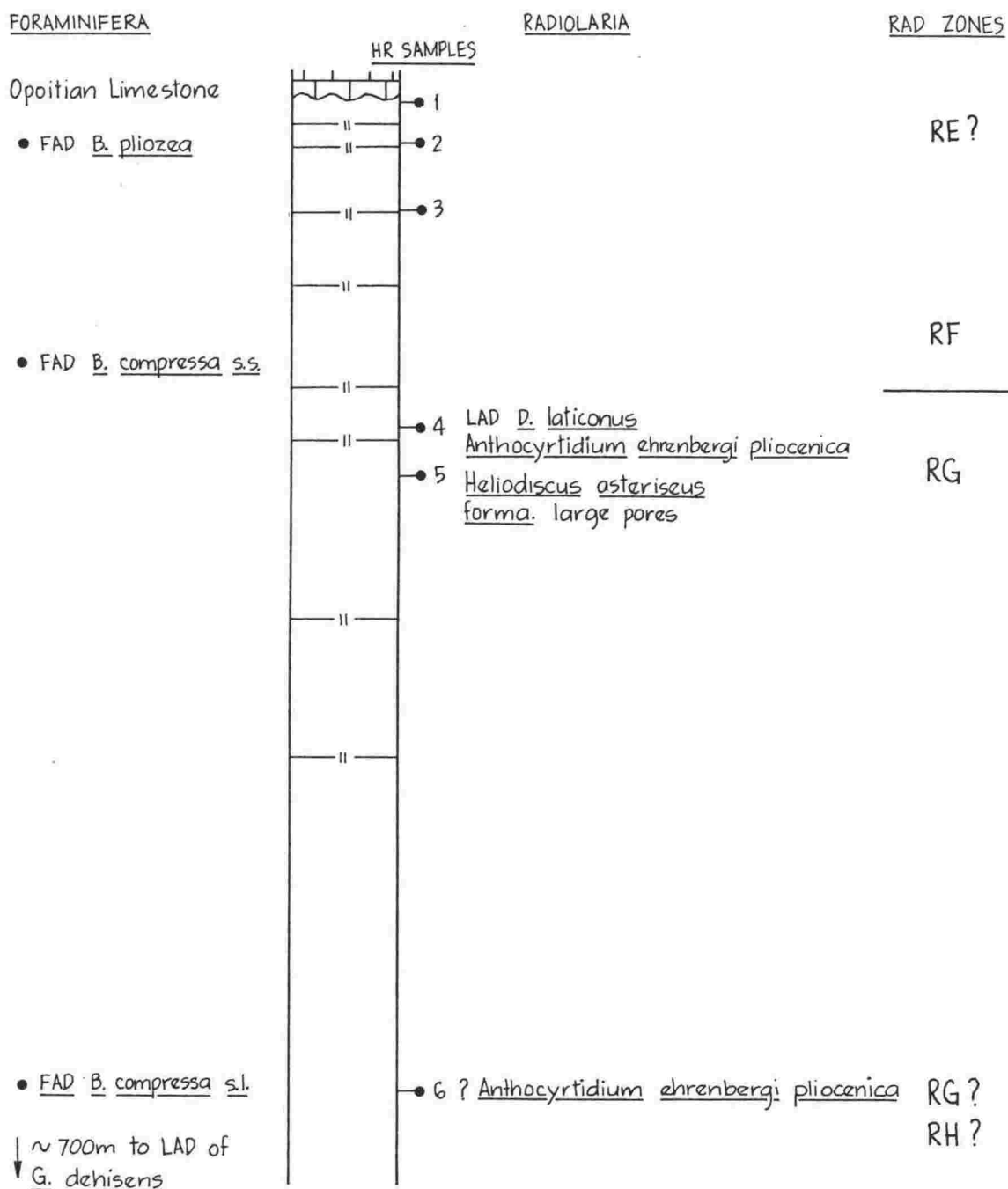
Next is a moderately well exposed, 760m, interbedded sandstone (up to 1.5m) and mudstone (up to 3m) unit with bedding generally 30-40cm. One tuff is exposed near the middle of this unit and rare pumiceous sands are also present. Sample X18/f17 (43m above the base of the unit) contains both *Bolivinita quadrilatera* and *B. pohana* and sample X18/f15 (approximately 30m below the top of this unit) marks the LAD of *Globoquadrina dehiscens* in this section. These two samples and one other (X18/f16, 15m below the tuff) are barren.

Overlying is a 930m, massive mudstone with common tuff bands. This unit is indistinctly bedded at the top. The FAD of populations of *Bolivinita compressa* s.s. is recorded 730m above the base of this unit although forms close to *B. compressa* occur below this. The upper 30m contains populations of *B. pliozea*. Poor to reasonable populations of *Globorotalia miotumida*, throughout the unit, have 50-66% five chambered forms. Seven samples were examined from this unit, all contain Radiolaria and are used in this thesis (HR01-07).

At least 50m of Opoitian limestone disconformably overlies the massive mudstone. A sample from a friable fine sandstone at the base of the limestone unit (X18/f7) is barren.

Radiolaria: The Radiolaria from the Waiauan strata and oldest Tongaporutuan sample (HR07) proved to be too recrystallised for even generic placement. Four of the other six Tongaporutuan samples are suitable for statistical analysis with moderate preservation ($N = 29$ to 44) and moderate diversity ($Q = 7.93$ to 11.21). The oldest radiolarian-bearing sample suitable for study (HR06), lacks *Didymocyrtis laticonus* but is below that taxa's LAD. The sample contains one tentative identification of *Anthocyrtidium ehrenbergi pliocenica* and probably comes from near the boundary between the *Didymocyrtis laticonus* Subzone and the *Heliodiscus asteriscus forma* large pores Subzone although this sample is approximately 700m above the LAD of *Globoquadrina dehiscens* in this section. Samples HR05 to HR02 contain some *Anthocyrtidium ehrenbergi pliocenica* and the large pored form of *Heliodiscus asteriscus*. The LAD of *Didymocyrtis laticonus* occurs in sample HR04 and marks the transition into the *Anthocyrtidium ehrenbergi pliocenica* Subzone. There are only two tentative identifications of members of the *Diartus hughesi* group in samples HR04 and HR05 and although it should be present (on an age basis) in some of the younger samples it is lacking. Consequently the top of the *Anthocyrtidium ehrenbergi pliocenica* Subzone is unrecognisable in this section. The youngest radiolarian bearing sample in the section

FIGURE A9
HANGAROA RIVER SECTION : upper part



Key to radiolarian zones : Figure A9.

RE = *Didymocyrtis* sp. A ZoneRF = *Anthocyrtidium ehrenbergi pliocenica* SubzoneRG = *Heliodiscus asteriscus* forma large pores SubzoneRH = *Didymocyrtis laticonus* Subzone

(HR01) has a very low diversity, lacking nassellarians and containing only recrystallised Spongodiscidae and didymocyrtids. This sample is interesting in that it contains *Spongaster pentas* (an early Pliocene tropical zonal taxa) in strata older than 6 Ma (just above the *Bolivinita pohana* - *pliozea* transition) and supports the view presented by Casey and McMillen (1977), that the restricted presence of this taxa in the early Pliocene tropics may be provincial.

Reference: Gosson (in prep.), G. Scott, NZ Geological Survey.

FIGURE A10 RUAKITURI SECTION

Location: Figure A7

FORAMINIFERAL
DATUMS:

RK SAMPLES:

- FAD G. conomiozea
conomiozea

Radiolarian Zone
RK $\phi 2, \phi 3, \phi 4$ belong
in the Didymocyrtis
laticonus Subzone

- FAD B. compressa s.s.

- LAD G. dehiscens

- FAD B. compressa sl. (=)

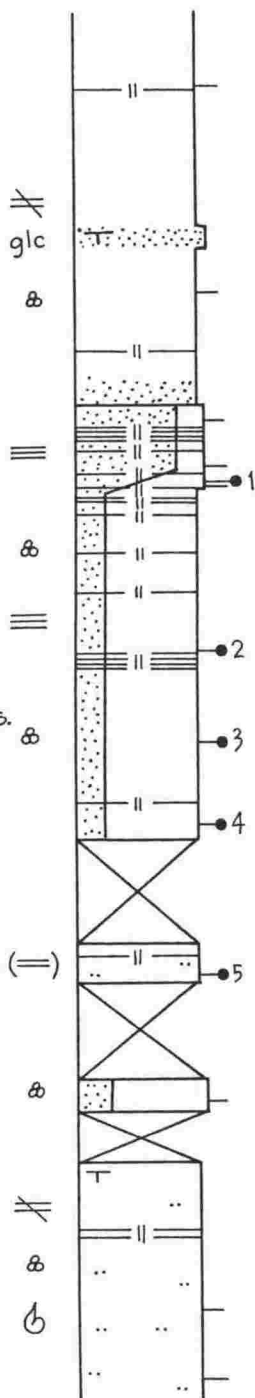
500

200

100

0

VERTICAL SCALE
(metres)



SILTSTONE: massive, rare tuffs

coarse sand, glauconitic, indurated

gradational

SANDSTONE/MUDSTONE: interbedded, common
tuffs, generally 1-20cm bedding; sandstone
(1-2m) and siltstones (0.5m) thicker and
coarser at top.

sandy tuffaceous mudstone

?

MUDSTONE: slightly sandy, rare mollusca,
occasional tuffs, massive

A.8 RUAKITURI RIVER SECTION

Location: Along Ruakituri River from 7 to 9km northwest of Te Reinga. See figure A.7.

Stratigraphic column: Figure A.10.

Comment: The best exposures are on the eastern riverbank. The section is a composite of two with the oldest sediment exposed on the river bank upstream from Pihanga Station. The river then turns and runs along strike (above the radiolarian bearing zone), the younger sediments being exposed when the river again flows south from its confluence with Whakapune Stream.

Lithology and Age: The basal 300m of the section is a massive sandy mudstone with minor amounts of tephric material, occasional tuffs and a two metre redeposited tuff.

Next in the sequence is a 840m interbedded sandstone (1-10cm) and mudstone (5-20cm) unit with occasional tuff beds. This unit is poorly exposed in its lower half and well exposed in its upper half. Radiolaria are present except in the lower 100m of this unit. The unit contains *Bolivinita* cf. *compressa* and predominantly five chambered *Globorotalia miotumida* in the lower half, and abundant, well preserved *B. compressa* s.s. and a larger percentage of 4/4.5 chambered *G. miotumida* in the upper half. *Globoquadrina dehiscens* is very rare in the samples examined but Kennett's faunal slides of N106/f563 and f564 (between RK03 and RK04) contain good specimens. Kennett (1965) marks the LAD of *G. dehiscens* in sample N106/f563.

The next unit has a gradational base and is represented by approximately 70m of interbedded sandstones (2m) and mudstones (1.5m). The two legs of the section correlate within this unit.

Above this the section is generally poorly exposed except where the river cuts into some harder, sandier, glauconitic strata. The FAD of *Globorotalia conomiozea conomiozea* (N106/f553) is at or slightly above this greensand.

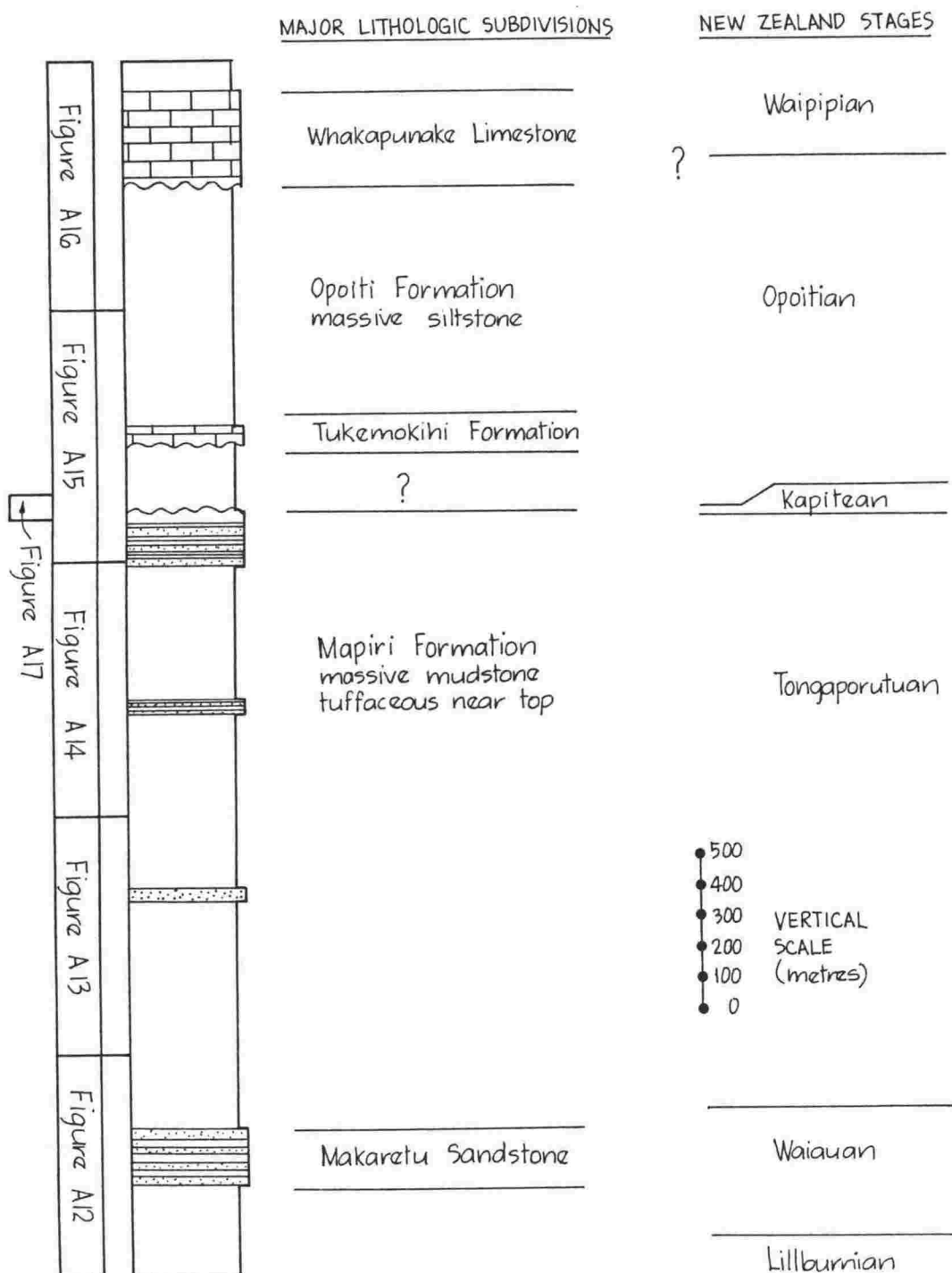
Samples: Twelve samples were examined from the basal two units (X18/f22-33), five of which contain Radiolaria and are used in this thesis (RK01-05). The five samples encompass LAD of *G. dehiscens* as recorded by Kennett (1965). One Opoitian sample (N106/f548) is barren.

Radiolaria: Of the five radiolarian bearing samples examined, the youngest (RK01) contains a fauna too poorly preserved for statistical study with only *Thecosphaera* spp. and some spongodiscids preserved. The oldest sample (RK05) contains a fauna too recrystallised for identification. The other three samples (RK02-04) have low numbers (NG = 161 to 223), moderate preservation (N = 25 to 36), and low to moderate diversity (Q = 6.44 to 9.70). All three samples belong to the *Didymocyrtis laticonus* Subzone with positive identifications of *Didymocyrtis laticonus* in RK02 and a tentative identification in RK04, and lacking *Anthocyrtidium ehrenbergi pliocenica* or the large pored form of *Heliodiscus asteriscus*. This radiolarian age agrees with the LAD of *Globoquadrina dehiscens* in sample RK04.

References: Kennett (1965, 1966e).

FIGURE A11 MANGAPOIKE RIVER - TUKEMOKIHI STREAM COMPOSITE COLUMN

Left hand column shows the position of the more detailed columns
(compiled with G. Gosson)



A.9 WAIKAREMOANA - ARDKEEN SECTION

Location: Roadcut samples taken at large stratigraphic intervals on the road from Aniwanuiwa to Ardkeen on the Lake Waikaremoana - Frasertown road. See figure A.7.

Samples: Three mudstone samples near Aniwanuiwa containing *Bolivinita pohana*, *Globorotalia miotumida* and *Globoquadrina dehiscens* (lower Tongaporutuan) and six mudstone samples at regular intervals from Piripaua to Ardkeen (three Tongaporutuan, two Kapitean, one Opoitian) are all barren.

Reference: Grant-Taylor and Hornibrook, 1976.

A.10 MANGAPOIKE - TUKEMOKIHI SECTION

Location: Excellent exposure on the banks of the Mangapoike River and in Tukemokihi Stream from the confluence of the Mangapoike and Wairoa Rivers to the headwaters of the Tukemokihi Stream about 17km due east. See figure A.7.

Stratigraphic columns: Figures A.11 - A.17

Lithology and Age: The basal unit is a generally massive siltstone with some thin sandy layers and packets (up to 30m thick) of interbedded sandstone and siltstone. This unit is at least 320m thick and is well exposed near its top but poorly exposed near its base. The lowest sample collected in the section X19/f39 is Lillburnian, sample X19/f40 (84m above) is Waiauian. Two samples within the top 40m of this unit are barren.

Overlying is a 182m, lithified, predominantly well-bedded sandstone unit, with some interbedded siltstones (Makaretu Sandstone). The sandstone is deeply gorged by Tukemokihi Stream. The contact with the underlying siltstone is gradational over about 50m with the frequency of sandy layers increasing towards the top of the siltstone. No samples were examined for Radiolaria.

Overlying the Makaretu Sandstone is a 1373m thick unit of massive siltstones with occasional sandy beds (commonly thin but one 34m thick bed just below X19/f54), rare concretionary layers and occasional tuff beds in the upper 570m which increase in frequency towards the top. Exposure is excellent in the banks of the entrenched Tukemokihi Stream and in the banks of the Mangapoike River with only one 35m covered interval near the top of this unit. A sample 7m above the Makaretu Sandstone (X19/f100) contains *Loxostomum truncatum* and sample X19/f98, 20m above, marks the incoming of the *Bolivinita* lineage (basal Tongaporutuan) which has been paleomagnetically dated at 10.3 Ma (Wright, 1985). Near the middle of this unit, sample X19/f110 marks the LAD of *Globoquadrina dehiscens*, approximately 5m above the 34m sandstone (Wright, Ashby, and Hoskins, 1985). Five samples from regular intervals in this unit were barren of Radiolaria. Another 15 samples were taken from exposures of this unit along strike in the banks of Mangapoike River but contained no Radiolaria.

Next in the sequence is a 90m, interbedded sandstone (up to 5cm) and mudstone (up to 20cm) unit. One mudstone sample from near the middle of this unit is barren.

TUKEMOKIHI STREAM (in part)

Location: Geographic - Figure A7 Stratigraphic - Figure A11

FORAMINIFERAL DATUMS and AGES

(B. Hoskins, pers. comm)

$$(\equiv)$$
 \neq 

- FAD Bolivinita sp.
- Loxostomum truncatum

um

 $(=)$

1



+

1

三

- Waiauan

- Lillburnian

Figure A13

MUDSTONE: massive, sandier towards base, indistinct 2m bedding in places

cemented sandstone layers

SANDSTONE / MUDSTONE : interbedded
indurated sandstones and softer
mudstones

MUDSTONE: massive, occasional sandy layers, packets of interbedded sands and muds present.

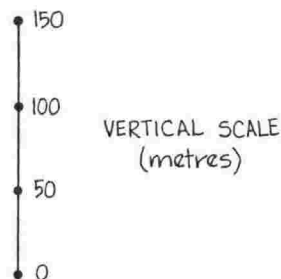


FIGURE A14

MANGAPOIKE RIVER - TUKEMOKIHI STREAM (in part)

Location: Geographic - Figure A7 Stratigraphic - Figure A11

FORAMINIFERAL AND
RADIOLARIAN DATUMS:

- LC.0 *Cyrtocapsella* spp.

TM SAMPLES:

- *G. miotumida* 50% five chambered forms

- FAD *B. compressa* s.s.
no *Diartus hughesi*

150
100
50
0

VERTICAL
SCALE
(metres)

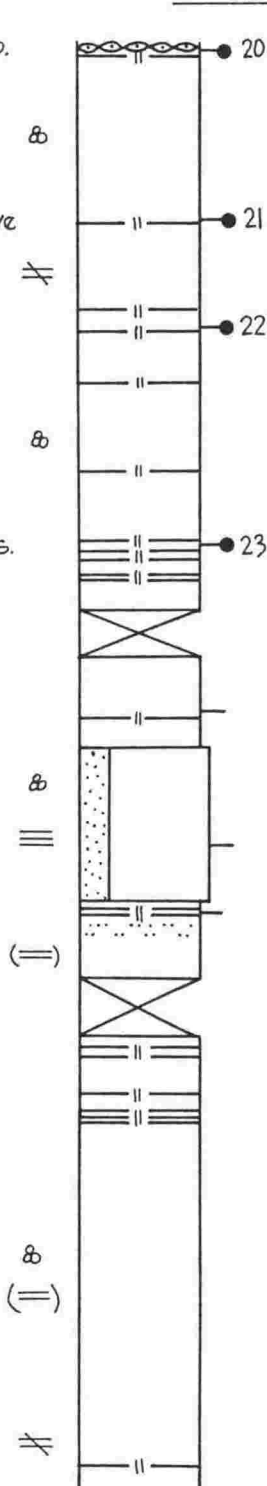


Figure A15 ↑

MUDSTONE: massive, common tuff beds

fault block
} approximately 30 tuffs

MUDSTONE/SANDSTONE: interbedded medium
sandstones (5cm thick) and mudstone,
approx 5 sandstone beds per metre.

gradational

MUDSTONE: massive, some sandy layers
towards top.

indistinct 3m bedding

Figure A13 ↓

Overlying this is a 404m, massive mudstone, sandy in places, with abundant tuff beds, especially near the base. There is a 28m part of the unit which appears to represent a soft-sediment rotational slump with no appreciable loss of section (grid ref. X19/077448). Sample X19/f59 (TM23) marks the FAD of *Bolivinita compressa* s.s. and is the oldest radiolarian bearing sample in the section. Reasonable populations of *Globorotalia miotumida* have about 30-50% five chambered forms although the youngest sample in the unit contains only 16%. Five samples were examined for Radiolaria from this unit and only the lowermost was barren, the other four being used in this thesis (TM20-TM23).

Next in the sequence is 168m of alternating massive, hemipelagic mudstones (10-29m thick) and packets of interbedded sandstones and mudstones (16-21m thick). The base of the unit is marked by a layer of large concretions (up to 2m). A paleomagnetically inferred disconformity representing the period 6.42 to 6.86 Ma is placed at this concretionary layer (Wright, 1985). The top of the unit is represented by an angular unconformity. There is no exposure of the unconformity on the banks of the Mangapoike River but good exposure on a roadcut section next to the river at grid reference X19/06754502. The unconformity pinches out to the south, the river section exposing approximately 30m more section than the roadcut. This unit contains common tuff bands, one tuff band immediately below the unconformity in the roadcut has been dated at 5.80 ± 0.55 Ma by Dr. D. Seward (Hornibrook, 1984a). Sparse to good populations of *G. miotumida* are present, the good populations showing a variation from 8 to 20% five chambered forms. *Globorotalia conomiozea conomiozea* is lacking. Four river and ten roadcut samples were examined, 12 of which contained Radiolaria (4 and 8 respectively) and seven were used in this thesis (TM14, TM18-20 from the river and TM15-17 from the roadcut).

Unconformably overlying is a 230m, sandy mudstone to muddy sandstone unit which tends to get sandier towards the top, with rare macrofossils, occasional concretionary layers and tuff beds. The unconformity has a 5° angular displacement and is marked, at the southern end of the roadcut, by a discontinuous line of glauconitic nodules up to 10cm long, with scattered smaller nodules in the sandy mudstone up to 1m above. At the northern end of the roadcut at least 1.5m of glauconitic, sandy mudstone overlies the unconformity. Another period of slow deposition is marked by a 3m glauconitic mudstone with scattered nodules about 65m above the base of the unit. The basal part (c.25m) of this unit contains rare *G. conomiozea conomiozea* and common *G. sphericomiozea*. The FAD's of *G. puncticulata puncticulata*, *G. crassaformis*, and *G. pliozea* occur about 40m above the unconformity. Five roadcut samples and six river samples were examined from this unit. One sample (TM13) from about 9m above the unconformity in the roadcut contained rare, recrystallised Radiolaria, the rest are barren.

Overlying is the Tukemokihi Formation, a 43m, indurated, pebbly calcareous grit and sand which contains the mollusc, *Phialopecten triphooki ongleyi*. No samples were examined for Radiolaria.

FIGURE A 15 MANGAPOIKE RIVER (in part)

Location: Geographic - Figure A7 Stratigraphic - Figure A11

FORAMINIFERAL DATUMS:
RADIOLARIAN ZONES:

TM SAMPLES:

Figure A16

• FAD G. margaritae

Lychnocanium grande
Subzone

• G. puncticulata
G. crassaformis

• LAD G. sphericomiozea
• FAD G. conomiozea mons

• FAD G. sphericomiozea

Didymocyrtis sp. A
Zone

• G. miotumida 20% five
chambered.

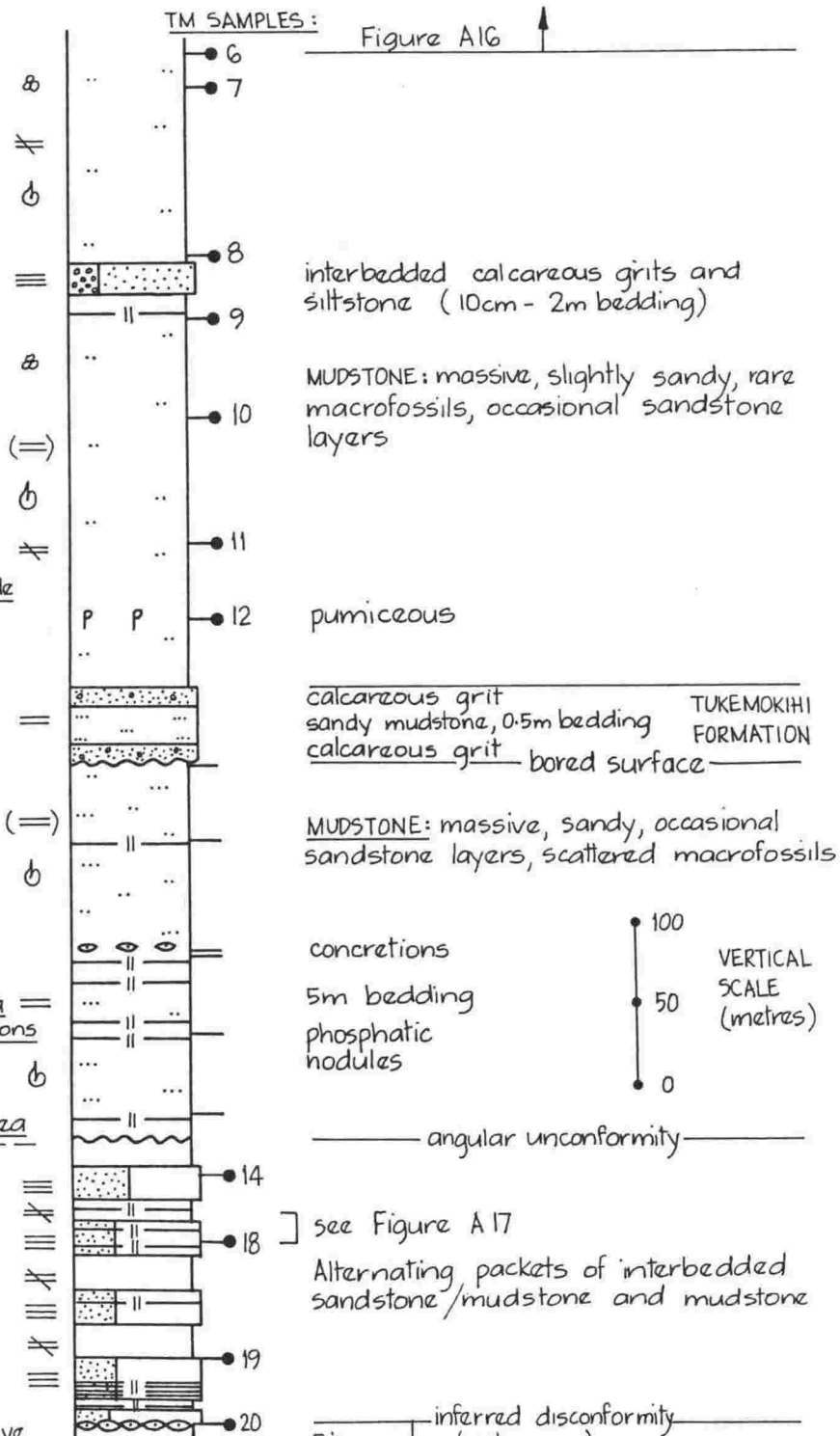


FIGURE A16
MANGAPOIKE RIVER (in part)

Location: Geographic - Figure A7 Stratigraphic - Figure A11

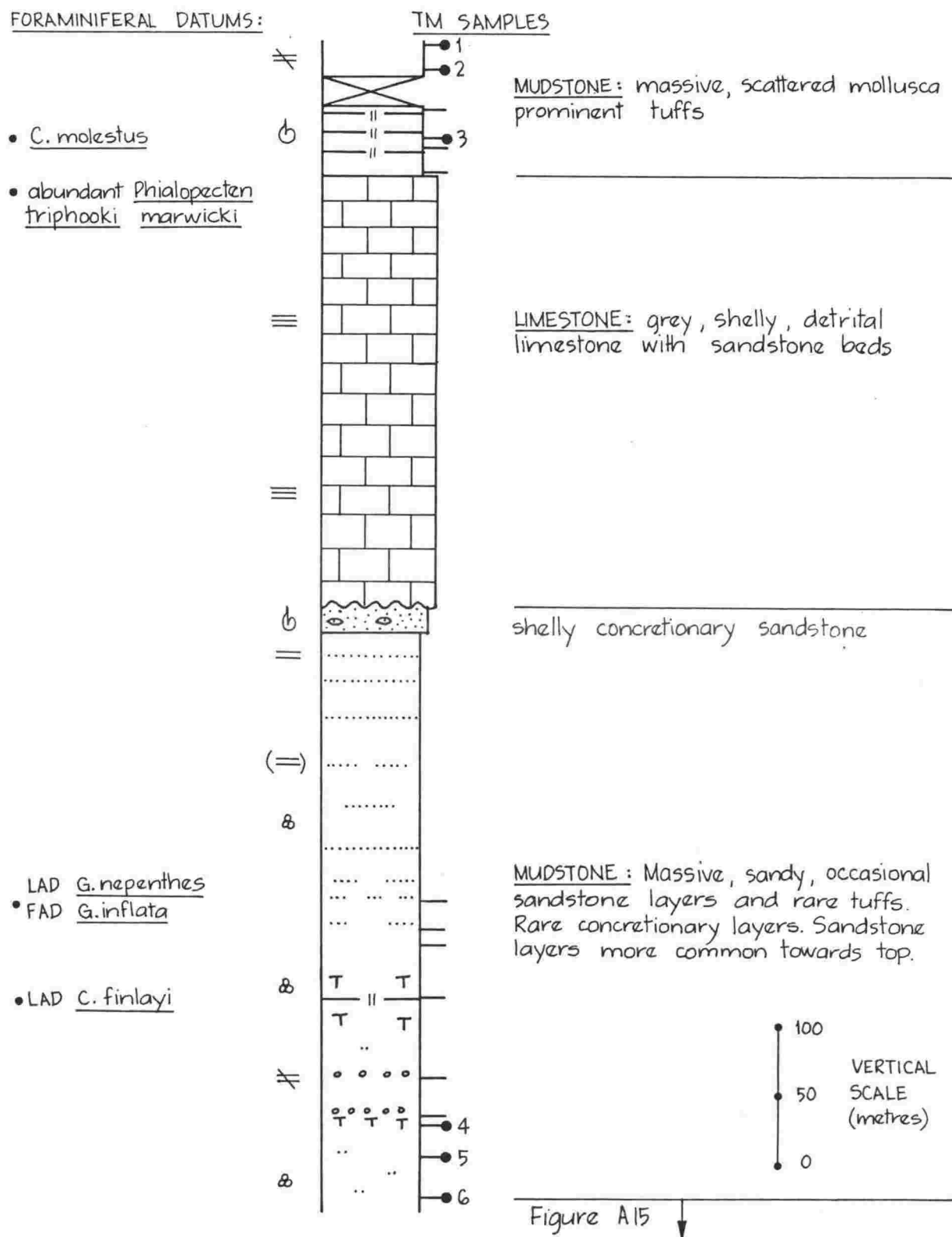


Figure A15

FIGURE A17 MANGAPOIKE: (road cut section)

Location: Geographic - Figure A7 Stratigraphic - Figure A11

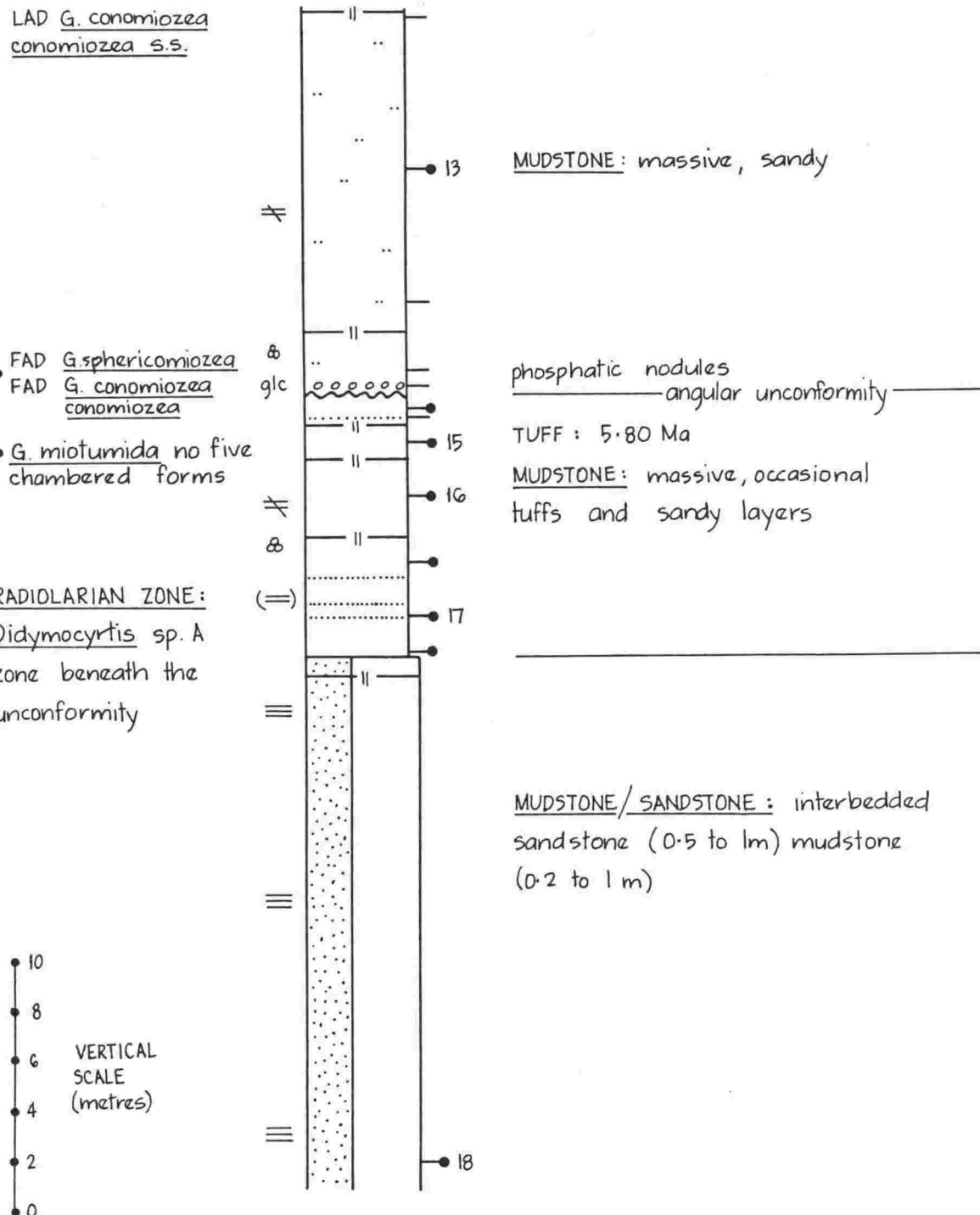
FORAMINIFERAL DATUMS:

- LAD G. conomiozea
conomiozea S.S.
- FAD G. sphericomiozea
- FAD G. conomiozea
conomiozea
- G. miotumida no five
chambered forms

RADIOLARIAN ZONE:

Didymocyrtis sp. A
zone beneath the
unconformity

T.M. SAMPLES



Next is a 800m massive sandy mudstone with occasional sandy layers (with an increasing frequency of calcareous sands towards the top), grits, concretionary bands, rare macrofossils and tuffs. The FAD of *Globorotalia inflata* is about 215m from the top of this unit. Sixteen samples were examined for Radiolaria, the lower ten (TM04-12) containing rare specimens. The portion of this section from the LAD of *G. conomiozea conomiozea* to the top of this unit has been designated the Opoitian lectostratotype.

Overlying is a 300m predominantly barnacle coquina (Whakapunake Limestone) which is deeply incised by the Mangapoike River through Haupatanga Gorge. This limestone contains abundant *Phialopecten triphooki marwicki* (Waipipian).

The youngest unit in the section is a massive siltstone with scattered mollusca and tuff beds, at least 90m thick, exposed in the Mangapoike River west of the Whakapunake Limestone (Kotare Road). This siltstone contains *Cibicides molestus*, *Globorotalia crassaformis*, and sinistral *G. crassaformis*. Five samples were examined, three of which contain Radiolaria (TM01-03).

Radiolaria: Of the 13 radiolarian bearing samples above the Miocene/Pliocene unconformity, only three (TM06,07,12) contain a radiolarian fauna with more than a few poorly preserved spongodiscids. Of these three TM06 was the only sample that warranted statistical analysis ($N = 28$, $Q = 6.32$). This sample contains *Lychnocanium* sp. aff. *grande* and in TM07 there is a tentative identification of *Didymocyrtis* sp. A. Although no *Didymocyrtis tetrathalmus tetrathalmus* is present it is apparent that these samples are from the *Lychnocanium* sp. aff. *grande* Subzone being between the FAD of *Globorotalia crassaformis* and the FAD of *Globorotalia inflata* in this section. Sample TM12 contains a fauna too poor for zonal identification. Of the Miocene samples (TM14-23) only two contain assemblages too poor for statistical analysis (TM17,18), the other eight Miocene samples having faunas with moderate to good preservation ($N = 32-41$) and poor to good diversity ($Q = 7.39-12.38$). The samples lack *Didymocyrtis laticonus* or members of the *Diartus hughesi* group and nearly all contain *Didymocyrtis* sp. A and belong in the *Didymocyrtis* sp. A Zone. *Cyrtocapsella japonica*, and *C. tetrapera* disappear at the inferred disconformity of Wright (1985).

References: McInnes (1964) - Pliocene and upper Miocene foraminifera

- McInnes (1965) - Miocene/Pliocene boundary foraminifera
- Kennett and Watkins (1974) - Pliocene paleomagnetism
- Weaver (1976a) - Pliocene paleomagnetism
- Beu *et al* (1980) - Limestone facies
- Scott (1982b) - Tk/Wo boundary foraminifera
- Hornibrook (1983) - Field trip guide
- Hornibrook (1984a) - Miocene/Pliocene boundary
- Wright (1985, and in prep.) - Miocene paleomagnetism
- Gosson (in prep.) - Tephrostratigraphy
- NZGS Micropaleontology Section stratigraphic columns



Plate A1.1

Example of exposure : the entrenched nature of Tukemokihi Stream gives 100% exposure for 1000m of stratigraphic thickness above the Makaretu Sandstone.



Plate A1.2

Example of exposure : although not part of the Tukemokihi Stream - Mangapoiike River Section, these cliffs that expose strata along strike from Tukemokihi Stream give an indication of the type of exposure present in the banks of Mangapoiike River.

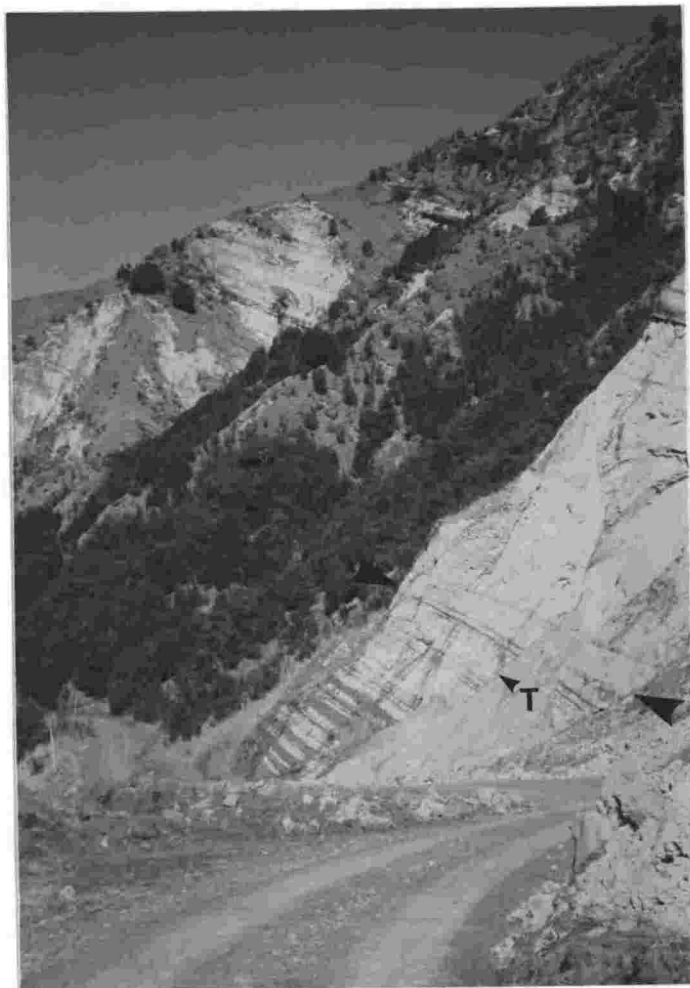


Plate A1.3

Roadcut unconformity : the unconformity (arrowed) with a 5° angular discordance represents a possible Miocene/Pliocene boundary with *Globorotalia sphericomiozea* in strata immediately above. A tuff (marked T), immediately below the unconformity has been dated at 5.80 ± 0.55 Ma (Dr. D. Seward). Radiolarians are abundant in strata from below the unconformity (*Didymocyrtis* sp. A Zone), but are very poorly preserved, if present, above.



Plate A1.4

Roadcut unconformity : the angular unconformity is marked by a discontinuous line of glauconitic nodules up to 10cm long, with scattered smaller nodules in the sandy mudstone up to 1m above. The 50 cent piece is 32mm in diameter.

A.11 MAHIA PENINSULA SITE

Location: Mokotahi Point at the south end of Mahia Beach. See figure A.7.

Comment: Sample (SMH1) 3m below a tuff (Hornibrook FT37) dated at 6.39 ± 1.14 Ma (Dr. D. Seward, pers. comm.) contains abundant Radiolaria and is used in this thesis. The foraminiferal fauna includes *Bolivinita pohana*, *Globorotalia miotumida* (approximately 50% five chambered) and lacks *Globoquadrina dehiscens*.

Radiolaria: This sample has moderate preservation and diversity ($N = 37$, $Q = 8.69$). With *Didymocyrtis* sp. A present but lacking *Didymocyrtis laticonus* or members of the *Diartus hughesi* group, this sample belongs in the *Didymocyrtis* sp. A Zone.



Plate A1.5

Mokotahi Point : strata from these cliffs at the south end of Mahia Beach contain Radiolaria from the *Didymocyrtis* sp. A Zone and a tuff dated 6.39 ± 1.14 Ma (Dr. D. Seward).

FIGURE A18 WAIATAI VALLEY SECTION

Location: Figure A7

FORAMINIFERAL AND
RADIOLARIAN DATUMS:

WA SAMPLES:

FAD L. gamphonycha

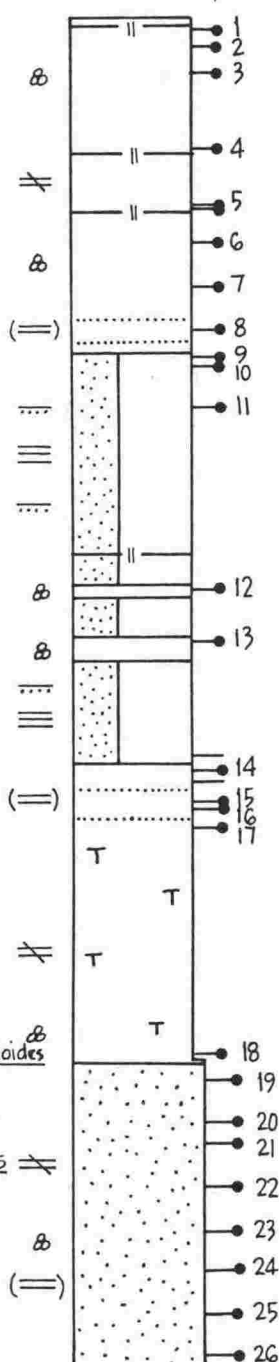
- change from dextral to sinistral G. crassaformis

• FAD G. crassula

• ET G. puncticulata puncticuloides

• LAD L. hannah

- change from sinistral to dextral G. crassaformis



TOP OF TE UHI HILL

MUDSTONE: massive, occasional tuff beds, occasional sandy graded beds near base

SANDSTONE / MUDSTONE: interbedded, sandstones: soft, brown, graded

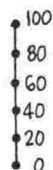
7m mudstone

15-20m mudstone

MUDSTONE: tuffaceous, occasional sandstone beds (some graded) near top, slightly carbonaceous

SANDSTONE: poorly bedded to massive, some prominent beds

VERTICAL
SCALE
(metres)



A.12 WAIATAI VALLEY SECTION

Location: On the northern slopes of Waiatai Valley and roadcuts on Te Uhi Hill between Trig P and the top Te Uhi Hill (10 to 1.5km east of Wairoa). See figure A.7.

Stratigraphic column: Figure A.18.

Comment: The beds dip southwest at 5-6° and exposure is generally poor so the thicknesses are difficult to measure accurately. The following text is taken in part from Hornibrook (1981b).

Lithology and Age: In the steep slopes below Trig P is 208m of poorly bedded silty sandstone containing small numbers of planktic foraminifera, including *Globorotalia puncticulata puncticulata*. Benthic foraminifera include *Notorotalia kingmai*, *Cibicides molestus*, the highest occurrence of which is adopted in this section as the principal benthic foraminiferal marker for the top of the Waipipian, is only in the lower half of the sandstone. *Globorotalia crassaformis* populations, coiling predominantly dextrally, are in the topmost 30m.

Above the poorly bedded sandstone, the lithology changes to a 217m thick tuffaceous, carbonaceous mudstone containing occasional beds of sandstone, some of which show graded bedding. Planktic foraminifera are much more abundant in these beds and the typically deep water *Notorotalia profunda* replaces *N. kingmai*, apparently in response to a rapid deepening of the basin. Near the base of the mudstone in sample WA18 *Globorotalia*

Radiolaria: Twenty-nine samples were examined from throughout the section, 27 contained Radiolaria and 26 are used in this thesis (WA01-WA26). The only two samples which are barren are from the top of the 217m thick tuffaceous mudstone unit, immediately above a radiolarian rich horizon (WA15-17). Radiolaria are generally rare in the lower 230m of the section (WA18-WA26) but three samples proved suitable for statistical analysis (WA19,23,26) with low to moderate N (24 to 33) and low to moderate Q (4.33 to 7.28). All three samples contain *Lamprocyrtis heteroporos* although the identification is only tentative in WA26 (the oldest radiolarian bearing sample in the section) and this sample may mark the level of the transition from *Lamprocyrtis hannah*. The LAD of *Lamprocyrtis hannah* occurs in WA19. This places these samples within the *Lamprocyrtis heteroporos* Zone with WA26 probably near the base.

Above WA18 radiolaria are generally better preserved especially towards the top of the 217m thick tuffaceous mudstone unit (WA15,16,17: N=31-38, Q=6.01-8.21), within thick mudstone beds in the 295m thick interbedded sandstone and mudstone unit (WA13: N=35, Q=8.45), and from the youngest samples studied (WA01,03: N=29-34, Q=6.23-8.50). Of the other samples above WA18, one contained only a couple of unidentifiable spongodiscids (WA09) and the rest very low diversity faunas not suitable for statistical analysis (WA04-06,08,11,12,14). The FAD of *Lamprocyrtis gamphonycha* occurs in WA07, although one sample (WA15) contains a form transitional with *Lamprocyrtis heteroporos*.

References: Hornibrook, 1981 ; NZGS Micropaleontology Section unpublished stratigraphic column.

A.13 WAIROA-NUHAKA ROAD SITES

Location: Sites collected from roadcuts on the northern side of the Wairoa-Nuhaka Highway (SH2) between Whakaki and Tuhara. See figure A.7.

Lithology and Age: Four samples of massive mudstones with occasional tuff bands were looked at, three of which contain Radiolaria and are used in this thesis (SWN1-SWN3). Stratigraphic distances between the sites are difficult to assess. Sample SWN2 is an approximate recollection of X19/f9523 (=N116/f523) which contains *Globorotalia crassaformis*, *G. tosaensis*, *G. inflata*, *G. ruber*, and *G. puncticulata*. The samples are from the lateral equivalent of the 217m tuffaceous, carbonaceous mudstone exposed in Waiatai Valley between the LAD of *Cibicides molestus* and FAD of *Globorotalia crassa* and using strike correlations fill the sampling gap between WA17 and WA18 in the Waiatai Valley Section.

Radiolaria: Generally radiolaria are poorly preserved in these samples, none being suitable for statistical analysis. No definitive radiolarian age determinations can be made.

Reference: Hornibrook (1976b).

A.14 TAHAENUI-KOHUKOHU ROAD SECTION

Location: A composite column of strata exposed in the low hills to the south of the main highway opposite Tahaenui Station and at the entrance to Tahaenui Station plus roadcut localities up Kohukohu Road (4km west of Nuhaka). See figure A.7.

Samples and Age: Nine Waipipian samples examined, seven of which contain Radiolaria and six were analysed in this thesis (TK01-TK06). The seventh sample (JAA444) is an approximate recollection of TK01. One Tongaporutuan? sample from immediately below the Whakapunake Limestone (at the northern end of Kohukohu Road) is barren.

Radiolaria: Of the six samples studied only one (TK05) warranted detailed investigation, the others containing only rare, recrystallised spongodiscids and the occasional member of the genus *Thecosphaera*. Even TK05 has a very poor fauna (NG=6, N=14, Q=4.84). No definitive zonal age could be determined but the presence of the thicker spined form of "*Sphaerostylus*" sp. aff. *timmsi* supports a post-Miocene age.

References: NZGS Micropaleontology Section unpublished stratigraphic column.

A.15 CRICKLEWOOD ROAD SECTION

Location: The valley slopes on either side of Hura-mua Stream beside the lower part of Cricklewood Road, about 2.5km due west of Ohinepaka. See figure A.7.

Lithology and Age: The section is represented by tuffaceous mudstones which are poorly exposed and slumped in the neighbouring Waihua Valley Section. The *Globorotalia crassula* - dextral *Globorotalia crassaformis* overlap zone is recognised on the south side of the road (at least 5m thick).

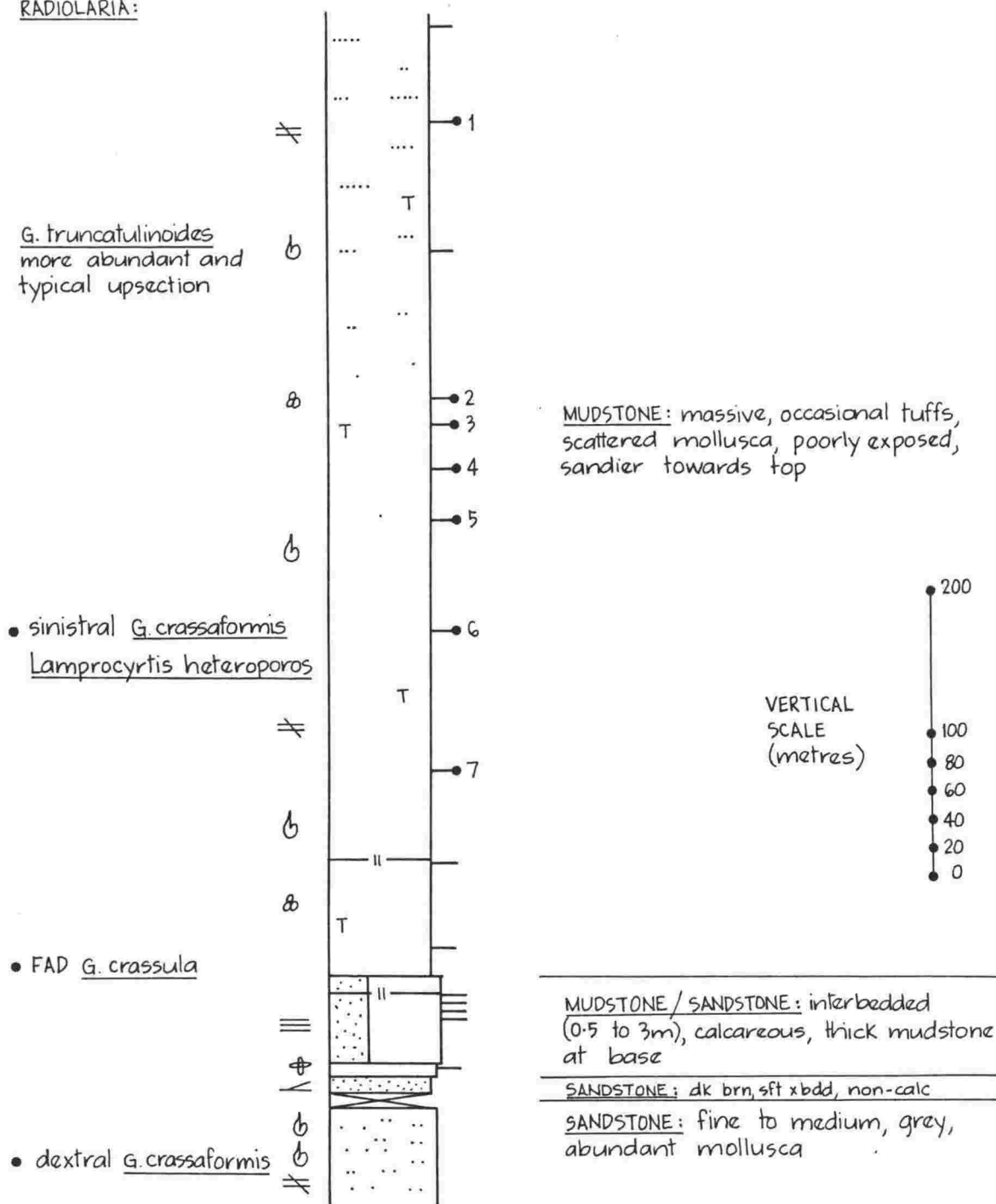
Samples: Samples range in age from Mangapanian to Nukumaruan. Six samples were examined (W19/f8659-8664), four of which contain Radiolaria and are used in this thesis (CR01-04).

Radiolaria: The two youngest radiolarian bearing samples are from above the dextral *Globorotalia crassaformis* - *G. crassula* overlap zone (CR01,02) and contain only rare spongodiscids and sample CR04, from below the overlap zone, contains relatively common spongodiscids and *Thecosphaera* sp., all three samples obviously affected by dissolution. Sample CR03 contains a poor assemblage (NG=12, N=21, Q=5.05), with post Miocene indicators such as *Amphirhopalum* cf. *ypsilon* and the thicker spined form of "*Sphaerostylus*" sp. aff. *timmsi*, but no zonal radiolarian fossils. The sample comes from the top of the overlap zone and is probably from the *Lamprocyclas gamphonycha* Zone.

References: Hornibrook (1981b), NZGS Micropaleontology Section unpublished stratigraphic column.

Location: Figure A7

WH SAMPLES



A.16 WAIHUA VALLEY SECTION

Location: Roadcut and riverbank samples along the Waihua River Valley from the junction with Ngamahanga Stream to the Waihua River mouth. See figure A.7.

Stratigraphic column: Figure A.19.

Lithology and Age: The base of the section consists of a medium grey sandstone with abundant mollusca dated as Waitotaran by Marwick (1965). Foraminifera include abundant *Notorotalia kingmai*, rare, very small angular juveniles of *Globorotalia truncatulinoides* morphotypes and a small population of predominantly dextral *Globorotalia crassaformis*.

Overlying this is a 15m weathered dark brown, non-calcareous soft sandstone.

Next in the sequence is a 10m weathered mudstone containing dextral *G. crassaformis*.

The next unit is a distinctive interbedded sandstone-mudstone unit about 60m thick which is a useful local marker unit.

Overlying is a thick (approximately 650m) interval of massive tuffaceous mudstone which in places is slumped and generally poorly exposed. A single specimen of *G. crassaformis* was found a few metres above the base of this unit (N115/f596) indicating a lower Nukumaruan age. One sample containing sinistral *G. crassaformis* was found near the middle of this unit (N115/f552). Consequently the *Globorotalia crassaformis* - dextral *Globorotalia crassaformis* overlap zone is difficult to define precisely in this section. In the upper part of the mudstone *G. truncatulinoides* becomes more abundant and typical.

Samples: Six samples from the Mangapanian part of the section (X19/f7, f10-14) are barren. Two Nukumaruan samples were examined from the same collection (NZ Geological Survey) of which only sample N115/f552 contains Radiolaria. Nine samples were collected from the Nukumaruan tuffaceous mudstone, six of which contained Radiolaria and are used in this thesis (WH01-05, WH07). Sample N115/f552 (WH06) was also used in this thesis.

Radiolaria: Of the seven samples examined only samples WH03 and WH06 warranted statistical treatment, the other five generally containing poor faunas dominated by *Spongotrochus glacialis*. The two statistical samples have a low preservation and diversity typical of radiolarian faunas from Pleistocene samples (NG=22-23, N=23-26, Q=6.83-7.85). Sample WH03 lacks zonal radiolarians but contains post-Miocene indicators such as *Actinomma leptodermum*, the thicker spined form of "*Sphaerostylus*" sp. aff. *timmsi* and *Amphirhopalum* cf. *ypsilon* and is probably from the *Lamprocyclas gamphonycha* Zone. Sample WH06 contains *Lamprocyrtilis heteroporos* but lacks *Lamprocyclas gamphonycha* which places the sample in the *Lamprocyrtilis heteroporos* Zone.

References: Marwick (1965), Hornibrook (1981b), NZGS Micropaleontology Section unpublished stratigraphic column.

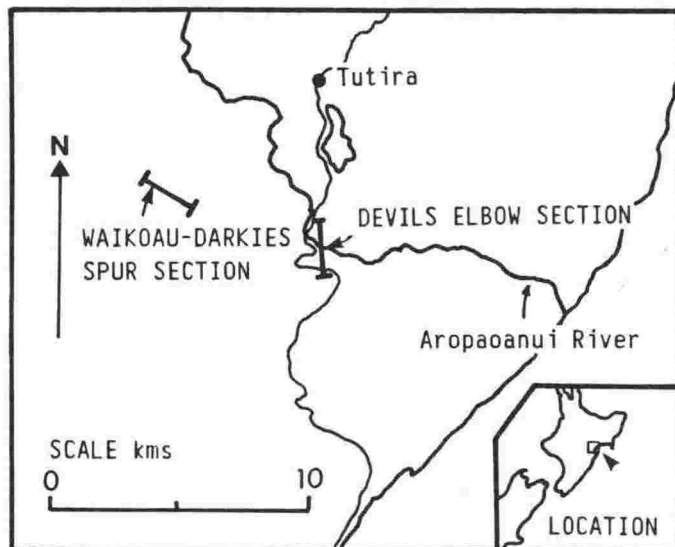


Figure A.20

Location of sections : Tutira area (central Hawke's Bay).

A.17 WAIKOAU-DARKIES SPUR SECTION

Location: Western edge of a 350m high limestone plateau above Waikoau, about 7km due west of Lake Tutira which is on the Napier-Wairoa Highway. See figure A.20.

Samples: Three lower Nukumaruan samples (V20/f12-f14) were found to be barren.

References: Hornibrook (1981), NZGS Micropaleontology Section unpublished stratigraphic column.

A.18 DEVILS ELBOW SECTION

Location: Along the Napier-Wairoa Highway on the steep southern face of the Aropoanui River Valley, about 4km south of Lake Tutira. See figure A.20.

Samples: Two lower Nukumaruan samples (N124/f580, f583) were found to be barren.

References: Grant-Taylor and Hornibrook (1976), Hornibrook (1981), NZGS Micropaleontology Section unpublished stratigraphic column.

A.19 ONEKAWA DRILLHOLE

Samples: Four lower Nukumaruan samples from this drillhole near Napier (V21/436815 - 40.5m, 45.7m, 62.1m, 84.4m) contain very rare radiolarian specimens but were not examined in detail in this thesis.

Reference: Hornibrook (1981).

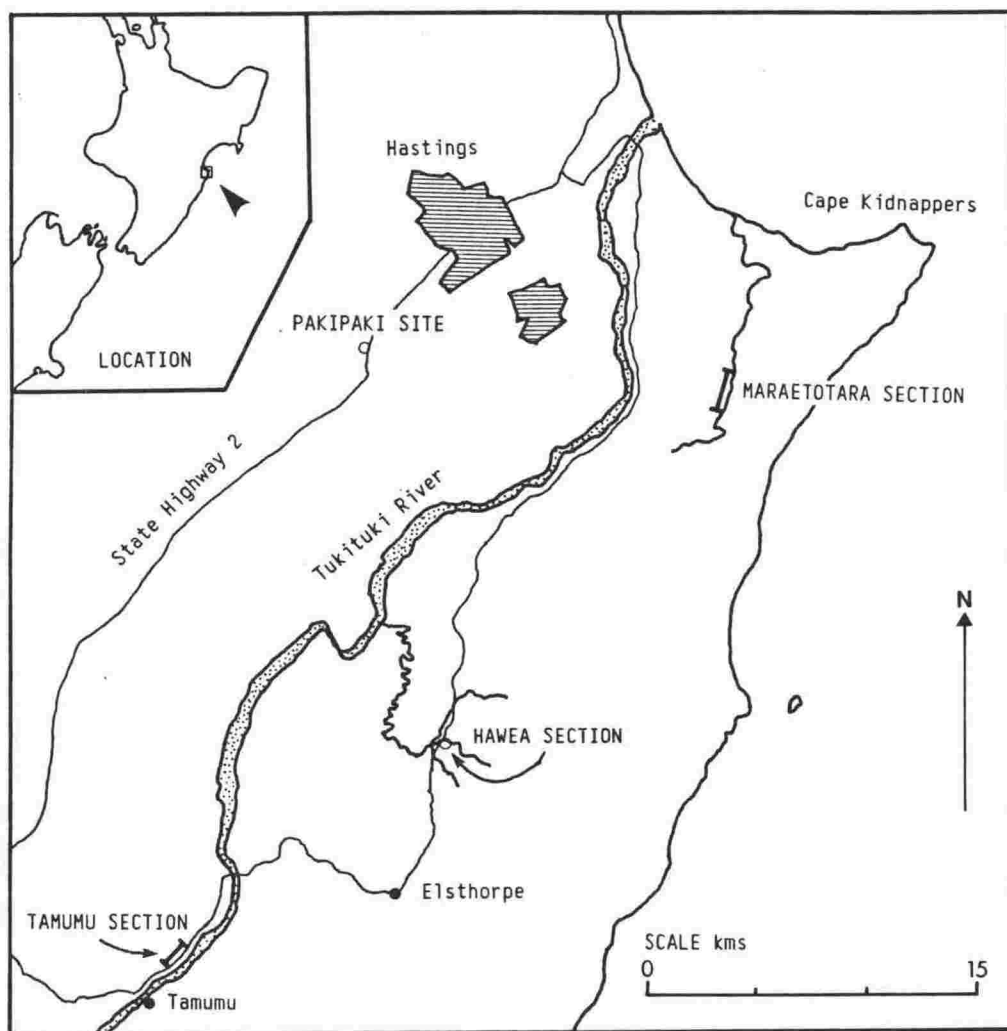


Figure A.21

Location of sections and site : Hastings area.

A.20 MARAETOTARA RIVER SECTION

Location: Along the middle reaches of the Maraetotara River, about 14km southeast of Hastings. The section is moderately well exposed in a gorge immediately to the east of Maraetuna Homestead and in the entrenched river banks in younger strata to the north. Exposures are very poor in older strata to the south. See figure A.21.

Stratigraphic columns: Figures A.22 and A.23.

Lithology and Age: At least 880m of massive moderately hard mudstone with rare macrofossils near the base and sandier facies in the upper 170m. No distinct tuff beds were found but glass shards are present in some of the residues and one sample contained pumiceous granules up to 5mm. The FAD of *Bolivinita compressa* was recorded by Kennett 580m from the top of this unit (N135/f565). Although planktic foraminiferal faunas are generally poor there appears to be an abrupt change from five chambered *Globorotalia miotumida* to predominantly 4/4.5 chambered forms about 44m from the top of this unit.

Overlying is at least 40m of interbedded hard (5-10cm) and soft (0.5-1m) muddy sandstone which gets more massive up-section. This unit contains *Globorotalia crassaformis* and *G. puncticulata puncticulata*.

Kennett (1966e) stated that the "contact between the Taranaki and Wanganui Series is not exposed, but no more than 150ft of strata is covered at this horizon" and he believed a disconformity was present between Opoitian and Tongaporutuan strata. In a small riverbank (W21/51986009) the unconformity is now exposed with a sharp contact between underlying blue-grey massive mudstone containing forms approaching *Globorotalia conomiozea conomiozea* (MT03) and a 5cm shelly conglomerate which grades into the alternating hard and soft muddy sandstone unit. The first soft bed, about 10cm above the sharp contact (MT02), contains rare *G. puncticulata*, *G. crassaformis*, and one specimen of *G. conomiozea mons*.

Samples: Two samples below the FAD of *B. compressa* are barren. Between the FAD of *B. compressa* and the unconformity, 18 samples were examined, 13 of which from the upper 150m contained Radiolaria. Seven of these samples are examined in this thesis (MT04-MT10). Two samples from above the unconformity are barren of Radiolaria.

Radiolaria: Of the seven radiolarian bearing samples, five were suitable for statistical analysis. The three lower samples (MT08-10: N = 34, Q = 7.82-8.60) all contain *Didymocyrtis laticonus* with MT09 and possibly MT10 containing the large pored form of *Heliodiscus asteriscus* and MT18 *Anthocyrtidium ehrenbergi pliocenica*. This places these samples in the *Heliodiscus asteriscus forma* large pores Subzone. *Diartus hughesi* is possibly present in MT08 but not in any younger samples. The LAD of *Didymocyrtis laticonus* is in sample MT08 and between MT07 and MT08 there is an abrupt change from five to 4/4.5 chambered *Globorotalia miotumida*. As forms very close to *Globorotalia conomiozea conomiozea* start appearing only 30m above it is assumed that there is some time missing between MT07 and MT08 (possibly the *Anthocyrtidium ehrenbergi pliocenica* Subzone).

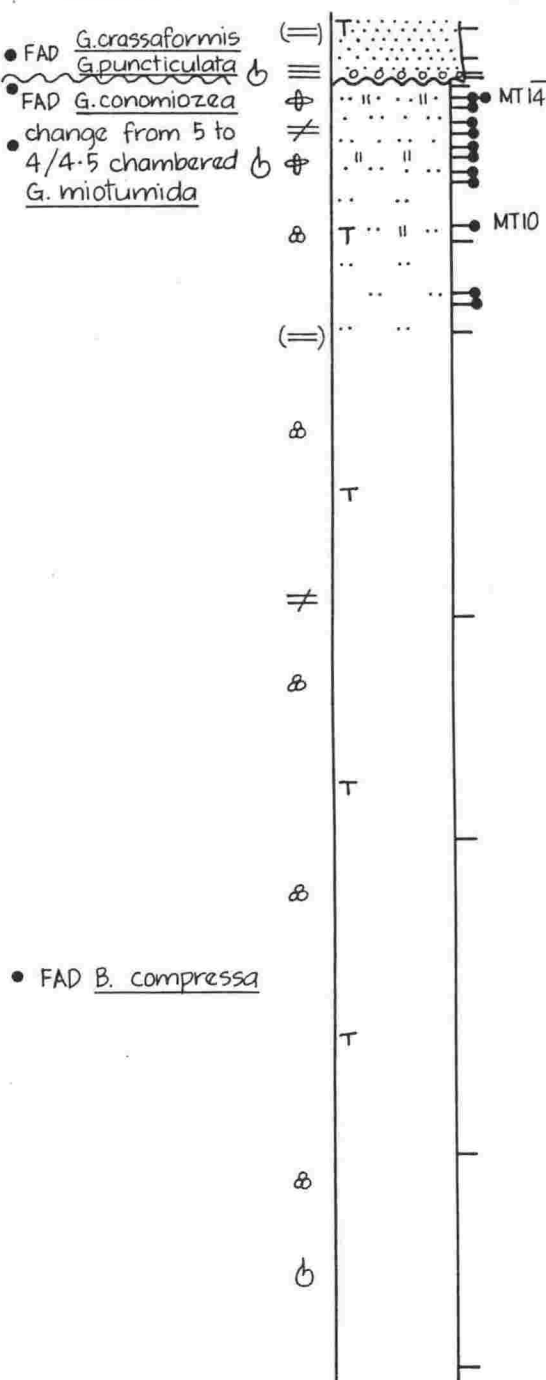
Reference: Kennett (1966e).

Location: Figure A21

- FAD G. crassaformis
- FAD G. puncticulata
- FAD G. conomiozea
- change from 5 to 4/4.5 chambered
- G. miotumida

SEE FIGURE A23 FOR DETAIL OF THE
RADIOLARIAN - BEARING PART OF SECTION

MUDSTONE: mass, s at top, (tf) at top,
indistinct cm-bdd in places, microbiod



VERTICAL SCALE (metres)

FIGURE A23 MARAETOTARA RIVER SECTION (detail of radiolarian bearing portion)

Location: Figure A 21

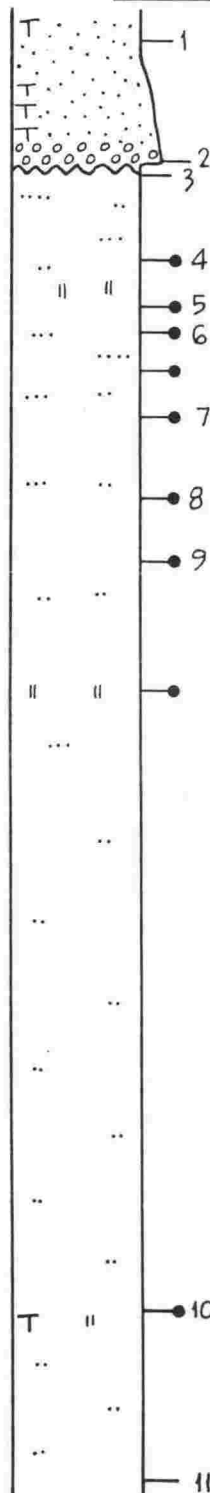
FORAMINIFERA AND RADIOLARIA:

- FAD G. crassaformis, G. puncticulata
- FAD G. conomiozea conomiozea s.l.
- ? Didymocyrtis antepenultima

- abrupt change from five to 4/4.5 chambered G. miotumida
- LAD D. laticonus
- ? Diartus hughesi: present

- Heliodiscus asteriscus forma
large pores

MT SAMPLES:



RADIOLARIAN ZONES

Didymocyrtis sp. A Zone

Anthocyrtidium ehrenbergi
pliocenica subzone missing

Heliodiscus asteriscus forma
large pores Subzone

VERTICAL
SCALE
(metres)



A.21 HAWEA STREAM SECTION

Location: Part of Hawea Stream, 0.4km east of the Elsthorpe - Hastings Highway, 7km north of Elsthorpe. See figure A.21.

Samples: Eight possible Southland Series samples (N141/f1402-f1409) were examined and two samples (f1408, f1409) contained rare, recrystallised Radiolaria and were not studied in this thesis.

References: Gibson (1963, 1967).

A.22 TAMUMU SECTION

Location: West bank of the Tukituki River, 2.8km north of Tamumu Bridge. See figure A.21.

Samples: Five Waiauan to mid Tongaporutuan samples (N141/f1410, f1414-f1416, f1418) are barren.

References: Gibson (1963, 1967).

A.23 PAKIPAKI SITE

Location: Abandoned lime quarry at Pakipaki, 7km south of Hastings. See figure A.21.

Samples: Two samples from the *Globorotalia crassula* - dextral *Globorotalia crassaformis* overlap zone (V21/f7, f8) were found to be barren.

Reference: Hornibrook (1981).

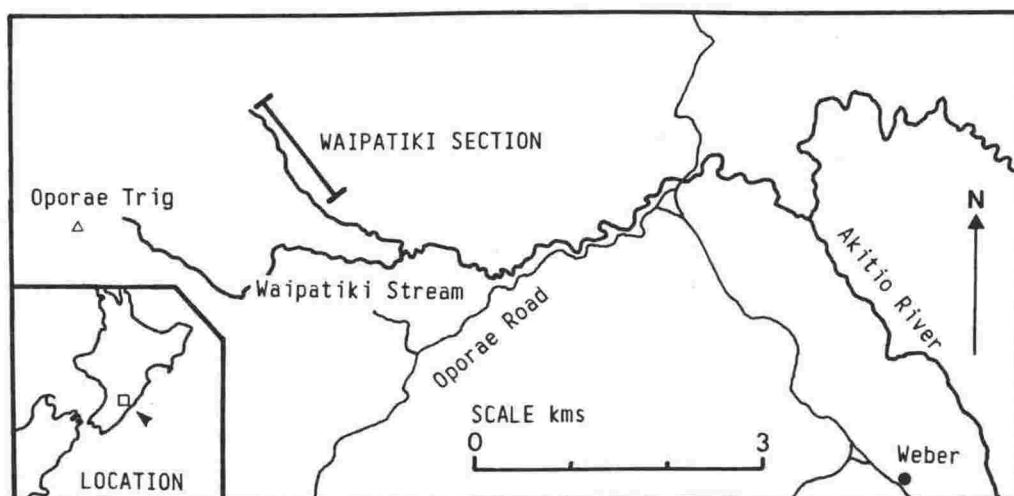


Figure A.24

Location of section : Waipatiki (northern Wairarapa).

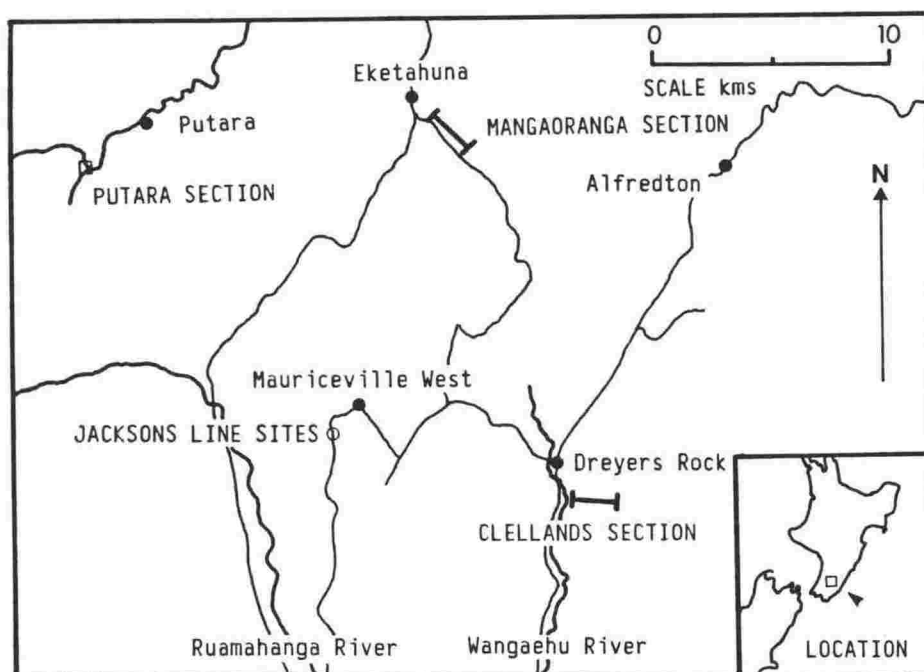


Figure A.25

Location of sections and sites : Mauriceville area (northern Wairarapa).

A.24 WAIPATIKI SECTION

Location: Well exposed section in a tributary of the Waipatiki Stream, 2.4km east of Oporae Trig and 7km west-northwest of Weber. See figure A.24.

Samples: Three samples from the Kapitean part of the section (N150/f1032,1035,1038) and two from the lower Opoitian (N150/f1041,1042), all from massive silty mudstones are barren.

References: Laing (1964), Kennett (1966d).

A.25 MANGAORANGA SECTION

Location: Exposed in the banks of the Mangaoranga Stream from 1.4 to 3.2km southeast of Eketahuna. See figure A.25.

Samples: Five samples were examined from Kennett's collection N153/f1172,1170 (Wo), f1165 (Tt/Tk), f1159,1160 (MTt), one of which (f1165) contained rare Radiolaria. A collection of 14 samples made by G. Scott and H. Morgans of the Geological Survey was then examined and two samples (T25/f14,15) contained rare, pyritised Radiolaria from sediments containing *Bolivinita pliozea*, *Globorotalia miotumida* (predominantly four chambered), and some conical forms approaching *G. conomiozea conomiozea*. The Radiolaria were considered to be too poorly preserved to be used in this thesis.

References: Kennett (1966d), Neef (1984).

A.26 PUTARA SECTION

Location: Moderately well exposed in cliffs cut by the Mangatainoka River immediately north of Putara and for 2.4km northwest up a stream that flows into the Mangatainoka River. About 10km due east of Eketahuna. See figure A.25.

Samples: One sample examined from Kennett's collection (N153/f1153 - Opoitian mudstone) is barren.

Reference: Kennett (1966d).

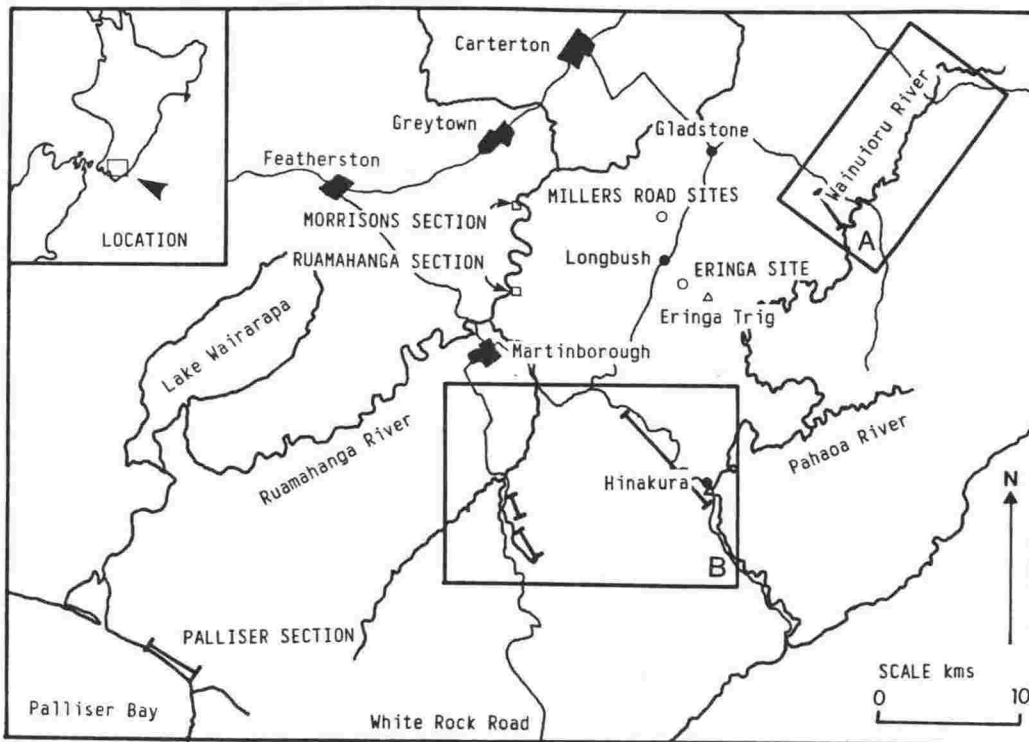


Figure A.26

Location of sections and sites : southern Wairarapa.

Inset A corresponds to figure A.27.

Inset B corresponds to figure A.28.

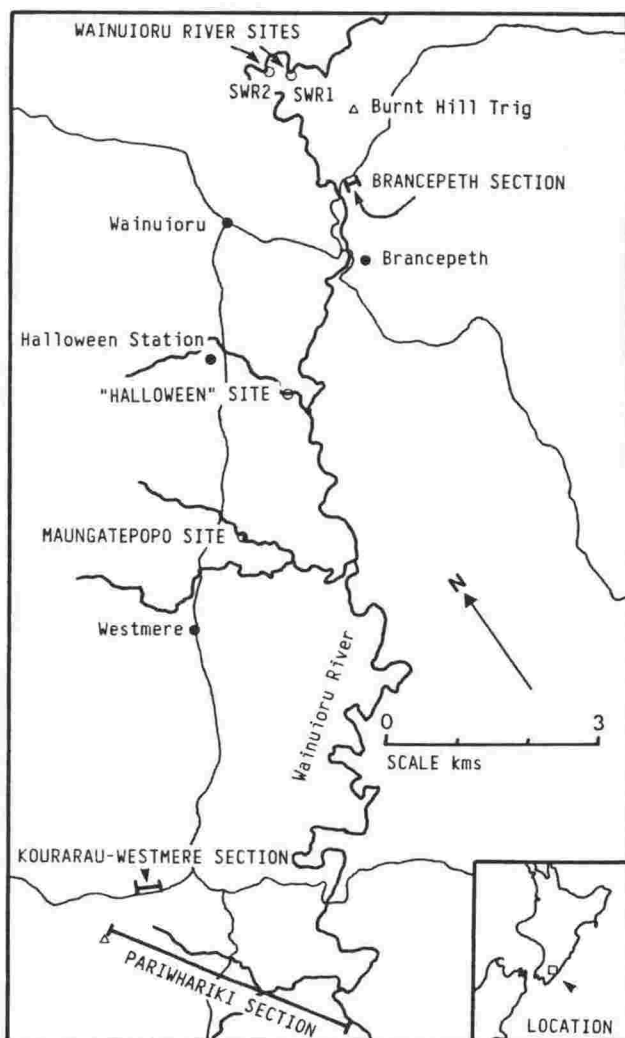


Figure A.27

Location of sections and sites :

Wainuioru Valley area.

A.27 JACKSONS LINE SITES

Location: East of Forsberg Trig, in roadcuts on Jacksons Line, about 2km southwest of Mauriceville West (T25/348447). See figure A.25.

Samples: Two Opoitian massive mudstone samples examined are barren.

A.28 CLELLANDS ROAD SECTION

Location: Samples from roadcuts on Clellands Road which runs west from the Masterton-Alfredton Road, 1.7km south of Dreyers Rock. Samples taken from between grid references T25/446417 and T25/462417. See figure A.25.

Samples: Eleven Kapitean to Opoitian samples were examined from this section. Two samples immediately above and below a tuff (T25/453416) contain poorly preserved, recrystallised Radiolaria which were not examined in this thesis. The tuff is believed to be an equivalent of the Hikawera tuff (Ford, 1975).

References: Orbell (1962), Vella (1963a, 1963b), Ford (1975).

A.29 BRANCEPETH SECTION

Location: Roadcut in the Masterton-Stronvar Road, 1km northeast of the entrance to Brancepeth Station. See figure A.27.

Comment: This section contains the lithostratotype of the Cannonball Sandstone and Brancepeth Tuff (Crundwell, in prep.)

Samples and Age: Six samples from this roadcut (T26/f267-270, 229, 230) are all within Crundwell's *Neogloboquadrina pachyderma* Zone (upper Tt - lower Tk).

Twenty-nine samples were examined from this section, two contain Radiolaria and one sample (SWR5), 3.5m above the Brancepeth Tuff is used in this thesis.

Radiolaria: Although moderate numbers of Radiolaria are present in this sample, only etched spongodiscids are represented. No age diagnostic radiolarians could be found.

A.30 WAINUIORU RIVER SITES

Location: River bank approximately 1.5km northwest of Burnt Hill Trig. See figure A.27.

Samples and Age: Two radiolarian bearing samples from the uppermost part of the Wainuioru River Section (Crundwell, in prep.) are used in this thesis (SWR1, SWR2). The samples contain *Globorotalia crassaformis* and *G. conomiozea mons* (basal Opoitian).

Radiolaria: Although both samples have a relatively poor preservation and diversity (N=23,29; Q=3.71,7.08) this is typical of lower Pliocene samples (average N=27.33, Q=5.90). Both samples contain *Didymocyrtis tetrathalmus tetrathalmus* although one only tentatively (SWR2). Both contain *Lychnocanium* sp. aff. *grande* placing the samples in the *Lychnocanium* sp. aff. *grande* Subzone.

A.31 MAUNGATEPOPO STREAM SITE

Location: Approximately 1.4km northeast of Westmere in a tributary of the Maungatepopo Stream. See figure A.27.

Sample and Age: Sample T26/f132 from the basal Opoitian (*Globorotalia crassaformis*, *G. pliozea*) contains Radiolaria and is used in this thesis (SWR3). This sample is 40m above T26/f133 which contains *G. sphericomiozea*.

Radiolaria: This sample has moderate preservation and diversity ($N = 26$, $Q = 5.40$) but lacks age diagnostic radiolarians but foraminiferal faunas suggest an age within the *Lychnocanium* sp. aff. *grande* Subzone.

A.32 "HALLOWEEN" STREAM SITE

Location: In an unnamed stream 0.7km east of the Westmere Road, 2.5km south of Wainuioru in the stream bank. See figure A.27.

Sample and Age: One sample from lower Tongaporutuan mudstone (T26/f142), 0.1m below a tuff. This radiolarian bearing sample is below the LAD of *Globoquadrina dehiscens* and contains predominantly five chambered *Globorotalia miotumida* and is used in this thesis (SWR4).

Radiolaria: This sample has moderate preservation ($N = 35$) but low diversity ($Q = 6.66$). The tentative identification of *Didymocyrtis laticonus* and no accompanying *Anthocyrtidium ehrenbergi pliocenica* or large pored *Heliodiscus asteriscus* or *Heliodiscus umbonatum* places the sample within the *Didymocyrtis laticonus* Subzone which agrees with the sample being below the LAD of *Globoquadrina dehiscens*.

A.33 KOURARAU-WESTMERE ROAD SECTION

Location: In a road cut 1km east of Pariwhariki Trig on the Kourarau-Westmere Road. See figure A.27.

Samples and Age: Six samples examined from upper Waipipian and lower Mangapanian strata, the youngest five of which contain Radiolaria and are studied in this thesis. In the section the incoming of *Globorotalia crassula* has been recorded in sample T27/f254, 155m above the youngest radiolarian bearing sample. The samples containing Radiolaria (KW01-05) lack *Cibicides molestus* but a sample (Station 18 of Berry, 1972), which is about 15m below the oldest radiolarian-bearing sample has *C. molestus*.

Radiolaria: All of the five radiolarian bearing samples were analysed and although numbers are reasonable, spongodiscids and cenosphaerids dominate the faunas with no nassellarians or age diagnostic radiolarians present.

References: Berry (1972), Crundwell (in prep.).

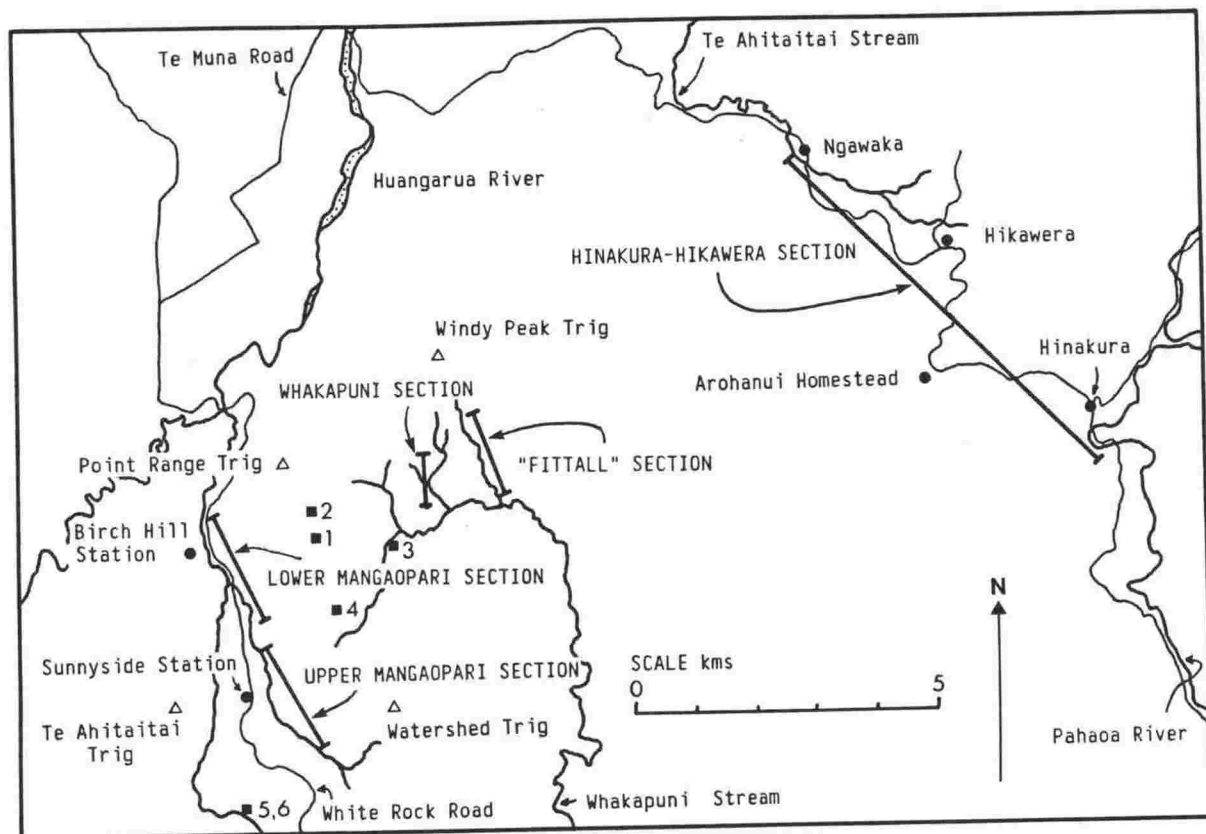


Figure A.28

Location of sections and sites : Mangaopari area.

SMA samples (Point Range sites and Mangapari-Whakapuni Stream area sites) are shown as numbered solid boxes.

A.34 PARIWHARIKI TRIG SECTION

Location: Well exposed in Wainuioru River, Pahuri Stream, Mangoariki Stream, Manga-a-whanaki Stream and a bluff under Pariwhariki Trig. The top of the section is 1km south of the Kourarau-Westmere Road Section. See figure A.27.

Lithology and Age: The section extends from lower Tongaporutuan massive mudstone to lower Nukumaruan coquina limestone.

Samples: One lower Tongaporutuan sample (N162/f870), one mid Tongaporutuan sample (f872), two upper Tongaporutuan samples (f874, f876), and one Opoitian sample (f866) are all barren.

References: Bunopas (1966), Crundwell (in prep.).

A.35 MILLERS ROAD SITES

Location: An area south of Gladstone was mapped during the course of completing my BSc Honours degree (Ashby, 1978). This 9.25 sq. km. area lies almost entirely within NZMS 270, Sheet S27B, the northeastern corner extending into Sheet T27A. Millers Road, connecting the main Wairarapa Valley with the Longbush Road, intersects the area. See figure A.26.

Comment: One formation exposed in this area, Mangaopari Mudstone, contains in places, Radiolaria. Many of the samples are weathered, the foraminifera having been dissolved, but the Radiolaria preserved.

Samples: Twenty-one Opoitian to Waipipian samples were examined, 17 contain Radiolaria and two (SMR1, SMR2) are used in this thesis. Sample SMR1 contains *Globorotalia puncticulata puncticulata* and forms approaching *Globorotalia inflata* and SMR2 is barren of foraminifera.

Radiolaria: Of the two samples, only SMR1 is suitable for statistical work (N=31, Q=6.24). Both samples contain *Didymocyrtis tetrathalmus tetrathalmus* with SMR1 also containing *Didymocyrtis* sp. A and *Lychnocanium* sp. aff. *grande* present in SMR2 (tentative identification in SMR1). This indicates a *Lychnocanium* sp. aff. *grande* Subzone age for both samples.

Reference: Ashby (1978).

A.36 ERINGA SITE

Location: In the valley west of Eringa Trig (N162/118358). See figure A.26.

Sample: One Opoitian sample examined is barren.

FIGURE A 29 MORRISON'S SECTION

Location: Figure A26

FORAMINIFERA THROUGHOUT:

G. miotumida

more Bolivinita

pliozea than B. pohana,

no B. compressa

RADIOLARIA THROUGHOUT:

Didymocyrtis sp. A

Zone

10

5

4

3

2

1

0

VERTICAL
SCALE
(metres)

MO SAMPLES

SANDSTONE/MUDSTONE: interbedded
coarse, brown, calcarenites grading
into fine dark grey sands, bedding
30-70cm

SANDSTONE: massive, grey, very muddy,
some mollusca

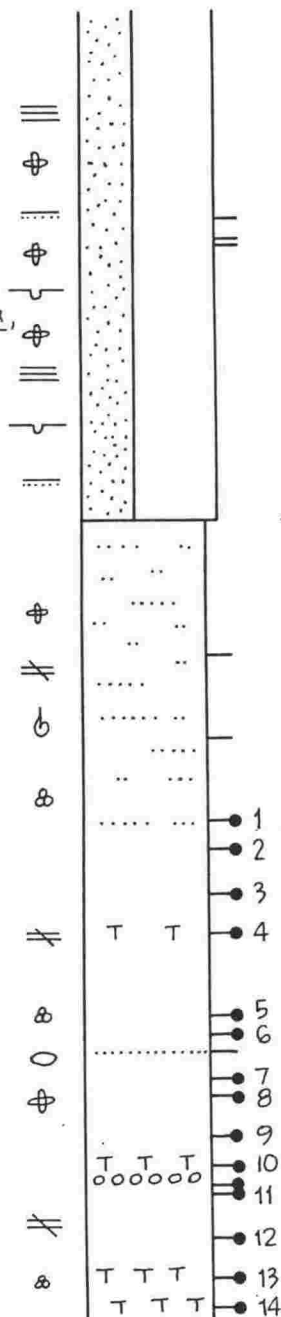
gradational

MUDSTONE: massive, tuffaceous in places

well sorted, quartz sand (up to 4cm)
lensoidal

pumiceous horizon

weathered at base



A.37 MORRISONS SECTION

Location: Southern banks of the Ruamahanga River, 0.6km north of Glenmorven Homestead. See figure A.26.

Stratigraphic column: Figure A.29.

Lithology: At least 12m of massive mudstone with two tephric horizons, sandy layers, and rare mollusca which grades into a 6m massive muddy sandstone with some mollusca. This is overlain by at least 13m of regularly bedded (30-70cm) coarse calcareous sands grading into fine sands.

Age: Planktic foraminiferal faunas are poor, the few specimens of *Globorotalia miotumida* tend to be dominated by five chambered forms. The *Bolivinita* fauna is dominated by *B. pliozea* with some *B. cf. pohana*. No *B. compressa* was found.

Samples: Three samples from the bedded unit and 18 from the sandstone and mudstone units were examined. 14 samples from the mudstone and the lowermost sample from the muddy sandstone contained radiolarian faunas and are used in this thesis (MO01-MO14).

Radiolaria: The radiolarian faunas from this short section are very good. Of the 14 radiolarian bearing samples studied, nine were considered good enough for statistical work and of these NG varied from 292 to 1112, N from 31 to 42, and Q from 8.67 to 13.74. The samples lack *Diartus hughesi* and *Didymocyrtis laticonus*, but *Didymocyrtis* sp. A is well represented. These samples are assigned to the *Didymocyrtis* sp. A Zone.

FIGURE A 30 RUAMAHANGA RIVER SECTION

Location: Figure A 26

FORAMINIFERA THROUGHOUT:

25% to 90% five chambered
G. miotumida, Bolivinita pohana

B. cf. pliozea, no B. compressa

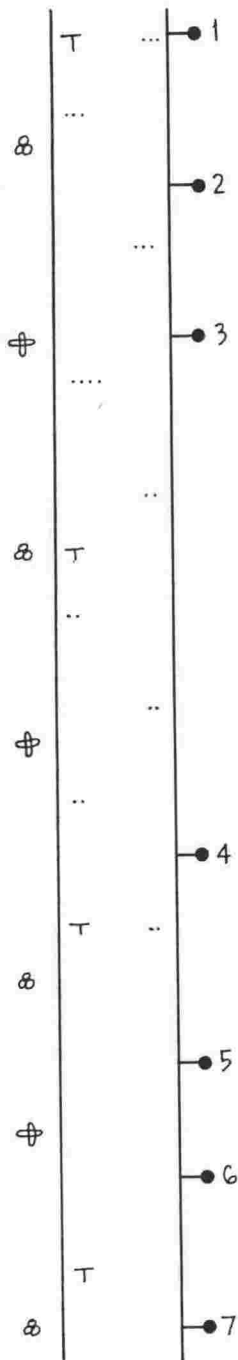
RADIOLARIAN DATUMS:

• LAD Diartus hughesi

2
1
0

VERTICAL SCALE
(metres)

RM SAMPLES:



MUDSTONE: massive, sandy to slightly
sandy, microbioturbated, light green-
grey, slightly carbonaceous in places

—— gradational ——

MUDSTONE: massive, microbioturbated
light green-grey, slightly
glauconitic at top.

A.38 RUAMAHANGA RIVER SECTION

Location: In the cliffs on the east side of the Ruamahanga River at Riverside, 4.5km north of Martinborough. See figure A.26.

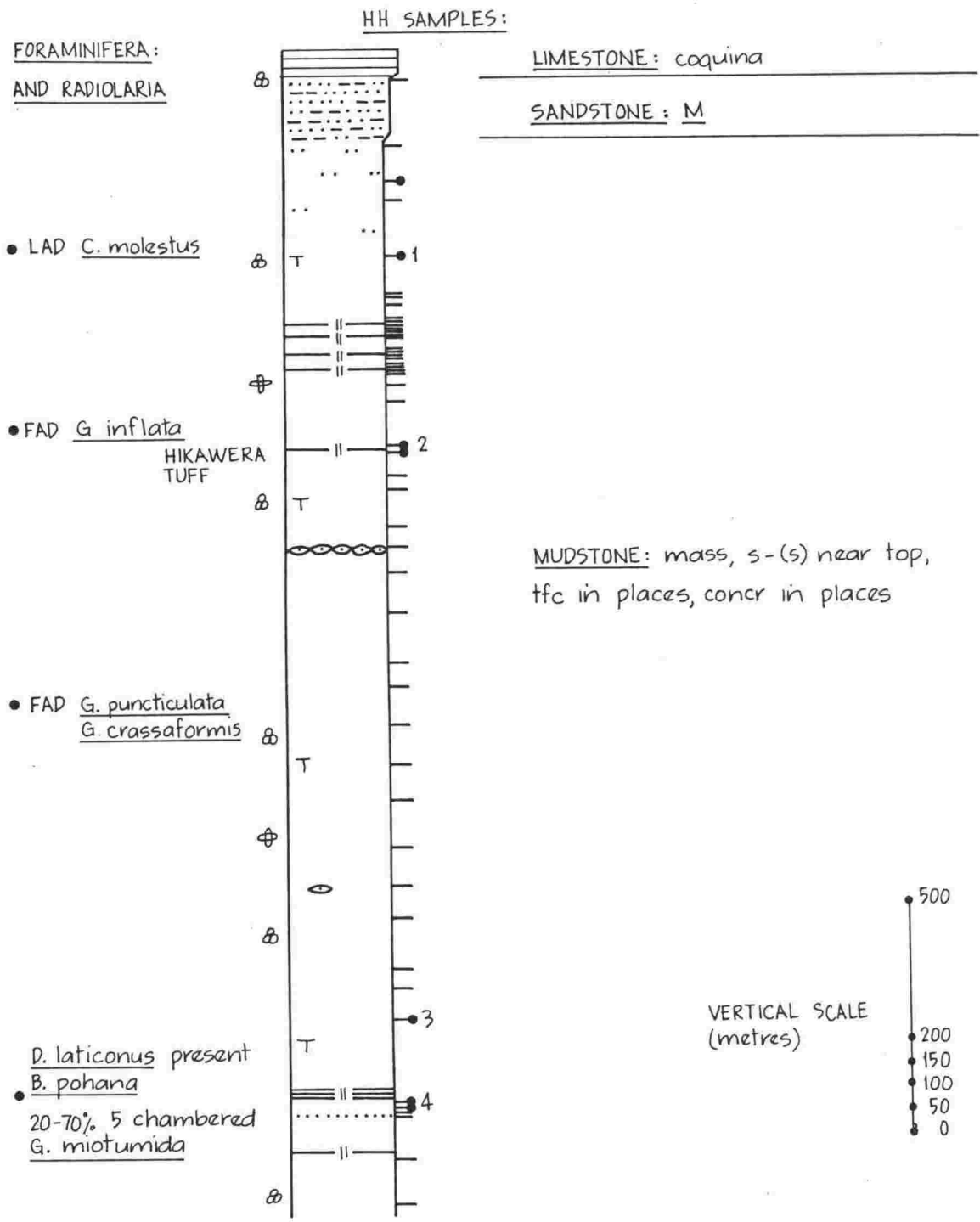
Stratigraphic column: Figure A.30.

Samples and Lithology: The lower five samples examined contain abundant, well preserved Radiolaria in sediments ranging from massive mudstone to massive sandy mudstone (RM03-RM07) and the upper two samples from a sandier lithology contain rare Radiolaria (RM01-RM02).

Age: Generally planktic foraminifera are poor in the samples examined but those with reasonable populations of *Globorotalia miotumida* contain faunas ranging from 25% to 90% five chambered forms. Both *Bolivinita pohana* and *B. cf. pliozea* are present but the samples lack *B. compressa*.

Radiolaria: Of the seven radiolarian bearing samples the lower five (RM03-07) contained faunas suitable for statistical work with N varying from 31 to 41 and Q varying from 6.47 to 17.30 (Note: this is the highest Q value of all the samples studied). *Didymocyrtis laticonus* is lacking but identifications of *Diartus hughesi* in RM05 indicates that at least the three oldest samples all lie within the *Anthocyrtidium ehrenbergi pliocenica* Subzone. Samples RM01-RM04, lack both *Didymocyrtis laticonus* and *Diartus hughesi* belong in the *Didymocyrtis* sp. A Zone. The LAD of *Diartus hughesi* coincides with a slightly glauconitic interval which may represent a period of slow deposition.

FIGURE A31
HINAKURA - HIKAWERA SECTION (partially after Vella & Collen 1984, Choong, 1983)
 Location: Figure A28



A.39 HINAKURA-HIKAWERA SECTION

Location: Poorly to moderately well exposed in the headwaters of Te Ahitaitai Stream from Ngawaka Homestead to Hikawera; on ridge top roadcuts between Hikawera and Arohanui Homestead; from Arohanui Homestead to Hinakura in the east flowing stream next to Hinakura Road ; and in the banks of the Pahaoa River, 0.5km south of Hinakura. See figure A.28.

Stratigraphic column: Figure A.31.

Lithology: The section comprises of approximately 2500m of massive mudstone with occasional tuff bands, concretionary, and sandy layers. At the top of the section the sequence grades through muddy sandstone into the Pukenui Limestone. The mudstones range in age from Tongaporutuan to Hautawan.

Samples: Fifty-one mudstone samples were examined at regular intervals throughout the section (with a concentration of sampling in the upper Opoitian), six contained Radiolaria and the following four are used in this thesis.

HH01 - near the top of the range of *Cibicides molestus*.

HH02 - immediately above the Hikawera Tuff (paleomagnetic age 3.29 ± 0.10 Ma. This sample is 50m below the FAD of *Globorotalia inflata* and 325m above the joint FAD's of *Globorotalia puncticulata* and *G. crassaformis*.

HH03 and HH04 - near the base of the section. The samples contain typical *Bolivinita pohana* and *Globorotalia miotumida* with 26 to 66% five chambered forms and lack *B. compressa* and *Globoquadrina dehiscens*.

Radiolaria: The radiolarian faunas from this section are particularly poor, the only sample containing any age diagnostic radiolarians being HH04 which contains *Didymocyrtis laticonus*. This sample either belongs to the *Didymocyrtis laticonus* Subzone or could belong to the *Heliodiscus asteriscus forma* large pores Subzone with the large pored form of *Heliodiscus asteriscus* and *Anthocyrtidium ehrenbergi pliocenica* not represented because of dissolution. The latter situation is the preferred case as the samples lack *Globoquadrina dehiscens*.

References: Lienert, Christoffel and Vella (1972), Collen and Vella (1973), Choong (1983), Vella and Collen (1984).

A.40 POINT RANGE SITES

Location: Two sites collected in farm track cuttings about 1.2km southeast of Point Range Trig and 3.2km north of the Mangaopari Stream Section. See figure A.28.

Comment: These samples were taken from near the axis of an anticline, the structure being defined by a greensand bed a few thin tephric beds in otherwise massive mudstone (P. Vella, pers. comm.).

Samples: Both samples contain good radiolarian faunas and are used in this thesis (SMA1, SMA2). Both samples have a poor planktic foraminiferal faunas but contain specimens of mainly four chambered *Globorotalia miotumida*. The added presence of abundant *Bolivinita pliozea* and *B. compressa* morphotypes indicates an upper Tongaporutuan age.

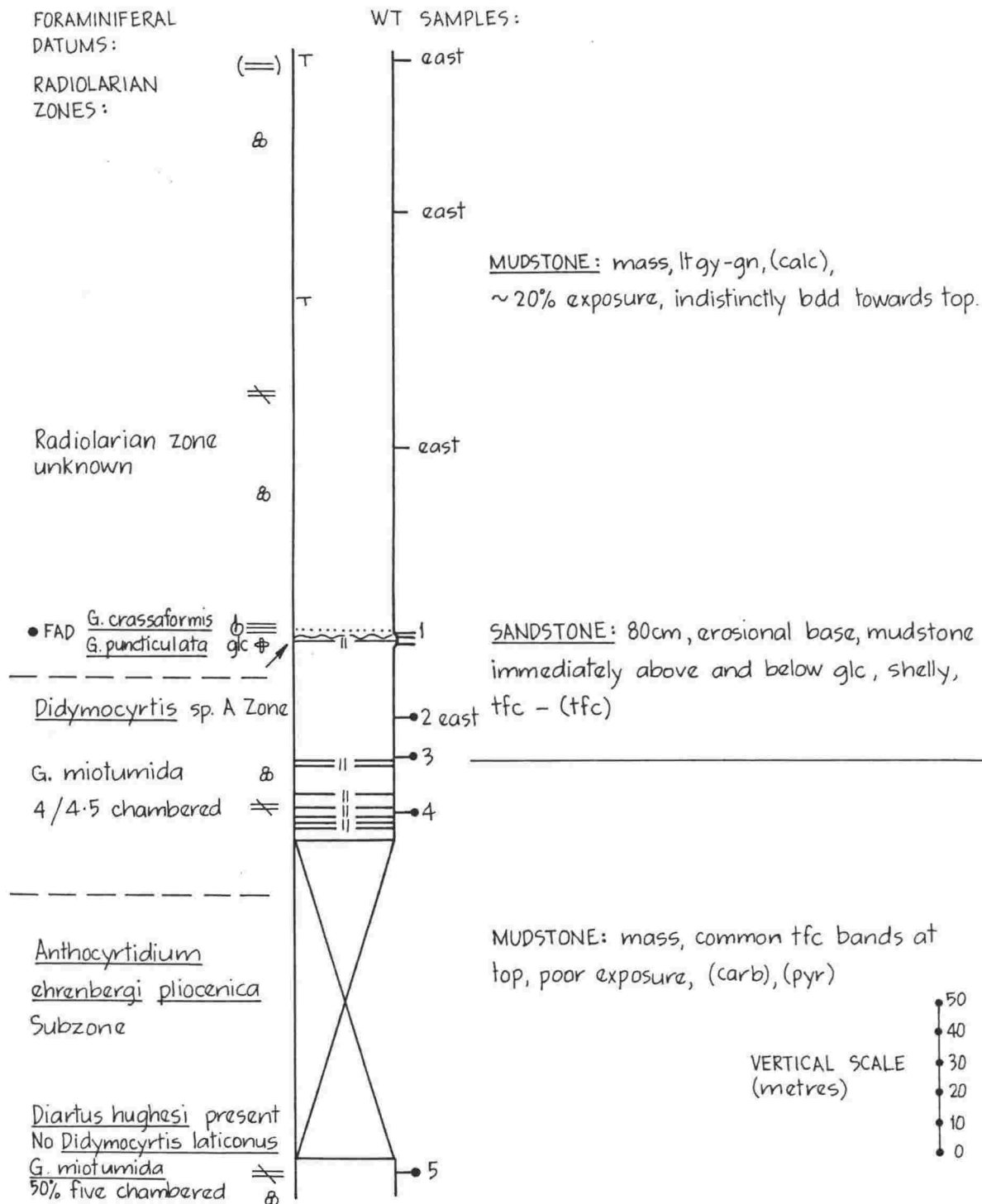
Radiolaria: Of the two radiolarian bearing samples, one (SMA1) was diverse enough for statistical work ($N=26$, $Q=7.76$) and contains *Didymocyrtis antepenultima* but lacks *Didymocyrtis laticonus* and *Diartus hughesi* indicating a *Didymocyrtis* sp. A Zone age. Sample SMA2 contains mainly resistant spongodiscids, stylosphaerids, and a few nassellarians.

Reference: Geological Map of Sheet S27 (P. Vella and J. Collen, Victoria University, in prep.).

FIGURE A 32 WHAKAPUNI TRIBUTARY SECTION

Location: Figure A28

Samples projected from the East Fork are marked.



A.41 WHAKAPUNI TRIBUTARY SECTION

Location: Poorly exposed section in a south flowing tributary stream of Whakapuni Stream, due south of Windy Peak Trig. The section is a composite of exposures in two forks of this tributary. See figure A.28.

Stratigraphic column: Figure A.32.

Lithology and samples: The section consists of 370m of massive mudstone, indistinctly bedded towards the top, with common tuff beds near the middle of the section. An 80cm sandstone bed (exposed in the western fork: S27/20498595) with an erosional base, that grades upwards into a glauconitic mudstone, represents a probable time break and slow period of deposition. The sandstone is at the top of the radiolarian bearing portion of the section. Below the sandstone bed five samples were examined, four of which contain Radiolaria (WT02-05). Foraminifera from these samples included small populations of *Globorotalia miotumida* (moderately conical forms are present immediately below the sandstone). Members of the genus *Bolivinita* are very rare.

Immediately overlying the sandstone, sample WT01 contains *Globorotalia crassaformis*, *G. puncticulata*, and rare *G. conomiozea mons.* This and three other samples above the sandstone are barren.

Radiolaria: Of the four radiolarian bearing samples (WT02-05) two were considered suitable for statistical work. Sample WT03 contains a reasonable fauna ($N = 28$, $Q = 5.33$) and WT05 a diverse fauna ($N = 38$, $Q = 9.15$). The latter sample contains *Diartus hughesi* but lacks *Didymocyrtis laticonus* and belongs to the *Anthocyrtidium ehrenbergi pliocenica* Subzone. The upper three samples (WT02-04) lack *Diartus hughesi* and belong to the *Didymocyrtis* sp. A Zone.

Reference: Fittall (1979).

A.42 "FITTALL" STREAM SECTION

Location: Tributary of Whakapuni Stream (herein named after the collector of the samples), about 1km east of the radiolarian bearing Whakapuni Tributary Section. See figure A.28.

Comment: The sediments in this section represent the upper part of the Whakapuni Tributary Section and younger strata.

Lithology: Massive mudstone with three thin tuff bands exposed which are thought to correspond to the Seddelbahr, Missing, and Hikawera Tuff of Vella and Collen (1984).

Samples and Age: Seven Opoitian samples examined (S27/f206-211, f219) are all barren.

Reference: Fittall (1979).

A.43 MANGAOPARI-WHAKAPUNI STREAM AREA SITES

One sample from a farm track in Whakapuni Stream Valley (about 1.1km southwest of the Whakapuni Tributary Section) contained rare *Globorotalia miotumida*, *Bolivinita pohana* and some forms approaching *B. compressa* s.s., and common Radiolaria and is used in this thesis (SMA3). The absence of *Diartus hughesi* and *Didymocyrtis tetrathalmus tetrathalmus* and tentative presence of *Didymocyrtis antepenultima* indicates an age within the *Didymocyrtis* sp. A Zone.

One sample of weathered mudstone from a farm track overlooking the headwaters of the Whakapuni Stream, about halfway between the Whakapuni Tributary and Upper Mangaopari Stream Sections, is barren of foraminifera but contains abundant Radiolaria and is used in this thesis (SMA4). This sample contains *Diartus hughesi* but lacks *Didymocyrtis laticonus* and therefore belongs in the *Anthocyrtidium ehrenbergi pliocenica* Subzone.

Two samples in a west flowing creek approximately 2km south of Sunnyside Station contain *G. miotumida* (20% five chambered forms), *B. compressa*, and Radiolaria and are used in this thesis (SMA5, SMA6). The radiolarian faunas are not diverse ($Q = 4.58-5.26$) but SMA5 contains *Didymocyrtis laticonus* and the large pored form of *Heliodiscus asteriscus* indicating an age from the *Heliodiscus asteriscus forma* large pores Subzone. The foraminiferal fauna suggests an age slightly younger in the Tongaporutuan.

A.44 LOWER MANGAOPARI STREAM SECTION

Location: Mangaopari Stream Valley from the bluffs 0.6km north of Birch Hill Station upstream to Mesozoic basement outcropping at grid reference S27/177835, about 0.15km east of the White Rock Road. See figure A.28.

Comment: This section has been described in detail (Devereux, Hendy and Vella, 1970; Vella and Briggs, 1971; Hornibrook, 1981).

Samples: Three samples from between 10cm above and 1m below the Spooner Tuff (S27/173843) and three samples from between 5cm above and 5m below a paired tuff in the Bridge Sandstone Member (S27/175842) were investigated. All six Opoitian samples are barren. The Bells Creek Mudstone outcropping in lower Mangaopari Stream was not sampled because of the detailed sampling of this part of the column in the upper reaches of Mangaopari Stream.

FIGURE A33 UPPER MANGAOPARI STREAM SECTION (partially after Eggo 1979)

Location: Figure A28

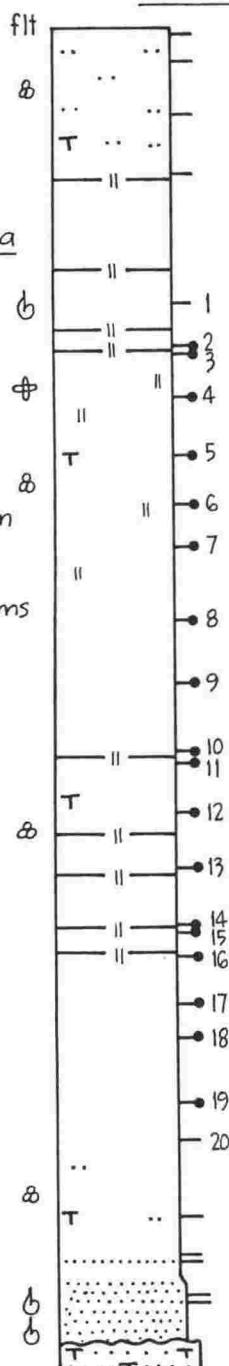
FORAMINIFERAL
DATUMS

- FAD G. inflata
- FAD G. crassaformis
G. puncticulata
- FAD G. sphericomiozea
- FAD G. conomiozea

Approximate transition
• to less than 20%
five chambered forms
of G. miotumida

- LAD G. dehiscens

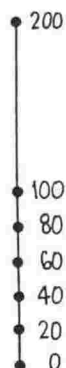
MS SAMPLES:



SEE FIGURE A34 FOR DETAIL OF
THE RADIOLARIAN - BEARING PART
OF THE SECTION

MUDSTONE: mass, tfc in places, s-(s) at top
and base, (carb) in places, pyr microbioctd
in places

VERTICAL SCALE
(metres)



gradational
SANDSTONE: mass, med, crs at base, abnd molc in places
GREYWACKE: med - crs s, hd

A.45 UPPER MANGAOPARI STREAM SECTION

Location: Mangaopari Stream, generally between Sunnyside Station and Watershed Trig, from the point where the Mangaopari Fault intersects Mangaopari Stream (S27/178831) to the headwaters of the stream (S27/188815). See figure A.28.

Stratigraphic columns: Figures A.33 and A.34.

Lithology: The basal unit comprises approximately 35m of massive medium sandstone with abundant mollusca in places. This unit has a coarse sandstone base resting on an irregular greywacke surface and grades into 730m of massive mudstone with occasional tuff layers and rare mollusca. The upper 90m of the mudstone is slightly sandy.

Samples and Age: Twenty-nine samples at regular intervals throughout the section were examined for Radiolaria. Eighteen samples contained Radiolaria and are used in this thesis (MS02-MS19).

The oldest radiolarian bearing sample (MS19) marks the LAD of *Globoquadrina dehiscens* (rare in this sample) in the section.

Sample MS01, which is 21m above the youngest radiolarian bearing sample (MS02), contains *G. conomiozea conomiozea* and a good population of *G. miotumida* (10% five chambered forms). Within the radiolarian bearing zone the *Bolivinita* population is dominated by *B. pohana*, with *B. cf. pliozea* in the uppermost samples. Rare *B. compressa* morphotypes start appearing about 120m from the top of the radiolarian bearing horizon (MS07) and although populations of *G. miotumida* are generally poor this is about the level of transition from >20% to <20% five chambered forms.

The top of the radiolarian bearing zone is about 47m below the FAD of *G. sphericomiozea*, 100m below the joint FAD's of *G. crassaformis* and *G. puncticulata*, and about 165m below the FAD of *G. inflata* (after Eggo, 1979).

Radiolaria: Of the 18 radiolarian bearing samples, 16 proved to be suitable for statistical analysis. Sample MS02 contains a poorly preserved fauna of mainly robust spongodiscids and some nassellarians and MS17 contains a very poor spongodiscid fauna. Of the other samples radiolarian preservation and diversity is generally high (N varies from 22 to 43 and Q from 5.08 to 14.13) with seven samples having a Q value >10 and nine having an N value >35. One sample MS16 (N = 23, Q = 3.76) occurs in the part of the section with poor preservation (near MS17). The radiolarian faunas indicate all the late Tongaporutuan radiolarian zones are present. Samples MS18 and MS19 contain *Didymocyrtis laticonus* before the FAD of *Anthocyrtidium ehrenbergi pliocenica* and the large pored form of *Heliodiscus asteriscus* indicating the *Didymocyrtis laticonus* Subzone. Sample MS16 marks the FAD of *Heliodiscus asteriscus forma* large pores and MS14 the FAD of *Anthocyrtidium ehrenbergi pliocenica* (although a tentative identification exists in MS15). From MS16 to MS12 (the LAD of *Didymocyrtis laticonus*) defines the *Heliodiscus asteriscus forma* large pores Subzone. The LAD of members of the *Diartus hughesi* group occurs in MS08 marking the top of the *Anthocyrtidium ehrenbergi pliocenica* Subzone. Above this samples MS02 to MS07 belong in the *Didymocyrtis* sp. A Zone.

References: Eggo (1979), Gosson (in prep.).

FIGURE A 34
UPPER MANGAOPARI STREAM SECTION (detail of radiolarian bearing portion)

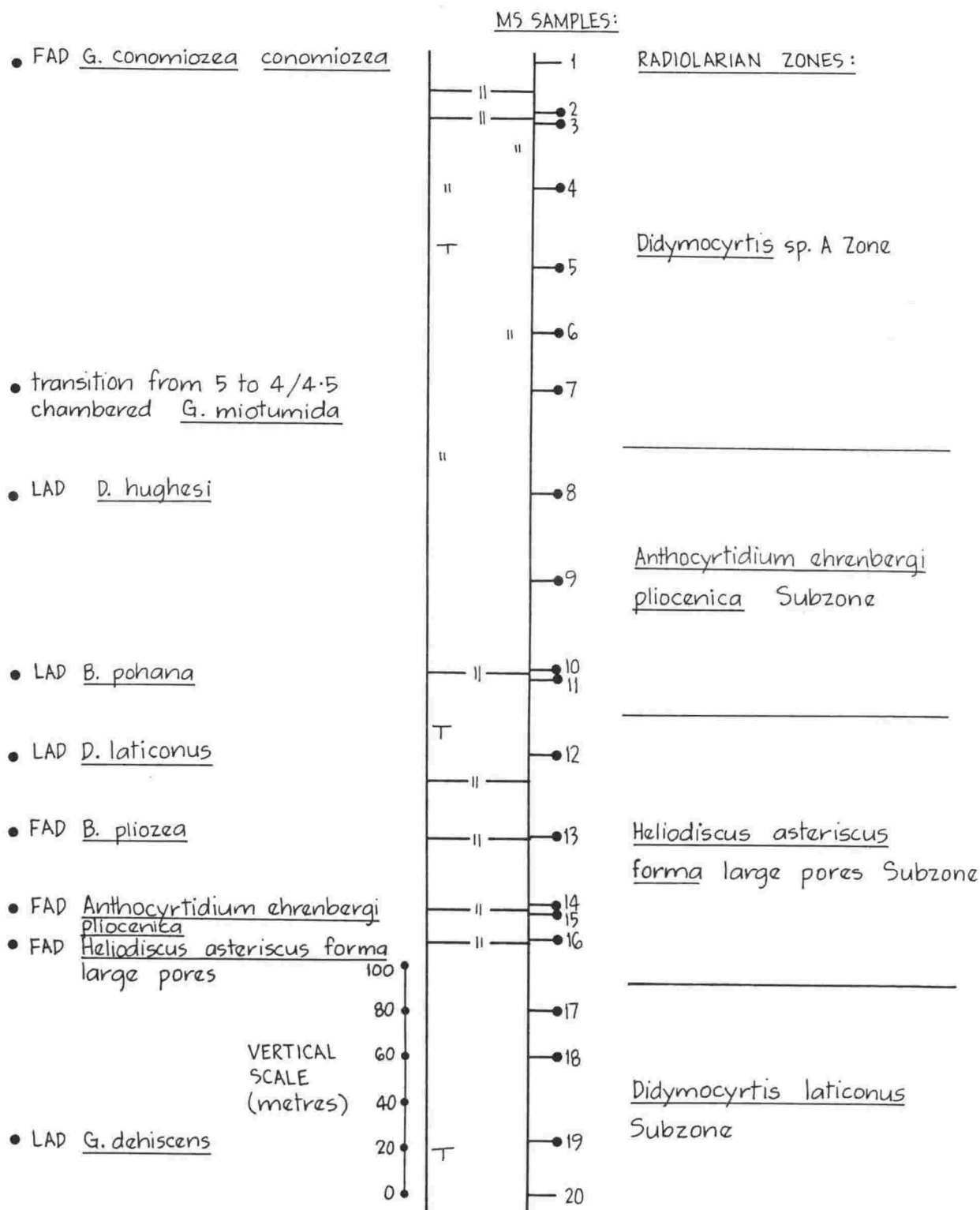


FIGURE A35 PALLISER BAY SECTION

Location: Figure A26

FORAMINIFERAL DATUMS
AND AGES:

Nukumaruan

— ? —

Mangapanian

— ? —

Waipipian

— ? —

• FAD G. puncticulata

• FAD G. crassaformis

• FAD G. sphericomiozea

• FAD G. conomiozea
conomiozea

• FAD B. pliozea

• rare B. pohana

• FAD B. quadrilatera

SW?

PB SAMPLES:

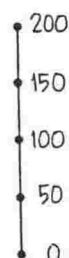
MUDSTONE: massive, sandy and
shelly at top and base.

SEE FIGURE A36 FOR DETAIL OF
THE RADIOLARIAN BEARING PORTION
OF THE SECTION

TUFF: 7.27 ± 1.28 Ma
bored surface

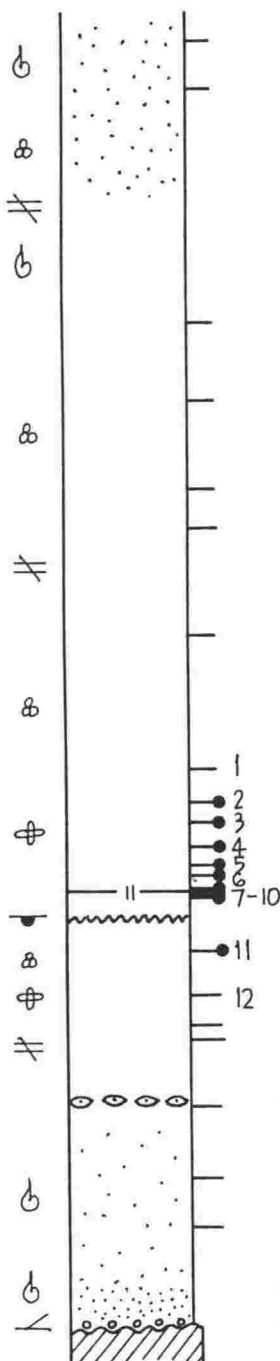
concretionary layer

VERTICAL
SCALE
(metres)



SANDSTONE, coarse, xbdd and conglomeratic at base

GREYWACKE



A.46 PALLISER BAY SECTION

Location: At the northeastern end of Palliser Bay in coastal cliffs between Whangimoana and the mouth of Hurupi Stream. See figure A.26.

Stratigraphic columns: Figures A.35 and A.36.

Lithology and Age: The base of the section is marked by a 2.5m conglomeratic bed resting on an irregular greywacke surface. This is overlain by a 10m of gritty sandstone with shell fragments and thin conglomerate lenses.

Overlying this is a 1130m sequence of massive mudstone which is sandier in the lower and upper thirds of the unit. Rare macrofossils and concretionary layers are present and one 10cm tuff is exposed near the middle of the mudstone.

The basal part of the section is probably Waiauan, the FAD of *Bolivinita quadrilatera* being recorded by Gibson (1963) approximately 170m above the greywacke (N165/f693). *Bolivinita pohana* occurs approximately 50m above in sample N165/f693. The top of the section (S28/f74) is Nukumaruan. The section appears to be continuous but is subject to slumping and some portions are poorly exposed.

Samples: Twenty-six samples at regular intervals (with a concentration of samples in the upper Tongaporutuan part of the section) were examined from throughout the section. Eleven samples contained Radiolaria and ten are used in this thesis (PB02-PB11). The age of the radiolarian bearing horizon is hard to determine because planktic foraminifera are generally rare in this section but the horizon encompasses a tuff dated at 7.27 ± 1.28 Ma (Dr. D. Seward, pers. comm.). Sample PB01, 25m above the youngest radiolarian bearing sample, contains a good population of *Globorotalia miotumida* with 13% being five chambered forms, and some conical forms are very close to *Globorotalia conomiozea*. The only other sample with a good population of *G. miotumida* is PB05, from near the middle of the radiolarian bearing horizon, contains 33% five chambered forms. The FAD of *Bolivinita pliozea* occurs in sample PB04 (36m above the tuff) which is in good agreement with Scott (1982b) who shows the position of this datum to be 50m above the tuff. *Globorotalia sphericomiozea* first appears (in S28/f59) about 190m above the youngest radiolarian bearing sample and the joint FAD's of *Globorotalia puncticulata* and *G. crassaformis* occurs approximately 50m above this in sample S28/f62. The FAD of *Bolivinita compressa* occurs in sample PB06. The oldest radiolarian-bearing sample (PB11) has a poor foraminiferal fauna but some specimens of *Bolivinita pohana* and *B. cf. pohana* are present. *Globoquadrina dehiscens* has not been recorded and could not be found in this section.

Radiolaria: Of the ten radiolarian bearing samples examined six were considered suitable for statistical analysis and generally have good preservation (N = 22-35 with five in the range 28-35) and good diversities (Q = 6.14-10.56). Members of the *Diartus hughesi* group are positively identified in PB03 and tentatively identified in PB04,06,09. With only a tentative identification of *Didymocyrtis laticonus* in the oldest radiolarian bearing sample in the section (PB11), samples PB03-11 are placed in the *Anthocyrtidium ehrenbergi pliocenica* Subzone, PB11 being close to the base of this zone. There is an unknown amount of time missing represented by a bored surface between PB10 and PB11. Sample PB02 is placed in the *Didymocyrtis* sp. A Zone because of the lack of members of the *Diartus hughesi* group

FIGURE A36
PALLISER BAY SECTION (radiolarian bearing portion)

Location: Figure A26

FORAMINIFERAL AND RADIOLARIAN DATUMS

- FAD G. conomiozea
conomiozea

- LAD D. hughesi

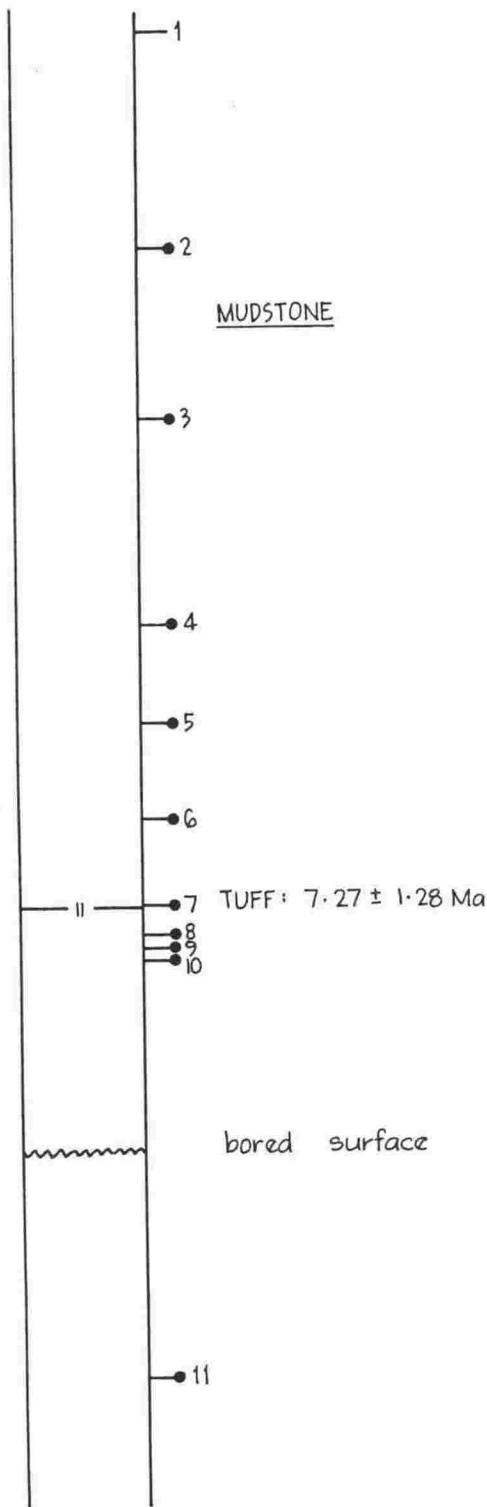
- FAD B. pliozea



VERTICAL SCALE
(metres)

- ? D. laticonus present

PB SAMPLES



but this absence may be due to the sample having a low preservation ($N = 22$).

References: Kennett (1966d), Bates (1967), Scott (1982b).



Plate A1.6

Palliser Bay Section : view looking east from slumped Kapitean massive mudstone to cliff-forming Tongaporutuan massive sandy mudstone.

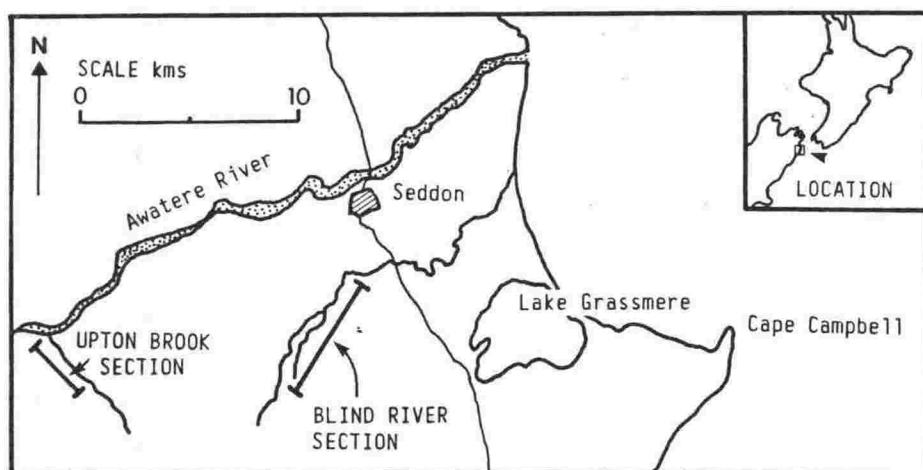


Figure A.37

Location of sections : Marlborough area.

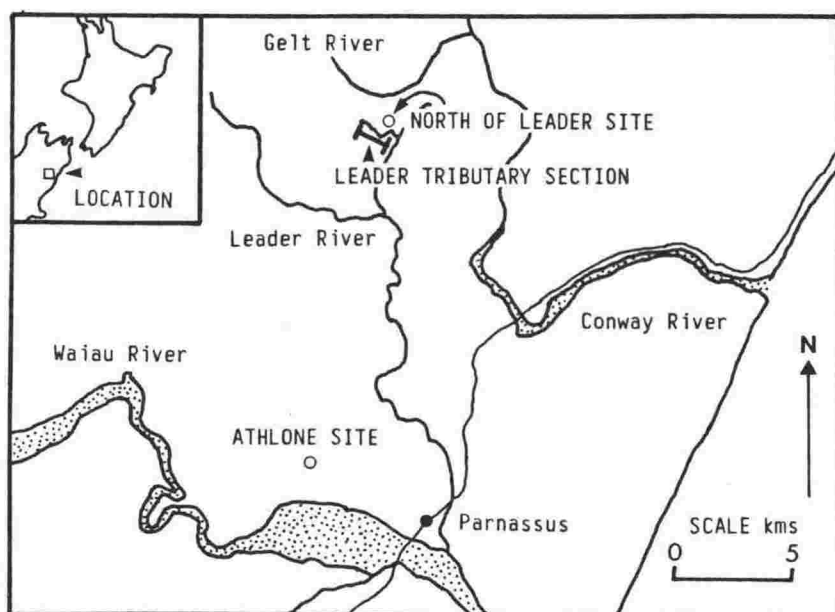


Figure A.38

Location of section and sites : northern Canterbury area.

A.47 BLIND RIVER SECTION

Location: In north east Marlborough, approximately 7km south of Seddon. See figure A.37.

Comment: The section has been investigated in detail for biostratigraphy (Kennett, 1966a, 1966b, 1966c; Scott, 1979, 1982b; Mildenhall, 1979), magnetostratigraphy (Kennett and Watkins, 1974), and paleoclimatology (Loutit and Kennett, 1979). A summary of the previous work and an integration of the bio-lithostratigraphy is given by Morgans (1980).

Lithology and Age: The base of this 2800m sequence consists of coarse conglomerate and sandstone resting unconformably on Mesozoic greywacke. Overlying this is a moderately exposed, conformable sequence of Tongaporutuan to Opoitian mudstones and fine sandstones with occasional concretionary layers.

Kennett (1965) noted the occurrence of *Globoquadrina dehiscens* in samples S29/f603 and f635. Exhaustive searches of Kennett's slides and other samples has failed to confirm its presence in this section. The FAD of *Bolivinita compressa* occurs at about 6.52 Ma (sample P29/f20) if the paleomagnetic interpretation of Loutit and Kennett (1979) is used.

Samples: Fifteen samples at regular intervals in the lower 75% of the Tongaporutuan strata, including Kennett's S29/f618, f635-f637 and Scott's P29/f23-f29 are barren, as is one sample of Kennett's (S29/f656) from near the top of the Kapitean.

A.48 UPTON BROOK SECTION

Location: From near the junction of Upton Brook and Awatere River to about halfway up Upton Brook. Approximately 14.5km southwest of Seddon. See figure A.37.

Lithology, Age, and Samples: Two samples from the upper Tongaporutuan (massive silty mudstones with occasional thin sandstone beds, concretionary layers, and conglomerate beds - S28/f566, f567) and two samples from the Opoitian (poorly bedded siltstones - S28/f577, f580) are barren.

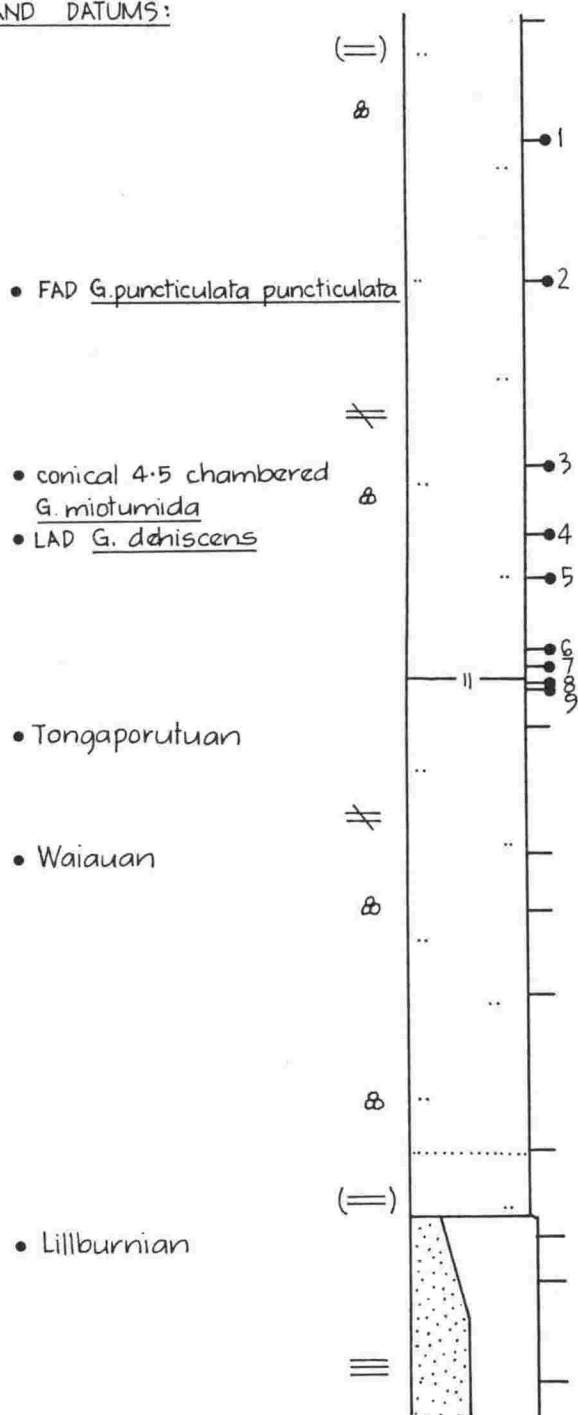
Reference: Kennett (1966c).

FIGURE A 39 LEADER TRIBUTARY SECTION

Location: Figure A38

FORAMINIFERAL AGES
AND DATUMS:

LT SAMPLES:



A.49 LEADER TRIBUTARY SECTION

Location: Eighteen kilometres north of Parnassus in the headwaters of a northern tributary of the Leader River. See figure A.38.

Stratigraphic columns: Figures A.39 and A.40.

Comment: The exposure is moderate to good. This section is in the southernmost extension of the East Coast Deformed Belt.

Lithology: The basal 67m of this section consists of interbedded sandstones and mudstones which grade into approximately 300m of massive mudstone with some sandy layers and a 1.8m tuff bed near the middle. In the upper 140m the massive mudstone becomes sandier.

Age: A sample near the top of the interbedded unit (O32/f78) yielded a Lillburnian foraminiferal fauna. The lower half of the massive mudstone is probably Waiauian with sample O32/f77 (133m from the base of this unit) containing a Waiauian foraminiferal fauna. Sample O32/f76 (46m above f77 and 16.5m below the tuff) is Tongaporutuan in age. Sample O32/f70 (LT04) marks the LAD of *Globoquadrina dehiscens* in this section and is 53m above the tuff. The next sample in the section (O32/f69: LT03) appears to be near the top of the Tongaporutuan with conical 4.5 chambered forms of *Globorotalia miotumida* present. This sample is only 25m above the LAD of *G. dehiscens* and there is a distinct probability that part of the upper Tongaporutuan is missing between the two sites. A sample from the base of the sandy mudstone (O32/f68: LT02) contains *G. puncticulata puncticulata* (Opoitian). The Kapitean is either missing or not sampled between sites LT02 and LT03.

Eighteen samples at subregular intervals throughout the section were examined with eight samples containing Radiolaria (LT01-03,05-09) ranging in position from just below the tuff (LTt) to within the sandy mudstone (Wo).

Radiolaria: Of the eight radiolarian bearing samples, five were considered suitable for statistical analysis. Of the four statistical Miocene samples (LT05,06,08,09) the NG values are very high (727-1188) with N varying from 28 to 38 and Q from 5.21 to 13.71. The Pliocene sample (LT01) has a much lower abundance (NG = 74, N = 28) but a comparable diversity (8.61). Sample LT09 marks the LAD of *Heliodiscus umbonatum* and is placed in the *Heliodiscus umbonatum* Subzone. Above this, samples LT08-05 contain *Didymocyrtis laticonus* but lack *Anthocyrtidium ehrenbergi pliocenica* or the large pored form of *Heliodiscus asteriscus* indicating the *Didymocyrtis laticonus* Subzone. The LAD of members of the *Diartus hughesi* group is in LT06 (possibly in LT05) indicating that LT03 is possibly from the *Didymocyrtis* sp. A Zone although this sample has poor preservation and *Diartus hughesi* may be missing for that reason. If LT03 is in the *Didymocyrtis* sp. A Zone then all of the *Heliodiscus asteriscus forma* large pores Subzone and *Anthocyrtidium ehrenbergi pliocenica* Subzone is missing between LT05 and LT03 (LT04 lacks radiolarians). This correlates with the projected gap as determined from the *Globorotalia miotumida* populations. Sample LT01 contains *Didymocyrtis tetralthmus tetralthmus* and lacks *Anthocyrtidium ehrenbergi pliocenica* and *Didymocyrtis* sp. A and is placed in the *Lamprocyrtis hannai* Subzone.

References: Gosson (in prep.), G. Warren, NZ Geological Survey is regionally mapping this area.

FIGURE A40

LEADER TRIBUTARY SECTION (detail of the radiolarian bearing portion)

LT SAMPLES:

• Lamprocyrtis hannah Subzone

• FAD G. puncticulata puncticulata

• conical 4-5 chambered G. miotumida
Didymocyrtis sp. A zone

• LAD G. dehiscens

• Didymocyrtis laticonus Subzone

• Didymocyrtis laticonus subzone

• Heliodiscus umbonatum subzone

~ 20% exposure

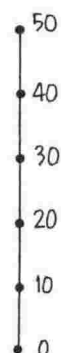


~ 80% exposure

MUDSTONE: massive, slightly
sandy in places

? All of the Anthocyrtidium
ehrenbergi pliocenica Subzone
and Heliodiscus asteriscus
forma large pores Subzone
missing.

VERTICAL SCALE
(metres)



A.50 NORTH OF LEADER TRIBUTARY SITE

Samples: Two samples from 20cm above and immediately below a tuff outcropping in a tributary north of the Leader Tributary Section were examined for Radiolaria. The sample immediately below (SPA1) contains Radiolaria and is used in this thesis. The tuff outcrop is only 500m along strike from the tuff in the Leader Tributary Section and is geochemically identical (G. Gosson, pers. comm.). See figure A.38.

Radiolaria: The possible identification of *Didymocyrtis laticonus* in this sample lacking the large pored form of *Heliodiscus asteriscus* and *Anthocyrtidium ehrenbergi pliocenica* and *Heliodiscus umbonatum* indicates an age in the *Didymocyrtis laticonus* Subzone. The diversity is moderate for this sample ($Q = 6.42$) but it is interesting to note that this value of Q agrees well with LT08 ($Q = 5.20$) from immediately below the tuff in the Leader River Tributary Section. Sample LT08 is in a section where Q values are generally alot higher (>8.50).

A.51 ATHLONE STREAM SITE

This site is located 6km northwest of Parnassus on the south side of Athlone Stream Valley in ?mid?-upper Tongaporutuan strata. Samples 5m above, immediately below, and 0.5m below a 50cm thick tuff were examined for Radiolaria. The sample above was barren and the samples below contained rare Radiolaria but were not used in this thesis. See figure A.38.

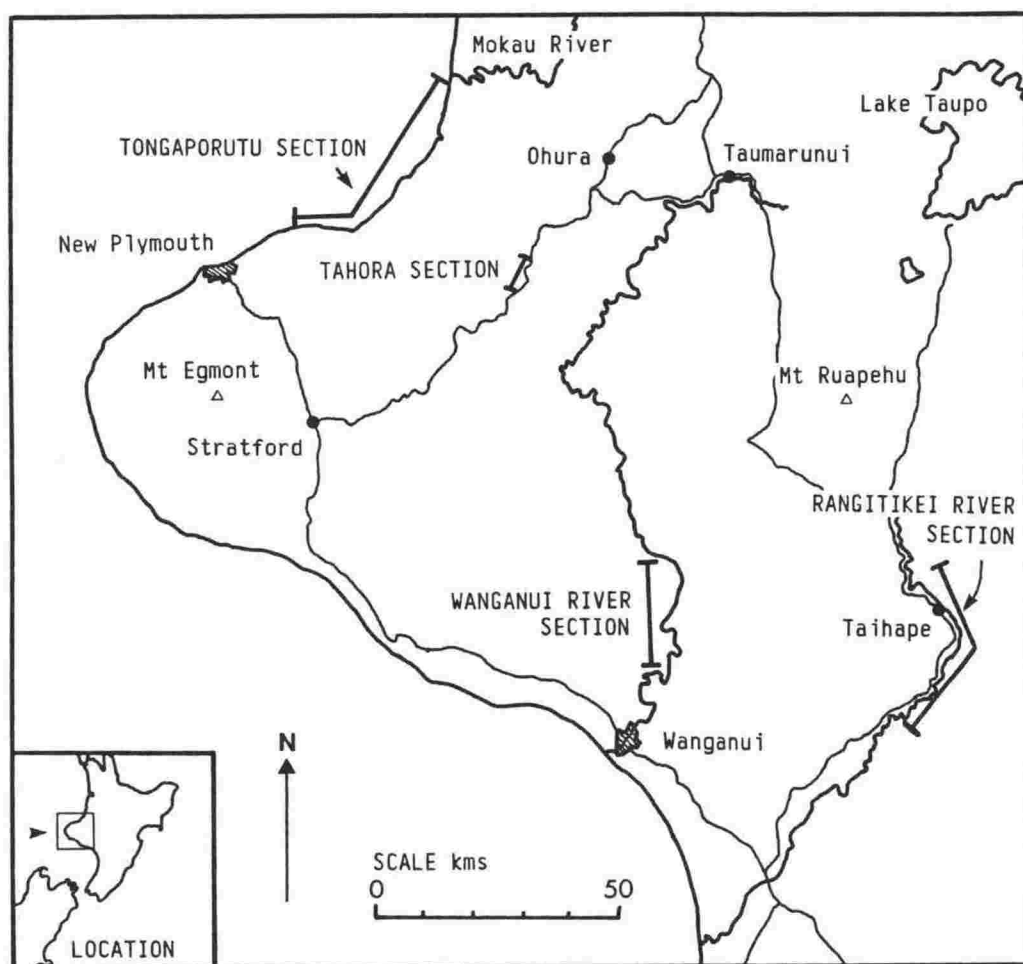


Figure A.41

Location of sections : West Coast, North Island.

A.52 TONGAPORUTU COASTAL SECTION

Location: Between Waitara and Mokau on the north Taranaki Coast. Forty kilometres of coastal cliffs providing excellent exposure of the Tongaporutuan holostatotype. See figure A.41.

Comment: The section straddles a deep-seated structural feature, the Patea-Tongaporutu High, which separates the Taranaki and Wanganui Basins (Hunt, 1980).

Lithology: The predominant lithologies are well-bedded mudstone, siltstone, and fine sandstone with occasional submarine channels infilled with quartz pebbles and sandstone clasts.

Age: Basal Tongaporutuan beds occur at N100/f547 and the LAD of *Globoquadrina dehiscens* at N99/f514 (which approximates the FAD of *Bolivinita compressa* in this section (G. Scott pers. comm.). Above the LAD of *G. dehiscens* the section continues to an unconformable contact with the Pouakai Volcanic Group between Waitara and Urenui. The youngest samples in the section contain specimens close to *Bolivinita pliozea* (G. Scott, pers. comm.).

Samples: Twenty-three samples collected at regular intervals from the finest grained sediments in the section by G. Gosson and one sample of Gibson's (N99/f573) are barren.

References: Gibson (1963, 1967), Gosson (in prep.).

A.53 TAHORA SECTION

Location: Between Tahora and Kahuratahi on the Stratford-Ohura Highway. See figure A.41.

Samples: Six lower to mid Tongaporutuan samples (N110/f38-f43) are barren.

References: Gibson (1963, 1967).

A.54 WANGANUI RIVER SECTION

Location: On the banks of the Wanganui River between Ranana and Parikino. The samples examined were collected by J.D. Collen of Victoria University at the same time as N.D. Watkins and J.P. Kennett collected paleomagnetic samples (ZM series). See figure A.41.

Samples: Forty-four samples were examined, the oldest being N131/f515 (Wo) and the youngest N138/f551 (Wm). Radiolaria were found to be present in ten samples: N131/f524, f525, f528-f532 (Taihape Mudstone - Wo); N131/f535 (Koroniti Sandstone - Wo/Wp); N131/f537, f538 (lower Raumati Sandstone and upper Koroniti Sandstone - Wp). Faunas are generally impoverished.

Reference: Collen (1972b).

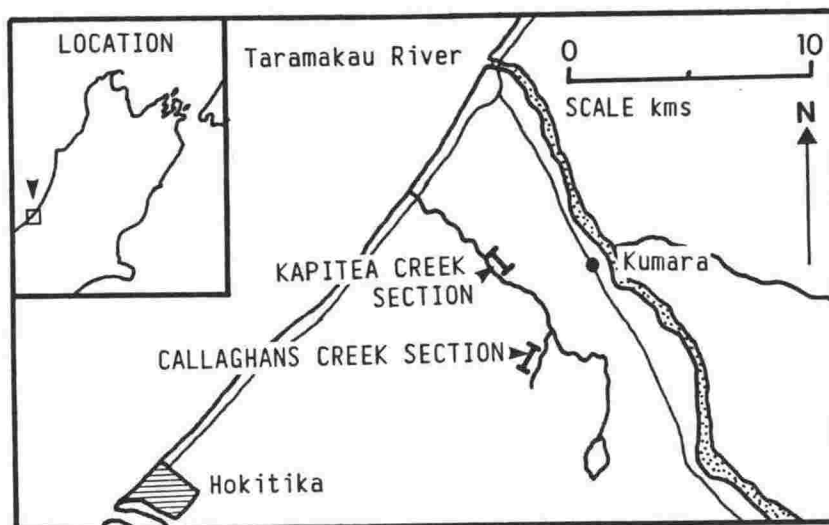


Figure A.42

Location of sections : West Coast, South Island.

A.55 RANGITIKEI RIVER SECTION

Location: Samples collected from roadcuts on State Highway One up to 12km north of Taihape, on the Napier-Taihape road between Moawhango and Taihape, and on State Highway One between Ohingaiti and Taihape; in the Rangitikei River Valley. See figure A.41.

Samples: Thirteen samples examined.

Register Numbers	Fossil Record Numbers	Age
JAA289	N132/f507 (projected)	Wo
JAA274	N132/f509	Wo
JAA272	N132/f510 (projected)	Wo
JAA273	between N132/f510-f511 (projected)	Wo
JAA275	N132/f511	Wo
JAA276	N132/f512	Wo
JAA277	N132/f514	Wp
JAA278	N139/f539	Wp
JAA653	between N139/f539-f540	Wp
JAA652	N139/f540	Wp
JAA279	between N139/f541-f542	Wm
JAA651	between N139/f542-f543	Wm
JAA280	N139/f544	Wm

Only two of the samples, JAA279 and JAA651 from the Mangapanian portion of the Mangaweka Mudstone, contain Radiolaria and these were only impoverished faunas containing mainly unrecognisable recrystallised forms.

Reference: Collen (1972b).

A.56 KAPITEA CREEK SECTION

Location: In low bluffs extending about 1.5km down Kapitea Creek from its junction with Maori Gully; about 4.5km west of Kumara. See figure A.42.

Comment: Holostratotype Kapitean.

Lithology, Age, and Samples: Six samples examined from massive medium blue-grey mudstones (S51/f642, f644-f648). All the samples are Kapitean except one Waiau sample (f642) and all are barren of Radiolaria.

References: Kennett (1966a, 1966b), Jenkins (1971), Scott (1980b, 1982b).

A.57 CALLAGHANS CREEK SECTION

Location: This section is 3.2km southeast of the Kapitea Creek Section in an artificial sludge channel constructed during the late 19th century to drain gold-sluicing claims. See figure A.42.

Samples: Two lower Tongaporutuan samples (S51/f652, f653) are barren.

References: Kennett (1966a, 1966b).

Appendix B

SAMPLE DESCRIPTIONS

B.1 INTRODUCTION

This appendix describes the samples selected for study in this thesis. The order of presentation is by sections (arranged consecutively north to south) then sample descriptions from sites (sites prefixed by an S : e.g. SWR1) again arranged north to south. To save space the terms foraminifera and Radiolaria have been abbreviated to forams and rads.

To explain the layout of each description the first sample breaks down as follows:

EC01 : Thesis sample number as quoted in text and figures. The first two letters define the section (in this case East Cape) and the numerals the sample number in that section with 01 being the youngest sample discussed and samples getting progressively older as numbers get higher. With sites the sample number is prefixed by "S".

Z14/f46 : New Zealand Fossil Record File number.

Z14/96907135 : Metric grid reference for NZMS 260 maps. Eight digit references indicate that a small scale base map for the section or site was drawn during the course of this study.

N72/91604965 : Imperial grid reference for NZMS 1 maps.

JAA814 : Personal sample register as lodged at Victoria University.

E589 : Field collection number.

PRM : Collector. Abbreviations for the various collectors are as follows:

DAH	David Heath, Victoria University of Wellington
GHS	George Scott, New Zealand Geological Survey, Lower Hutt
GJG	Greg Gosson, Victoria University of Wellington
GWG	Graham Gibson, Victoria University of Wellington
JDC	John Collen, Victoria University of Wellington
JNA	Jeff Ashby, Victoria University of Wellington
MEF	Mike Fittall, Victoria University of Wellington
MPC	Martin Crundwell, Victoria University of Wellington
NBH	Norcott Hornibrook, New Zealand Geological Survey, Lower Hutt
PPV	Paul Vella, Victoria University of Wellington
PRM	Phil Moore, New Zealand Geological Survey, Lower Hutt

29-04-80 : Date of sample collection.

Next in the description is a brief account of the lithology of the sample including (in brackets) the percentage of the sample that is coarser than 54μ , presence of microfossil groups, and any pertinent remark about the sample. Occasionally in the remarks the position of the sample in relation to a tuff will be given, the tuff being designated a "G" number. This "G" number is the number of the tuff as designated by Gosson (in prep.).

Finally there is an account of how the microfossils from the sample are stored. Two abbreviations are used here:

TL : transmitted light, and

SEM : scanning electron microscope

B.2 EAST CAPE SECTION

EC01 Z14/f46 Z14/96907135 N72/91604965 JAA814 E589 PRM 29-04-80
Indurated, light grey-green mudstone (6.0%), black carbonaceous specks, forams present, abundant spicules, glass shards present. In alternating fine sandstone, mudstone, tuff sequence, bedding approximately 40cm. Youngest rad-bearing sample in the section.
Rads - SEM stub. Forams - mounted slide.

EC02 Z14/f38A Z14/96857185 N63/91505020 JAA813 E590 PRM 29-04-80
Grey-green mudstone (7.8%), bioturbation picked out by concentration of white specks, oxidation halos where the specks are concentrated, common forams, abundant spicules, glass shards present. In alternating fine sandstone, mudstone, tuff sequence bedding approximately 40cm.
Rads - TL slide. Forams - mounted slide.

EC03 Z14/f113 Z14/981736 N63/928522 JAA763 EAST1 GJG 12-02-82
Massive, grey-green mudstone (8.5%), some black carbonaceous fragments up to 2mm, forams present, spicules present, glass shards present.
Rads - SEM stub. Forams - mounted slide.

EC04 Z14/f112 Z14/984737 N63/932523 JAA764 EAST2 GJG 12-02-82
Massive, grey-green mudstone (10.2%), pumiceous? fragments up to 3mm, common forams, spicules present, glass shards present. Oldest rad-bearing sample in the section but rads are recrystallised. Seems to be the shallowest sample in the section as the benthic/planktic foraminifera ratio is high.
Rads - TL slide. Forams - mounted slide.

B.3 KAITI BEACH SECTION

KB01 Y18/f92 Y18/470685 N98/403357 JAA530 K13 GHS 08-03-81
Massive, grey-green mudstone (1.8%), mm-scale bioturbation picked out by black oxidised burrows, abundant forams, spicules present, glass shards present. Youngest rad-bearing sample from the section.
Rads - TL slide, SEM stub. Forams - mounted slide.

KB02 Y18/f209 Y18/471682 N98/403353 JAA800 KAI4 GJG 13-02-82
Weakly bedded to massive, grey-green mudstone (2.1%), indurated, black carbonaceous specks, forams present, common spicules, rads recrystallised.
Rads - SEM stub. Forams - mounted slide.

KB03 Y18/f94 Y18/473682 N98/405352 JAA528 K10 GHS 08-03-81
Massive, grey-green mudstone (1.4%), thin black carbonaceous fragments, forams present, glass shards present, rads recrystallised.
Rads - SEM stub. Forams - mounted slide.

KB04 Y18/f100 Y18/476677 N98/409348 JAA522 K4 GHS 08-03-81
Massive, grey-green mudstone (4.6%), black and white speckled, common forams, common spicules, glass shards present, diatoms present, rads recrystallised. Oldest rad-bearing sample in the section.
Rads - SEM stub. Forams - mounted slide.

B.4 HANGAROA RIVER SECTION

HR01 X18/f8 X18/103658 N97/001316 JAA578 H2 GHS 07-03-81
Indistinctly bedded to massive, grey-green mudstone (5.8%), brown carbonaceous specks, bioturbated (up to 8mm diameter with 3mm oxidation halos), common forams, common spicules, tuffaceous, diatoms present. Youngest rad bearing sample in section. 5-10cm below a fine sandstone unit. In the top of the Mapiri Formation?

Rads - SEM stub. Forams - mounted slide.

HR02 X18/f9 X18/104659 N97/002317 JAA579 H3 GHS 07-03-81
Indurated, indistinctly bedded (0.5m) grey-green mudstone (2.9%), minor black carbonaceous specks, abundant spicules, forams present, glass shards present, diatoms present. Immediately above a tuff (G143).

Rads - TL slide, SEM stub. Forams - mounted slide.

HR03 X18/f10 X18/105659 N97/003317 JAA580 H4 GHS 07-03-81
Indistinctly bedded to massive, grey-green mudstone (3.6%), shell fragments, tuffaceous, forams present, abundant spicules. Immediately above a tuff (G144).

Rads and forams - mounted slide.

HR04 X18/f11 X18/106662 N97/004320 JAA581 H5 GHS 07-03-81
Indistinctly bedded to massive, grey-green mudstone (3.6%), black carbonaceous specks, abundant spicules, glass shards present, common forams.

Rads - TL slide, SEM stub. Forams - mounted slide.

HR05 X18/f12 X18/106663 N97/004321 JAA582 H6 GHS 07-03-81
Massive, grey-green mudstone (3.3%), black and brown carbonaceous specks, abundant spicules, tuffaceous, common forams.

Rads - TL slide, SEM stub. Forams - mounted slide.

HR06 X18/f13 X18/112665 N97/011324 JAA583 H7 GHS 07-03-81
Massive, grey-green mudstone (3.9%), abundant spicules, common forams, glauconite common, shell fragments, glass shards present.

Rads - TL slide. Forams - mounted slide.

HR07 X18/f14 X18/116668 N97/015327 JAA584 H8 GHS 07-03-81
Massive, grey-green mudstone (7.4%), white specks up to 1mm concentrated in patches, abundant forams, abundant spicules, rads rare and recrystallised. Oldest rad bearing sample in the upper part of the section. Immediately below a 15-20cm tuff (G146).

Forams - mounted slide.

B.5 RUAKITURI RIVER SECTION

RK01 X18/f29 X18/955580 N106/842226 JAA538 R7 GHS 06-03-81
Massive, grey-green mudstone (8.1%), some 2mm tuffaceous fragments, common forams, abundant spicules, rads rare, diatoms present. 19m above a tuff (G140). 80cm above a smaller tuff. 5m below alternating massive sands (2m) and massive silts (1.5m). Youngest rad bearing sample in section.

Forams - mounted slide.

RK02 X18/f28 X18/953583 N106/840229 JAA537 JR1 JNA 06-03-81
Massive, grey-green mudstone (1.9%), tuffaceous, common rads, common forams (recrystallised), common spicules. Occasional thin (1-2cm) sandstone beds. 1.5m above a reworked tuff (70cm thick).

Rads - TL slide. Forams - mounted slide.

RK03 X18/f27 X18/952583 N106/839229 JAA536 R6 GHS 06-03-81
Grey-green mudstone (2.6%) from interbedded mudstones (20cm) and sandstones (5-8cm), white tuffaceous specks, forams present, common rads (recrystallised), forams present, abundant spicules, glass shards present.

Rads - TL slide. Forams - mounted slide.

RK04 X18/f26 X18/951585 N106/838231 JAA535 R5 GHS 06-03-81
Indurated, grey-green mudstone (1.6%) from interbedded mudstones (1cm) and sandstones (5-7cm), shell fragments, minor black carbonaceous specks, common forams, common spicules, common rads, diatoms present.

Rads - TL slide, SEM stub. Forams - mounted slide.

RK05 X18/f25 X18/951586 N106/837232 JAA534 R4 GHS 06-03-81
Massive, grey-green mudstone (13.8%), black carbonaceous specks, iron-stained along joints, abundant forams, glass shards present, common spicules (etched), rads present (recrystallised), sterrasters common.

Forams - mounted slide.

B.6 MANGAPOIKE RIVER SECTION

TM01 X19/f9 X19/012471 N106/908109 JAA128 16 NBH 14-03-78
Massive, grey-brown sandy mudstone (17.6%), brown carbonaceous specks, scattered mollusca and shell fragments, common spicules, forams present, very rare rads. Youngest rad bearing sample in section.

Forams - mounted slide.

TM02 X19/f8 X19/012471 N106/908109 JAA129 15 NBH 14-03-78
Massive, grey-green sandy mudstone (17.7%), brown carbonaceous specks, tuffaceous, rare forams, common spicules, diatoms present, very rare rads, common sterrasters.

Forams - mounted slide.

TM03 X19/f6 X19/020473 N106/916111 JAA131 12 NBH 14-03-78
Massive, grey-green sandy mudstone (29.1%), forams present, rads rare. 25m above Whakapunake Limestone. 2m below the base of a 1m tuff.

Forams - mounted slide.

TM04 X19/f7761B X19/04854619 N106/94790998 JAA629 POIKE43 JNA 08-03-81
Massive, grey-green sandy mudstone (41.1%), sterrasters common, abundant spicules, glass shards present, forams present, rads rare, some mollusca. Occasional brown-white speckled, coarse, 20cm thick calcarenites.

Forams - mounted slide.

- TM05 X19/f77 X19/05084650 N106/95031033 JAA628 POIKE44 JNA 08-03-81
Massive, grey-green sandy mudstone (17.3%), tuffaceous, diatoms present, common forams, common spicules, rads rare, ostracods present.
Forams - mounted slide.
- TM06 X19/f7759B X19/05174653 N106/95131036 JAA627 POIKE45 JNA 08-03-81
Massive, grey-green sandy mudstone (24.0%), common forams, tuffaceous, common rads, common spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM07 X19/f7758B X19/05134622 N106/95091002 JAA626 POIKE46 JNA 08-03-81
Massive, grey-green sandy mudstone (22.2%), abundant forams, tuffaceous, common spicules, sterrasters common, rads present, diatoms present, rare ostracods. Occasional indurated sandier layers.
Rads - SEM stub. Forams - mounted slide.
- TM08 X19/f7757B X19/05344594 N106/95330972 JAA625 POIKE47 JNA 08-03-81
Massive, grey-green sandy mudstone (18.9%), bioturbated (mm-scale), common spicules, sterrasters common, rare forams, glass shards present, rads rare, ostracods present.
Forams - mounted slide.
- TM09 X19/f7756B X19/05444587 N106/95440965 JAA624 POIKE48 JNA 08-03-81
Massive, grey-green mudstone (14.6%), pumiceous fragments up to 3mm, common spicules, sterrasters common, ostracods present, rare forams, rads rare. 3m below a tuff (10cm, fining upwards, coarse base then 15cm coarse layer then 55cm of tephric mudstone).
Forams - mounted slide.
- TM10 X19/f7755A X19/05594576 N106/95610953 JAA623 POIKE49 JNA 08-03-81
Massive, grey-green sandy mudstone (23.0%), rare mollusca, common spicules, sterrasters common, common forams, glass shards present, rads rare. Occasional thin (1cm) sandier layers.
Forams - mounted slide.
- TM11 X19/f78 X19/05724553 N106/95760928 JAA622 POIKE50 JNA 08-03-81
Massive, grey-green sandy mudstone (31.3%), black carbonaceous specks, rads rare, common spicules, glass shards present, common forams, sterrasters common, some mollusca. Occasional thin iron-stained sandier layers.
Forams - mounted slide.
- TM12 X19/f7752B X19/05884559 N106/95930935 JAA621 POIKE51 JNA 08-03-81
Massive, grey-green sandy mudstone (41.3%), black carbonaceous specks, patches of 0.5-1mm tuffaceous burrows, shell fragments, rads present, common spicules, common forams, sparse mollusca, pumiceous fragments from 1 to 8mm.
Rads - SEM stub. Forams - mounted slide.
- TM13 X19/f7834 X19/06714502 N106/96840877 JAA134 16 NBH 21-09-75
Massive, grey-green sandy mudstone (18.1%), common forams, spicules present, rads rare (recrystallised), ostracods present. Above road-cut unconformity.
Forams - mounted slide.

- TM14 X19/f7738B X19/06734542 N106/96870919 JAA614 POIKE58 JNA 08-03-81
Massive, grey-green mudstone (3.0%), black carbonaceous specks, abundant rads, abundant spicules, common forams. Stratigraphically below the roadcut unconformity equivalent.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM15 X19/f75 X19/06754502 N106/96880876 JAA412 POIKE4 JNA 11-08-80
Massive, grey-green mudstone (2.2%), abundant spicules, abundant rads, abundant forams. 0.5m above a sandy ?tuffaceous? layer. Below road-cut unconformity.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM16 X19/f7830 X19/06754502 N106/96880876 JAA137 17 NBH 21-09-75
Massive, grey-green mudstone (0.9%), abundant rads, common forams, abundant spicules, glass shards present. Between two 10cm tuffs.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM17 X19/f76 X19/06754502 N106/96880876 JAA417 POIKE9 JNA 11-08-80
Massive, grey-brown sandy mudstone (18.6%), black carbonaceous specks, abundant spicules (etched), sterrasters abundant, rads rare, rare forams. Sandier layer within mudstone.
Rads - SEM stub. Forams - mounted slide.
- TM18 X19/f63 X19/06794501 N106/96940875 JAA833 T26 GHS 06-03-81
Massive, grey-green mudstone (3.6%), bioturbated (mm-scale), sterrasters present, rads present, forams present (recrystallised), abundant spicules, carbonaceous.
Rads - SEM stub. Forams - mounted slide.
- TM19 X19/f62 X19/06934496 N106/97100870 JAA836 T25 GHS 06-03-81
Massive, grey-green mudstone (1.9%), abundant spicules, tuffaceous, common rads, forams present, abundant diatoms. At base of a turbidite packet.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM20 X19/f61 X19/07024504 N106/97200879 JAA834 T24 GHS 06-03-81
Massive, grey-green mudstone (2.1%), abundant spicules, tuffaceous, abundant rads, common forams, diatoms present. 2m below a layer of irregularly shaped concretions.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM21 X19/f74 X19/07224496 N106/97420871 JAA611 POIKE34 JNA 06-03-81
Massive, grey-green mudstone (0.5%), abundant spicules, abundant rads, rare forams, abundant diatoms. 4m above top of a tuff (G79).
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM22 X19/f60 X19/07334494 N106/97540869 JAA831 T23 GHS 06-03-81
Massive, grey-green mudstone (0.3%), abundant rads, abundant forams, abundant spicules (some etched), diatoms present, glass shards present.
Rads - TL slide, SEM stub. Forams - mounted slide.
- TM23 X19/f59 X19/07594487 N106/97820862 JAA832 T22 GHS 06-03-81
Indurated, massive, grey-green mudstone (0.4%), tuffaceous burrows (mm scale) with oxidation halos, abundant rads, abundant spicules, forams present, glass shards present, diatoms present. Oldest rad bearing sample in section.
Rads - TL slide, SEM stub. Forams - mounted slide.

B.7 WAIATAI VALLEY SECTION

WA01 X19/f65 X19/941326 N116/835949 JAA575 TEUHI5 JNA 03-03-81
Massive, light brown-yellow-grey mudstone (0.1%), some black carbonaceous specks, glass shards present, abundant rads, common spicules, rare forams. Youngest sample in section. Immediately below a weathered tuff?

Rads - TL slide.

WA02 X19/f66 X19/942327 N116/836949 JAA576 TEUHI6 JNA 03-03-81
Massive, light grey-green mudstone (1.5%), black carbonaceous specks, abundant rads, tuffaceous, common spicules, rare forams, rare diatoms.

Rads - TL slide, SEM stub.

WA03 X19/f67 X19/942327 N116/837949 JAA574 TEUHI4 JNA 03-03-81
Massive, light grey-brown mottled mudstone (1.2%), tuffaceous, abundant rads, common spicules, rare forams.

Rads - TL slide, SEM stub.

WA04 X19/f68 X19/943328 N116/838950 JAA573 TEUHI3 JNA 03-03-81
Massive, light grey mudstone (0.7%), brown carbonaceous specks, tuffaceous, abundant rads, rare forams, spicules present.

Rads - SEM stub, mounted slide.

WA05 X19/f69 X19/943331 N116/838953 JAA571 TEUHI1 JNA 03-03-81
Massive, light grey-brown mudstone (8.6%), brown carbonaceous specks, tuffaceous fragments up to 1mm, abundant rads, common forams, spicules present, mollusca present. Immediately above a 30cm tuff with a 15cm, laminated, coarse base and a 15cm, bioturbated, medium-sand top.

Rads and forams - mounted slide.

WA06 X19/f9569 X19/95063276 N116/84509499 JAA206 47 NBH 24-09-75
Massive, grey-green mudstone (2.3%), minor brown carbonaceous specks, tuffaceous, common spicules, common rads, abundant forams.

Rads and forams - mounted slide.

WA07 X19/f19 X19/964344 N116/860967 JAA207 27 NBH 15-03-78
Massive, grey-green mudstone (2.4%), black carbonaceous specks, tuffaceous, abundant rads, abundant forams, abundant spicules. Occasional thin, graded, sandstone beds in outcrop.

Rads - TL slide, SEM stub. Forams - mounted slide.

WA08 X19/f18 X19/964344 N116/860967 JAA208 28 NBH 15-03-78
Massive, grey-green mudstone (3.0%), tuffaceous, common forams, common rads, common spicules. Occasional thin, graded, sandstone beds in outcrop.

Rads - SEM stub. Rads and forams - mounted slide.

WA09 X19/f9568 X19/96003383 N116/85499619 JAA209 42 NBH 24-09-75
Massive, grey-green mudstone (6.9%), brown carbonaceous specks up to 1mm, shell fragments, glass shards present, rads present, spicules present, common forams. Top of a graded bed unit.

Forams - mounted slide.

- WA10 X19/f30 X19/967341 N116/863965 JAA210 10 NBH 20-09-78
Massive, grey-green mudstone (4.0%), tuffaceous specks up to 0.5mm, abundant forams, abundant rads, glass shards present, common spicules (some etched). 10m below top of an alternating mudstone and graded, soft, brown sandstone unit.
Rads - TL slide, SEM stub. Forams and rads - mounted slide.
- WA11 X19/f70 X19/971341 N116/867965 JAA211 11 NBH 20-09-78
Massive, grey-green mudstone (4.1%), black carbonaceous specks, tuffaceous, rads present, spicules present. 40m below top of an alternating mudstone and graded, soft, brown sandstone unit. Sample from a 2m thick mudstone.
Rads - SEM stub, mounted slide.
- WA12 X19/f29 X19/978342 N116/874967 JAA212 12 NBH 20-09-78
Massive, grey-green mudstone (1.6%), shell fragments, abundant forams, common spicules, common rads.
Rads - SEM stub. Rads and forams - mounted slide.
- WA13 X19/f9567 X19/98603495 N116/88309750 JAA213 40 NBH 24-09-75
Massive, grey-green mudstone (1.4%), abundant rads, tuffaceous, abundant forams, abundant spicules. Near the top of a 15-20m mudstone within the alternating unit.
Rads - TL slide, SEM stub. Forams - mounted slide.
- WA14 X19/f9564 X19/99893537 N116/89709799 JAA215 37 NBH 23-09-75
Massive grey-brown sandy mudstone (19.8%), black carbonaceous specks, tuffaceous, forams present, rads present, spicules present.
Rads and forams - mounted slide.
- WA15 X19/f9562 X19/00073527 N116/89909789 JAA217 35 NBH 23-09-75
Massive, grey-green mudstone (3.5%), tuffaceous, common rads, common forams, common spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.
- WA16 X19/f9561 X19/00073527 N116/89909789 JAA218 34 NBH 23-09-75
Massive, grey-green mudstone (1.5%), tuffaceous, rads present, common forams, common spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.
- WA17 X19/f9560 X19/00073527 N116/89909789 JAA219 33 NBH 23-09-75
Massive, grey-green mudstone (3.3%), tuffaceous, common rads, common forams, abundant spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.
- WA18 X19/f9534 X19/00813553 N116/90709820 JAA197 2 NBH 30-10-72
Massive, grey-green sandy mudstone (13.5%), forams present, spicules present, rads rare, diatoms present, sterrasters common.
Rads and forams - mounted slide.

- WA19 X19/f9535 X19/02583694 N116/92599979 JAA198 10 NBH 31-10-72
Massive, grey-green sandy mudstone (14.7%), glass shards present, diatoms present, black carbonaceous specks, spicules present, rads rare, common forams.
Rads - TL slide. Forams and rads - mounted slide.
- WA20 X19/f9536 X19/02493685 N116/92499969 JAA199 11 NBH 31-10-72
Massive, grey-green mudstone (2.2%), tuffaceous, abundant forams, common spicules, rads rare.
Forams - mounted slide.
- WA21 X19/f9537 X19/02493685 N116/92499969 JAA200 12 NBH 31-10-72
Massive, grey-green mudstone (1.8%), tuffaceous, abundant forams, abundant spicules, rads rare, sterrasters common.
Forams - mounted slide.
- WA22 X19/f9538 X19/02493667 N116/92509950 JAA201 13 NBH 31-10-72
Massive, grey-green mudstone (1.6%), tuffaceous, common forams, abundant spicules, rads rare, sterrasters common.
Rads and forams - mounted slide.
- WA23 X19/f9539 X19/02493667 N116/92509950 JAA202 14 NBH 31-10-72
Massive, grey-green mudstone (2.6%), abundant forams, diatoms present, common rads, spicules present.
Rads - TL slide. Forams - mounted slide.
- WA24 X19/f9540 X19/02303649 N116/92309929 JAA203 15 NBH 31-10-72
Massive, grey-green mudstone (2.9%), shell fragments, common forams, common spicules, rads rare, sterrasters common.
Forams - mounted slide.
- WA25 X19/f9541 X19/02303640 N116/92309919 JAA204 16 NBH 31-10-72
Massive, grey-green mudstone (4.4%), abundant forams, diatoms present, abundant spicules, rads rare, sterrasters common.
Forams - mounted slide.
- WA26 X19/f9542 X19/02293622 N116/92299900 JAA205 17 NBH 31-10-72
Massive, grey-green mudstone (6.3%), abundant forams, diatoms present, common spicules, rads rare. Oldest sample in section.
Rads - TL slide. Forams - mounted slide.

B.8 TAHAENUI-KOHUKOHU ROAD SECTION

- TK01 X19/f15 X19/163308 N116/078935 JAA140 24 NBH 15-03-78
Massive, grey-green sandy mudstone (17.3%), abundant forams, abundant spicules, rads rare, sterrasters abundant, diatoms present. 1m below base of a 6m tuff. Youngest sample in section.
Forams - mounted slide.

TK02 X19/f14 X19/150295 N116/065920 JAA141 22 NBH 15-03-78
Massive, grey-green sandy mudstone (21.7%), common forams, abundant spicules (etched), rads rare.
Forams - mounted slide.

TK03 X19/f9493 X19/15182945 N116/06609199 JAA142 NBH 30-10-72
Massive, grey-green sandy mudstone (21.5%), common forams, abundant spicules, rads rare, sterrasters abundant. Forams - mounted slide.

TK04 X19/f13 X19/158293 N116/073919 JAA143 20 NBH 15-03-78
Massive, grey-green sandy mudstone (12.3%), rare forams, diatoms present, abundant spicules, rads rare, sterrasters abundant.
Forams - mounted slide.

TK05 X19/f12 X19/158292 N116/073917 JAA144 18 NBH 15-03-78
Massive, grey-brown sandy mudstone (15.5%), scattered mollusca, rare forams, abundant spicules, common rads, sterrasters common. 1m below base of a 1m tuff.
Rads - TL slide, SEM stub. Forams - mounted slide.

TK06 X19/f11 X19/158292 N116/073917 JAA145 17 NBH 15-03-78
Massive, grey-green mudstone (10.2%), scattered mollusca, common forams, spicules present, rare rads. 20m above the top of the Whakapunake Limestone.
Forams - mounted slide.

B.9 CRICKLEWOOD ROAD SECTION

CR01 W19/f8664 W19/833337 N115/717957 JAA107 31 NBH 23-09-75
Massive, grey-green sandy mudstone (12.7%), black carbonaceous specks, common forams, spicules present, rads rare, diatoms present, sterrasters present. Youngest rad bearing sample in section. Immediately underlies a 2m white tuff.
Forams - mounted slide.

CR02 W19/f8662 W19/834341 N115/717962 JAA109 29 NBH 23-09-75
Massive, grey-green-brown sandy mudstone (16.4%), black carbonaceous specks, forams present, rads present, spicules present, glass shards present, sterrasters present.
Forams - mounted slide.

CR03 W19/f8661 W19/834341 N115/717962 JAA110 28 NBH 23-09-75
Massive, light grey-brown mudstone (3.0%), brown carbonaceous specks, abundant forams, tuffaceous, rads rare, scattered small mollusca.
Rads - TL slide, SEM stub. Forams - mounted slide.

CR04 W19/f8659 W19/834347 N115/717967 JAA112 25 NBH 23-09-75
Massive, light grey-green mudstone (0.7%), tuffaceous, common spicules, rads present, common forams, abundant small mollusca. Oldest rad bearing sample in section.
Rads - SEM stub. Forams - mounted slide.

B.10 WAIHUA VALLEY SECTION

WH01 W19/f42 W19/820284 N115/703898 JAA570 WAIHUA8 JNA 03-03-81
Massive, grey-green sandy mudstone (44.4%), black carbonaceous specks, micaceous, common forams, common spicules, sterrasters common, glass shards present, rads rare, some mollusca, ostracods present. Youngest rad bearing sample in section.

Rads and forams - mounted slide.

WH02 W19/f43 W19/800288 N115/681902 JAA568 WAIHUA6 JNA 03-03-81
Massive, light grey-green mudstone (7.8%), some black tephric burrows up to 2cm with yellow oxidation halos, common spicules, sterrasters common, common forams, rads present, glass shards present, diatoms present.

Rads and forams - mounted slide.

WH03 W19/f44 W19/798289 N115/679903 JAA567 WAIHUA5 JNA 03-03-81
Massive, light grey-green mudstone (2.7%), common thin black carbonaceous fragments up to 5mm long, rare small mollusca, sterrasters common, common spicules, abundant forams, rads present, diatoms present.

Rads - TL slide. Rads and forams - mounted slide.

WH04 W19/f45 W19/791288 N115/672902 JAA566 WAIHUA4 JNA 03-03-81
Indurated, massive, light grey-green mudstone (5.9%), common forams, common spicules, sterrasters common, glass shards present, rads rare.

Rads - SEM stub. Rads and forams - mounted slide.

WH05 W19/f46 W19/790292 N115/670906 JAA565 WAIHUA3 JNA 03-03-81
Massive, grey-green sandy mudstone (12.7%), minor black carbonaceous specks, some mollusca up to 2cm, abundant forams, common spicules (etched), sterrasters common, rads rare, glass shards present, ostracods present.

Rads and forams - mounted slide.

WH06 W19/f8552 W19/784304 N115/663919 JAA120 8 NBH 19-11-69
Massive, light grey-green mudstone (2.0%), common forams, rads present, spicules present, scattered mollusca, glass shards present.

Rads - TL slide. Forams - mounted slide.

WH07 W19/f47 W19/773303 N115/652918 JAA564 WAIHUA2 JNA 03-03-81
Massive, grey-green mudstone (11.8%), black carbonaceous specks, common spicules, common forams, glass shards present, rads present, scattered mollusca. Oldest rad bearing sample in section. 130m above top of graded bed unit.

Rads and forams - mounted slide.

B.11 MARAETOTARA RIVER SECTION

MT01 W21/f45 W21/51996016 N135/39631428 JAA440 MARAE15 JNA 10-08-80
Massive, grey-green muddy sandstone (68.2%), brown-white-black speckled, shell fragments common, forams present (recrystallised), rare spicules (etched), ostracods abundant. Above Wo/Tt unconformity.

Forams - mounted slide.

MT02 W21/f44 W21/51986009 N135/39631420 JAA439 MARAE14 JNA 10-08-80
Grey muddy sandstone (70.9%) in an alternating sequence of indurated (5-10cm) and non-indurated (0.5-1m) layers, white-black speckled, abundant ostracods, forams present. Sample from the first non-indurated layer immediately above a 5cm pebbly, shelly sandstone. Immediately above the Wo/Tt unconformity.

Forams - mounted slide.

MT03 W21/f43 W21/51986009 N135/39631420 JAA437 MARAE12 JNA 10-08-80
Massive, grey-green sandy mudstone (20.8%) with grey-black-brown-white-green speckled patches, shell fragments, rare forams. Grades into a 5cm pebbly, shelly sandstone. Immediately below the Wo/Tt unconformity.

Forams - mounted slide.

MT04 W21/f42 W21/51986004 N135/39631415 JAA436 MARAE11 JNA 10-08-80
Indurated massive, grey-green sandy mudstone (16.2%), bioturbation (1mm) picked out by lighter material, some rounded pumiceous fragments up to 0.5cm, glass shards present, common rads, spicules present, rare forams. Youngest rad bearing sample in section.

Rads - TL slide, SEM stub. Forams - mounted slide.

MT05 W21/f41 W21/51996001 N135/39641412 JAA435 MARAE10 JNA 10-08-80
Indurated, massive, grey-green sandy mudstone (19.4%), some brown and black carbonaceous specks, shell fragments, common spicules, common rads, forams present.

Rads - SEM stub. Rads and forams - mounted slide.

MT06 W21/f40 W21/52006001 N135/39651411 JAA434 MARAE9 JNA 10-08-80
Indurated, massive, grey-green sandy mudstone (28.7%), spicules present (etched), forams present (recrystallised), rads present, glass shards present.

Rads - SEM stub. Rads and forams - mounted slide.

MT07 W22/f51 W22/52035997 N135/39681407 JAA432 MARAE7 JNA 10-08-80
Massive, grey-green sandy mudstone (13.9%), tuffaceous, spicules present, rads present, forams present.

Rads - TL slide, SEM stub. Forams - mounted slide.

MT08 W22/f50 W22/52045993 N135/39701403 JAA431 MARAE6 JNA 10-08-80
Indurated, massive, grey-green mudstone (11.9%), black carbonaceous specks, common spicules, rads present, forams present, glass shards present.

Rads - TL slide, SEM stub. Forams - mounted slide.

MT09 W22/f49 W22/52055989 N135/39711399 JAA430 MARAE5 JNA 10-08-80
Indurated, massive, grey-green mudstone (10.5%), glass shards present, some mollusca, common spicules, rads present, forams present.

Rads - TL slide, SEM stub. Forams - mounted slide.

MT10 W22/f48 W22/51925955 N135/39581361 JAA427 MARAE2 JNA 10-08-80
Massive, grey-green sandy mudstone (12.9%), slight brown mottling in places, common spicules (etched), common forams, rads rare. Oldest rad bearing sample in section.

Rads - TL slide, SEM stub. Forams - mounted slide.

MT11 W22/f47 W22/51835946 N135/39481351 JAA426 MARAE1 JNA 10-08-80
Massive grey-brown mottled sandy mudstone (16.2%), brown carbonaceous specks, rare spicules, rare forams, weathering picks out indistinct 3-5cm bedding.
Forams - mounted slide.

B.12 KOURARAU-WESTMERE ROAD SECTION

KW01 T27/f207 T27/39660810 N162/21544457 JAA749 KW1 JNA 23-02-81
Massive, grey-green mudstone (1.6%), scattered rare mollusca, micaceous, bioturbated (mm-scale), rads present, diatoms present, common forams, abundant spicules, glass shards present. Youngest rad bearing sample in section.
Rads and forams - mounted slide.

KW02 T27/f206 T27/39720808 N162/21604455 JAA750 KW2 JNA 23-02-81
Massive, grey-green mudstone (3.7%), bioturbated (mm-scale), tuffaceous, abundant spicules, rare forams, rads rare.
Rads and forams - mounted slide.

KW03 T27/f205 T27/39760807 N162/21654454 JAA751 KW3 JNA 23-02-81
Massive, grey-green sandy mudstone (13.3%), black carbonaceous specks, common spicules (etched), common forams, diatoms present, shell fragments, bioturbated (mm-scale), abundant mollusca.
Rads and forams - mounted slide.

KW04 T27/f204 T27/39810806 N162/21704453 JAA752 KW4 JNA 23-02-81
Massive, grey-green mudstone (10.1%), scattered rare mollusca, common spicules, sterrasters common, glauconitic, common forams, rads rare, diatoms present.
Rads and forams - mounted slide.

KW05 T27/f203 T27/39890798 N162/21794445 JAA753 KW5 JNA 23-02-81
Massive, grey-green mudstone (4.0%), shell fragments, rads rare, abundant spicules (some etched), forams present, diatoms present. Oldest rad bearing sample in section.
Rads and forams - mounted slide.

B.13 MORRISON'S SECTION

MO01 S27/f488 S27/17680416 N161/97633958 JAA367 MOR6 JNA 05-04-80
Massive, grey-green sandy mudstone (39.2%), black carbonaceous specks in patches with oxidation halos up to 1cm, common forams, common spicules, rads present (some etched). Youngest rad bearing sample in section. 6m below interbedded 20-60cm, grey-green, fine to medium sands and 10cm, commonly bioturbated, coarse calcarenites.
Rads and forams - mounted slide.

MO02 S27/f489 S27/17670415 N161/97623957 JAA368 MOR7 JNA 05-04-80
Massive grey-green-black mudstone (11.8%), some black speckled burrows up to 2mm in diameter, common rads, abundant forams, common spicules, carbonaceous fragments common.
Rads - TL slide, SEM stub. Forams - mounted slide.

- MO03 S27/f490 S27/17670415 N161/97623957 JAA369 MOR8 JNA 05-04-80
Massive grey-green-brown mudstone (3.6%), common forams, pyritised burrows, common rads, common spicules.
Rads - TL slide. Forams - mounted slide.
- MO04 S27/f491 S27/17660414 N161/97613956 JAA370 MOR9A JNA 05-04-80
Massive, grey-green mudstone (8.9%), abundant spicules, common forams, common rads, glass shards present.
Rads - SEM stub. Rads and forams - mounted slide.
- MO05 S27/f492 S27/17660414 N161/97613956 JAA371 MOR9 JNA 05-04-80
Massive, grey-green mudstone (5.8%), common forams, common rads, common spicules.
Rads - TL slide. Forams - mounted slide.
- MO06 S27/f493 S27/17650413 N161/97603955 JAA372 MOR10 JNA 05-04-80
Massive grey-green-brown mudstone (10.2%), with white speckled patches, abundant forams, abundant rads, abundant spicules. 0.5m above a lensoidal (up to 4cm thick), yellow stained, well sorted quartz sand.
Rads - TL slide, SEM stub. Forams - mounted slide.
- MO07 S27/f494 S27/17640411 N161/97593952 JAA374 MOR12 JNA 05-04-80
Massive, light grey-brown mudstone (5.2%), minor black carbonaceous specks, glauconitic, abundant forams, abundant rads, abundant spicules. 0.5m below a lensoidal (up to 4cm thick), yellow stained, well sorted quartz sand.
Rads - TL slide, SEM stub. Forams - mounted slide.
- MO08 S27/f495 S27/17640411 N161/97593952 JAA375 MOR13 JNA 05-04-80
Massive, grey-brown mudstone (5.5%), minor black carbonaceous specks, common spicules, common forams, common rads.
Rads - SEM stub. Rads and forams - mounted slide.
- MO09 S27/f496 S27/17630410 N161/97583951 JAA376 MOR14 JNA 05-04-80
Massive, grey-green mudstone (4.4%), white specks, common rads, common forams, common spicules.
Rads - SEM stub. Rads and forams - mounted slide.
- MO10 S27/f497 S27/17630410 N161/97583951 JAA377 MOR15 JNA 05-04-80
Massive, grey-green mudstone (3.6%), black carbonaceous specks, abundant rads, spicules present, glass shards present, common forams. 35cm above a horizon containing rounded pumice blocks up to 2cm in diameter.
Rads - TL slide, SEM stub. Forams - mounted slide.
- MO11 S27/f498 S27/17620409 N161/97573950 JAA378 MOR16 JNA 05-04-80
Massive, grey-green mudstone (3.0%), abundant rads, common spicules, glass shards present, rare forams. 35cm below a horizon containing rounded pumice blocks up to 2cm in diameter.
Rads - TL slide. Forams - mounted slide.

MO12 S27/f499 S27/17620409 N161/97573950 JAA379 MOR17 JNA 05-04-80
Massive, grey-green mudstone (6.1%), black carbonaceous specks, common spicules, common rads, common forams.
Rads and forams - mounted slide.

MO13 S27/f500 S27/17610408 N161/97563949 JAA380 MOR18 JNA 05-04-80
Massive, grey-green mudstone (3.6%), black carbonaceous specks concentrated in burrows 7mm across, abundant rads, glass shards present, common forams, common spicules, mollusca present.
Rads - TL slide, SEM stub. Forams - mounted slide.

MO14 S27/f501 S27/17600407 N161/97553948 JAA381 MOR19 JNA 05-04-80
Massive green-grey-brown mudstone (3.5%), abundant rads, glass shards present, common spicules, no forams. Oldest sample in section.
Rads - TL slide.

B.14 RUAMAHANGA RIVER SECTION

RM01 S27/f18 S27/17840030 N161/97933537 JAA196 18 PPV 04-07-76
Massive, dark grey-green mottled sandy mudstone (26.1%), abundant forams, rads rare, spicules present. Youngest rad bearing sample in section.
Rads - SEM stub. Forams - mounted slide.

RM02 S27/f17 S27/17840032 N161/97933539 JAA195 17 PPV 04-07-76
Massive, grey-black speckled sandy mudstone (33.8%), spicules present, rads present, forams present.
Rads - SEM stub. Rads and forams - mounted slide.

RM03 S27/f15 S27/17850034 N161/97943541 JAA194 15 PPV 04-07-76
Massive, grey-green sandy mudstone (21.4%), black carbonaceous specks, abundant spicules, abundant forams, common rads.
Rads - TL slide, SEM stub. Forams - mounted slide.

RM04 S27/f7 S27/17860040 N161/97953548 JAA193 7 PPV 04-07-76
Massive, grey-black speckled sandy mudstone (13.8%), common rads, common forams, common spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.

RM05 S27/f4 S27/17870042 N161/97963550 JAA192 4 PPV 04-07-76
Massive, grey-green mudstone (9.9%), abundant rads, glauconitic, common forams, abundant spicules, diatoms present.
Rads - TL slide, SEM stub. Forams - mounted slide.

RM06 S27/f8 S27/17870043 N161/97963551 JAA191 8 PPV 04-07-76
Massive, grey-brown mudstone (6.3%), minor black carbonaceous specks, diatoms present, abundant rads (etched), common spicules (some etched), common forams.
Rads - TL slide, SEM stub. Forams - mounted slide.

RM07 S27/f11 S27/17870044 N161/97963552 JAA190 11 PPV 04-07-76
Massive, light grey-green mudstone (5.4%), brown carbonaceous specks, common rads, abundant forams, common spicules, diatoms present. Oldest rad bearing sample in section.
Rads - TL slide, SEM stub. Forams - mounted slide.

B.15 HINAKURA-HIKAWERA SECTION

HH01 S27/f9917 S27/270909 N166/082254 JAA456 HK17A PPV 11-11-69
Massive, grey-green mudstone (4.1%), abundant spicules (etched), common forams, rads present. Youngest rad bearing sample in section.
Rads and forams - mounted slide.

HH02 S27/f565 S27/29238955 N166/10712397 JAA655 ABOVEHK JNA 30-09-80
Massive grey-green-brown mottled mudstone (3.5%), bioturbation (mm-scale) picked out by tuffaceous material in burrows especially on weathered surfaces, tuffaceous, common spicules, forams very rare, rads present. Immediately above the Hikawera Tuff.
Rads - mounted slide.

HH03 T27/f233 T27/31498730 N166/13252158 JAA759 HINK5 JNA 25-02-82
Indurated massive, grey-green mudstone (1.0%), carbonaceous, rads rare, forams present.
Forams - mounted slide.

HH04 T27/f8899 T27/319869 N166/137212 JAA481 HK26 PPV 11-11-69
Massive, grey-green mudstone (1.1%), minor black carbonaceous specks up to 1mm with 0.5mm oxidation halos, tephric burrows (0.5mm), abundant forams (recrystallised), rads present (recrystallised), rare spicules (etched). Oldest rad bearing sample in section.
Associated tuffs in the outcrop.
Rads and forams - mounted slide.

B.16 WHAKAPUNI TRIBUTARY SECTION

WT01 S27/f570 S27/20498595 N166/01271976 JAA561 TWHAK8 JNA 23-02-81
Massive, grey-green mudstone (5.3%), black carbonaceous specks, white tephric burrows (1mm), abundant forams, glass shards present, glauconitic, small mollusca up to 3mm. 2m above a tuff (G105).
Forams - mounted slide.

WT02 S27/f569 S27/20668589 N166/01461970 JAA557 TWHAK4 JNA 23-02-81
Massive, grey-green mudstone (1.7%), brown and black carbonaceous specks, bifurcating thin black bands throughout the sample, glass shards present, pyritic, forams present (pyritic infillings), spicules present (etched), sterrasters common, rads present (etched). Youngest rad bearing sample in section.
Rads - mounted slide.

WT03 S27/f568 S27/20568585 N166/01351966 JAA559 TWHAK6 JNA 23-02-81
Massive grey-green-brown mudstone (3.8%), black carbonaceous specks with oxidation halos up to 4mm, common forams, common rads, abundant spicules (etched), sterrasters common. 2m above a tuff (G104).
Rads - TL slide, SEM stub. Forams - mounted slide.

WT04 S27/f567 S27/20638581 N166/01431961 JAA558 TWHAK5 JNA 23-02-81
Light grey-brown massive mudstone (2.4%), mottled yellow in places, tiny black carbonaceous specks with 2mm oxidation halos, a couple of thin black bands in sample, forams present, rads present, common spicules (etched). Between two tuffs (G100 and G101).

Rads and forams - mounted slide.

WT05 S27/f566 S27/20778559 N166/01661925 JAA562 TWHAK10 JNA 23-02-81
Light grey-brown massive mudstone (3.1%), brown carbonaceous specks, common forams, common rads (recrystallised), rare spicules (etched). Oldest sample in section.

Rads - TL slide, SEM stub. Forams - mounted slide.

B.17 UPPER MANGAOPARI STREAM SECTION

MS01 S27/f502 S27/18018221 N165/98681560 JAA326 MANG36 JNA 06-04-80
Massive, grey-green mudstone (6.7%), black carbonaceous specks, common forams, common spicules (etched), no shards, no rads, rare mollusca.

Forams - mounted slide.

MS02 S27/f503 S27/18038217 N165/98701555 JAA327 MANG33 JNA 06-04-80
Massive, grey-green mudstone (7.1%), burrows with admixed tephra and mud up to 8mm, forams present, common spicules, large pumiceous shards up to 3mm, common rads (poor preservation). Youngest rad bearing sample in section. Between two tuffs (G113 and G111).

Rads - SEM stub. Rads and forams - mounted slide.

MS03 S27/f504 S27/18038217 N165/98701555 JAA331 MANG31 JNA 06-04-80
Massive, grey-green mudstone (2.9%), black carbonaceous specks, diatoms present, forams present, abundant spicules, glass shards present, abundant rads. 1m below a tuff (G111).

Rads - TL slide, SEM stub. Forams - mounted slide.

MS04 S27/f505 S27/18058209 N165/97731547 JAA335 MANG27 JNA 06-04-80
Massive, grey-green mudstone (3.2%), white tuffaceous burrows (1mm), common forams, common spicules, glass shards present, common rads, diatoms present.

Rads - TL slide, SEM stub. Forams - mounted slide.

MS05 S27/f506 S27/18108205 N165/98781543 JAA336 MANG26 JNA 06-04-80
Massive, grey-green mudstone (3.0%), black carbonaceous specks up to 1mm with 2mm oxidation halos, common forams, spicules present, glass shards present, common rads.

Rads - TL slide, SEM stub. Forams - mounted slide.

MS06 S27/f507 S27/18138200 N165/98821537 JAA337 MANG25 JNA 06-04-80
Massive, grey-green mudstone (2.2%), black carbonaceous specks, diatoms present, common forams, spicules present (slightly etched), rads present.

Rads - TL slide, SEM stub. Forams - mounted slide.

- MS07 S27/f508 S27/18198198 N165/98881535 JAA338 MANG24 JNA 06-04-80
Massive, light grey-green mudstone (3.4%), some black carbonaceous specks concentrated in patches 5mm across, abundant spicules, forams present, glass shards present, abundant rads.
Rads - TL slide. Forams - mounted slide.
- MS08 S27/f509 S27/18238190 N165/98931527 JAA339 MANG23 JNA 06-04-80
Massive, grey-green mudstone (2.3%), black carbonaceous fragments up to 10mm long, common forams, common spicules, common rads.
Rads - TL slide. Forams - mounted slide.
- MS09 S27/f510 S27/18318188 N165/99021525 JAA340 MANG22 JNA 06-04-80
Massive, grey-green mudstone (1.8%), some brown mottling, abundant forams, common rads, common spicules.
Rads - TL slide, SEM stub. Forams - mounted slide.
- MS10 S27/f511 S27/18388184 N165/99091520 JAA341 MANG21 JNA 06-04-80
Massive, grey-green mudstone (1.7%), black carbonaceous fragments up to 8mm long, white tuffaceous burrows (1mm), abundant forams, glass shards present, common spicules, rads present (minor dissolution). 2m above a thin lensoidal tuff.
Rads - TL slide. Forams - mounted slide.
- MS11 S27/f512 S27/18388184 N165/99091520 JAA343 MANG19 JNA 06-04-80
Massive, grey-green mudstone (1.7%), black carbonaceous specks, pyritic burrows, common forams, common spicules, common rads, glass shards present.
Rads - TL slide. Forams - mounted slide.
- MS12 S27/f513 S27/18448183 N165/99161520 JAA344 MANG18 JNA 06-04-80
Massive, grey-green mudstone (4.6%), black carbonaceous specks, abundant forams, abundant rads, abundant spicules.
Rads - TL slide, SEM stub. Forams - mounted slide.
- MS13 S27/f514 S27/18468175 N165/99181511 JAA345 MANG17 JNA 06-04-80
Massive, grey-green mudstone (2.1%), abundant forams, abundant spicules, abundant rads. 1m above a tuff (G109).
Rads - TL slide. Forams - mounted slide.
- MS14 S27/f515 S27/18518173 N165/99241509 JAA346 MANG16 JNA 06-04-80
Massive, grey-green mudstone (2.2%), black carbonaceous specks, 3-4mm burrows with white tuffaceous material and thin dark oxidation halos, abundant forams, abundant spicules, abundant rads. 1m above a tuff (G108).
Rads - TL slide. Forams - mounted slide.
- MS15 S27/f516 S27/18518173 N165/99241509 JAA348 MANG14 JNA 06-04-80
Massive, grey-green mudstone (2.2%), black carbonaceous specks, abundant forams, abundant rads, abundant spicules, glass shards present. Between two tuffs (G108 and G107).
Rads - TL slide, SEM stub. Forams - mounted slide.

MS16 S27/f517 S27/18518167 N165/99241502 JAA352 MANG13 JNA 06-04-80
Massive, grey-green mudstone (1.8%), black carbonaceous specks, thin carbonaceous fragments up to 7mm long, common rads, common forams, abundant spicules, glass shards present. 1m below a tuff (G107).

Rads - TL slide, SEM stub. Forams - mounted slide.

MS17 S27/f518 S27/18558164 N165/99291499 JAA353 MANG9 JNA 06-04-80
Massive, grey-green mudstone (1.8%), abundant forams, common spicules, rads rare (etched).

Forams - mounted slide.

MS18 S27/f519 S27/18608164 N165/99341499 JAA354 MANG8 JNA 06-04-80
Massive, grey-green mudstone (1.6%) mottled brown-yellow in patches, black carbonaceous specks up to 3mm long, common rads (etched), common forams, common spicules.

Rads - TL slide, SEM stub. Forams - mounted slide.

MS19 S27/f520 S27/18648159 N165/99391494 JAA355 MANG7 JNA 06-04-80
Massive, light grey-green mudstone (3.4%), brown and black carbonaceous specks, spicules present, forams present, rads present. Oldest rad bearing sample in section.

Rads - TL slide, SEM stub. Forams - mounted slide.

MS20 S27/f521 S27/18728161 N165/99471496 JAA356 MANG6 JNA 06-04-80
Massive, grey-green mudstone (3.1%), black carbonaceous specks, brown oxidation patches up to 2mm, common forams, spicules present, no rads.

Forams - mounted slide.

B.18 PALLISER BAY SECTION

PB01 S28/f75 S28/94037383 N165/72590572 JAA155 PB1 JNA 10-05-79
Massive, grey-green mudstone (9.2%), common forams, no rads.

Forams - mounted slide.

PB02 S28/f76 S28/94107377 N165/72670565 JAA156 PB2 JNA 10-05-79
Massive, grey-green mudstone (2.1%), black carbonaceous specks up to 0.5mm, abundant forams, abundant spicules, glass shards present. Youngest sample in rad horizon.

Rads - TL slide, SEM stub. Forams - mounted slide.

PB03 S28/f77 S28/94167371 N165/72730560 JAA157 PB3 JNA 10-05-79
Massive, grey-green mudstone (2.9%), abundant forams common spicules, glass shards present.

Rads - SEM stub. Forams - mounted slide.

PB04 S28/f78 S28/94227367 N165/72820555 JAA158 PB4 JNA 10-05-79
Massive, grey-green mudstone (2.2%), black carbonaceous specks, common forams, spicules present, glass shards present.

Rads - TL slide, SEM stub. Forams - mounted slide.

PB05 S28/f79 S28/94257362 N165/72860550 JAA159 PB5 JNA 10-05-79
Massive, grey-green mudstone (2.7%), black carbonaceous specks, abundant forams, common spicules, glass shards present.

Rads - TL slide, SEM stub. Forams - mounted slide.

PB06 S28/f80 S28/94287359 N165/72890548 JAA160 PB6 JNA 10-05-79
Massive, grey-green mudstone (2.2%), black carbonaceous specks, abundant forams, abundant spicules, glass shards present.
Rads - TL slide, SEM stub. Forams - mounted slide.

PB07 S28/f81 S28/94317357 N165/72930545 JAA161 PB7A JNA 10-05-79
Massive, light grey-green mudstone (2.2%), abundant forams, abundant spicules, glass shards present. 3m above base of tuff dated at 7.27 ± 1.28 Ma (D. Seward, pers. comm.).
Rads - SEM stub. Forams - mounted slide.

PB08 S28/f82 S28/94317357 N165/72930545 JAA164 PB7D JNA 10-05-79
Massive, light grey-green mudstone (2.2%), abundant forams, abundant spicules, glass shards present. 10cm below base of dated tuff.
Rads - SEM stub. Forams - mounted slide.

PB09 S28/f115 S28/94317357 N165/72930545 JAA165 PB7E JNA 10-05-79
Massive, grey-green mudstone (2.1%), abundant forams, diatoms present, black carbonaceous specks some with oxidation halos up to 5mm, spicules present, glass shards present. 1m below base of dated tuff.
Rads - TL slide.

PB10 S28/f83 S28/94317357 N165/72930545 JAA166 PB7F JNA 10-05-79
Massive, grey-green mudstone (4.2%), brown carbonaceous specks, some tuffaceous burrows up to 5mm diameter and 2cm long, common forams, common spicules. 3m below base of dated tuff.
Rads - SEM stub. Forams - mounted slide.

PB11 S28/f84 S28/94457347 N165/73110536 JAA167 PB8 JNA 10-05-79
Massive, grey-green mudstone (5.5%), black carbonaceous specks, tuffaceous, common forams, common spicules. Oldest rad bearing sample in the section.
Rads - TL slide, SEM stub. Forams - mounted slide.

B.19 LEADER RIVER TRIBUTARY SECTION

LT01 O32/f67 O32/31645006 S55/58377354 JAA508 LEAD9 JNA 04-01-81
Massive, grey-green mudstone (11.6%), micaceous, forams present, rads present, common spicules. Youngest rad bearing sample in section.
Rads - TL slide, SEM stub. Forams - mounted slide.

LT02 O32/f68 O32/31694997 S55/58437344 JAA507 LEAD10 JNA 04-01-81
Massive, grey-green sandy mudstone (14.3%), minor brown carbonaceous specks, glass shards present, common diatoms, rads rare (etched), rare forams, common spicules.
Forams - mounted slide.

LT03 O32/f69 O32/31794992 S55/58547338 JAA506 LEAD11 JNA 04-01-81
Massive, grey-green sandy mudstone (32.3%), rare forams, rads present (etched), glass shards present, common spicules, diatoms present.
Rads - SEM stub. Rads and forams - mounted slide.

LT04 O32/f70 O32/31834992 S55/58587338 JAA505 LEAD12 JNA 04-01-81
Massive, grey-green sandy mudstone (18.5%), thin carbonaceous fragments, forams present, rare spicules.
Forams - mounted slide.

LT05 O32/f71 O32/31864991 S55/58617337 JAA504 LEAD13 JNA 04-01-81
Massive, light grey-green mudstone (7.1%), brown carbonaceous specks, tuffaceous, common forams (iron stained), common rads, common spicules.
Rads - TL slide, SEM stub. Forams - mounted slide.

LT06 O32/f72 O32/31904990 S55/58657336 JAA503 LEAD14 JNA 04-01-81
Massive, light grey-green mudstone (9.3%), glass shards present, common forams, common rads, common spicules.
Rads - TL slide, SEM stub. Forams - mounted slide.

LT07 O32/f73 O32/31914990 S55/58677336 JAA502 LEAD3 JNA 04-01-81
Massive, light grey-green mudstone (10.8%), some oxidation halos up to 3mm, glass shards present, forams present, rads rare, common spicules. 3m above a tuff (G20).
Rads - SEM stub. Rads and forams - mounted slide.

LT08 O32/f74 O32/31914990 S55/58677336 JAA501 LEAD2 JNA 04-01-81
Massive, light grey-green sandy mudstone (19.4%), rare black carbonaceous specks, glass shards present, abundant forams, abundant spicules, common rads. Immediately below a tuff (G20).
Rads - TL slide, SEM stub. Forams - mounted slide.

LT09 O32/f75 O32/31914990 S55/58677336 JAA500 LEAD1 JNA 04-01-81
Massive, grey-green mudstone (9.4%), carbonaceous streaks with oxidation halos, abundant forams, common spicules, common rads. 2m below a 1.8m thick tuff (G20). Oldest rad bearing sample in section.
Rads - TL slide, SEM stub. Forams - mounted slide.

B.20 WAIMATA VALLEY SITE

SWM1 Y17/f29 Y17/487830 N98/416516 JAA796 WAIM1 GJG 10-02-82
Indurated, massive, grey-green mudstone (4.0%), white speckled patches (1-2cm), some mollusca, common forams, common spicules, rads present, sterrasters common. 0.5m above a 2-3cm tuff.
Rads - TL slide. Forams - mounted slide.

B.21 CAVES ROAD SITE

SCV1 Y18/f169 Y18/497739 N98/430417 JAA824 C7 GHS 18-02-82
Massive, grey-green mudstone (3.8%), common spicules, common rads, forams present (recrystallised), glass shards present.
Rads - TL slide, SEM stub. Forams - mounted slide.

B.22 WAIROA - NUHAKA ROAD SITES

SWN1 X19/f73 X19/030311 N116/932934 JAA448 K8 JNA 11-08-80
Massive, grey-green mudstone (2.7%), iron-stained along joints, glass shards present, common spicules, abundant forams, rads present, diatoms present. 0.5m above a 2-4cm tuff.
Rads and forams - mounted slide.

SWN2 X19/f72 X19/037309 N116/940932 JAA446 K6 JNA 11-08-80
Massive, grey-green mudstone (2.8%), minor black carbonaceous specks, abundant forams, glass shards present, common spicules, diatoms present, rads present. 0.2m below a 1-10cm tuff.
Rads - SEM stub. Rads and forams - mounted slide.

SWN3 X19/f71 X19/048304 N116/952927 JAA654 K5 JNA 11-08-80
Massive, grey-green mudstone (5.6%), common forams, common rads, spicules present, diatoms present, carbonaceous.
Rads - SEM stub. Rads and forams - mounted slide.

B.23 MAHIA PENINSULA SITE

SMH1 Y19/f27 Y19/307238 N116/237862 JAA270 2 NBH 03-02-80
Massive, grey-green mudstone (3.0%), tuffaceous, abundant rads, abundant forams, common spicules. 3.0m below a tuff dated at 6.39 ± 1.14 Ma (D. Seward, pers. comm.).
Rads - TL slide. Forams - mounted slide.

B.24 WAINUIORU VALLEY SITES

SWR1 T26/f167 T26/48091639 N162/30495390 JAA811 147 MPC 29-10-81
Massive, grey-green mudstone (0.7%), black carbonaceous specks, pyritic, common rads, abundant forams, common spicules.
Rads - TL slide. Forams - mounted slide.

SWR2 T26/f168 T26/47851662 N162/30225414 JAA812 148 MPC 29-10-81
Massive, grey-green mudstone (0.8%), black carbonaceous specks, micaceous, glauconitic, tuffaceous, abundant forams, diatoms present, spicules present, rads present.
Rads - TL slide. Forams - mounted slide.

SWR3 T26/f132 T26/43841133 N162/26004823 JAA809 112 MPC 18-09-81
Massive, grey-green mudstone (0.5%), black carbonaceous specks, pyritic, abundant forams, abundant rads (some etched), common spicules. 1.3m below the base of a tuff.
Rads - TL slide. Forams - mounted slide.

SWR4 T26/f142 T26/45501267 N162/27784975 JAA810 122 MPC 22-09-81
Massive, grey-green mudstone (2.1%), glauconitic, rare ostracods, abundant forams, common spicules (some etched), common rads.
Rads - TL slide, SEM stub. Forams - mounted slide.

SWR5 T26/f230 T26/479147 N162/304521 JAA302 STRON20 JNA 06-04-80
Massive, grey-green mudstone (3.9%), minor brown carbonaceous specks, common forams, rads rare (etched), carbonaceous. 3.5m above the Brancepeth Tuff. Top of a graded bed in a sequence of slightly graded beds (1-2m thick).
Rads and forams - mounted slide.

B.25 MILLERS ROAD SITES

SMR1 S27/f149 S27/285052 N162/094411 JAA002 MR2 JNA 19-06-78
Massive, grey-green mudstone (0.6%), common spicules, common forams, rads present.
Rads - TL slide, SEM stub. Forams - mounted slide.

SMR2 S27/f153 S27/285053 N162/094412 JAA006 H1 JNA 09-05-78
Massive, grey-brown-yellow mottled mudstone (0.7%), common rads, spicules present, no forams.
Rads - SEM stub.

B.26 MANGAOPARI-WHAKAPUNI AREA SITES

SMA1 S27/f557 S27/188850 N165/995187 JAA761 FT1 JNA 26-02-82
Indurated, massive, grey-brown mudstone (7.6%), bioturbated (mm-scale), tuffaceous, common forams, common spicules, common rads. 50cm above a thin tuff.
Rads - TL slide, SEM stub. Forams - mounted slide.

SMA2 S27/f558 S27/187854 N165/993191 JAA762 FT2 JNA 26-02-82
Massive, grey-green mudstone (5.8%), abundant rads, glass shards present (some etched), abundant forams, abundant spicules. Occasional thin layers of glauconitic sandstone. 1m below a tuff.
Rads - SEM stub. Rads and forams - mounted slide.

SMA3 S27/f196 S27/200849 N166/008186 JAA078 MF9 MEF 10-03-79
Massive, grey-green mudstone (5.9%), common forams, common rads.
Rads - TL slide, SEM stub. Forams - mounted slide.

SMA4 S27/f98 S27/191838 N165/998174 JAA096 3/16 DAH 11-03-78
Massive grey-brown mudstone (2.3%), brown carbonaceous specks, pyritic, abundant rads.
Rads - TL slide, SEM stub.

SMA5 S27/f111 S27/174805 N165/981137 JAA098 X2 JDC 18-03-78
Massive, grey-green mudstone (1.6%), black carbonaceous specks up to 2mm with 5mm oxidation halos, abundant forams, common spicules, rads present.
Rads - TL slide, SEM stub. Forams - mounted slide.

SMA6 S27/f112 S27/175804 N165/982136 JAA099 JDC 18-03-78
Massive, grey-green mudstone (4.3%), black carbonaceous specks up to 2mm with 5mm oxidation halos, rads present, spicules present, common forams.
Rads - TL slide. Forams - mounted slide.

B.27 NORTH OF LEADER SITE

SPA1 O32/f79 O32/322505 S55/590740 JAA517 NLEAD2 GJG 04-01-81

Massive, grey-brown-yellow mottled sandy mudstone (15.5%), black carbonaceous specks up to 2mm, tuffaceous, forams present, rads present, abundant spicules. Immediately below a tuff (G21).

Rads - TL slide. Forams - mounted slide.

Appendix C

TECHNIQUES PAPER

The following paper entitled:

Improvements in the technique for the extraction and statistical faunal analysis of radiolarians from Neogene mudstones.

was published in *Micropaleontology* 29 (4) : 146-149 in 1983.

Parts of this paper have been reproduced within Chapter Two to enhance the readability of that chapter.

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Improvements in the technique for the extraction and statistical faunal analysis of radiolarians from Neogene mudstones

ABSTRACT

Improvements in three aspects of standard radiolarian faunal analysis are: the use of monolen mesh for wet sieving to avoid contamination; the use of zinc bromide solution as a heavy liquid for best separation of radiolarians from sandy residues; and modifications of Moore's (1973) technique for mounting randomly dispersed radiolarian skeletons on microscope slides.

INTRODUCTION

Upper Miocene and Pliocene tuffaceous mudstones that crop out east of the main axial ranges of the North Island, New Zealand contain, in places, abundant fossil Radiolaria. I have used previously described methods for washing and mounting specimens (e.g., Riedel and Sanfilippo, 1977), with additional procedures for preventing contamination, for concentration and for making mounts of randomly dispersed specimens.

WET SIEVING

Wet sieving over brass or stainless steel meshes is preferred by most laboratories. At Scripps Institute of Oceanography, the meshes are cleaned after each use by washing in strong jets of water and rubbing vigorously with a paper towel to break and dislodge skeletons. The sieves have to be repaired fairly often (Riedel, personal communication). Furthermore, the composition and open pore structure of many radiolarian skeletons renders ineffective the common staining techniques used to detect contamination, such as dipping the mesh in methylene blue.

Baker (1951) described a technique by which cloth (organdy and silk) sieves were used for separating microfossils from muddy matrix. The advantages are reduction of damage owing to the cushioning effect of the cloth, and the ease of cleaning fabrics.

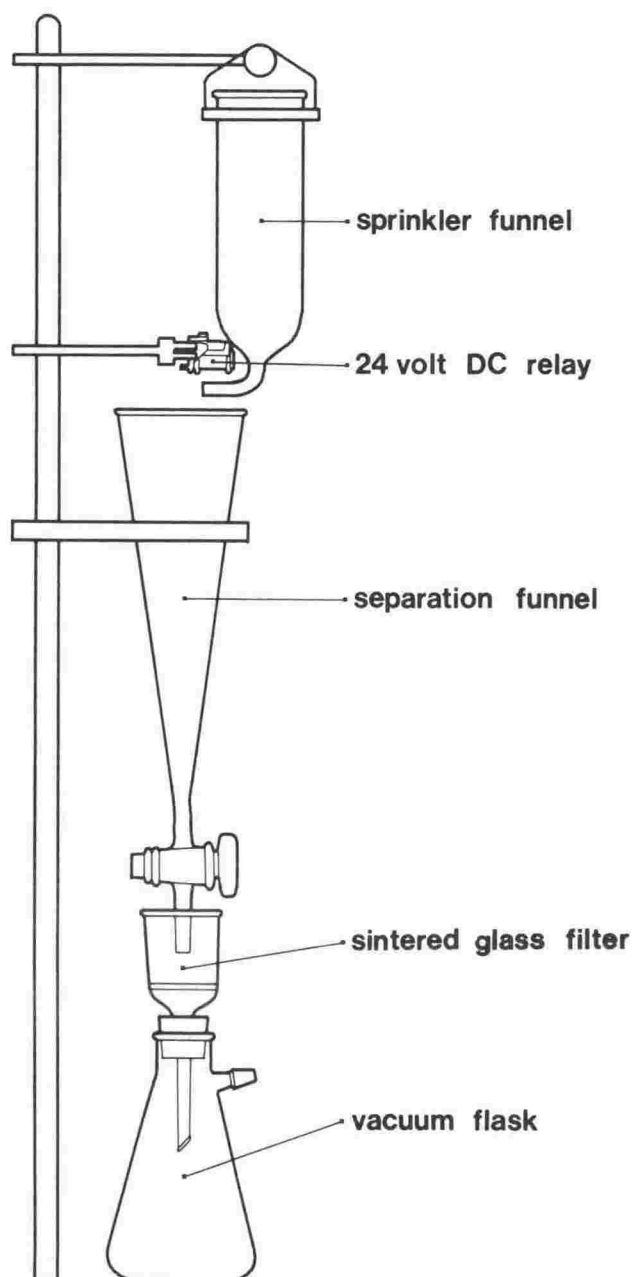
The technique described in the present paper involves the use of monolen mesh held taut in a PVC frame. Monolen is a polyester and nylon combination resistant to 40% hydrofluoric acid. In order to avoid contamination, the mesh is immersed in 20% aqueous hydrofluoric acid after each preparation, dissolving attached siliceous skeletons, then neutralized in a sodium bicarbonate solution. Monolen is very durable.

DENSITY SEPARATION USING ZINC BROMIDE SOLUTION

Residues of New Zealand Neogene mudstones almost always contain sand-sized inorganic mineral grains. In most cases the siliceous biogenic component is small, requiring concentration by density separation. As quantitative data on the radiolarians are required, the separate must be representative of the assemblage in the sample. Density separation, using a heavy liquid, is the usual method of concentration. Carbon tetrachloride has a maximum specific gravity of 1.6 at 20°C, which is insufficient for good specific gravity separations. Solutions of bromoform (tribromoethane) adjusted to a density of 2.2 to 2.4 are suitable for separating foraminiferal specimens (Gibson and Walker, 1967).

To concentrate radiolarian samples for quantitative analysis, flotation in aqueous solutions of zinc bromide has been found to be effective. Zinc bromide solution is commonly used in palynology, and Brady (1977) described its use for the flotation of diatom frustules. The maximum specific gravity obtainable at 18°C is 2.64. Its advantages over bromoform is that it is miscible in water, relatively non-toxic and more viscous, allowing for slower and therefore more accurate separation. Zinc bromide solutions are made up using 10% hydrochloric acid to prevent the precipitation of zinc hydroxide and discoloration of the solution by ferric ions from the residues. Hydrogen ions in the acid solutions transform ferric complexes into ferrous chloride, which is almost colorless (a slight yellow tinge may develop with use). The acid in the heavy liquid makes it unusable for foraminiferal flotation. The specific gravity of the zinc bromide solution is adjusted by evaporating or adding water.

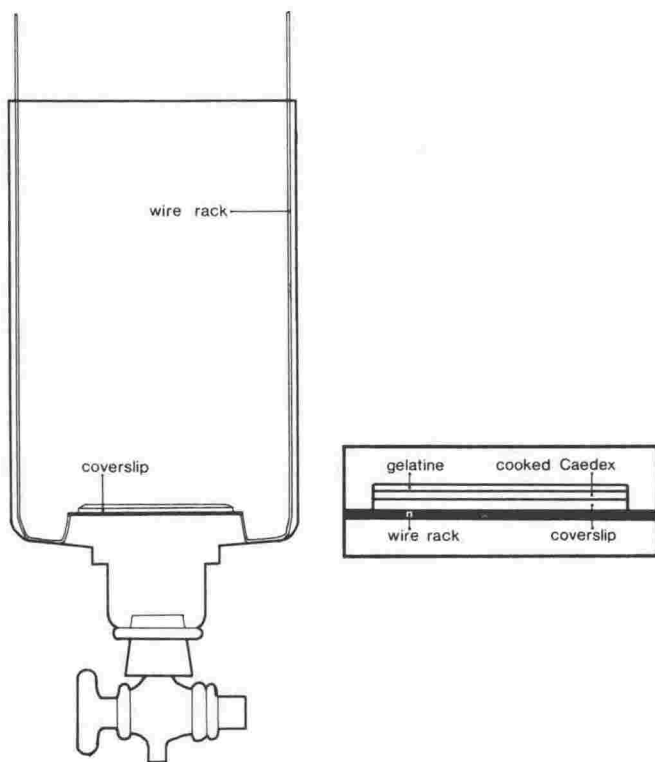
A split for radiolarian analysis is washed in dilute hydrochloric acid, then rinsed and dried. A separating funnel is used in a way similar to that described by Hecht (1933) (text-fig. 1). The separating funnel is filled with zinc bromide solution (specific gravity 2.3) and the acid-washed residue sprinkled onto the surface of the liquid, using a slow-feed device similar to that described by Faul and Davis (1959). The residue must be fed slowly into the heavy liquid to prevent radiolarians from being pushed to the bottom of the separating funnel. After separation is complete, the stopcock is opened and the heavy fraction is allowed to run off into a sintered glass filter placed on top of a vacuum flask. The zinc bromide solution is then vacuumed into the flask. Next, the heavy fraction is washed off the sintered glass filter with a jet of water. The filter is rinsed in acetone and dried. The light fraction that contains most of the radiolarians is then allowed to run off onto the glass filter, and the zinc bromide solution is vacuumed into the flask as before. The use of the vacuum flask enables approximately 99% of the heavy liquid to be retained without change in its specific gravity. The sintered glass filter that contains most of the light fraction is then placed on a different vacuum flask, and the rest of the light fraction left clinging to the sides of the funnel is washed through onto the filter with water from a wash bottle. The filtrant is returned to the wash bottle, and the filtrate is washed into a beaker with a jet of water. Filter paper cannot be used with zinc bromide solutions because the paper fibers swell and burst. In any case, filter papers should not be used to collect radiolarian residues, as the specimens tend to stick to the paper (Burma, 1965). Contamination from the sintered glass filter is eliminated by scrubbing the filter with a stiff 1-cm paintbrush and rinsing thoroughly after each sample treatment.



TEXT-FIGURE 1
Apparatus for heavy liquid separation.

MOUNTING TECHNIQUE

For quantitative work, the radiolarian residues are mounted in Caedex. The following method works equally well using Canada Balsam, but it is advisable to cook the balsam at a slightly lower temperature (85–90°C) than normal (100–110°C) and for a longer time. At the lower temperature the balsam remains slightly more fluid, making it easier to cover the slide without enclosing air bubbles.



TEXT-FIGURE 2
Cross section of settling container, showing positioning of coverslip.

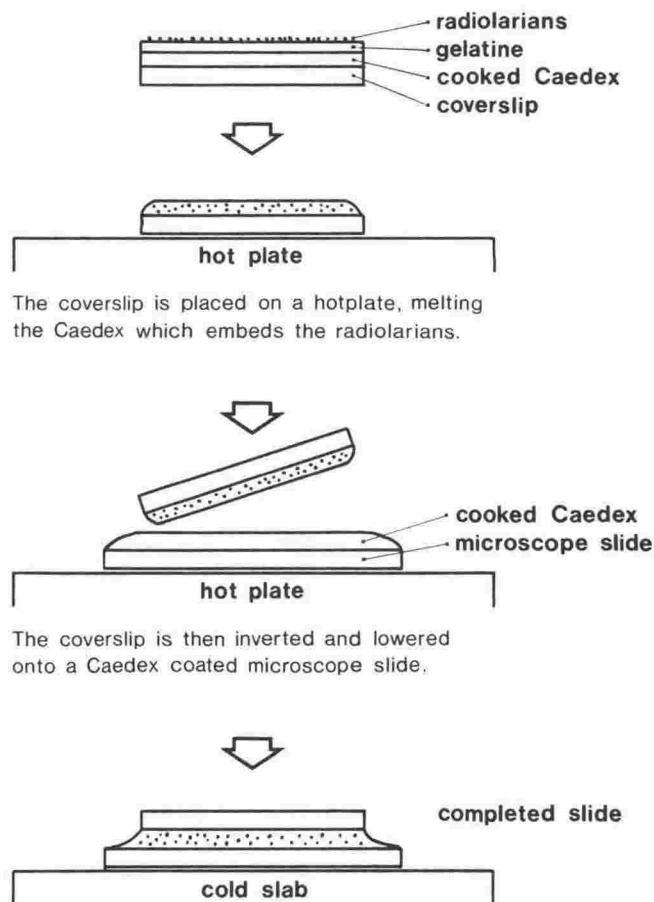
A common method is to pipette a drop of radiolarian skeletons in suspension in water onto a glass slide. However, the heavy skeletons sink to the bottom of the drop and remain at the center when the drop is placed on the slide, while delicate forms are carried to the sides. The distribution of skeletons on the slide cannot be randomized by stirring with a probe (Moore, 1973).

Radiolarian skeletons are too large for the spraying method of McIntyre et al. (1967). Moore (1973) described a more reliable method of achieving a random distribution of species, by settling the radiolarian skeletons onto a microscope slide from a water suspension. Moore's technique is as follows. A gelatin-coated slide is placed at the bottom of a container filled with water. The residue is placed in the water, which is then stirred with a vertical motion. The radiolarians are allowed to settle. Then all but 1 cm of water is siphoned out of the container, and the rest is dried under an infra-red lamp. When the surface of the slide is dry (in about two hours), the coverslip can be mounted using the preferred medium.

My modifications to the formerly developed technique include the use of a coverslip instead of a glass slide at the bottom of the settling container, the added presence of a thin film of cooked Caedex between the

gelatin and the coverslip, the use of a settling container with a stopcock at its base (text-fig. 2) and the use of a wire rack in the settling container.

The coverslip is prepared by smearing about five drops of a 1:10 Caedex to xylene mixture onto the coverslip and placing it on a hotplate. After the Caedex has been cooked and cooled, the surface is scored with fine emery paper, and a thin film of gelatin solution (10–20 mg in 50 ml of water) is brushed onto the Caedex. The gelatin solution is left to dry on the Caedex-coated coverslip, after which it is placed on the wire rack in the settling container. The container is then filled with water and the residue is added. The water is stirred with a vertical motion as recommended by Moore. After the specimens have settled onto the coverslip, the stopcock is opened and the container is emptied. No undue turbulence is created if the container is emptied slowly and the stopcock is closed to a drip as the falling water level reaches the surface of the coverslip, in order to avoid runoff carrying specimens off the slide. By releasing the water in this way specimens which have not sunk, owing to entrapment of air, are



TEXT-FIGURE 3
Diagram showing four stages involved in mounting coverslip onto glass slide.

deposited randomly on the coverslip. The wire rack is used to ease emplacement and removal of the coverslip from the bottom of the container.

After the water has been emptied from the container, the coverslip is removed and dried. The specimens are then glued to the gelatin. The coverslip is placed on a hot plate (text-fig. 3) and the skeletons drop into the melted Caedex. The coverslip can then be inverted without losing specimens. A slide is prepared with Caedex and the inverted coverslip lowered slowly onto it. Duplicate slides can be prepared either by splitting the radiolarian float or collecting and re-suspending the specimens that do not collect on the coverslip.

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Appendix D

PRESENCE AND ABSENCE DATA

This appendix tabulates the presence or absence of radiolarian species and varieties in the samples studied. Absence is indicated by a ' . ' and presence is indicated in two categories. A closed square ' ■ ' indicates positive occurrence and an open square ' □ ' tentative occurrence in that the identification may be based on a fragment or on badly corroded or recrystallised specimens.

The samples are arranged with sections and sites in north to south geographical order :

A73 - A79	East Cape, Waimata, Caves, Kaiti, Hangaroa
A80 - A86	Ruakituri, Mangapoike, Mahia
A87 - A93	Waiatai
A94 - A100	Wairoa-Nuhaka, Tahaenui, Waihua, Cricklewood
A101 - A107	Maraetotara, Wainuioru, Kourarau-Westmere
A108 - A114	Millers, Morrisons, Hinakura-Hikawera
A115 - A121	Ruamahanga, Whakapuni, Mangaopari sites
A122 - A128	Upper Mangaopari
A129 - A135	Palliser, north Leader, Leader

	EC01	EC02	EC03	EC04	SWM1	SCV1	KB01	KB02	KB03	KB04	HR01	HR02	HR03	HR04	HR05	HR06
Suborder SPUMELLARIA																
Family OROSPHAERIDAE																
Genus <i>OROPELEX</i>																
? <i>Oropelex</i> sp.	□
Family COLLOSPHAERIDAE																
Genus <i>COLLOSPHAERA</i>																
<i>C. cf. polygona</i>	□
<i>C. sp. aff. huxleyi</i>	.	■	.	■	.	■	■	■	.	■	■	■
<i>Collosphaera</i> sp. A
Genus <i>ACROSPHAERA</i>																
<i>A. spinosa echinoides</i>	■	□
<i>A. spinosa spinosa</i>	.	■	.	■	.	■	■	■	.	□
Genus <i>SIPHONOSPHAERA</i>																
<i>S. polysiphonia</i>
Genus <i>OTOSPHAERA</i>																
<i>O. polymorpha</i>
Family ACTINOMMIDAE																
Genus <i>ACTINOMMA</i>																
<i>A. antarcticum</i>	.	■	.	■	.	■	■	■	.	■	■	■
<i>A. cf. medianum</i>	■
<i>A. leptodermum</i>
<i>A. cf. leptodermum</i>	■	.
<i>A. polycanthum</i> group	.	■	.	■	■	■	■	■	■	■	■	■
Genus <i>CLADOCOCCUS</i>																
<i>C. dentata</i>	■
<i>C. stalactites</i>	.	.	.	■	□	.	□	.	.
Genus <i>CENOSPHAERA</i>																
<i>C. cristata</i>	.	■	.	■	■	□	□
<i>Cenosphaera</i> sp. A	■	■	.	■	.	■
<i>Cenosphaera</i> sp. B	■	■
<i>Cenosphaera</i> sp. C	■
<i>Cenosphaera</i> sp. D	.	■	.	.	□	.	■
Genus <i>ACANTHOSPHAERA</i>																
<i>A. dodecastyla</i>	.	.	.	□
<i>A. sp. A</i> : few spines	■	■	■	.	■
<i>A. sp. A</i> : many spines
<i>Acanthosphaera</i> sp. B	.	.	.	□	.	.	■	■	.	.

	EC01	EC02	EC03	EC04	SWM1	SCV1	KB01	KB02	KB03	KB04	HR01	HR02	HR03	HR04	HR05	HR06
Genus <i>HEXACONTIUM</i>																
<i>H. enthacanthum sensu stricto</i>	.	■	.	■	.	■	■	■	■	■
<i>H. enthacanthum</i> : oval form
<i>H. enthacanthum</i> : quadrate form	■	■	■
<i>H. enthacanthum</i> X <i>laevigatum</i>	.	■	.	■	.	.	■	■	■	.
<i>H. laevigatum sensu stricto</i>	.	□	.	■	■	.	■
<i>H. laevigatum</i> : oval form
<i>H. laevigatum</i> : quadrate form	■	■	.	■	■	.
<i>H. laevigatum</i> : long spined	■	■	.
Genus <i>THECOSPHERA</i>																
<i>T. cf. akitaensis</i>	■
<i>T. grecoi</i> group	.	■	□	■	■	■	■	■	.	■	■	■
Genus <i>PRUNULUM</i>																
<i>Prunulum</i> spp.	.	■	.	■	■	■	■	■	.	■	■	■
Genus <i>STYPTOSPHERA</i>																
<i>S. stupacea</i>	■
<i>S. spumacea</i>
Genus ' <i>STYLATRACTUS</i> '																
' <i>S. neptunus</i> forma. large pores	.	□	■	.	■	■	■	■	.	■	■	■
' <i>S. universus</i> : small pores	■	■	.	■
' <i>S. universus</i> : large pores	.	□	.	■	.	.	■
Genus ' <i>SPHAEROSTYLUS</i> '																
' <i>S.</i> sp. aff. <i>timmsi</i> : sensu Campbell	.	□	.	.	.	□	■	.	■	■	■
' <i>S.</i> sp. aff. <i>timmsi</i> : symmetrical
Genus ' <i>XIPHATRACTUS</i> '																
' <i>Xiphatractus</i> ' sp. A	■	□	.	.	.	■	.	■	■	.
Genus <i>PRUNOPYLE</i>																
? <i>P. antarctica</i>	.	■	.	■	■	■	■	■	■
<i>Prunopyle</i> sp. A	.	.	.	■	.	■	□	□	.	□	■	□
Genus <i>SPONGURUS</i>																
<i>S. pylomaticus</i>	.	.	.	□	.	□	■	.	.	□	.
<i>Spongurus</i> sp. A	.	■	.	■	■	■	■	□	.	.	.	■	.	.	■	■
Genus <i>SPONGOCORE</i>																
<i>S. puella</i>	.	■	.	■	■	■	■	■	■	■	■	■
<i>Spongocore</i> sp. A
Family PHACODISCIDAE																
Genus <i>HELIODISCUS</i>																
<i>H. asteriscus</i> : large pores	■	□	□	■	■	.
<i>H. asteriscus</i> : small pores	■	■	■	.	.	■	.	■	■	■	■	■
<i>H. asteriscus</i> : long spines	.	■
<i>H. cf. echiniscus</i>	■	■	.	.
<i>H. umbonatum</i>	■

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

	EC01	EC02	EC03	EC04	SWM1	SCV1	KB01	KB02	KB03	KB04	HR01	HR02	HR03	HR04	HR05	HR06
<i>D. antepenultima</i>	□	■	□	.	.
<i>D. antepenultima</i> X <i>laticonus</i>
<i>D. laticonus</i>	□	■	■	■	.
<i>D. virgineum</i> : non-constricted	■	■	■	■	.	■	.
<i>D. virgineum</i> : constricted	■	.	.
<i>D. virgineum</i> : tuberculate	■	.	.	.
<i>D. sp. A</i> : non-constricted	■	■	■	.	.	■	■	■	■	■	■
<i>D. sp. A</i> : constricted	□	.	■
<i>D. sp. A</i> : spherical
<i>D. sp. A</i> : narrow	■
<i>D. tetrathalmus tetrathalmus</i>	.	■	.	.	□

Genus *DIARTUS*

<i>D. hughesi</i> group	■	□	□	.
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Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

<i>A. cf. ypsilon</i>	■
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Genus *DICTYOCORYNE*

<i>D. profunda</i>	.	■	.	■	■	■	■	□	■	■	■	■	■	■	■	■
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Genus *HYMENIASTRUM*

<i>H. euclidis</i>	.	■	.	■	■	□	■	.
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Genus *SPONGASTER*

<i>S. pentas</i>	■
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Genus *STYLODICTYA*

<i>S. validispina sensu stricto</i>	.	■	.	■	■	■	■	■	■	■	■	■
<i>S. validispina</i> : spinose form	■	■	■	■
<i>S. validispina</i> : quadrate form	.	.	.	.	.	.	.	.	.	.	.	■	.	.	.	.
<i>S. cornuspira</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Genus *PORODISCUS*

<i>Porodiscus</i> sp. A : normal form	■	■	■	■	■	■	■	■	.	□	■	■	■	■	■	■
<i>Porodiscus</i> sp. A : spiral form	■	.	.
<i>Porodiscus</i> sp. B	.	□	.	■	.	■	■

Genus *STYLOCHLAMYDIUM*

<i>S. asteriscus</i>	■	.	.
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Genus *SPONGOTROCHUS*

<i>S. glacialis</i>	■	■	■	■	■	■	■	.	■	■	.	■	■	■	■	■
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Family PYLONIIDAE

Genus *HEXAPYLE*

<i>H. cf. dodecantha</i>	■	□	.	.
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Genus *TETRAPYLE*

<i>T. octacantha</i> group	.	■	.	■	■	■	■	■	.	■	■	■
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[illegible]

	EC01	EC02	EC03	EC04	SWM1	SCV1	KB01	KB02	KB03	KB04	HR01	HR02	HR03	HR04	HR05	HR06
Genus <i>THEOCALYPTRA</i>																
<i>T. bicornis</i>
<i>T. davisiana davisiana</i>	□	□	.
Genus <i>LAMPROMITRA</i>																
<i>L. butschlii</i>
<i>L. erosa</i>
<i>L. tiara</i> : flaring
<i>L. tiara</i> : U-shaped	□	.	.
Genus <i>THEOCAMPE</i>																
? <i>T. cf. mongolfieri</i>
Genus <i>EUCYRTIDIUM</i>																
<i>E. acuminatum</i>	■	■	■	.
<i>E. cienkowskii</i>	□	■	■	■	■	■	■
<i>E. hexagonatum</i>	.	□	.	■	.	□	■	□	□	■	.	■
<i>E. calvertense</i>	.	.	.	■	.	■	■	■	■	■	■	■
<i>E. calvertense</i> X <i>inflatum</i>
<i>E. inflatum</i>
<i>E. punctatum</i>	.	□	.	.	.	■	■	.	□	.	.	■	.	■	■	■
<i>E. cf. montiparum</i>	■	■
<i>Eucyrtidium</i> sp. A
<i>E. vincentense</i> : small pores
<i>E. vincentense</i> : large pores
Genus <i>STICHOCORYS</i>																
<i>S. peregrina</i>	.	■	.	■	■	■	■	■	■	■	■	■
<i>S. peregrina</i> X <i>delmontensis</i>	.	.	.	■	.	■	■	.	■	.	■
<i>S. delmontensis</i>	.	.	.	■	□	■	■	■	.	■	■	■
<i>Stichocorys</i> sp. A	■
Genus <i>GONDWANARIA</i>																
<i>G. dogeli</i> group	□
Genus ' <i>ARTOSTROBUS</i> '																
'A.' <i>pretabulatus</i>	■
Family PTEROCORYTHIDAE																
Genus <i>ANTHOCYRTIDIUM</i>																
<i>A. ehrenbergi pliocenica</i>	■	.	■	.	□
? <i>Anthocyrtidium</i> sp. A	■	■	■
<i>A. zanguebaricum</i>	□	■
Genus <i>LAMPROCYCLAS</i>																
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>
<i>Lamprocyclas</i> (?) sp. A	■	□	.	■	.	.
<i>Lamprocyclas</i> sp. B	■	□	.
<i>Lamprocyclas</i> sp. C	.	■	.	■	.	■	□	□	.	.	.	■	.	■	■	■
<i>Lamprocyclas</i> sp. C X D	■	■	.
<i>Lamprocyclas</i> sp. D	.	■	■	□	.	.	■	.
<i>Lamprocyclas</i> sp. E	□

	RK02	RK03	RK04	TM06	TM07	TM12	TM14	TM15	TM16	TM17	TM18	TM19	TM20	TM21	TM22	TM23	SMH1
Suborder SPUMELLARIA																	
Family OROSPHAERIDAE																	
Genus <i>OROPELEX</i>																	
? <i>Oropelex</i> sp.
Family COLLOSPHAERIDAE																	
Genus <i>COLLOSPHAERA</i>																	
<i>C. cf. polygona</i>
<i>C. sp. aff. huxleyi</i>	.	.	□	.	.	.	■	■	■	.	.	■	■	■	■	■	■
<i>Collosphaera</i> sp. A
Genus <i>ACROSPHAERA</i>																	
<i>A. spinosa echinoides</i>	.	.	.	■
<i>A. spinosa spinosa</i>	■	□	■	.	.	□	.	.	■	.	□
Genus <i>SIPHONOSPHAERA</i>																	
<i>S. polysiphonia</i>
Genus <i>OTOSPHAERA</i>																	
<i>O. polymorpha</i>	■	■	.	.	.
Family ACTINOMMIDAE																	
Genus <i>ACTINOMMA</i>																	
<i>A. antarcticum</i>	■	.	■	■	.	.	■	■	■	□	.	■	■	■	■	■	■
<i>A. cf. medianum</i>	■
<i>A. leptodermum</i>	.	.	.	■
<i>A. cf. leptodermum</i>	■	□	■	.	■	■	.
<i>A. polycanthum</i> group	■	■	■	■	.	■	□	■	■	.	■	■	■	■	■	■	■
Genus <i>CLADOCOCCUS</i>																	
<i>C. dentata</i>	□	■	□	.	□	.
<i>C. stalactites</i>	.	.	.	■	■	.	■	■	■	.	■	■	□
Genus <i>CENOSPHAERA</i>																	
<i>C. cristata</i>	□	.	.	■	.	.	.	□	.	.	.	□	□	□	□	.	□
<i>Cenosphaera</i> sp. A	.	■	■	.	.	.	■	■	■	.	.	■	■	.	.	■	.
<i>Cenosphaera</i> sp. B	.	■	■	■	.	.	■	.	■
<i>Cenosphaera</i> sp. C	.	.	.	□
<i>Cenosphaera</i> sp. D	■	.	■
Genus <i>ACANTHOSPHAERA</i>																	
<i>A. dodecastyla</i>	■	.
<i>A. sp. A</i> : few spines	■	■	□	.	.	.	■	■	□	.	.	□	■	□	■	.	.
<i>A. sp. A</i> : many spines	.	.	.	■
<i>Acanthosphaera</i> sp. B	.	.	.	□	■	□

[illegible]

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

	RK02	RK03	RK04	TM06	TM07	TM12	TM14	TM15	TM16	TM17	TM18	TM19	TM20	TM21	TM22	TM23	SMH1
<i>D. antepenultima</i>	■	□	■	.	□	■	□
<i>D. antepenultima</i> X <i>laticonus</i>
<i>D. laticonus</i>	■	.	□
<i>D. virgineum</i> : non-constricted	■	.	.	■	■	■	.	■	.
<i>D. virgineum</i> : constricted	■	■	■	.	.
<i>D. virgineum</i> : tuberculate	■	.	.	.	■	■	■	■	.	.
<i>D. sp. A</i> : non-constricted	■	■	■	.	□	.	■	■	■	.	■	■	■	■	■	■	■
<i>D. sp. A</i> : constricted	■
<i>D. sp. A</i> : spherical	.	■
<i>D. sp. A</i> : narrow
<i>D. tetrathalmus tetrathalmus</i>

Genus *DIARTUS*

<i>D. hughesi</i> group
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Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

<i>A. cf. ypsilon</i>
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Genus *DICTYOCORYNE*

<i>D. profunda</i>	■	■	■	■	.	.	■	■	■	.	.	■	■	■	■	■	■
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Genus *HYMENIASTRUM*

<i>H. euclidis</i>	.	.	■	□	.	.	.	□	.	.	.	■	.	.	□	.	.
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Genus *SPONGASTER*

<i>S. pentas</i>
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Genus *STYLODICTYA*

<i>S. validispina sensu stricto</i>	■	■	■	■	.	.	■	■	■	.	.	■	■	■	■	■	■
<i>S. validispina</i> : spinose form	■	■	■	.	■	.	.	.
<i>S. validispina</i> : quadrate form	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>S. cornuspira</i>	.	■	.	.	.	.	.	.	.	.	.	.	.	.	.	■	.

Genus *PORODISCUS*

<i>Porodiscus</i> sp. A : normal form	■	■	■	■	.	■	■	■	■	.	.	■	■	■	■	■	■
<i>Porodiscus</i> sp. A : spiral form	■	.
<i>Porodiscus</i> sp. B	.	.	.	□	.	.	■	■	■

Genus *STYLOCHLAMYDIUM*

<i>S. asteriscus</i>	.	■	■	.	■	■	■	.	.
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Genus *SPONGOTROCHUS*

<i>S. glacialis</i>	■	■	■	■	.	■	■	■	■	■	.	■	■	■	■	■	■
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Family PYLONIIDAE

Genus *HEXAPYLE*

<i>H. cf. dodecantha</i>	■	.	.
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Genus *TETRAPYLE*

<i>T. octacantha</i> group	.	■	□	■	.	.	■	■	■	.	.	■	■	■	■	■	□
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	RK02	RK03	RK04	TM06	TM07	TM12	TM14	TM15	TM16	TM17	TM18	TM19	TM20	TM21	TM22	TM23	SMH1
Genus <i>THEOCALYPTRA</i>																	
<i>T. bicornis</i>
<i>T. davisiana davisiana</i>	□	□	.	■	.	.
Genus <i>LAMPROMITRA</i>																	
<i>L. butschlii</i>
<i>L. erosa</i>	■
<i>L. tiara</i> : flaring	■	■	■	.	.
<i>L. tiara</i> : U-shaped	□	■	.
Genus <i>THEOCAMPE</i>																	
? <i>T. cf. mongolfieri</i>
Genus <i>EUCYRTIDIUM</i>																	
<i>E. acuminatum</i>	■	.	■	■	■	.	.	■	.	■	■	■	.
<i>E. cienkowski</i>	■	□	■	.	.	.	■	■	■	.	.	.	■	■	■	■	□
<i>E. hexagonatum</i>	■	□	.	.	.	□	■	□	■	.	.
<i>E. calvertense</i>	■	■	■	□	.	.	■	■	■	.	.	■	■	■	■	■	.
<i>E. calvertense</i> X <i>inflatum</i>	■	■
<i>E. inflatum</i>	.	.	□	.	.	.	■	■
<i>E. punctatum</i>	■	■	■	.	.	.	■	■	□	.	.	■	■	■	■	■	■
<i>E. cf. montiparum</i>	□	□	■	■	.	.
<i>Eucyrtidium</i> sp. A	□	□
<i>E. vincentense</i> : small pores	■	.
<i>E. vincentense</i> : large pores	■
Genus <i>STICHOCORYS</i>																	
<i>S. peregrina</i>	■	■	■	□	.	.	■	■	■	.	.	■	■	■	■	■	■
<i>S. peregrina</i> X <i>delmontensis</i>	■	■	■	.	.	.	■	■	■	.	.	■	■	■	■	■	□
<i>S. delmontensis</i>	■	■	■	.	.	.	■	■	■	.	.	■	□	■	■	■	.
<i>Stichocorys</i> sp. A	■	.	■
Genus <i>GONDWANARIA</i>																	
<i>G. dogeli</i> group
Genus ' <i>ARTOSTROBUS</i> '																	
'A' <i>pretabulatus</i>
Family <i>PTEROCORYTHIDAE</i>																	
Genus <i>ANTHOCYRTIDIUM</i>																	
<i>A. ehrenbergi pliocenica</i>	■	■	■	.	■	■	□
? <i>Anthocyrtidium</i> sp. A	■	■	.	.	.	■	□	■	■	■	.
<i>A. zanguebaricum</i>	■	□	■	■	.	.
Genus <i>LAMPROCYCLAS</i>																	
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>	□
<i>Lamprocyclas</i> (?) sp. A	□	.	□	.	.	.
<i>Lamprocyclas</i> sp. B	■	■	.	□	□	■	.
<i>Lamprocyclas</i> sp. C	■	■	□	.	.	.	■	.	■	.	.	■	■	■	■	■	■
<i>Lamprocyclas</i> sp. C X D	■	■	■	.	.	.	■	■	■	■	■	.
<i>Lamprocyclas</i> sp. D	.	.	■	□	.	.	■	■	.	.	■	.	.
<i>Lamprocyclas</i> sp. E	■	.	■	■	.

Suborder SPUMELLARIA

Family OROSPHAERIDAE

Genus *OROPELEX*

? *Oropelex* sp.

WA01 WA02 WA03 WA04 WA05 WA06 WA07 WA08 WA10 WA11 WA12 WA13 WA14 WA15 WA16 WA17 WA18 WA19 WA22 WA23 WA26

. ■

Family COLLOSPHAERIDAE

Genus *COLLOSPHAERA*

C. cf. polygona

C. sp. aff. huxleyi

Collosphaera sp. A

.

. □ □ □ □ □ .

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Genus *ACROSPHAERA*

A. spinosa echinoides

A. spinosa spinosa

■ ■ . . . ■ □ □

■

Genus *SIPHONOSPHAERA*

S. polysiphonia

. ■

Genus *OTOSPHAERA*

O. polymorpha

.

Family ACTINOMMIDAE

Genus *ACTINOMMA*

A. antarcticum

A. cf. medianum

A. leptodermum

A. cf. leptodermum

A. polycanthum group

■ ■ ■ ■ . . ■ . ■ . . ■ . ■ ■ ■ . ■ . ■ ■

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■ ■ ■ . . □ ■ □ ■ □ . ■ . ■ ■ ■ . □ . . □

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■ ■ ■ . . ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■

Genus *CLADOCOCCUS*

C. dentata

C. stalactites

.

. □ □ ■ □ . . . ■ . . .

Genus *CENOSPHAERA*

C. cristata

Cenosphaera sp. A

Cenosphaera sp. B

Cenosphaera sp. C

Cenosphaera sp. D

■ ■ ■ ■ . . ■ □ ■ . . ■ . □ ■ ■ . ■ . ■ ■

. □ □ □

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Genus *ACANTHOSPHERA*

A. dodecastyla

A. sp. A : few spines

A. sp. A : many spines

Acanthosphaera sp. B

. ■ □ .

□ □ ■ □ . ■ . ■ . .

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. ■ ■ . . . □ . . □ . . ■ ■ . . ■ . .

Family CARPOCANIIDAE

WA01
WA02
WA03
WA04
WA05
WA06
WA07
WA08
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WA11
WA12
WA13
WA14
WA15
WA16
WA17
WA18
WA19
WA22
WA23
WA26

Genus *LAMPROCYRTIS*

L. (?) apollinis

L. hannai

L. heteroporos

L. (?) junonis

L. (?) cf. junonis

WA01	WA02	WA03	WA04	WA05	WA06	WA07	WA08	WA10	WA11	WA12	WA13	WA14	WA15	WA16	WA17	WA18	WA19	WA22	WA23	WA26
.	.	□
.	■	.	.	□
.	.	□	.	.	.	■	■	.	■	.	■	.	■	□
.
.	■

Family ARTOSTROBIIDAE

Genus *BOTRYOSTROBUS*

B. aquilonaris

B. auritus-australis group

B. bramlettei

.	■	■	■	.
■	■	■	.	■	□	■	.	■	.	.	■	■	■	■	■	.	■	■	■	■
■	□	■	■	□	□	.	■	.	.	.

Genus *PHORMOSTICHOARTUS*

P. fistula

Phormostichoartus sp. A

.	■	■	.
.

Genus *SIPHOCAMPE*

S. arachnea group

S. lineata : strictured

S. lineata : smooth

S. nodosaria

.
.	.	□	□	□
□	■	■	□
.	■	■

Genus *SIPHOSTICHARTUS*

S. corona

.	□	□
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Genus *SPIROCYRTIS*

S. subscalaris

■	■	■	.	.	.	□	■	□	■	□	■	.	■	.
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Family CANNOBOTRYIDAE

Genus *BOTRYOPYLE*

B. dictyocephalus sensu stricto

B. dictyocephalus : large lobe

.	■	■	■	□	■
.	■

[illegible]

[illegible]

	SWN1	SWN2	SWN3	TK05	WH01	WH02	WH03	WH04	WH05	WH06	WH07	CR03	CR04
Family COCCODISCIDAE													
Genus <i>DIDYMOCYRTIS</i>													
<i>D. antepenultima</i>
<i>D. antepenultima</i> X <i>laticonus</i>
<i>D. laticonus</i>
<i>D. virgineum</i> : non-constricted	■	.
<i>D. virgineum</i> : constricted
<i>D. virgineum</i> : tuberculate
<i>D. sp. A</i> : non-constricted
<i>D. sp. A</i> : constricted
<i>D. sp. A</i> : spherical
<i>D. sp. A</i> : narrow
<i>D. tetralthmus tetralthmus</i>
Genus <i>DIARTUS</i>													
<i>D. hughesi</i> group
Family SPONGODISCIDAE													
Genus <i>AMPHIRHOPALUM</i>													
<i>A. cf. ypsilon</i>	■	.	.	■	.	■	.
Genus <i>DICTYOCORYNE</i>													
<i>D. profunda</i>	■	.	.	■	.	.	■	□	.	■	■	■	□
Genus <i>HYMENIASTRUM</i>													
<i>H. euclidis</i>	.	□	■	.
Genus <i>SPONGASTER</i>													
<i>S. pentas</i>
Genus <i>STYLODICTYA</i>													
<i>S. validispina sensu stricto</i>	■	.	.	■	.	.	■	.	■	■	.	■	■
<i>S. validispina</i> : spinose form
<i>S. validispina</i> : quadrate form
<i>S. cornuspira</i>
Genus <i>PORODISCUS</i>													
<i>Porodiscus</i> sp. A : normal form	■	■	■	■	.	■	■	.	.	■	■	■	■
<i>Porodiscus</i> sp. A : spiral form
<i>Porodiscus</i> sp. B	□	□	.
Genus <i>STYLOCHLAMYDIUM</i>													
<i>S. asteriscus</i>	■
Genus <i>SPONGOTROCHUS</i>													
<i>S. glacialis</i>	■	■	■	■	.	■	■	■	■	■	■	■	.
Family PYLONIIDAE													
Genus <i>HEXAPYLE</i>													
<i>H. cf. dodecantha</i>
Genus <i>TETRAPYLE</i>													
<i>T. octacantha</i> group	.	.	■	□	.	.	■	.	.	■	.	■	.

[illegible]

[illegible]

[illegible]

[illegible]

	MT04	MT05	MT06	MT07	MT08	MT09	MT10	SWR1	SWR2	SWR3	SWR4	SWR5	KW01	KW02	KW03	KW04	KW05
Suborder SPUMELLARIA																	
Family OROSPHAERIDAE																	
Genus <i>OROPELEX</i>																	
? <i>Oropelex</i> sp.
Family COLLOSPHAERIDAE																	
Genus <i>COLLOSPHAERA</i>																	
<i>C. cf. polygona</i>
<i>C. sp. aff. huxleyi</i>	■	.	.	.	■	■	■	.	.	.	□
<i>Collosphaera</i> sp. A
Genus <i>ACROSPHAERA</i>																	
<i>A. spinosa echinoides</i>	□
<i>A. spinosa spinosa</i>	■	.	■	□
Genus <i>SIPHONOSPHAERA</i>																	
<i>S. polysiphonia</i>	■
Genus <i>OTOSPHAERA</i>																	
<i>O. polymorpha</i>
Family ACTINOMMIDAE																	
Genus <i>ACTINOMMA</i>																	
<i>A. antarcticum</i>	■	■	■	■	■	■	■	■	■	.	■
<i>A. cf. medianum</i>	■
<i>A. leptodermum</i>	□	□
<i>A. cf. leptodermum</i>	.	.	.	□	□	■
<i>A. polycanthum</i> group	■	.	.	■	■	■	■	■	■	■	■	.	■
Genus <i>CLADOCOCCUS</i>																	
<i>C. dentata</i>	■	■
<i>C. stalactites</i>
Genus <i>CENOSPHAERA</i>																	
<i>C. cristata</i>	■	.	.	■	■	■	■	□	■	■	■
<i>Cenosphaera</i> sp. A
<i>Cenosphaera</i> sp. B	□	□	■	■	□	□
<i>Cenosphaera</i> sp. C
<i>Cenosphaera</i> sp. D	■	□
Genus <i>ACANTHOSPHERA</i>																	
<i>A. dodecastyla</i>	■
<i>A. sp. A</i> : few spines	□	■	■	.	■
<i>A. sp. A</i> : many spines	■
<i>Acanthosphaera</i> sp. B

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

<i>D. antepenultima</i>	□	.	.	.	■	■	■	.	.	.	.	■	.	.	.	.	.	.	.
<i>D. antepenultima</i> X <i>laticonus</i>	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>D. laticonus</i>	.	.	.	.	■	□	.	.	.	.	.	□	.	.	.	.	.	.	.
<i>D. virgineum</i> : non-constricted	.	.	.	.	■	■	■	.	.	.	■	.	.	.	.	.	.	.	.
<i>D. virgineum</i> : constricted	■	.	.	.	.	.	.	.	.	.	.	■	.	.	.	.	.	.	.
<i>D. virgineum</i> : tuberculate	■	.	.	.	.	.	.	.	.	.	.	■	.	.	.	.	.	.	.
<i>D. sp. A</i> : non-constricted	■	.	■	■	■	■	■	.	.	.	.	■	.	.	.	.	.	.	.
<i>D. sp. A</i> : constricted	■	.	.	■	■	■	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>D. sp. A</i> : spherical	■	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>D. sp. A</i> : narrow	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>D. tetralthalmus tetralthalmus</i>	.	.	.	.	.	.	.	.	.	.	■	□	.	.	.	.	.	.	.

Genus *DIARTUS*

D. hughesi group □

Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

A. cf. ypsilon □

Genus *DICTYOCORYNE*

D. profunda ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ . ■ ■ ■ ■ .

Genus *HYMENIASTRUM*

H. euclidis ■ . □

Genus *SPONGASTER*

S. pentas

Genus *STYLODICTYA*

<i>S. validispina sensu stricto</i>	■	□	.	■	■	■	■	■	■	■	■	■	■	□	.	.	.	□	.
<i>S. validispina</i> : spinose form	.	.	.	.	■	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>S. validispina</i> : quadrate form	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>S. cornuspira</i>	.	.	.	.	.	.	.	.	.	.	■	.	.	.	.	.	.	.	.

Genus *PORODISCUS*

Porodiscus sp. A : normal form ■ . ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ . ■ ■
Porodiscus sp. A : spiral form
Porodiscus sp. B □

Genus *STYLOCHLAMYDIUM*

S. asteriscus ■ □

Genus *SPONGOTROCHUS*

S. glacialis

Family PYLONIIDAE

Genus *HEXAPYLE*

H. cf. dodecantha □ . . . □ ■

Genus *TETRAPYLE*

T. octacantha group ■ . . ■ ■ ■ □ ■ ■ ■ ■

	MT04	MT05	MT06	MT07	MT08	MT09	MT10	SWR1	SWR2	SWR3	SWR4	SWR5	KW01	KW02	KW03	KW04	KW05
Family LARNACIDAE																	
Genus LARNACILLA																	
<i>L. typus</i>
Family THOLONIIDAE																	
Genus CUBOTHOLUS																	
<i>C. rhombicus</i>
Family LITHELIIDAE																	
Genus LITHELIUS																	
<i>L. minor</i>	■	.	.	■	■	■	■	■	■	■	■	.	□	.	.	□	.
<i>L. nautiloides</i>	■	.	.	■	□	■
<i>Lithelius</i> sp. A
<i>Lithelius</i> sp. B	■
Genus PYLOSPIRA																	
<i>P. octopyle</i>	■
Suborder NASSELLARIA																	
Family PLAGONIIDAE																	
Genus ANTARCTISSA																	
<i>A. antedenticulata</i>	□	■
<i>A. conradae</i>	.	.	.	■	■
<i>A. longa</i>
<i>A. strelkovi</i>
Genus LITHOMELISSA																	
(?) <i>L. setosa sensu stricto</i>
(?) <i>L. setosa</i> : tri-legged
Genus LOPHOPHAENA																	
<i>L. macrencephala</i> group	□	.	.	■	□	.	□	■	□
Family ACANTHODESMIIDAE																	
Genus DESMOSPYRIS																	
<i>D. rhodospyroides</i>	■	■
<i>D. sp. aff. rhodospyroides</i>	■
<i>Desmospyris</i> (?) sp. A.
Genus GORGOSPYRIS																	
<i>G. sp. aff. perizostra</i>
Genus PHORMOSPYRIS																	
<i>P. stabilis antarctica</i> group	□	.	.	.	□	.	□	.	■	.	■
<i>P. stabilis scaphipes</i> group

[illegible]

	MT04	MT05	MT06	MT07	MT08	MT09	MT10	SWR1	SWR2	SWR3	SWR4	SWR5	KW01	KW02	KW03	KW04	KW05
Genus <i>THEOCALYPTRA</i>																	
<i>T. bicornis</i>
<i>T. davisiana davisiana</i>	□
Genus <i>LAMPROMITRA</i>																	
<i>L. butschlii</i>	□
<i>L. erosa</i>
<i>L. tiara</i> : flaring	■
<i>L. tiara</i> : U-shaped
Genus <i>THEOCAMPE</i>																	
? <i>T. cf. mongolfieri</i>
Genus <i>EUCYRTIDIUM</i>																	
<i>E. acuminatum</i>	■	.	□
<i>E. cienkowskii</i>	■	.	■	■	■	■	■	■	■	□	□
<i>E. hexagonatum</i>	.	.	.	■	□
<i>E. calvertense</i>	■	■	.	■	■	■	■	■	■	.	■
<i>E. calvertense</i> X <i>inflatum</i>	■	.	■
<i>E. inflatum</i>	■	.	□	■
<i>E. punctatum</i>	■	.	.	■	■	■	.	■	■	.	■
<i>E. cf. montiparum</i>	□	■
<i>Eucyrtidium</i> sp. A	■
<i>E. vincentense</i> : small pores
<i>E. vincentense</i> : large pores
Genus <i>STICHOCORYS</i>																	
<i>S. peregrina</i>	■	■	.	■	■	■	■	■	■	■	■
<i>S. peregrina</i> X <i>delmontensis</i>	■	.	.	■	□	■	■	■	■	.	■
<i>S. delmontensis</i>	■	.	□	■	■	□
<i>Stichocorys</i> sp. A
Genus <i>GONDWANARIA</i>																	
<i>G. dogeli</i> group
Genus ' <i>ARTOSTROBUS</i> '																	
' <i>A.</i> <i>pretabulatus</i>	□
Family <i>PTEROCORYTHIDAE</i>																	
Genus <i>ANTHOCYRTIDIUM</i>																	
<i>A. ehrenbergi pliocenica</i>	■	.	.	■
? <i>Anthocyrtidium</i> sp. A	■	■
<i>A. zanguebaricum</i>
Genus <i>LAMPROCYCLAS</i>																	
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>	■	■	■
<i>Lamprocyclas</i> (?) sp. A	□	.	.	□
<i>Lamprocyclas</i> sp. B
<i>Lamprocyclas</i> sp. C	□	.	.	■	□	■	■	■	■	■
<i>Lamprocyclas</i> sp. C X D
<i>Lamprocyclas</i> sp. D	□	□	.	.	■	■
<i>Lamprocyclas</i> sp. E	□	■	.	.	■	■

[illegible]

Family LARNACIDAE

Genus LARNACILLA

L. typus

SMR1	SMR2	MO01	MO02	MO03	MO04	MO05	MO06	MO07	MO08	MO09	MO10	MO11	MO12	MO13	MO14	HH01	HH02	HH04
.

Family THOLONIIDAE

Genus CUBOTHOLUS

C. rhombicus

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Family LITHELIIDAE

Genus LITHELIUS

L. minor

L. nautiloides

Lithelius sp. A

Lithelius sp. B

■	.	□	■	■	.	■	■	□	.	.	□	■	.	■	□	.	□	.
□	.	.	□	■	.	■	□	□	.	.	■	■	.	.	■	.	.	.
.
.

Genus PYLOSPIRA

P. octopyle

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Suborder NASSELLARIA

Family PLAGONIIDAE

Genus ANTARCTISSA

A. antedenticulata

A. conradae

A. longa

A. strelkovi

.	■	■	■	.	.	.
.	.	.	■	■	.	■
.	.	.	■	■	.	.	■	.	.	■	■	■	■	■	■	.	.	.
■	.	.	■	.	.	■	■	.	.	■	■

Genus LITHOMELISSA

(?) *L. setosa sensu stricto*

(?) *L. setosa* : tri-legged

.	■	.	.	.	■
.	.	.	■	.	.	.	■	.	.	.	■	.	■

Genus LOPHOPHAENA

L. macrencephala group

■	.	.	■	□	.	■	■	■	.	.	■	■	.	■	■	.	.	.
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Family ACANTHODESMIIDAE

Genus DESMOSPYRIS

D. rhodospyroides

D. sp. aff. rhodospyroides

Desmospyris (?) sp. A.

.	.	■	.	■	.	■	■	■	■
.	.	.	■
.

Genus GORGOSPYRIS

G. sp. aff. perizostra

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Genus PHORMOSPYRIS

P. stabilis antarctica group

P. stabilis scaphipes group

■	.	.	■	.	.	■	■	.	.	■	■	.	■	■
.	■

	SMR1	SMR2	MO01	MO02	MO03	MO04	MO05	MO06	MO07	MO08	MO09	MO10	MO11	MO12	MO13	MO14	HH01	HH02	HH04
Genus <i>THEOCALYPTRA</i>																			
<i>T. bicornis</i>	■	■	■	■	■	■	.	.	.
<i>T. davisiana davisiana</i>	.	.	.	■	.	.	□	□	.	.	.	■	□
Genus <i>LAMPROMITRA</i>																			
<i>L. butschlii</i>	□	■	■
<i>L. erosa</i>
<i>L. tiara</i> : flaring	■
<i>L. tiara</i> : U-shaped	.	.	.	■	■	.	.	■	.	.	.
Genus <i>THEOCAMPE</i>																			
? <i>T. cf. mongolfieri</i>
Genus <i>EUCYRTIDIUM</i>																			
<i>E. acuminatum</i>	■	□	■	■
<i>E. cienkowskii</i>	□	.	.	■	■	.	■	■	■	.	■	■	■	.	■	■	.	.	.
<i>E. hexagonatum</i>	□
<i>E. calvertense</i>	■	.	■	■	□	■	■	■	■	.	□	■	■	.	■	■	.	.	.
<i>E. calvertense</i> X <i>inflatum</i>	■	■
<i>E. inflatum</i>	■
<i>E. punctatum</i>	■	■	■	□	□	■	■	■	■	□	□	■	■	.	■	■	.	.	.
<i>E. cf. montiparum</i>	.	.	.	■	.	.	■	■	.	.	.
<i>Eucyrtidium</i> sp. A	■
<i>E. vincentense</i> : small pores
<i>E. vincentense</i> : large pores
Genus <i>STICHOCORYS</i>																			
<i>S. peregrina</i>	□	.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	.	.	■
<i>S. peregrina</i> X <i>delmontensis</i>	.	.	.	■	.	■	■	.	■	.	■	■	.	.	■	■	.	.	.
<i>S. delmontensis</i>	.	.	■	■	■	.	□	■	■	.	.	■	■	.	■	■	.	.	.
<i>Stichocorys</i> sp. A
Genus <i>GONDWANARIA</i>																			
<i>G. dogeli</i> group	■
Genus ' <i>ARTOSTROBUS</i> '																			
'A.' <i>pretabulatus</i>
Family <i>PTEROCORYTHIDAE</i>																			
Genus <i>ANTHOCYRTIDIUM</i>																			
<i>A. ehrenbergi pliocenica</i>	.	.	.	■	■	□	■	■	■	.	□	■	■	.	■	■	.	.	.
? <i>Anthocyrtidium</i> sp. A	.	.	.	■	■	■	■	■	■	■	.	■	■	■	■	■	.	.	.
<i>A. zanguebaricum</i>	.	.	.	□	.	.	■	.	□	.	.	□	□	.	□	■	.	.	.
Genus <i>LAMPROCYCLAS</i>																			
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>	■
<i>Lamprocyclas</i> (?) sp. A	□	■
<i>Lamprocyclas</i> sp. B	.	.	■	□	□	.	■	.	.	□
<i>Lamprocyclas</i> sp. C	.	■	■	■	■	■	■	■	■	■	■	■	■	.	■	■	.	.	.
<i>Lamprocyclas</i> sp. C X D	.	.	.	■	.	.	■	.	.	■	■	■	■	.	■	■	.	.	.
<i>Lamprocyclas</i> sp. D	■	.	.	■	.	.	■	■	.	.	.	■
<i>Lamprocyclas</i> sp. E	.	.	■

Genus *LAMPROCYRTIS*

L. (?) apollinis

L. hannai

L. heteroporos

L. (?) junonis

L. (?) cf. junonis

SMR1	SMR2	MO01	MO02	MO03	MO04	MO05	MO06	MO07	MO08	MO09	MO10	MO11	MO12	MO13	MO14	HH01	HH02	HH04
.	.	.	■	■	.	■
.	.	.	■	.	.	■	□	.	■
.
.	■	■	.	.	■
.	■	.	.	.	■

Family ARTOSTROBIIDAE

Genus *BOTRYOSTROBUS*

B. aquilonaris

B. auritus-australis group

B. bramlettei

.	.	.	.	■	■	■	□	■	.	■	□	.	.	■	■	.	.	.
■	.	.	■	■	.	□	■	■
■	.	■	.	■	■	■	■	.	.	■	■	■	.	■	■	.	.	.

Genus *PHORMOSTICHOARTUS*

P. fistula

Phormostichoartus sp. A

■	.	.	□	■	.	■	■	.	□
.	□	■	■	.	.	■	■	.	□	■	■	.	.	.

Genus *SIPHOCAMPE*

S. arachnea group

S. lineata : strictured

S. lineata : smooth

S. nodosaria

.	.	.	.	■	□
.	.	■	■	.	.	■	■	■	.	.	■	■	■	■	■	.	.	.
.	.	.	■	.	■	■	.	■	.	.	■	■	.	■	■	.	.	.
.	.	.	■	.	■	.	.	□	.	.	■	.	.	■

Genus *SIPHOSTICHARTUS*

S. corona

.	■	.	.	■
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Genus *SPIROCYRTIS*

S. subscalaris

■	□	.	.	.	■	■	.	.	.	■	.	.	.	■	■	.	.	.
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Family CANNOBOTRYIDAE

Genus *BOTRYOPYLE*

B. dictyocephalus sensu stricto

B. dictyocephalus : large lobe

.	.	.	.	■	.	■	■	■	.	.	■	■	.	■	■	.	.	.
.	.	.	■	■	.	.	■	□	.	.	.

[illegible]

[illegible]

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

- D. antepenultima*
D. antepenultima X *laticonus*
D. laticonus
D. virgineum : non-constricted
D. virgineum : constricted
D. virgineum : tuberculate
D. sp. A : non-constricted
D. sp. A : constricted
D. sp. A : spherical
D. sp. A : narrow
D. tetrathalmus tetrathalmus

Genus *DIARTUS*

- D. hughesi* group

Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

- A. cf. ypsilon*

Genus *DICTYOCORYNE*

- D. profunda*

Genus *HYMENIASTRUM*

- H. euclidis*

Genus *SPONGASTER*

- S. pentas*

Genus *STYLODICTYA*

- S. validispina sensu stricto*
S. validispina : spinose form
S. validispina : quadrate form
S. cornuspira

Genus *PORODISCUS*

- Porodiscus* sp. A : normal form
Porodiscus sp. A : spiral form
Porodiscus sp. B

Genus *STYLOCHLAMYDIUM*

- S. asteriscus*

Genus *SPONGOTROCHUS*

- S. glacialis*

Family PYLONIIDAE

Genus *HEXAPYLE*

- H. cf. dodecantha*

Genus *TETRAPYLE*

- T. octacantha* group

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	WT02	WT03	WT04	WT05	SMA1	SMA2	SMA3	SMA4	SMA5	SMA6
<i>D. antepenultima</i>	.	.	□	.	■	.	□	.	■	.	■	■	.	□	.	□	.
<i>D. antepenultima</i> X <i>laticonus</i>	■
<i>D. laticonus</i>	■	.
<i>D. virgineum</i> : non-constricted	■	■	.	.	■	■	■	.	■	.	■	■	.	■	■	■	■
<i>D. virgineum</i> : constricted	.	.	■	■	■	.	.	.	■	.	■	■
<i>D. virgineum</i> : tuberculate	■	■	■
<i>D. sp. A</i> : non-constricted	.	.	■	.	■	■	■	.	■	.	.	■	.	□	■	.	■
<i>D. sp. A</i> : constricted	■	■
<i>D. sp. A</i> : spherical	■
<i>D. sp. A</i> : narrow	■	.	.	.	■
<i>D. tetrathalmus tetrathalmus</i>
<i>D. hughesi</i> group	■	■	.	.	.	■	.	.
<i>A. cf. ypsilon</i>
<i>D. profunda</i>	.	.	■	■	■	■	■	.	■	.	■	■	.	■	■	■	■
<i>H. euclidis</i>	.	.	.	□	■	■	.	.	.	□	.	.
<i>S. pentas</i>
<i>S. validispina sensu stricto</i>	.	.	■	■	■	■	■	.	■	.	■	■	.	■	■	■	■
<i>S. validispina</i> : spinose form	.	.	■	.	■	■
<i>S. validispina</i> : quadrate form	■
<i>S. cornuspira</i>	.	.	.	■	■	■
<i>Porodiscus</i> sp. A : normal form	.	■	■	■	■	■	■	.	■	.	■	■	■	■	■	■	■
<i>Porodiscus</i> sp. A : spiral form	■	■	.	.
<i>Porodiscus</i> sp. B	■	■	.	.
<i>S. asteriscus</i>	■	■	.	.	■	.	.
<i>S. glacialis</i>	.	■	■	■	■	■	■	■	■	.	■	■	■	■	■	■	■
<i>H. cf. dodecantha</i>
<i>T. octacantha</i> group	■	■	■	■	■	■	■	.	□	.	■	.	.	□	□	□	■

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	WT02	WT03	WT04	WT05	SMA1	SMA2	SMA3	SMA4	SMA5	SMA6
Family LARNACIDAE																	
Genus LARNACILLA																	
<i>L. typus</i>
Family THOLONIIDAE																	
Genus CUBOTHOLUS																	
<i>C. rhombicus</i>	□	□	.	.	.	□	.
Family LITHELIIDAE																	
Genus LITHELIUS																	
<i>L. minor</i>	.	.	■	■	□	■	■	.	■	.	□	■	.	■	■	■	■
<i>L. nautiloides</i>	.	.	■	■	□	□	□	■	.	□	■	.	□
<i>Lithelius</i> sp. A	■	■
<i>Lithelius</i> sp. B
Genus PYLOSPIRA																	
<i>P. octopyle</i>	■	■	.	.	.
Suborder NASSELLARIA																	
Family PLAGONIIDAE																	
Genus ANTARCTISSA																	
<i>A. antedenticulata</i>	■	■
<i>A. conradae</i>	■	■	.	.	.
<i>A. longa</i>	■	.	.	.	■	.	■	■
<i>A. strelkovi</i>	.	.	■	■	□	■	□
Genus LITHOMELISSA																	
(?) <i>L. setosa sensu stricto</i>	.	.	.	■	.	.	□
(?) <i>L. setosa</i> : tri-legged	■	■
Genus LOPHOPHAENA																	
<i>L. macrencephala</i> group	.	.	.	■	■	.	■	.	.	.	■	.	.	□	□	■	.
Family ACANTHODESMIIDAE																	
Genus DESMOSPYRIS																	
<i>D. rhodospyroides</i>	.	.	.	■	□	.	■	□	.	.	.	■	.
<i>D. sp. aff. rhodospyroides</i>	■	□	■	■	■
<i>Desmospyris</i> (?) sp. A.
Genus GORGOSPYRIS																	
<i>G. sp. aff. perizostra</i>	■
Genus PHORMOSPYRIS																	
<i>P. stabilis antarctica</i> group	.	.	.	■	■	■	■	.	■	.	■	■	.	■	.	.	.
<i>P. stabilis scaphipes</i> group	■	.	□

Genus *THEOCALYPTRA*

T. bicornis

T. davisiana davisiana

Genus *LAMPROMITRA*

L. butschlii

L. erosa

L. tiara : flaring

L. tiara : U-shaped

Genus *THEOCAMPE*

? *T. cf. mongolfieri*

Genus *EUCYRTIDIUM*

E. acuminatum

E. cienkowski

E. hexagonatum

E. calvertense

E. calvertense X *inflatum*

E. inflatum

E. punctatum

E. cf. montiparum

Eucyrtidium sp. A

E. vincentense : small pores

E. vincentense : large pores

Genus *STICHOCORYS*

S. peregrina

S. peregrina X *delmontensis*

S. delmontensis

Stichocorys sp. A

Genus *GONDWANARIA*

G. dogeli group

Genus '*ARTOSTROBUS*'

'*A.*' *pretabulatus*

Family *PTEROCORYTHIDAE*

Genus *ANTHOCYRTIDIUM*

A. ehrenbergi pliocenica

? *Anthocyrtidium* sp. A

A. zanguebaricum

Genus *LAMPROCYCLAS*

L. gamphonycha

L. maritalis sensu stricto

L. cf. maritalis

Lamprocyclas (?) sp. A

Lamprocyclas sp. B

Lamprocyclas sp. C

Lamprocyclas sp. C X D

Lamprocyclas sp. D

Lamprocyclas sp. E

	RM01	RM02	RM03	RM04	RM05	RM06	RM07	WT02	WT03	WT04	WT05	SMA1	SMA2	SMA3	SMA4	SMA5	SMA6
<i>T. bicornis</i>	.	.	□	□	■	■	■	.	.	.
<i>T. davisiana davisiana</i>	■	■	■
<i>L. butschlii</i>	■
<i>L. erosa</i>
<i>L. tiara</i> : flaring	.	.	.	■	.	■	■	.	.	.	■
<i>L. tiara</i> : U-shaped	■
? <i>T. cf. mongolfieri</i>
<i>E. acuminatum</i>	■	■	□	.	.	.	■	■	.	.	■	.	.
<i>E. cienkowski</i>	.	.	■	■	■	■	■	.	.	.	■	□	.	■	■	■	■
<i>E. hexagonatum</i>	.	.	.	□	.	■	□	□	□	.
<i>E. calvertense</i>	.	.	■	■	■	■	■	.	■	.	■	■	.	■	■	■	■
<i>E. calvertense</i> X <i>inflatum</i>	.	.	.	■	.	.	■
<i>E. inflatum</i>	■
<i>E. punctatum</i>	.	.	.	■	■	■	■	.	□	.	■	■	□	■	■	■	.
<i>E. cf. montiparum</i>	.	.	.	■	.	■	□
<i>Eucyrtidium</i> sp. A
<i>E. vincentense</i> : small pores
<i>E. vincentense</i> : large pores
<i>S. peregrina</i>	.	■	■	■	■	■	■	.	□	.	■	■	.	■	■	■	■
<i>S. peregrina</i> X <i>delmontensis</i>	.	.	■	■	.	■	■	■	.	■	■	.	.
<i>S. delmontensis</i>	.	.	.	■	■	■	■	.	.	.	■	□	.	■	■	■	■
<i>Stichocorys</i> sp. A
<i>G. dogeli</i> group	■	.	■
' <i>A.</i> ' <i>pretabulatus</i>	■
<i>A. ehrenbergi pliocenica</i>	.	■	■	■	■	■	■	.	.	.	■
? <i>Anthocyrtidium</i> sp. A	.	■	.	■	.	■	■	.	■	.	□	.
<i>A. zanguebaricum</i>	.	□	.	□	.	■	■	■	.	□	.	.	.
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>	.	.	.	■	■
<i>Lamprocyclas</i> (?) sp. A	.	■	.	.	□	.	□	■	.	.
<i>Lamprocyclas</i> sp. B	.	.	.	■	.	.	□	.	.	.	■
<i>Lamprocyclas</i> sp. C	.	■	■	■	■	■	■	.	■	.	■	■	.	■	■	■	.
<i>Lamprocyclas</i> sp. C X D	.	■	.	.	■	■	.	.	.
<i>Lamprocyclas</i> sp. D	.	.	■	.	.	■	■	.	.	.	■	■	.	.	.	■	.
<i>Lamprocyclas</i> sp. E	■	■	.	.	■	■	□	■

Genus *LAMPROCYRTIS*

L. (?) apollinis

L. hannai

L. heteroporos

L. (?) junonis

L. (?) cf. junonis

RM01	RM02	RM03	RM04	RM05	RM06	RM07	WT02	WT03	WT04	WT05	SMA1	SMA2	SMA3	SMA4	SMA5	SMA6
.	.	□	■	■
.	■	.	■	■	■	■	.	.	.	■
.
.	.	■	■	■	■	■
.

Family ARTOSTROBIIDAE

Genus *BOTRYOSTROBUS*

B. aquilonaris

B. auritus-australis group

B. bramlettei

.	.	■	■	■	■	■	■	■	■
.	.	.	.	■	■	■	.	■	□	■	■
.	.	.	■	■	■	■	.	.	.	■	■	.	■	■	■	.

Genus *PHORMOSTICHOARTUS*

P. fistula

Phormostichoartus sp. A

.	.	.	■	.	.	■	■
.	.	.	.	■	.	■	■	.	.

Genus *SIPHOCAMPE*

S. arachnea group

S. lineata : strictured

S. lineata : smooth

S. nodosaria

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.	.	.	■	■	■	■	.	.	.	■	■	.	■	.	.	■
.	.	.	.	■	■	■	.	■	.	.	■
.	.	.	.	■	.	■	.	.	.	■	■	□

Genus *SIPHOSTICHARTUS*

S. corona

.	■	.
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Genus *SPIROCYRTIS*

S. subscalaris

.	.	.	■	■	■	■	■	.	■	■	□	.
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Family CANNOBOTRYIDAE

Genus *BOTRYOPYLE*

B. dictyocephalus sensu stricto

B. dictyocephalus : large lobe

.	.	.	■	■	.	■	.	□	.	■	■	.	■	■	.	■
.	■	■	■	.	.	■

[illegible]

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

<i>D. antepenultima</i>	.	□	□	.	□	.	.	.	.	.	■	.	■	■	.	□	■
<i>D. antepenultima</i> X <i>laticonus</i>	.	.	.	.	■	.	.	■	.	.	■	.	.	.	.	.	.
<i>D. laticonus</i>	.	.	.	□	.	.	.	.	.	.	■	□	■	■	■	■	■
<i>D. virgineum</i> : non-constricted	.	■	■	■	■	■	.	.	.	.	■	■	.	.	■	■	■
<i>D. virgineum</i> : constricted	.	■	■	.	.	.	■	■	.	.	.	■	■	■	.	.	.
<i>D. virgineum</i> : tuberculate	.	.	.	.	■	.	.	.	.	.	.	■	.	.	.	.	.
<i>D. sp. A</i> : non-constricted	■	■	■	■	■	■	■	■	.	.	■	■	■	■	■	■	■
<i>D. sp. A</i> : constricted	.	.	.	.	.	.	■	.	.	.	■	.	■	■	.	.	.
<i>D. sp. A</i> : spherical	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>D. sp. A</i> : narrow	■	□	.	.	.
<i>D. tetralthalmus tetralthalmus</i>

Genus *DIARTUS*

<i>D. hugesi</i> group	■	■	.	■	□	.	■	■	.	.	□
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Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

<i>A. cf. ypsilon</i>
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Genus *DICTYOCORYNE*

<i>D. profunda</i>	■	■	■	■	■	■	■	■	.	□	■	■	■	■	■	■	■
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Genus *HYMENIASTRUM*

<i>H. euclidis</i>	□	■	■	.	□	■
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Genus *SPONGASTER*

<i>S. pentas</i>
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Genus *STYLODICTYA*

<i>S. validispina sensu stricto</i>	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
<i>S. validispina</i> : spinose form	.	■	■	.	.	■	■	■	■
<i>S. validispina</i> : quadrate form	.	■	■	.	.	.	■	.	.	.	.	.	.	.	■	.	.
<i>S. cornuspira</i>	.	.	■	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Genus *PORODISCUS*

<i>Porodiscus</i> sp. A : normal form	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
<i>Porodiscus</i> sp. A : spiral form	■	■	.	.	.
<i>Porodiscus</i> sp. B

Genus *STYLOCHLAMYDIUM*

<i>S. asteriscus</i>	.	.	■
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Genus *SPONGOTROCHUS*

<i>S. glacialis</i>	■	■	□	■	■	■	■	■	■	■	■	■	■	■	■	■	■
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Family PYLONIIDAE

Genus *HEXAPYLE*

<i>H. cf. dodecantha</i>	.	.	■
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Genus *TETRAPYLE*

<i>T. octacantha</i> group	.	■	■	■	■	■	■	■	.	■	■	■	■	■	□	.	■
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	MS02	MS03	MS04	MS05	MS06	MS07	MS08	MS09	MS10	MS11	MS12	MS13	MS14	MS15	MS16	MS18	MS19
Family LARNACIDAE																	
Genus <i>LARNACILLA</i>																	
<i>L. typus</i>
Family THOLONIIDAE																	
Genus <i>CUBOTHOLUS</i>																	
<i>C. rhombicus</i>	■	.	□
Family LITHELIIDAE																	
Genus <i>LITHELIUS</i>																	
<i>L. minor</i>	.	■	■	■	■	■	■	■	□	■	■	■	■	■	.	■	■
<i>L. nautiloides</i>	.	■	■	■	■	■	■	□	■	■	■	■	■	□	■	□	■
<i>Lithelius</i> sp. A	.	■	■	■
<i>Lithelius</i> sp. B	■	.
Genus <i>PYLOSPIRA</i>																	
<i>P. octopyle</i>	■	■	□	■	.
Suborder NASSELLARIA																	
Family PLAGONIIDAE																	
Genus <i>ANTARCTISSA</i>																	
<i>A. antedenticulata</i>	.	□	.	■	■	□	■	.	.	□	□	■	□
<i>A. conradae</i>	.	■	.	.	.	■	.	■	.	■	■	■	.	□	.	.	.
<i>A. longa</i>	.	.	■	.	.	■	■	.	.	■	■	■	■
<i>A. strelkovi</i>	.	■	■
Genus <i>LITHOMELISSA</i>																	
(?) <i>L. setosa sensu stricto</i>	□	■	■	.	.	□	■
(?) <i>L. setosa</i> : tri-legged	.	■	□	.	■	.	■	■	.	.	.
Genus <i>LOPHOPHAENA</i>																	
<i>L. macrencephala</i> group	.	■	■	□	■	□	■	□	■	■	□	■	■	■	.	.	.
Family ACANTHODESMIIDAE																	
Genus <i>DESMOSPYRIS</i>																	
<i>D. rhodospyroides</i>	.	.	□	.	.	.	■	■	.	.	.	□	.	.	■	■	■
<i>D. sp. aff. rhodospyroides</i>	■	□	□	■	■	■	■	.	.	■
<i>Desmospyris</i> (?) sp. A.
Genus <i>GORGOSPYRIS</i>																	
<i>G. sp. aff. perizostra</i>	■
Genus <i>PHORMOSPYRIS</i>																	
<i>P. stabilis antarctica</i> group	.	■	■	.	.	□	■	.	.	■	■	■	■	■	.	.	□
<i>P. stabilis scaphipes</i> group	.	.	□	.	■	.	.	■	.	□	.	.	■

Family CARPOCANIIDAE

Genus *CARPOCANARIUM*

C. papillosum

Carpocanarium sp. A

Genus *CARPOCANISTRUM*

C. sp. A : with terminal teeth

C. sp. A : toothless

C. sp. A : very constricted

Genus *CYSTOPHORMIS*

C. sp. A : with terminal teeth

C. sp. A : toothless

Cystophormis sp. B

Family THEOPERIDAE

Genus *CORNUTELLA*

C. profunda : three spines

C. profunda : six spines

Genus *PLECTOPYRAMIS*

P. dodecomma

Genus *PERIPYRAMIS*

P. cf. circumtexta

Genus *DICTYOPHIMUS*

D. hirundo group

Genus *PSEUDODICTYOPHIMUS*

P. gracilipes

Genus *LYCHNOCANIUM*

L. sp. aff. grande : vertical feet

L. sp. aff. grande : divergent feet

Genus *LYCHNOCANELLA*

L. conicum

Genus *ARCHIPILIUM*

A. macropus

Genus *CYRTOCAPSELLA*

C. japonica : inflated abdomen

C. japonica : rounded abdomen

C. tetrapera

Genus *CYRTOLAGENA*

C. laguncula sensu stricto

C. laguncula : spiralling form

Genus *STICHOPHORMIS*

S. cornutella

MS02 MS03 MS04 MS05 MS06 MS07 MS08 MS09 MS10 MS11 MS12 MS13 MS14 MS15 MS16 MS18 MS19

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Genus *THEOCALYPTRA*

T. bicornis

T. davisiana davisiana

MS02	MS03	MS04	MS05	MS06	MS07	MS08	MS09	MS10	MS11	MS12	MS13	MS14	MS15	MS16	MS18	MS19
.	□	■	.	.	.	■
.	■	■	■	■	□	■	■	□	□	.	.	□

Genus *LAMPROMITRA*

L. butschlii

L. erosa

L. tiara : flaring

L. tiara : U-shaped

.	□	■
.	■	.	■	□	.	□	.
.	□
.	■	■	.	□	■	■	.	.	.	■	■	■

Genus *THEOCAMPE*

? *T. cf. mongolfieri*

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Genus *EUCYRTIDIUM*

E. acuminatum

E. cienkowskii

E. hexagonatum

E. calvertense

E. calvertense X *inflatum*

E. inflatum

E. punctatum

E. cf. montiparum

Eucyrtidium sp. A

E. vincentense : small pores

E. vincentense : large pores

.	□	■	.	■	.	.	■	□	.	.	.	■
.	■	■	■	■	■	■	■	.	■	■	■	■	■	■	.	■
.	□	■	■	.	.	.	■	.	□	.	.	.
■	■	■	■	■	■	■	■	.	■	■	■	■	■	□	□	□
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.	.	□	.	.	■	■
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Genus *STICHOCORYS*

S. peregrina

S. peregrina X *delmontensis*

S. delmontensis

Stichocorys sp. A

■	■	■	■	■	■	■	■	□	■	■	■	■	■	■	□	■
.	■	.	■	■	.	■	.	□	.	■	■	■
.	.	■	.	.	.	■	■	.	.	■	■	■	■	.	□	■
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Genus *GONDWANARIA*

G. dogeli group

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Genus '*ARTOSTROBUS*'

'*A.* pretabulatus

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Family *PTEROCORYTHIDAE*

Genus *ANTHOCYRTIDIUM*

A. ehrenbergi pliocenica

? *Anthocyrtidium* sp. A

A. zanguebaricum

■	■	■	.	■	□	.	□	.	.	□	.	■	□	.	.	.
■	■	■	.	□	.	■	■	■	■	.	.	■
.	.	■	■	■	■	.	.

Genus *LAMPROCYCLAS*

L. gamphonycha

L. maritilis sensu stricto

L. cf. maritilis

Lamprocyclas (?) sp. A

Lamprocyclas sp. B

Lamprocyclas sp. C

Lamprocyclas sp. C X D

Lamprocyclas sp. D

Lamprocyclas sp. E

.
.
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□	□
.	.	.	■	■	□	□	□	.	■	.	.	■
.	■	■	■	■	■	■	■	.	■	■	■	■	■	■	■	■
.	■	.	■
.	■	■	.	.	.	□	□	.	.	■	■	□
.	.	■	■	■	.	■	■	.	□	.	.	■

Genus *LAMPROCYRTIS*

L. (?) apollinis

L. hannaï

L. heteroporos

L. (?) junonis

L. (?) cf. junonis

MS02	MS03	MS04	MS05	MS06	MS07	MS08	MS09	MS10	MS11	MS12	MS13	MS14	MS15	MS16	MS18	MS19
.	■	■
.	□
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Family ARTOSTROBIIDAE

Genus *BOTRYOSTROBUS*

B. aquilonaris

B. auritus-australis group

B. bramlettei

■	□	.	□	■	■	■	.	□
.	■	■	■	□	.	.
.	■	■	■	■	■	■	■	.	.	■	■	■	■	■	■	■

Genus *PHORMOSTICHOARTUS*

P. fistula

Phormostichoartus sp. A

.	□	.	.	■	□	■	■	■
.	.	■	□	■	□	■

Genus *SIPHOCAMPE*

S. arachnea group

S. lineata : strictured

S. lineata : smooth

S. nodosaria

■	■	■
■	■	■	■	■	■	■	■	.	■	■	■	■	■	■	■	■
□	□	■	■	.	■	■	■	■	■	.	.	■
.	■	.	□	■	□	■	■	.	.	■	■	■	■	.	.	.

Genus *SIPHOSTICHARTUS*

S. corona

.	□	.	.	■	□
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Genus *SPIROCYRTIS*

S. subscalaris

.	.	■	■	.	■	■	□	.	.	□	■	□	■	.	.	■
---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Family CANNOBOTRYIDAE

Genus *BOTRYOPYLE*

B. dictyocephalus sensu stricto

B. dictyocephalus : large lobe

.	■	■	.	■	.	■	.	.	.	■	■	■	■	.	.	■
.	.	■	■	.	■	■	.	.	.	■	■	■	■	.	.	■

[illegible]

Family COCCODISCIDAE

Genus *DIDYMOCYRTIS*

D. antepenultima
D. antepenultima X *laticonus*
D. laticonus
D. virgineum : non-constricted
D. virgineum : constricted
D. virgineum : tuberculate
D. sp. A : non-constricted
D. sp. A : constricted
D. sp. A : spherical
D. sp. A : narrow
D. tetralthalmus tetralthalmus

Genus *DIARTUS*

D. hughesi group

Family SPONGODISCIDAE

Genus *AMPHIRHOPALUM*

A. cf. ypsilon

Genus *DICTYOCORYNE*

D. profunda

Genus *HYMENIASTRUM*

H. euclidis

Genus *SPONGASTER*

S. pentas

Genus *STYLODICTYA*

S. validispina sensu stricto
S. validispina : spinose form
S. validispina : quadrate form
S. cornuspira

Genus *PORODISCUS*

Porodiscus sp. A : normal form
Porodiscus sp. A : spiral form
Porodiscus sp. B

Genus *STYLOCHLAMYDIUM*

S. asteriscus

Genus *SPONGOTROCHUS*

S. glacialis

Family PYLONIIDAE

Genus *HEXAPYLE*

H. cf. dodecantha

Genus *TETRAPYLE*

T. octacantha group

	PB02	PB03	PB04	PB05	PB06	PB07	PB08	PB09	PB10	PB11	SPA1	LT01	LT03	LT05	LT06	LT07	LT08	LT09
<i>D. antepenultima</i>	□	■	■	.	■	■
<i>D. antepenultima</i> X <i>laticonus</i>	□	■
<i>D. laticonus</i>	□	□	.	.	■	■	■	□	■
<i>D. virgineum</i> : non-constricted	.	.	■	■	■	■	□	.	■	■	■	.	.	.	■	.	.	■
<i>D. virgineum</i> : constricted	.	.	■	.	■	■	■	.	■	.	■
<i>D. virgineum</i> : tuberculate	■	■	.	■	.
<i>D. sp. A</i> : non-constricted	.	.	■	.	■	■	■	■	■	■	.	.	.	■	■	.	.	■
<i>D. sp. A</i> : constricted	.	.	■	■	■	■	■	■	■
<i>D. sp. A</i> : spherical	■
<i>D. sp. A</i> : narrow	■	.	.	.
<i>D. tetralthalmus tetralthalmus</i>	■
<i>D. hughesi</i> group	.	■	□	.	□	.	.	□	□	■	.	.	□
<i>A. cf. ypsilon</i>
<i>D. profunda</i>	■	.	■	■	■	■	■	■	■	■	■	■	■	■	■	.	■	■
<i>H. euclidis</i>	■	□	.	.	.	■	■	.	■	.
<i>S. pentas</i>
<i>S. validispina sensu stricto</i>	■	■	■	■	■	■	.	■	■	■	■	■	.	■	■	■	■	■
<i>S. validispina</i> : spinose form	■	.	■	.	■	■	.	.	.
<i>S. validispina</i> : quadrate form	.	.	.	■	■
<i>S. cornuspira</i>	.	.	■	■	■	■	■
<i>Porodiscus</i> sp. A : normal form	■	■	■	■	■	.	■	■	■	■	■	■	.	■	.	■	■	■
<i>Porodiscus</i> sp. A : spiral form	■	■
<i>Porodiscus</i> sp. B	■	.	.	.	■	.	□	■
<i>S. asteriscus</i>	□	.	.	□	.	■	.	■	.	.	■	.	.	■
<i>S. glacialis</i>	■	■	■	■	■	.	.	■	■	■	■	■	.	■	.	■	■	■
<i>H. cf. dodecantha</i>	.	.	■	□
<i>T. octacantha</i> group	.	■	■	■	■	.	□	■	.	■	■	■	.	■	■	.	■	■

	PB02	PB03	PB04	PB05	PB06	PB07	PB08	PB09	PB10	PB11	SPA1	LT01	LT03	LT05	LT06	LT07	LT08	LT09
Family LARNACIDAE																		
Genus <i>LARNACILLA</i>																		
<i>L. typus</i>	.	.	■	□	.	.	■	.	.	.
Family THOLONIIDAE																		
Genus <i>CUBOTHOLUS</i>																		
<i>C. rhombicus</i>	□	□	.	.	□	■
Family LITHELIIDAE																		
Genus <i>LITHELIUS</i>																		
<i>L. minor</i>	■	.	■	■	■	.	■	■	.	■	■	■	.	■	■	■	.	■
<i>L. nautiloides</i>	■	.	■	.	■	.	.	■	.	■	■	.	.	■	□	.	.	■
<i>Lithelius</i> sp. A	.	.	■	□	■
<i>Lithelius</i> sp. B	.	.	■
Genus <i>PYLOSPIRA</i>																		
<i>P. octopyle</i>	■	■	.	.	.	■	.	■	■
Suborder NASSELLARIA																		
Family PLAGONIIDAE																		
Genus <i>ANTARCTISSA</i>																		
<i>A. antedenticulata</i>	■
<i>A. conradae</i>	.	.	.	■	.	.	.	■	■	■	.	■	.
<i>A. longa</i>	.	.	.	■	.	.	.	■	■
<i>A. strelkovi</i>	■	■
Genus <i>LITHOMELISSA</i>																		
(?) <i>L. setosa sensu stricto</i>	□
(?) <i>L. setosa</i> : tri-legged	■
Genus <i>LOPHOPHAENA</i>																		
<i>L. macrencephala</i> group	.	.	□	■	.	.	.	■	.	■
Family ACANTHODESMIIDAE																		
Genus <i>DESMOSPYRIS</i>																		
<i>D. rhodospyroides</i>	□	.	.	■	■	.	■	■
<i>D. sp. aff. rhodospyroides</i>	■	.	.	■	■	.	■	■
<i>Desmospyris</i> (?) sp. A.
Genus <i>GORGOSPYRIS</i>																		
<i>G. sp. aff. perizostra</i>	□	□	.	.	.
Genus <i>PHORMOSPYRIS</i>																		
<i>P. stabilis antarctica</i> group	.	.	■	.	■	■	.	.	■	□	.	.	.
<i>P. stabilis scaphipes</i> group	.	.	□	■	.	.	■	.	.	■	■

Family CARPOCANIIDAE

Genus CARPOCANARIUM

C. papillosum

Carpocanarium sp. A

Genus CARPOCANISTRUM

C. sp. A : with terminal teeth

C. sp. A : toothless

C. sp. A : very constricted

Genus CYSTOPHORMIS

C. sp. A : with terminal teeth

C. sp. A : toothless

Cystophormis sp. B

Family THEOPERIDAE

Genus CORNUTELLA

C. profunda : three spines

C. profunda : six spines

Genus PLECTOPYRAMIS

P. dodecomma

Genus PERIPYRAMIS

P. cf. circumtexta

Genus DICTYOPHIMUS

D. hirundo group

Genus PSEUDODICTYOPHIMUS

P. gracilipes

Genus LYCHNOCANIUM

L. sp. aff. grande : vertical feet

L. sp. aff. grande : divergent feet

Genus LYCHNOCANELLA

L. conicum

Genus ARCHIPILIUM

A. macropus

Genus CYRTOCAPSELLA

C. japonica : inflated abdomen

C. japonica : rounded abdomen

C. tetrapera

Genus CYRTOLAGENA

C. laguncula sensu stricto

C. laguncula : spiralling form

Genus STICHOPHORMIS

S. cornutella

	PB02	PB03	PB04	PB05	PB06	PB07	PB08	PB09	PB10	PB11	SPA1	LT01	LT03	LT05	LT06	LT07	LT08	LT09
<i>C. papillosum</i>	.	.	■	■	.	.	.	■	.	.	■	.	.	■	.	.	■	.
<i>Carpocanarium</i> sp. A	■	.	■	■	■	.	.	■	.	■	■	.	■	.
<i>C. sp. A</i> : with terminal teeth	.	.	■	■	.	.	.
<i>C. sp. A</i> : toothless	■	.	■	■	■	.	■	■	.	■	□	.	.	■	■	■	■	■
<i>C. sp. A</i> : very constricted	■	■	■
<i>C. sp. A</i> : with terminal teeth	■	■	■	■	■	■	.	.	.	■	■	.	.	■	.	.	■	■
<i>C. sp. A</i> : toothless	■	.	■	■	.	■	.	■	.	■	■	.	.	■	.	.	■	■
<i>Cystophormis</i> sp. B	■
<i>C. profunda</i> : three spines	.	.	■	■	■	.	.	■	■	■	.	■
<i>C. profunda</i> : six spines	■	.	.	■	.	■	■	■	.	■	■	.	■	■
<i>P. dodecomma</i>	■	■	■	■	.	■	.	■	.	■	■	■	.	■	■	.	■	.
<i>P. cf. circumtexta</i>
<i>D. hirundo</i> group	■	.	■	■	■	.	.	■	.	■	■	.	.	□	■	■	■	■
<i>P. gracilipes</i>	■	■
<i>L. sp. aff. grande</i> : vertical feet	.	.	■	.	.	■	.	■	.	□	.	.	■	■	■	.	.	■
<i>L. sp. aff. grande</i> : divergent feet	.	■	■	■	■	■	.	■	.	■	.	.	.	■	.	■	■	■
<i>L. conicum</i>	■	.	■	■	■	□	.	.	■	■	.	.	■
<i>A. macropus</i>	■
<i>C. japonica</i> : inflated abdomen	.	.	□	.	□	.	.	.	□	.	□	□
<i>C. japonica</i> : rounded abdomen
<i>C. tetrapera</i>	.	■	.	.	■	.	.	.	□	■	■	.	.	.
<i>C. laguncula sensu stricto</i>	■	■	.	.
<i>C. laguncula</i> : spiralling form
<i>S. cornutella</i>	■

	PB02	PB03	PB04	PB05	PB06	PB07	PB08	PB09	PB10	PB11	SPA1	LT01	LT03	LT05	LT06	LT07	LT08	LT09
Genus <i>THEOCALYPTRA</i>																		
<i>T. bicornis</i>	□
<i>T. davisiana davisiana</i>	□	.	.	□	.	□	.	□	.	■
Genus <i>LAMPROMITRA</i>																		
<i>L. butschlii</i>
<i>L. erosa</i>	■
<i>L. tiara</i> : flaring	□	■
<i>L. tiara</i> : U-shaped
Genus <i>THEOCAMPE</i>																		
? <i>T. cf. mongolfieri</i>
Genus <i>EUCYRTIDIUM</i>																		
<i>E. acuminatum</i>	■	□	.	.	■	□	.	■	■
<i>E. cienkowskii</i>	.	□	□	■	■	■	.	■	.	■	■	.	■	■	□	.	.	■
<i>E. hexagonatum</i>	□	□	.	.	.	□	.	.	.	□	□	.	.	.
<i>E. calvertense</i>	.	.	■	■	■	.	□	■	.	■	■	■	■	□	■	■	■	■
<i>E. calvertense</i> X <i>inflatum</i>	■	□	.	■	■	.	■	.	■	■	.
<i>E. inflatum</i>	.	.	■	■	■	■	.	.	.	■	.	.	□
<i>E. punctatum</i>	.	.	■	□	■	□	■	■	.	.	■
<i>E. cf. montiparum</i>
<i>Eucyrtidium</i> sp. A
<i>E. vincentense</i> : small pores
<i>E. vincentense</i> : large pores
Genus <i>STICHOCORYS</i>																		
<i>S. peregrina</i>	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	.	□	■
<i>S. peregrina</i> X <i>delmontensis</i>	■	■	■	■	■	■	.	■	■	■	.	.	.	■	.	.	■	.
<i>S. delmontensis</i>	.	■	■	□	■	.	.	■	.	■	.	.	■	■	■	.	■	□
<i>Stichocorys</i> sp. A
Genus <i>GONDWANARIA</i>																		
<i>G. dogeli</i> group	■	.	.	.
Genus ' <i>ARTOSTROBUS</i> '																		
' <i>A.</i> ' <i>pretabulatus</i>	■
Family PTEROCORYTHIDAE																		
Genus <i>ANTHOCYRTIDIUM</i>																		
<i>A. ehrenbergi pliocenica</i>	.	.	□	□	■	.	.	■	□	■
? <i>Anthocyrtidium</i> sp. A	.	.	■	.	■	.	.	■	■	■	.	.	.	■
<i>A. zanguebaricum</i>	□	.	.	.	■	□	■	.	.	■	.	.	.	■
Genus <i>LAMPROCYCLAS</i>																		
<i>L. gamphonycha</i>
<i>L. maritalis sensu stricto</i>
<i>L. cf. maritalis</i>	■
<i>Lamprocyclas</i> (?) sp. A	.	.	.	■	.	.	□	■
<i>Lamprocyclas</i> sp. B	.	.	.	■	.	.	□	.	.	■	■	.	■	.
<i>Lamprocyclas</i> sp. C	■	■	■	■	■	■	■	■	.	■	■	■	■	■	□	■	■	■
<i>Lamprocyclas</i> sp. C X D	■	■	■	.	■	.	.	■	■	■	.	.	■
<i>Lamprocyclas</i> sp. D	.	.	■	■	■	.	■	■	.	■	.	.	.	■	■	.	.	■
<i>Lamprocyclas</i> sp. E	■	.	.	.	■	■	.	■	■	■

	PB02	PB03	PB04	PB05	PB06	PB07	PB08	PB09	PB10	PB11	SPA1	LT01	LT03	LT05	LT06	LT07	LT08	LT09
Genus <i>LAMPROCYRTIS</i>																		
<i>L. (?) apollinis</i>	■	.	.	■	■
<i>L. hannai</i>	□
<i>L. heteroporos</i>
<i>L. (?) junonis</i>
<i>L. (?) cf. junonis</i>
Family ARTOSTROBIIDAE																		
Genus <i>BOTRYOSTROBUS</i>																		
<i>B. aquilonaris</i>	.	■	■	.	.	■	□	.	■	■
<i>B. auritus-australis</i> group	□	.	■	.	■
<i>B. bramlettei</i>	.	.	■	.	■	.	.	■	■	.	■	.	.	■	■	.	.	■
Genus <i>PHORMOSTICHOARTUS</i>																		
<i>P. fistula</i>	■	.	.	■	.	.	■	.	.	■	.	.	.	□
<i>Phormostichoartus</i> sp. A	■	■	□	.	.	.	■
Genus <i>SIPHOCAMPE</i>																		
<i>S. arachnea</i> group	□	.	.	.	■	.	.	□
<i>S. lineata</i> : strictured	.	.	■	□	■	.	.	■	.	■	■	■	.	■	■	.	■	■
<i>S. lineata</i> : smooth	.	.	.	■	■	.	.	■	.	□	■	.	.	■	■	□	■	■
<i>S. nodosaria</i>	■	■	.	.	.	□	■	.	.	□
Genus <i>SIPHOSTICHARTUS</i>																		
<i>S. corona</i>	□	■
Genus <i>SPIROCYRTIS</i>																		
<i>S. subscalaris</i>	.	.	■	■	■	■
Family CANNOBOTRYIDAE																		
Genus <i>BOTRYOPYLE</i>																		
<i>B. dictyocephalus sensu stricto</i>	.	.	.	■	■	□	.	■	.	■	.	.	.	■
<i>B. dictyocephalus</i> : large lobe	.	.	.	■	■	■	■	.	■	■

Appendix E

RAW AND REDUCED DATA SETS

E.1 INTRODUCTION

This appendix contains all the raw and reduced data sets that are used in this thesis. The data originates from counts made on transmitted light slides on samples with reasonable radiolarian faunal preservation.

E.2 RAW COUNTING DATA

This section tabulates the original counts made on the transmitted light slides. Samples (97) are listed in the alphabetical order of their thesis numbers. The variables listed are indexed on the facing page.

RA	=	<i>Lamprocyclas gamphonycha</i> Zone
RB	=	<i>Lamprocyrtis heteroporos</i> Zone
RC	=	<i>Lamprocyrtis hannai</i> Subzone
RD	=	<i>Lychnocanium</i> sp. aff. <i>grande</i> Subzone
RE	=	<i>Didymocyrtis</i> sp. A Zone
RF	=	<i>Anthocyrtidium ehrenbergi pliocenica</i> Subzone
RG	=	<i>Heliodiscus asteriscus forma</i> large pores Subzone
RH	=	<i>Didymocyrtis laticonus</i> Subzone
RI	=	<i>Heliodiscus umbonatum</i> Subzone

SAM : thesis sample number

AGE : New Zealand Stage

ZN : Radiolarian zone

1 : *Collosphaera* spp.

2 : *Acrosphaera* spp.

3 : *Actinomma antarcticum*

4 : *Actinomma leptodermum*

5 : *Actinomma polycanthum* group

6 : *Cladococcus* spp.

7 : *Cenosphaera* spp.

8 : *Acanthosphaera* spp.

9 : *Hexacontium enthacanthum*

10 : *Hexacontium laevigatum*

11 : *Thecosphaera* spp.

12 : *Prunulum* spp.

13 : *Styptosphaera* spp.

14 : "*Stylatractus*" spp.

15 : "*Sphaerostylus*" sp. aff. *timmsi*

SAM	AGE	ZN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CR03	LWn	RA	0	0	0	0	8	0	3	0	5	0	6	13	0	8	0
EC02	LWo	RD	4	4	4	0	2	0	9	0	6	1	15	18	0	4	0
EC04	LTK	RE	2	1	2	0	5	1	5	0	9	0	16	26	0	4	0
HR02	UTt	RF	1	0	4	0	2	0	4	0	5	3	10	13	0	9	4
HR04	UTt	RG	2	3	3	0	0	0	1	2	2	3	18	19	0	4	1
HR05	UTt	RG	1	0	1	1	2	0	0	0	5	2	5	17	0	9	1
HR06	UTt	RH	1	0	1	0	6	0	2	0	4	0	7	27	0	11	2
KB01	LTt	RH	0	4	3	0	3	0	9	1	21	2	6	26	0	4	0
LT01	LWo	RC	0	1	4	0	5	0	0	0	4	3	6	12	0	7	0
LT05	LTt	RH	0	0	2	0	2	0	3	1	19	7	18	24	0	5	5
LT06	LTt	RH	0	0	0	0	1	0	11	1	11	3	19	32	0	11	4
LT08	LTt	RH	0	0	2	1	5	0	16	0	14	2	13	22	0	15	0
LT09	LTt	RI	0	0	4	1	4	0	14	1	14	3	14	30	0	18	1
MO02	UTt	RE	1	0	2	3	19	0	4	0	3	6	11	25	0	8	1
MO03	UTt	RE	1	0	1	2	11	0	9	0	10	3	6	42	0	14	8
MO05	UTt	RE	0	0	2	1	6	0	5	0	3	1	7	22	0	4	2
MO06	UTt	RE	1	0	2	2	4	0	5	0	4	1	6	30	0	4	7
MO07	UTt	RE	0	0	1	3	6	0	0	1	1	10	8	14	0	7	5
MO10	UTt	RE	0	0	3	1	6	2	3	0	3	2	6	18	0	7	1
MO11	UTt	RE	0	0	1	1	10	1	2	0	9	3	13	13	0	6	6
MO13	UTt	RE	0	2	3	2	5	3	3	0	13	2	9	12	0	9	0
MO14	UTt	RE	1	0	3	4	2	1	2	0	0	1	5	10	0	16	4
MS03	UTt	RE	0	0	0	4	4	0	5	2	2	2	6	19	0	5	3
MS04	UTt	RE	1	2	4	1	7	0	1	4	17	7	8	9	0	10	3
MS05	UTt	RE	0	0	1	2	3	0	7	0	6	1	6	27	0	14	1
MS06	UTt	RE	0	0	3	0	0	0	5	1	11	2	10	20	0	22	4
MS07	UTt	RE	0	0	4	1	2	0	9	2	19	2	7	19	0	11	0
MS08	UTt	RF	0	0	2	0	7	1	4	0	15	5	5	11	0	11	1
MS09	UTt	RF	0	0	1	0	6	0	5	0	7	0	11	20	0	7	0
MS10	UTt	RF	0	0	0	2	6	0	11	0	5	2	8	12	0	14	1
MS11	UTt	RF	0	0	1	2	4	0	6	1	7	5	17	31	0	21	1
MS12	UTt	RG	0	0	2	2	9	0	2	1	15	8	13	23	0	15	0
MS13	UTt	RG	0	0	7	4	27	1	4	4	8	10	10	19	0	11	3
MS14	UTt	RG	0	0	0	2	7	0	2	1	8	2	8	19	0	12	1
MS15	UTt	RG	0	0	3	0	7	0	5	1	19	1	11	19	0	11	0
MS16	UTt	RG	0	0	0	1	10	0	9	1	17	7	29	20	0	29	0
MS18	UTt	RH	1	0	1	0	2	0	6	0	9	0	18	28	0	6	0
MS19	LTt	RH	0	0	0	0	5	0	2	0	5	4	8	15	0	8	1
MT04	UTt	RE	1	0	2	0	6	0	4	0	2	3	15	15	0	6	0
MT07	UTt	RE	0	0	2	2	2	0	1	0	6	4	17	14	0	5	1
MT08	UTt	RG	1	0	0	1	4	0	4	0	3	2	6	21	0	8	4
MT09	UTt	RG	0	1	2	0	3	0	8	0	8	2	11	19	0	6	2
MT10	UTt	RG	1	0	0	0	4	0	0	1	4	1	11	32	0	3	1
PB02	UTt	RE	0	0	0	0	7	1	5	0	5	1	12	22	0	12	3
PB04	UTt	RF	2	1	4	1	18	0	13	1	8	3	11	19	0	18	4
PB05	UTt	RF	0	0	1	1	7	0	0	1	9	4	7	29	0	12	3
PB06	UTt	RF	0	0	2	1	9	0	6	0	10	2	5	22	0	6	7
PB09	UTt	RF	0	0	0	1	4	1	2	2	15	0	7	24	0	4	0
PB11	UTt	RF	2	0	3	0	6	0	9	3	10	5	4	31	0	8	2

SAM : thesis sample number

AGE : New Zealand Stage

ZN : Radiolarian zone

1 : *Collosphaera* spp.

2 : *Acrosphaera* spp.

3 : *Actinomma antarcticum*

4 : *Actinomma leptodermum*

5 : *Actinomma polycanthum* group

6 : *Cladococcus* spp.

7 : *Cenosphaera* spp.

8 : *Acanthosphaera* spp.

9 : *Hexacontium enthacanthum*

10 : *Hexacontium laevigatum*

11 : *Thecosphaera* spp.

12 : *Prunulum* spp.

13 : *Styptosphaera* spp.

14 : "*Stylatractus*" spp.

15 : "*Sphaerostylus*" sp. aff. *timmsi*

SAM	AGE	ZN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RK02	UTt	RH	0	0	1	1	8	0	5	1	8	2	4	29	0	5	1
RK03	UTt	RH	0	0	0	0	0	0	7	0	12	0	10	16	0	5	0
RK04	LTt	RH	0	0	2	0	5	0	3	1	2	6	10	23	0	9	0
RM03	UTt	RE	3	0	1	0	10	1	17	1	8	3	3	21	0	14	5
RM04	UTt	RE	0	0	2	0	6	0	4	0	3	3	2	14	0	7	6
RM05	UTt	RF	0	0	1	2	6	0	2	0	2	2	15	20	0	4	2
RM06	UTt	RF	1	1	3	1	2	0	3	0	6	0	7	21	0	7	4
RM07	UTt	RF	1	0	4	2	6	2	1	0	9	5	6	14	0	11	9
SCV1	UTt	RG	2	2	1	0	3	0	3	1	2	1	11	11	0	9	1
SMA1	UTt	RE	0	0	0	0	8	0	2	0	6	6	14	21	0	5	0
SMA3	UTt	RE	1	0	1	0	8	0	4	1	9	3	11	17	0	27	2
SMA4	UTt	RF	0	0	0	0	4	0	6	0	5	4	10	17	0	17	0
SMA5	UTt	RG	0	0	0	1	22	0	3	1	17	5	12	19	0	14	0
SMA6	UTt	?	0	1	0	0	7	0	4	0	7	4	16	23	0	8	1
SMH1	UTt	RE	2	1	1	0	7	1	7	0	0	0	18	29	0	8	2
SMR1	LWo	RD	0	0	7	4	8	0	1	0	10	1	13	14	0	12	0
SPA1	LTt	RH	0	0	1	2	6	0	5	0	4	1	9	24	0	13	2
SWM1	LWo	RC	0	0	0	0	3	0	13	0	3	3	5	43	0	16	0
SWR1	LWo	RD	0	0	2	2	8	0	5	3	3	8	6	22	0	27	0
SWR2	LWo	RD	0	1	2	1	11	0	4	0	3	3	8	17	0	9	4
SWR3	LWo	RD	0	0	0	0	10	0	11	0	4	3	14	43	0	7	1
SWR4	LTt	RH	1	0	1	4	5	0	7	1	21	5	21	26	0	14	2
TK05	Wop	?	0	0	0	0	1	0	3	0	0	1	2	2	0	1	0
TM06	Wop	RD	0	6	1	1	4	2	7	1	1	0	7	13	0	1	0
TM14	UTt	RE	3	0	6	0	2	0	7	0	11	3	11	10	0	15	0
TM15	UTt	RE	4	0	3	0	6	0	8	4	13	0	6	28	0	10	3
TM16	UTt	RE	0	0	2	2	9	0	4	2	18	5	9	13	0	10	4
TM19	UTt	RE	1	1	1	0	6	0	2	0	3	3	6	30	0	9	1
TM20	UTt	RE	3	0	2	3	5	0	5	1	1	3	6	17	0	4	0
TM21	UTt	RE	0	0	3	0	3	0	7	1	15	1	10	13	0	0	0
TM22	UTt	RE	1	0	1	1	3	0	2	1	10	1	4	14	0	17	2
TM23	UTt	RE	2	0	1	2	2	0	5	0	5	3	4	9	2	9	2
WA01	UWn	RA	0	1	1	4	15	0	16	1	23	1	9	24	1	18	1
WA02	UWn	RA	1	3	7	7	6	0	9	2	10	2	12	9	0	42	0
WA03	UWn	RA	0	0	5	17	8	1	6	0	3	2	7	10	0	64	18
WA07	UWn	RA	1	1	1	6	16	0	10	2	29	5	2	14	0	50	1
WA10	LWn	RB	0	0	0	4	24	0	9	0	7	5	19	13	0	21	2
WA13	Wm	RB	0	0	2	2	4	0	3	0	6	3	14	14	0	19	0
WA15	Wm	RB	1	0	1	12	12	0	5	1	9	5	6	18	0	19	2
WA16	Wm	RB	1	1	3	4	13	0	4	0	9	1	8	33	0	13	1
WA17	Wm	RB	0	2	5	5	13	0	10	0	15	4	4	20	0	0	0
WA19	Wm	RB	0	0	1	2	18	1	2	0	7	1	8	16	0	21	5
WA23	Wop	RB	1	0	3	0	1	0	2	0	4	4	16	11	0	11	0
WA26	Wop	RB	0	0	1	1	6	0	5	0	2	1	18	12	0	7	0
WH03	UWn	RA	0	2	4	0	12	0	10	0	0	1	18	31	0	5	1
WH06	UWn	RB	1	0	1	0	22	0	5	0	7	6	13	17	0	7	0
WT03	UTt	RE	0	0	0	1	4	0	34	0	8	6	40	23	0	23	0
WT05	UTt	RF	2	1	1	2	5	0	2	0	5	1	5	16	0	18	0

SAM : thesis sample number

16 : *Prunopyle* and *Spongurus* spp.

17 : *Spongocore puella*

18 : *Heliodiscus* spp.

19 : *Didymocyrtis antepenultima*

20 : *Didymocyrtis laticonus*

21 : *Didymocyrtis virgineum*

22 : *Didymocyrtis* sp. A

23 : *Didymocyrtis tetrathalmus tetrathalmus*

24 : *Diartus hughesi* group

25 : *Dictyocoryne* and *Hymeniastrum* spp.

26 : *Stylodictya* spp.

27 : *Porodiscus* spp.

28 : *Spongotrochus glacialis*

29 : *Tetrapyle octacantha* group

30 : *Cubotholus rhombicus*

SAM	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
CR03	0	0	1	0	0	1	0	0	0	4	3	36	63	0	0
EC02	2	3	3	0	0	0	0	0	0	16	28	44	66	11	0
EC04	4	0	0	0	0	0	0	0	0	11	42	48	56	7	0
HR02	5	1	2	0	0	0	0	0	0	10	7	29	69	6	0
HR04	6	0	1	1	0	1	0	0	0	16	15	43	46	6	1
HR05	6	0	1	0	0	1	0	0	0	13	9	37	42	1	1
HR06	4	2	2	0	0	0	0	0	0	8	5	30	66	5	0
KB01	3	5	5	3	3	0	0	0	0	5	29	17	62	20	0
LT01	5	2	4	0	0	0	0	0	0	10	7	31	88	13	1
LT05	2	0	3	5	2	0	0	0	0	6	18	24	43	3	0
LT06	3	3	4	3	1	1	0	0	0	6	10	25	74	2	0
LT08	2	0	0	2	1	0	0	0	0	9	23	37	66	4	0
LT09	3	5	2	2	2	0	0	0	0	6	28	33	60	2	0
MO02	0	1	4	1	0	0	0	0	0	13	19	31	54	6	0
MO03	3	1	4	0	0	0	0	0	0	12	17	29	60	4	0
MO05	1	0	4	0	0	0	0	0	0	6	11	46	39	5	0
MO06	5	1	5	0	0	2	0	0	0	10	7	32	56	3	0
MO07	2	1	3	0	0	1	0	0	0	8	14	33	58	3	0
MO10	12	2	3	0	0	0	0	0	0	7	10	39	49	9	0
MO11	6	2	2	2	0	0	0	0	0	8	11	50	62	4	0
MO13	4	0	0	1	0	0	0	0	0	13	16	31	43	6	0
MO14	9	0	2	0	0	1	0	0	0	9	6	45	41	9	0
MS03	3	0	0	0	0	2	0	0	0	18	17	43	56	7	0
MS04	3	0	1	1	0	3	0	0	0	5	14	19	53	11	0
MS05	1	1	4	0	0	1	0	0	0	10	13	26	58	2	0
MS06	1	1	3	1	0	0	0	0	0	7	14	22	41	4	0
MS07	1	2	2	0	0	1	0	0	0	10	16	21	55	2	0
MS08	5	2	2	0	0	0	0	0	0	6	18	44	47	2	0
MS09	2	1	2	0	1	0	0	0	0	17	11	37	61	8	0
MS10	0	0	3	0	0	0	0	0	0	0	3	7	19	0	0
MS11	2	0	4	0	0	0	0	0	0	1	16	25	49	1	0
MS12	5	2	5	1	1	2	0	0	1	7	12	35	37	2	0
MS13	8	1	3	0	0	0	0	0	0	8	20	23	39	6	0
MS14	5	1	3	0	0	1	0	0	0	6	14	23	57	2	0
MS15	3	1	3	4	0	0	0	0	0	12	20	15	59	3	0
MS16	0	0	0	0	0	0	0	0	0	5	16	30	36	0	0
MS18	0	0	1	3	0	3	0	0	0	3	11	26	59	0	0
MS19	4	3	0	0	0	2	0	0	0	10	12	46	61	2	0
MT04	2	2	2	0	0	3	0	0	0	8	15	31	70	5	0
MT07	1	1	7	0	0	0	0	0	0	11	16	39	69	1	0
MT08	3	0	0	3	1	2	0	0	0	7	22	31	89	3	0
MT09	4	0	5	4	1	1	0	0	0	10	18	47	78	6	0
MT10	6	0	1	4	0	1	0	0	0	11	7	23	49	1	0
PB02	1	0	6	0	0	0	0	0	0	1	6	22	36	0	0
PB04	4	0	6	0	0	3	0	0	0	5	11	21	45	7	1
PB05	1	1	7	0	0	0	0	0	0	13	23	33	76	3	0
PB06	3	1	0	3	0	3	0	0	0	24	21	32	53	5	1
PB09	3	2	3	0	0	0	0	0	0	10	13	23	92	4	0
PB11	2	0	6	0	0	0	0	0	0	9	12	30	70	11	0

SAM : thesis sample number

16 : *Prunopyle* and *Spongurus* spp.

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27 : *Porodiscus* spp.

28 : *Spongotrochus glacialis*

29 : *Tetrapyle octacantha* group

30 : *Cubotholus rhombicus*

SAM	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
RK02	3	0	1	0	0	0	0	0	0	11	9	47	36	0	1
RK03	4	0	2	0	0	0	0	0	0	22	23	41	73	2	0
RK04	2	3	0	0	0	0	0	0	0	13	20	34	85	2	0
RM03	1	1	4	1	0	0	0	0	0	2	2	3	14	4	0
RM04	2	2	2	0	0	1	0	0	0	13	14	41	46	8	0
RM05	1	0	2	1	0	1	0	0	0	10	9	27	58	6	0
RM06	0	1	0	0	0	2	0	0	0	8	8	45	45	1	0
RM07	2	0	2	1	0	1	0	0	0	6	10	37	41	4	0
SCV1	3	1	2	1	0	2	0	0	0	14	16	37	67	2	2
SMA1	2	0	1	4	0	0	0	0	0	12	17	38	75	0	1
SMA3	4	2	1	2	0	1	0	0	0	11	18	31	67	2	0
SMA4	3	2	1	0	0	0	0	0	0	3	13	47	75	2	0
SMA5	8	1	4	1	3	0	0	0	0	10	15	35	65	2	1
SMA6	2	0	2	0	0	2	0	0	0	11	23	31	70	0	0
SMH1	3	0	5	2	0	0	0	0	0	19	13	52	49	1	0
SMR1	1	0	1	0	0	0	0	0	0	20	23	19	95	9	0
SPA1	2	1	1	0	0	0	0	0	0	4	17	41	75	2	0
SWM1	1	2	1	0	0	0	0	0	0	22	50	45	63	2	0
SWR1	0	4	2	0	0	0	0	0	0	20	25	13	85	3	0
SWR2	0	3	0	0	0	0	0	0	0	21	15	34	44	2	0
SWR3	1	1	3	0	0	0	0	0	0	7	11	17	93	0	0
SWR4	2	0	1	3	0	1	0	0	0	4	17	18	62	2	0
TK05	3	0	0	0	0	0	0	0	0	3	0	9	13	1	0
TM06	0	1	3	0	0	0	0	0	0	23	23	34	99	10	0
TM14	2	0	3	0	0	0	0	0	0	16	17	20	49	8	0
TM15	6	1	2	2	0	1	0	0	0	8	14	43	49	9	0
TM16	0	0	5	0	0	3	0	0	0	10	21	34	49	2	0
TM19	5	0	1	0	0	0	0	0	0	24	15	46	36	1	0
TM20	8	3	1	1	0	0	0	0	0	7	9	43	46	7	0
TM21	4	3	0	0	0	0	0	0	0	16	15	34	30	7	1
TM22	5	2	0	1	0	0	0	0	0	12	23	46	38	11	0
TM23	7	1	0	0	0	0	0	0	0	12	21	35	26	9	0
WA01	2	2	0	0	0	0	0	0	0	9	16	32	70	6	0
WA02	0	1	1	0	0	0	0	1	0	13	7	13	71	5	0
WA03	3	0	0	0	0	0	0	1	0	4	8	22	61	8	0
WA07	2	1	0	0	0	0	0	2	0	6	13	8	34	3	0
WA10	1	0	0	0	0	0	0	0	0	1	0	11	21	0	0
WA13	0	3	2	0	0	0	0	1	0	21	8	29	79	5	0
WA15	5	3	0	0	0	0	0	0	0	17	10	18	54	6	0
WA16	0	3	0	0	0	0	0	0	0	18	16	30	45	4	0
WA17	1	5	0	0	0	0	0	0	0	13	6	20	55	10	0
WA19	4	4	1	0	0	0	0	0	0	18	15	22	53	1	0
WA23	0	2	0	0	0	0	0	3	0	29	19	33	72	4	1
WA26	1	0	0	0	0	0	0	0	0	19	17	62	63	0	0
WH03	4	3	2	0	0	0	0	0	0	22	9	32	76	1	0
WH06	1	0	0	0	0	0	0	0	0	10	13	24	85	0	0
WT03	1	0	1	2	0	2	0	0	0	3	5	14	31	1	0
WT05	8	1	4	0	0	0	0	0	1	8	21	36	50	4	1

SAM : thesis sample number

- 31 : *Lithelius minor*
- 32 : *Lithelius nautiloides*
- 33 : other Spumellarians
- 34 : *Antarctissa* and *Lithomelissa* spp.
- 35 : *Lophophaena* spp.
- 36 : *Desmospyris* and *Gorgospyris* spp.
- 37 : *Phormospyris* spp.
- 38 : Carpacaniidae
- 39 : *Cornutella profunda*
- 40 : *Plectopyramis dodecomma*
- 41 : *Dictyophimus hirundo* group
- 42 : *Lychnocanium* and *Lychnocanella* spp.
- 43 : *Cyrtocapsella japonica*
- 44 : *Cyrtocapsella tetrapera*
- 45 : *Theocalyptra* spp.
- 46 : *Lampromitra* spp.

SAM	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
CR03	2	0	34	0	0	0	0	4	0	1	0	0	0	0	0	0
EC02	2	0	34	0	0	0	0	5	0	0	0	0	0	0	0	0
EC04	3	1	37	0	0	0	0	7	1	1	0	0	0	0	0	0
HR02	3	2	18	0	0	0	0	6	1	0	0	0	0	0	0	0
HR04	4	1	15	0	5	1	0	9	3	0	1	2	0	1	1	1
HR05	0	4	23	0	0	0	0	9	0	0	0	1	0	1	0	0
HR06	0	0	32	1	0	0	0	6	1	0	0	0	0	0	0	0
KB01	3	6	62	0	0	4	0	21	2	0	0	1	3	0	0	0
LT01	1	0	46	0	2	0	0	0	3	0	0	0	0	0	1	0
LT05	3	3	25	0	3	1	2	17	3	0	1	0	0	0	0	0
LT06	3	1	25	0	0	1	1	9	2	2	0	1	0	0	0	0
LT08	4	1	26	0	0	1	0	12	1	0	1	0	0	0	0	0
LT09	6	1	29	0	0	3	1	14	3	0	0	0	0	0	0	0
MO02	3	1	52	0	5	0	1	5	1	0	0	1	0	0	0	0
MO03	3	0	71	0	1	0	0	16	0	0	0	0	0	0	0	0
MO05	4	1	60	0	3	0	0	12	0	0	0	0	0	0	3	0
MO06	3	1	54	0	3	0	0	5	1	0	1	2	0	0	1	0
MO07	1	2	51	0	4	0	0	7	2	0	0	3	0	0	0	0
MO10	2	4	42	0	4	0	2	5	1	0	2	2	0	0	0	0
MO11	1	3	66	1	10	0	2	5	2	0	2	2	2	0	1	0
MO13	1	0	42	0	6	0	2	4	2	0	0	3	0	0	2	1
MO14	1	1	45	1	4	0	3	5	1	1	0	1	0	0	0	0
MS03	1	2	41	0	6	0	0	5	0	0	1	1	0	0	1	0
MS04	3	3	31	0	0	1	1	2	2	0	2	2	0	0	0	0
MS05	2	1	49	0	1	0	0	8	2	1	2	2	0	0	0	0
MS06	2	1	25	0	6	0	1	10	1	0	1	5	0	0	0	0
MS07	3	1	34	1	1	0	1	6	8	0	1	3	0	0	0	2
MS08	2	0	30	0	4	1	0	5	0	0	5	3	0	0	1	4
MS09	3	2	39	0	1	1	0	15	1	0	1	0	0	0	0	0
MS10	1	1	14	0	1	1	0	1	0	0	2	0	0	0	0	0
MS11	7	3	60	0	3	1	3	14	2	0	0	0	0	0	0	0
MS12	4	2	51	0	2	0	1	3	0	0	4	2	0	0	0	0
MS13	2	1	36	0	3	0	0	5	1	0	2	0	0	0	1	0
MS14	3	3	48	1	5	3	0	7	1	0	1	2	1	0	3	0
MS15	4	5	34	0	4	0	0	7	3	0	2	1	0	0	1	0
MS16	1	0	41	0	0	0	0	4	1	0	0	1	0	0	0	0
MS18	6	1	52	0	0	1	0	10	0	0	3	0	0	0	0	0
MS19	5	1	42	0	0	1	1	8	0	1	1	0	0	0	1	0
MT04	0	0	35	0	1	0	1	13	1	0	0	4	1	0	0	0
MT07	1	0	35	0	4	0	0	17	2	0	0	0	3	0	0	0
MT08	2	0	40	0	1	0	1	17	1	0	0	2	1	0	0	0
MT09	3	0	38	0	0	0	0	8	1	0	0	0	0	0	0	0
MT10	1	0	41	0	2	0	2	4	1	0	0	0	0	0	0	0
PB02	9	0	36	0	0	0	0	4	0	0	2	0	0	0	0	0
PB04	3	3	41	0	2	0	0	8	0	0	1	1	0	0	0	0
PB05	3	0	52	0	0	0	0	5	0	1	0	0	0	0	0	0
PB06	6	3	41	0	0	0	0	4	0	0	0	1	0	0	0	0
PB09	3	3	43	0	0	0	0	8	0	0	1	0	0	0	0	0
PB11	3	2	37	0	0	0	0	2	0	0	0	1	0	0	2	0

SAM : thesis sample number

- 31 : *Lithelius minor*
- 32 : *Lithelius nautiloides*
- 33 : other Spumellarians
- 34 : *Antarctissa* and *Lithomelissa* spp.
- 35 : *Lophophaena* spp.
- 36 : *Desmospyris* and *Gorgospyris* spp.
- 37 : *Phormospyris* spp.
- 38 : Carpacaniidae
- 39 : *Cornutella profunda*
- 40 : *Plectopyramis dodecomma*
- 41 : *Dictyophimus hirundo* group
- 42 : *Lychnocanium* and *Lychnocanella* spp.
- 43 : *Cyrtocapsella japonica*
- 44 : *Cyrtocapsella tetrapera*
- 45 : *Theocalyptra* spp.
- 46 : *Lampromitra* spp.

SAM	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
RK02	4	1	28	0	0	0	2	8	0	0	1	2	1	0	0	0
RK03	1	0	24	0	0	0	1	8	0	0	0	0	2	0	0	0
RK04	3	0	29	0	0	0	1	2	1	0	0	0	1	1	0	0
RM03	1	0	58	0	0	0	0	12	0	0	0	11	0	0	0	0
RM04	3	0	43	0	5	0	0	8	0	0	0	3	0	0	1	0
RM05	1	1	46	0	2	0	4	8	2	1	0	2	0	0	1	1
RM06	2	1	54	0	0	1	0	4	0	0	4	2	0	0	1	0
RM07	1	0	52	2	1	0	0	4	0	0	2	1	0	0	2	0
SCV1	5	0	26	0	3	1	1	4	0	0	0	4	0	0	0	0
SMA1	2	1	53	0	0	1	1	6	1	0	1	0	0	0	0	0
SMA3	5	1	45	0	1	0	0	7	1	2	0	0	1	0	0	0
SMA4	7	1	56	0	1	0	0	6	0	0	0	0	0	0	0	0
SMA5	4	0	48	0	1	2	0	8	0	0	1	0	0	0	0	0
SMA6	6	1	47	0	0	1	0	7	0	1	1	0	1	0	0	0
SMH1	7	0	43	0	0	0	0	1	0	0	0	0	0	0	0	0
SMR1	3	1	42	0	0	0	0	1	0	0	0	0	0	0	0	0
SPA1	3	1	45	0	0	2	0	10	0	0	0	0	1	0	0	0
SWM1	1	1	29	0	0	0	0	0	0	0	0	0	0	0	0	0
SWR1	3	2	33	0	0	0	0	3	0	0	0	0	0	0	0	0
SWR2	5	1	32	0	0	0	0	5	0	0	0	1	0	0	0	0
SWR3	4	1	53	0	0	0	0	1	0	0	0	0	0	0	1	0
SWR4	3	1	52	1	0	0	0	16	1	1	0	3	0	0	0	0
TK05	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0
TM06	3	1	33	0	1	0	0	1	0	0	2	0	0	0	0	0
TM14	3	1	32	0	2	0	1	7	0	1	1	2	0	2	0	0
TM15	2	0	32	1	2	0	0	5	0	0	1	0	0	0	0	1
TM16	3	2	35	0	0	0	0	12	0	0	1	1	0	0	0	0
TM19	2	1	43	0	1	0	0	10	0	0	1	3	2	0	2	0
TM20	6	1	44	0	3	0	1	4	1	0	1	1	0	0	2	0
TM21	5	1	33	1	10	2	0	12	3	0	1	2	1	0	3	0
TM22	2	2	37	0	6	0	0	10	1	1	3	3	0	0	0	0
TM23	3	2	48	0	5	0	3	9	1	0	1	0	1	0	0	0
WA01	6	1	47	0	0	0	0	3	0	1	2	1	0	0	0	0
WA02	1	2	26	0	6	2	0	0	0	0	6	0	0	0	0	0
WA03	4	3	32	0	10	0	0	0	0	1	1	0	1	0	7	1
WA07	9	0	39	0	0	0	0	2	1	1	4	0	0	0	3	0
WA10	3	1	17	0	1	0	0	2	0	0	1	0	0	0	0	0
WA13	3	0	43	0	1	1	1	4	0	0	1	1	0	0	0	0
WA15	4	1	68	2	2	0	1	2	1	0	1	0	0	0	0	1
WA16	5	2	55	0	1	0	0	3	2	2	0	0	0	0	0	0
WA17	6	0	51	3	5	0	1	2	5	0	3	0	0	0	0	0
WA19	6	0	58	0	1	0	0	4	0	1	0	0	0	0	1	3
WA23	1	0	37	0	9	0	1	2	0	0	0	0	0	0	1	0
WA26	0	0	53	0	3	0	0	2	0	0	3	0	0	0	0	0
WH03	4	0	34	0	0	0	0	2	0	0	0	0	0	0	2	0
WH06	5	3	41	0	3	0	2	5	0	0	0	0	0	0	0	0
WT03	9	0	53	0	0	1	0	14	1	0	0	0	0	0	0	0
WT05	2	1	31	1	8	1	0	12	6	0	2	0	0	0	0	0

SAM : thesis sample number

47 : *E. acuminatum*, *E. cienkowski* group, and *E. hexagonatum*

48 : *E. calvertense* and *E. inflatum*

49 : *Eucyrtidium punctatum* group

50 : *Eucyrtidium* sp. A and *E. montiparum*

51 : *Stichocorys peregrina*

52 : *Stichocorys delmontensis*

53 : *Stichocorys* spp. (transitionals)

54 : *Anthocyrtidium* spp.

55 : *Lamprocyclas* and *Lamprocyrtis* spp.

56 : *Botryostrobus* spp.

57 : *Siphocampe* spp.

58 : *Spirocyrtis subscalaris*

59 : *Botryopyle dictyocephalus* group

NG : number of radiolarians per gram of sediment

TOT : total number of radiolarians counted

SAM	47	48	49	50	51	52	53	54	55	56	57	58	59	NG	TOT
CR03	0	0	1	0	1	1	0	0	2	3	0	0	0	12	200
EC02	1	0	1	0	5	4	0	0	3	0	0	0	2	130	297
EC04	0	0	0	0	1	3	1	0	1	2	0	0	0	225	297
HR02	0	2	2	0	23	7	10	0	0	0	1	0	0	370	259
HR04	7	3	6	0	14	17	5	0	3	9	4	2	1	269	309
HR05	11	1	2	0	23	29	5	1	2	6	1	0	1	535	275
HR06	4	0	1	0	21	31	6	1	5	4	2	2	0	285	300
KB01	5	1	1	0	0	0	1	0	3	3	7	1	2	568	357
LT01	0	0	0	0	16	5	5	0	5	0	17	0	2	74	306
LT05	2	1	1	0	3	3	1	0	5	5	11	0	4	829	286
LT06	1	1	2	0	0	1	2	0	2	3	8	0	1	1188	291
LT08	0	0	0	0	2	0	0	0	1	1	11	0	0	727	295
LT09	3	3	0	0	0	1	1	0	5	6	10	0	3	1187	336
M002	1	2	1	0	5	11	1	2	5	1	2	0	1	762	313
M003	0	1	1	0	7	2	2	4	2	11	0	0	0	292	358
M005	1	1	3	0	16	12	2	2	3	8	5	0	0	551	301
M006	0	1	0	0	13	8	1	1	2	16	1	0	1	532	302
M007	0	2	1	0	10	16	2	1	5	11	5	0	1	648	303
M010	4	1	2	0	8	15	6	0	1	10	4	0	0	1112	298
M011	0	3	3	0	14	20	2	5	2	2	8	0	3	568	371
M013	5	0	1	0	12	15	5	0	5	2	4	2	5	789	296
M014	1	2	2	0	11	8	9	2	5	3	8	0	0	735	285
MS03	3	2	0	0	4	8	2	0	10	2	4	0	2	715	293
MS04	7	1	0	1	2	23	5	2	3	9	12	0	6	692	302
MS05	1	0	0	0	9	3	1	0	10	9	6	0	0	204	291
MS06	3	0	0	0	6	7	1	2	7	38	6	1	1	405	296
MS07	0	0	2	0	3	4	0	1	4	12	4	6	2	395	285
MS08	5	1	0	0	6	8	3	0	0	12	13	1	1	512	293
MS09	1	2	0	0	12	7	1	0	5	4	2	0	0	303	294
MS10	0	0	0	0	5	0	0	0	2	0	0	0	0	61	121
MS11	0	3	0	0	4	1	0	0	2	0	1	0	0	56	298
MS12	0	1	0	0	13	8	3	0	3	7	2	1	0	418	307
MS13	2	1	1	0	1	8	4	1	3	4	3	4	4	482	303
MS14	1	1	1	0	10	7	2	1	3	9	5	3	1	378	296
MS15	1	0	1	0	2	11	9	1	7	8	1	1	3	402	303
MS16	0	3	1	0	5	0	0	0	3	21	0	0	0	93	291
MS18	0	1	1	0	3	2	0	0	2	1	1	0	0	50	261
MS19	0	2	1	0	14	5	2	1	3	6	1	1	2	109	287
MT04	1	0	0	0	6	19	2	0	4	4	6	0	1	140	291
MT07	0	0	0	0	3	6	2	0	6	3	9	0	0	111	290
MT08	2	3	0	0	8	3	1	1	6	0	0	0	0	56	304
MT09	1	1	1	0	2	13	0	0	1	6	4	1	5	236	321
MT10	2	1	0	0	12	15	1	0	8	5	4	1	1	111	262
PB02	0	0	0	0	4	2	0	0	5	0	0	0	0	17	202
PB04	1	0	0	0	3	11	11	0	5	0	1	0	0	131	297
PB05	0	4	0	0	6	13	3	0	4	0	0	0	1	172	323
PB06	2	4	0	0	3	14	2	6	3	0	0	0	1	155	306
PB09	1	0	0	0	11	4	0	1	4	2	4	0	0	90	295
PB11	1	0	0	0	3	5	3	0	2	0	1	0	1	617	286

SAM : thesis sample number

47 : *E. acuminatum*, *E. cienkowskii* group, and *E. hexagonatum*

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57 : *Siphocampe* spp.

58 : *Spirocyrtis subscalaris*

59 : *Botryopyle dictyocephalus* group

NG : number of radiolarians per gram of sediment

TOT : total number of radiolarians counted

SAM	47	48	49	50	51	52	53	54	55	56	57	58	59	NG	TOT
RK02	4	3	4	2	0	26	6	0	8	3	5	0	3	211	284
RK03	1	2	3	2	7	7	0	0	1	0	3	0	0	223	279
RK04	3	2	0	0	7	14	1	0	3	0	4	0	3	161	295
RM03	0	0	0	0	11	5	1	2	11	8	0	0	0	94	239
RM04	2	2	4	0	12	11	4	2	0	18	1	0	1	436	296
RM05	3	1	1	0	10	13	2	3	7	8	4	1	0	448	293
RM06	4	2	4	0	10	14	2	1	1	16	2	0	0	353	291
RM07	1	4	2	0	4	6	3	2	4	5	0	0	0	430	270
SCV1	4	0	2	0	18	8	10	1	3	5	1	0	0	596	290
SMA1	1	2	1	0	1	13	0	0	3	1	3	0	0	279	303
SMA3	2	1	1	0	7	7	0	0	8	3	0	0	1	617	316
SMA4	2	2	0	0	4	4	3	0	0	1	0	0	0	246	296
SMA5	1	0	1	0	4	3	2	1	4	16	1	3	0	125	339
SMA6	0	4	0	0	6	3	0	0	1	4	1	0	2	83	298
SMH1	1	0	1	0	8	3	1	0	0	0	1	0	0	344	286
SMR1	0	0	2	0	1	0	0	0	2	5	0	0	0	51	295
SPA1	0	1	0	0	5	2	0	0	0	1	3	0	0	613	284
SWM1	0	0	0	0	2	2	0	0	0	1	0	1	1	449	310
SWR1	1	10	0	1	2	5	0	1	2	2	0	0	1	271	304
SWR2	0	1	0	0	16	17	5	0	5	3	0	1	0	91	274
SWR3	1	0	0	0	5	4	2	0	1	1	0	0	0	104	300
SWR4	0	0	1	0	3	1	1	0	2	3	0	0	0	104	307
TK05	0	0	0	0	0	2	0	0	0	0	0	0	0	6	50
TM06	0	1	0	0	1	0	0	0	5	3	0	0	0	285	288
TM14	4	1	0	0	4	27	17	3	3	2	3	0	1	662	300
TM15	0	1	2	0	4	17	6	4	0	0	0	2	1	388	301
TM16	4	0	1	0	2	24	4	0	4	1	1	0	0	223	297
TM19	4	0	0	0	10	15	3	1	5	0	0	1	0	400	295
TM20	3	4	3	0	11	10	2	1	14	2	0	1	3	275	293
TM21	14	1	0	1	0	15	7	2	4	5	2	0	1	604	289
TM22	6	1	2	0	2	27	9	2	4	7	3	3	0	321	326
TM23	5	1	1	0	1	24	7	1	3	4	7	1	3	501	288
WA01	0	2	1	1	1	0	0	0	1	1	1	0	0	69	321
WA02	0	2	2	0	0	0	0	0	0	13	0	0	0	193	282
WA03	0	1	0	0	0	0	0	1	3	5	1	1	1	147	321
WA07	0	3	0	1	0	1	0	0	0	6	0	2	0	129	279
WA10	0	2	0	0	1	0	0	0	0	1	0	0	0	23	167
WA13	1	1	4	1	2	1	1	0	2	12	1	0	0	202	296
WA15	2	3	1	0	1	0	0	0	4	3	0	1	1	141	303
WA16	1	0	2	0	0	2	0	0	1	6	1	0	0	97	290
WA17	0	3	3	0	1	0	0	1	2	22	1	0	0	131	297
WA19	0	5	2	1	1	0	0	0	4	6	0	1	0	144	294
WA23	0	0	3	0	5	0	0	0	3	8	0	2	1	102	289
WA26	0	0	1	0	2	0	0	0	1	13	1	0	1	142	295
WH03	0	2	0	0	5	1	0	0	1	3	0	0	0	22	287
WH06	0	0	4	0	0	0	0	0	4	10	0	0	0	23	289
WT03	0	2	2	0	3	1	0	0	3	0	0	0	1	65	289
WT05	0	0	1	0	14	7	5	0	3	1	6	2	0	392	295

E.3 LIST OF FACTORS FOR STATISTICAL SAMPLES

This section contains the list of commonly quoted factors for the statistical samples. The samples are arranged in the alphabetical order of the thesis numbers (as in Appendix E.2). The factors listed are indexed as follows:

SAM : Thesis sample number

AGE : New Zealand Stage

ZN : Radiolarian zone or subzone code

Lamprocyclas gamphonycha Zone Code : RA

Lamprocyrtis heteroporos Zone Code : RB

Lamprocyrtis hannaï Subzone Code : RC

Lychnocanium sp. aff. *grande* Subzone Code : RD

Didymocyrtis sp. A Zone Code : RE

Anthocyrtidium ehrenbergi pliocenica Subzone Code : RF

Heliodiscus asteriscus forma large pores Subzone Code : RG

Didymocyrtis laticonus Subzone Code : RH

Heliodiscus umbonatum Subzone Code : RI

NG : Number of radiolarians per gram of sediment

TOT : Total number of radiolarians counted

N : Number of counting groups filled

This factor gives an idea of the preservation of radiolarians in the sample, the higher the number indicating better preservation because more delicate forms are preserved. Low N values indicate only the more robust species are preserved in samples with low preservation.

Q : the diversity statistic *Q* as defined by Kempton and Wedderburn (1978):

$Q = (N/2) / \ln (Q3/Q1)$, where *Q3* and *Q1* are the third and first quartiles of the series, *P_i*, where *i* = 1, 2, 3, 4 N (the proportional abundances of the radiolarian counting groups arranged in ascending order).

This diversity index emphasises the midrange values and deemphasises the extremes, which is advantageous for fossil assemblages in which extreme values could be a result of differential preservation (Riedel, Westberg-Smith and Budai, 1985).

On page A148 the samples are grouped by radiolarian zone and the means of NG, N, and Q listed.

SAM	AGE	ZN	NG	TOT	N	Q
CR03	LWn	RA	12	200	21	5.05
EC02	LWo	RD	130	297	27	6.68
EC04	LTk	RE	225	297	27	5.66
HR02	UTt	RF	370	259	29	9.00
HR04	UTt	RG	269	309	44	10.23
HR05	UTt	RG	535	275	35	7.93
HR06	UTt	RH	285	300	31	11.21
KB01	LTt	RH	568	357	37	15.91
LT01	LWo	RC	74	306	28	8.61
LT05	LTt	RH	829	286	38	13.71
LT06	LTt	RH	1188	291	38	8.50
LT08	LTt	RH	727	295	28	5.21
LT09	LTt	RI	1187	336	36	9.30
MO02	UTt	RE	762	313	38	8.76
MO03	UTt	RE	292	358	31	8.67
MO05	UTt	RE	551	301	33	10.56
MO06	UTt	RE	532	302	38	9.74
MO07	UTt	RE	648	303	36	8.84
MO10	UTt	RE	1112	298	37	12.78
MO11	UTt	RE	568	371	42	13.74
MO13	UTt	RE	789	296	37	11.19
MO14	UTt	RE	735	285	39	8.86
MS03	UTt	RE	715	293	34	13.18
MS04	UTt	RE	692	302	42	13.93
MS05	UTt	RE	204	291	35	7.93
MS06	UTt	RE	405	296	37	8.06
MS07	UTt	RE	395	285	39	12.94
MS08	UTt	RF	512	293	36	10.99
MS09	UTt	RF	303	294	32	6.67
MS10	UTt	RF	61	121	22	5.08
MS11	UTt	RF	56	298	31	5.90
MS12	UTt	RG	418	307	38	11.97
MS13	UTt	RG	482	303	40	14.43
MS14	UTt	RG	378	296	43	11.10
MS15	UTt	RG	402	303	38	7.92
MS16	UTt	RG	93	291	23	3.76
MS18	UTt	RH	50	261	28	6.12
MS19	LTt	RH	109	287	36	8.67
MT04	UTt	RE	140	291	33	9.97
MT07	UTt	RE	111	290	30	8.48
MT08	UTt	RG	56	304	34	8.60
MT09	UTt	RG	236	321	34	7.92
MT10	UTt	RG	111	262	34	7.82
PB02	UTt	RE	17	202	22	6.14
PB04	UTt	RF	131	297	35	10.24
PB05	UTt	RF	172	323	28	6.51
PB06	UTt	RF	155	306	33	10.56
PB09	UTt	RF	90	295	29	8.76
PB11	UTt	RF	617	286	31	10.31

SAM	AGE	ZN	NG	TOT	N	Q
RK02	UTt	RH	211	284	36	9.71
RK03	UTt	RH	223	279	25	6.44
RK04	LTt	RH	161	295	31	9.65
RM03	UTt	RE	94	239	31	6.48
RM04	UTt	RE	436	296	34	9.88
RM05	UTt	RF	448	293	41	9.84
RM06	UTt	RF	353	291	36	8.75
RM07	UTt	RF	430	270	38	17.30
SCV1	UTt	RG	596	290	39	8.94
SMA1	UTt	RE	279	303	26	7.76
SMA3	UTt	RE	617	316	36	6.87
SMA4	UTt	RF	246	296	31	7.49
SMA5	UTt	RG	125	339	27	5.26
SMA6	UTt	?	83	298	24	4.58
SMH1	UTt	RE	344	286	37	8.69
SMR1	LWo	RD	51	295	31	6.24
SPA1	LTt	RH	613	284	29	6.42
SWM1	LWo	RC	449	310	30	8.93
SWR1	LWo	RD	271	304	23	3.71
SWR2	LWo	RD	91	274	29	7.08
SWR3	LWo	RD	104	300	26	5.40
SWR4	LTt	RH	104	307	35	6.66
TK05	Wop	?	6	50	14	4.84
TM06	Wop	RD	285	288	28	6.32
TM14	UTt	RE	662	300	36	10.58
TM15	UTt	RE	388	301	35	11.70
TM16	UTt	RE	223	297	32	9.12
TM19	UTt	RE	400	295	34	7.39
TM20	UTt	RE	275	293	41	10.51
TM21	UTt	RE	604	289	38	7.62
TM22	UTt	RE	321	326	40	12.38
TM23	UTt	RE	501	288	40	10.39
WA01	UWn	RA	69	321	34	6.23
WA02	UWn	RA	193	282	29	8.51
WA03	UWn	RA	147	321	34	7.92
WA07	UWn	RA	129	279	33	7.34
WA10	LWn	RB	23	167	22	4.17
WA13	Wm	RB	202	296	35	8.45
WA15	Wm	RB	141	303	37	8.21
WA16	Wm	RB	97	290	31	6.01
WA17	Wm	RB	131	297	31	8.26
WA19	Wm	RB	144	294	33	6.76
WA23	Wop	RB	102	289	29	7.28
WA26	Wop	RB	142	295	24	4.33
WH03	UWn	RA	22	287	26	6.83
WH06	UWn	RB	23	289	23	7.85
WT03	UTt	RE	65	289	28	5.33
WT05	UTt	RF	392	295	38	9.15

MEANS OF NG, N, AND Q GROUPED BY RADIOLARIAN ZONE

Lamprocyclas gamphonycha Zone Code : RA

samples = 6 mean NG = 95 mean N = 29.5 mean Q = 6.98

Lamprocyrtis heteroporos Zone Code : RB

samples = 9 mean NG = 112 mean N = 29.4 mean Q = 6.81

Lamprocyrtis hannai Subzone Code : RC

samples = 2 mean NG = 262 mean N = 29.0 mean Q = 8.77

Lychnocanium sp. aff. *grande* Subzone Code : RD

samples = 6 mean NG = 155 mean N = 27.3 mean Q = 5.90

Didymocyrtis sp. A Zone Code : RE

samples = 31 mean NG = 435 mean N = 34.9 mean Q = 9.59

Anthocyrtidium ehrenbergi pliocenica Subzone Code : RF

samples = 15 mean NG = 289 mean N = 32.7 mean Q = 9.10

Heliodiscus asteriscus forma large pores Subzone Code : RG

samples = 12 mean NG = 308 mean N = 35.7 mean Q = 8.82

Didymocyrtis laticonus Subzone Code : RH

samples = 12 mean NG = 422 mean N = 32.7 mean Q = 9.02

Heliodiscus umbonatum Subzone Code : RI

samples = 1 mean NG = 1187 mean N = 36.0 mean Q = 9.30

E.4 REDUCED DATA SET

This section tabulates the reduced data set used in the thesis. This data set includes all the original counting groups and some combined groups which generally represent over 2% of the fauna. After these major elements of the fauna were chosen (13 groups) their percentages were recalculated to 100% and it is the recalculated percentages that are tabulated here. The samples are again arranged in alphabetical order of thesis number. The variables listed are indexed on the facing page.

On page A154 the samples are grouped by radiolarian biozone and the means of the 13 groups presented.

SAM : thesis sample number

AGE : New Zealand Stage

ZN : Radiolarian zone

R1 : *Actinomma* spp.

R2 : *Hexacontium* spp.

R3 : *Thecosphaera* spp.

R4 : *Cenosphaera* spp.

R5 : *Prunulum* spp.

R6 : Stylosphaerids

SAM	AGE	ZN	R1	R2	R3	R4	R5	R6
CR03	LWn	RA	5.1	3.2	3.8	1.9	8.2	5.1
EC02	LWo	RD	2.6	3.1	6.6	4.0	7.9	1.8
EC04	LTk	RE	2.9	3.8	6.7	2.1	10.9	1.7
HR02	UTt	RF	2.8	3.7	4.6	1.9	6.0	6.0
HR04	UTt	RG	1.3	2.2	7.8	0.4	8.2	2.2
HR05	UTt	RG	1.8	3.2	2.3	0.0	7.8	4.6
HR06	UTt	RH	2.9	1.7	2.9	0.8	11.2	5.4
KB01	LTt	RH	2.7	10.3	2.7	4.0	11.7	1.8
LT01	LWo	RC	4.1	3.2	2.7	0.0	5.5	3.2
LT05	LTt	RH	1.9	12.0	8.3	1.4	11.1	4.6
LT06	LTt	RH	0.4	6.1	8.3	4.8	13.9	6.5
LT08	LTt	RH	3.2	6.4	5.2	6.4	8.8	6.0
LT09	LTt	RI	3.4	6.5	5.3	5.3	11.5	7.3
MO02	UTt	RE	10.7	4.0	4.9	1.8	11.2	4.0
MO03	UTt	RE	5.3	5.0	2.3	3.4	16.0	8.4
MO05	UTt	RE	4.3	1.9	3.3	2.4	10.5	2.9
MO06	UTt	RE	3.7	2.3	2.8	2.3	14.0	5.1
MO07	UTt	RE	4.6	5.0	3.7	0.0	6.4	5.5
MO10	UTt	RE	4.9	2.5	3.0	1.5	8.9	3.9
MO11	UTt	RE	4.8	4.8	5.2	0.8	5.2	4.8
MO13	UTt	RE	4.9	7.3	4.4	1.5	5.9	4.4
MO14	UTt	RE	4.7	0.5	2.6	1.0	5.2	10.4
MS03	UTt	RE	3.8	1.9	2.9	2.4	9.1	3.8
MS04	UTt	RE	5.7	11.4	3.8	0.5	4.3	6.2
MS05	UTt	RE	2.8	3.3	2.8	3.3	12.8	7.1
MS06	UTt	RE	1.3	5.7	4.3	2.2	8.7	11.3
MS07	UTt	RE	3.3	10.0	3.3	4.3	9.0	5.2
MS08	UTt	RF	4.0	8.9	2.2	1.8	4.9	5.4
MS09	UTt	RF	3.1	3.1	4.9	2.2	8.9	3.1
MS10	UTt	RF	8.3	7.3	8.3	11.5	12.5	15.6
MS11	UTt	RF	3.4	5.8	8.3	2.9	15.0	10.7
MS12	UTt	RG	6.0	10.6	6.0	0.9	10.6	6.9
MS13	UTt	RG	17.1	8.1	4.5	1.8	8.6	6.3
MS14	UTt	RG	4.4	4.9	3.9	1.0	9.3	6.3
MS15	UTt	RG	4.5	9.0	5.0	2.3	8.6	5.0
MS16	UTt	RG	4.6	10.0	12.1	3.8	8.4	12.1
MS18	UTt	RH	1.6	4.8	9.7	3.2	15.1	3.2
MS19	LTt	RH	2.3	4.2	3.7	0.9	7.0	4.2
MT04	UTt	RE	3.5	2.2	6.6	1.8	6.6	2.6
MT07	UTt	RE	2.6	4.3	7.3	0.4	6.0	2.6
MT08	UTt	RG	2.2	2.2	2.6	1.7	9.1	5.2
MT09	UTt	RG	2.0	4.0	4.4	3.2	7.7	3.2
MT10	UTt	RG	2.1	2.7	5.9	0.0	17.0	2.1
PB02	UTt	RE	4.9	4.2	8.5	3.5	15.5	10.6
PB04	UTt	RF	10.7	5.1	5.1	6.0	8.8	10.2
PB05	UTt	RF	3.7	5.3	2.9	0.0	11.8	6.1
PB06	UTt	RF	5.4	5.4	2.2	2.7	9.9	5.8
PB09	UTt	RF	2.2	6.7	3.1	0.9	10.7	1.8
PB11	UTt	RF	4.2	7.0	1.9	4.2	14.6	4.7

SAM : thesis sample number

AGE : New Zealand Stage

ZN : Radiolarian zone

R1 : *Actinomma* spp.

R2 : *Hexacontium* spp.

R3 : *Thecosphaera* spp.

R4 : *Cenosphaera* spp.

R5 : *Prunulum* spp.

R6 : Stylosphaerids

SAM	AGE	ZN	R1	R2	R3	R4	R5	R6
RK02	UTt	RH	4.6	4.6	1.9	2.3	13.4	2.8
RK03	UTt	RH	0.0	5.1	4.2	3.0	6.8	2.1
RK04	LTt	RH	2.9	3.3	4.1	1.2	9.5	3.7
RM03	UTt	RE	7.9	7.9	2.1	12.1	15.0	13.6
RM04	UTt	RE	3.7	2.8	0.9	1.9	6.5	6.0
RM05	UTt	RF	4.4	1.9	7.3	1.0	9.7	2.9
RM06	UTt	RF	2.9	2.9	3.4	1.4	10.1	5.3
RM07	UTt	RF	6.6	7.7	3.3	0.5	7.7	10.9
SCV1	UTt	RG	1.8	1.4	5.0	1.4	5.0	4.5
SMA1	UTt	RE	3.5	5.3	6.1	0.9	9.2	2.2
SMA3	UTt	RE	3.8	5.1	4.7	1.7	7.3	12.4
SMA4	UTt	RF	1.8	4.1	4.6	2.7	7.8	7.8
SMA5	UTt	RG	9.0	8.6	4.7	1.2	7.5	5.5
SMA6	UTt	?	3.1	4.8	7.0	1.8	10.1	4.0
SMH1	UTt	RE	3.7	0.0	8.2	3.2	13.2	4.6
SMR1	LWo	RD	8.1	4.7	5.6	0.4	6.0	5.1
SPA1	LTt	RH	4.0	2.2	4.0	2.2	10.6	6.6
SWM1	LWo	RC	1.1	2.2	1.8	4.8	15.8	5.9
SWR1	LWo	RD	5.0	4.6	2.5	2.1	9.2	11.3
SWR2	LWo	RD	6.3	2.7	3.6	1.8	7.6	5.8
SWR3	LWo	RD	4.3	3.0	6.0	4.7	18.4	3.4
SWR4	LTt	RH	4.3	11.3	9.1	3.0	11.3	6.9
TK05	Wop	?	2.7	2.7	5.4	8.1	5.4	2.7
TM06	Wop	RD	2.7	0.5	3.2	3.2	5.9	0.5
TM14	UTt	RE	3.5	6.1	4.8	3.1	4.4	6.6
TM15	UTt	RE	4.0	5.8	2.7	3.6	12.4	5.8
TM16	UTt	RE	5.6	9.8	3.8	1.7	5.6	6.0
TM19	UTt	RE	3.1	2.7	2.7	0.9	13.5	4.5
TM20	UTt	RE	5.5	2.2	3.3	2.8	9.4	2.2
TM21	UTt	RE	3.2	8.5	5.3	3.7	6.9	0.0
TM22	UTt	RE	2.1	4.7	1.7	0.9	6.0	8.1
TM23	UTt	RE	2.6	4.2	2.1	2.6	4.7	5.8
WA01	UWn	RA	8.2	9.8	3.7	6.5	9.8	7.8
WA02	UWn	RA	9.0	5.4	5.4	4.1	4.1	19.0
WA03	UWn	RA	12.3	2.1	2.9	2.5	4.1	33.7
WA07	UWn	RA	11.2	16.5	1.0	4.9	6.8	24.8
WA10	LWn	RB	19.9	8.5	13.5	6.4	9.2	16.3
WA13	Wm	RB	3.6	4.0	6.2	1.3	6.2	8.4
WA15	Wm	RB	12.8	7.2	3.1	2.6	9.2	10.8
WA16	Wm	RB	9.5	4.8	3.8	1.9	15.7	6.7
WA17	Wm	RB	11.7	9.7	2.0	5.1	10.2	0.0
WA19	Wm	RB	10.4	4.0	4.0	1.0	8.0	12.9
WA23	Wop	RB	1.8	3.6	7.2	0.9	5.0	5.0
WA26	Wop	RB	3.4	1.3	7.8	2.2	5.2	3.0
WH03	UWn	RA	6.9	0.4	7.8	4.3	13.4	2.6
WH06	UWn	RB	10.2	5.8	5.8	2.2	7.6	3.1
WT03	UTt	RE	2.4	6.7	19.0	16.2	11.0	11.0
WT05	UTt	RF	3.7	2.8	2.3	0.9	7.4	8.3

SAM : thesis sample number

R7 : *Dictyocoryne* and *Hymeniastrum* spp.

R8 : *Stylodictya* spp.

R9 : *Porodiscus* spp.

R10 : *Spongotrochus glacialis*

R11 : *Carpocaniidae*

R12 : *Cyrtocapsella* and *Stichocorys* spp.

R13 : *Artostrobiidae*

SAM	R7	R8	R9	R10	R11	R12	R13
CR03	2.5	1.9	22.8	39.9	2.5	1.3	1.9
EC02	7.0	12.3	19.4	29.1	2.2	4.0	0.0
EC04	4.6	17.6	20.2	23.5	2.9	2.1	0.8
HR02	4.6	3.2	13.4	31.9	2.8	18.5	0.5
HR04	6.9	6.5	18.5	19.8	3.9	15.9	6.5
HR05	6.0	4.1	17.0	19.3	4.1	26.6	3.2
HR06	3.3	2.1	12.4	27.4	2.5	24.1	3.3
KB01	2.2	13.0	7.6	27.8	9.4	1.8	4.9
LT01	4.5	3.2	14.1	40.0	0.0	11.8	7.7
LT05	2.8	8.3	11.1	19.9	7.9	3.2	7.4
LT06	2.6	4.3	10.9	32.2	3.9	1.3	4.8
LT08	3.6	9.2	14.7	26.3	4.8	0.8	4.8
LT09	2.3	10.7	12.6	22.9	5.3	0.8	6.1
MO02	5.8	8.5	13.8	24.1	2.2	7.6	1.3
MO03	4.6	6.5	11.1	22.9	6.1	4.2	4.2
MO05	2.9	5.2	21.9	18.6	5.7	14.3	6.2
MO06	4.7	3.3	15.0	26.2	2.3	10.3	7.9
MO07	3.7	6.4	15.1	26.5	3.2	12.8	7.3
MO10	3.4	4.9	19.2	24.1	2.5	14.3	6.9
MO11	3.2	4.4	20.2	25.0	2.0	15.3	4.0
MO13	6.3	7.8	15.1	21.0	2.0	15.6	3.9
MO14	4.7	3.1	23.4	21.4	2.6	14.6	5.7
MS03	8.6	8.1	20.6	26.8	2.4	6.7	2.9
MS04	2.4	6.6	9.0	25.1	0.9	14.2	10.0
MS05	4.7	6.2	12.3	27.5	3.8	6.2	7.1
MS06	3.0	6.1	9.6	17.8	4.3	6.1	19.6
MS07	4.7	7.6	10.0	26.1	2.8	3.3	10.4
MS08	2.7	8.0	19.6	21.0	2.2	7.6	11.6
MS09	7.6	4.9	16.5	27.2	6.7	8.9	2.7
MS10	0.0	3.1	7.3	19.8	1.0	5.2	0.0
MS11	0.5	7.8	12.1	23.8	6.8	2.4	0.5
MS12	3.2	5.5	16.1	17.1	1.4	11.1	4.6
MS13	3.6	9.0	10.4	17.6	2.3	5.9	5.0
MS14	2.9	6.8	11.2	27.8	3.4	9.8	8.3
MS15	5.4	9.0	6.8	26.7	3.2	10.0	4.5
MS16	2.1	6.7	12.6	15.1	1.7	2.1	8.8
MS18	1.6	5.9	14.0	31.7	5.4	2.7	1.1
MS19	4.7	5.6	21.5	28.5	3.7	9.8	3.7
MT04	3.5	6.6	13.6	30.7	5.7	12.3	4.4
MT07	4.7	6.9	16.8	29.7	7.3	6.0	5.2
MT08	3.0	9.5	13.4	38.4	7.3	5.6	0.0
MT09	4.0	7.3	19.0	31.5	3.2	6.0	4.4
MT10	5.9	3.7	12.2	26.1	2.1	14.9	5.3
PB02	0.7	4.2	15.5	25.4	2.8	4.2	0.0
PB04	2.3	5.1	9.8	20.9	3.7	11.6	0.5
PB05	5.3	9.4	13.5	31.0	2.0	9.0	0.0
PB06	10.8	9.4	14.3	23.8	1.8	8.5	0.0
PB09	4.5	5.8	10.3	41.1	3.6	6.7	2.7
PB11	4.2	5.6	14.1	32.9	0.9	5.2	0.5

SAM : thesis sample number

R7 : *Dictyocoryne* and *Hymeniastrum* spp.

R8 : *Stylodictya* spp.

R9 : *Porodiscus* spp.

R10 : *Spongotrochus glacialis*

R11 : Carpocaniidae

R12 : *Cyrtocapsella* and *Stichocorys* spp.

R13 : Artostrobiidae

SAM	R7	R8	R9	R10	R11	R12	R13
RK02	5.1	4.2	21.8	16.7	3.7	15.3	3.7
RK03	9.3	9.7	17.4	30.9	3.4	6.8	1.3
RK04	5.4	8.3	14.0	35.1	0.8	9.9	1.7
RM03	1.4	1.4	2.1	10.0	8.6	12.1	5.7
RM04	6.0	6.5	19.1	21.4	3.7	12.6	8.8
RM05	4.9	4.4	13.1	28.2	3.9	12.1	6.3
RM06	3.8	3.8	21.6	21.6	1.9	12.5	8.7
RM07	3.3	5.5	20.2	22.4	2.2	7.1	2.7
SCV1	6.3	7.2	16.7	30.2	1.8	16.2	2.7
SMA1	5.3	7.5	16.7	32.9	2.6	6.1	1.8
SMA3	4.7	7.7	13.2	28.6	3.0	6.4	1.3
SMA4	1.4	5.9	21.5	34.2	2.7	5.0	0.5
SMA5	3.9	5.9	13.7	25.5	3.1	3.5	7.8
SMA6	4.8	10.1	13.7	30.8	3.1	4.4	2.2
SMH1	8.7	5.9	23.7	22.4	0.5	5.5	0.5
SMR1	8.5	9.8	8.1	40.6	0.4	0.4	2.1
SPA1	1.8	7.5	18.1	33.2	4.4	3.5	1.8
SWM1	8.1	18.4	16.5	23.2	0.0	1.5	0.7
SWR1	8.4	10.5	5.5	35.7	1.3	2.9	0.8
SWR2	9.4	6.7	15.2	19.7	2.2	17.0	1.8
SWR3	3.0	4.7	7.3	39.7	0.4	4.7	0.4
SWR4	1.7	7.4	7.8	26.8	6.9	2.2	1.3
TK05	8.1	0.0	24.3	35.1	0.0	5.4	0.0
TM06	10.5	10.5	15.5	45.2	0.5	0.5	1.4
TM14	7.0	7.4	8.7	21.4	3.1	21.8	2.2
TM15	3.6	6.2	19.1	21.8	2.2	12.0	0.9
TM16	4.3	9.0	14.5	20.9	5.1	12.8	0.9
TM19	10.8	6.7	20.6	16.1	4.5	13.5	0.4
TM20	3.9	5.0	23.8	25.4	2.2	12.7	1.7
TM21	8.5	7.9	18.0	15.9	6.3	12.2	3.7
TM22	5.1	9.8	19.6	16.2	4.3	16.2	5.5
TM23	6.3	11.1	18.4	13.7	4.7	17.4	6.3
WA01	3.7	6.5	13.1	28.6	1.2	0.4	0.8
WA02	5.9	3.2	5.9	32.1	0.0	0.0	5.9
WA03	1.6	3.3	9.1	25.1	0.0	0.4	2.9
WA07	2.9	6.3	3.9	16.5	1.0	0.5	3.9
WA10	0.7	0.0	7.8	14.9	1.4	0.7	0.7
WA13	9.3	3.6	12.9	35.1	1.8	1.8	5.8
WA15	8.7	5.1	9.2	27.7	1.0	0.5	2.1
WA16	8.6	7.6	14.3	21.4	1.4	1.0	3.3
WA17	6.6	3.1	10.2	28.1	1.0	0.5	11.7
WA19	9.0	7.5	10.9	26.4	2.0	0.5	3.5
WA23	13.1	8.6	14.9	32.4	0.9	2.3	4.5
WA26	8.2	7.3	26.7	27.2	0.9	0.9	6.0
WH03	9.5	3.9	13.8	32.8	0.9	2.6	1.3
WH06	4.4	5.8	10.7	37.8	2.2	0.0	4.4
WT03	1.4	2.4	6.7	14.8	6.7	1.9	0.0
WT05	3.7	9.7	16.6	23.0	5.5	12.0	4.1

- ZN : Radiolarian zone
R1 : *Actinomma* spp.
R2 : *Hexacontium* spp.
R3 : *Thecosphaera* spp.
R4 : *Cenosphaera* spp.
R5 : *Prunulum* spp.
R6 : Stylosphaerids
R7 : *Dictyocoryne* and *Hymeniastrum* spp.
R8 : *Stylodictya* spp.
R9 : *Porodiscus* spp.
R10 : *Spongotrochus glacialis*
R11 : Carpacaniidae
R12 : *Cyrtocapsella* and *Stichocorys* spp.
R13 : Artostrobiidae

MEANS OF R1 - R13 GROUPED BY RADIOLARIAN ZONE

ZN	R1	R2	R3	R4	R5	R6
RA	8.8	6.2	4.1	4.0	7.7	15.5
RB	9.3	5.4	5.9	2.6	8.5	7.4
RC	2.6	2.7	2.3	2.4	10.6	4.5
RD	4.9	3.1	4.6	2.7	9.2	4.7
RE	4.2	4.7	4.6	2.9	9.2	5.7
RF	4.5	5.2	4.3	2.7	9.7	7.0
RG	4.7	5.6	5.3	1.5	9.0	5.3
RH	2.6	6.0	5.3	2.8	10.9	4.5
RI	3.4	6.5	5.3	5.3	11.5	7.3

ZN	R7	R8	R9	R10	R11	R12	R13
RA	4.4	4.2	11.4	29.2	0.9	0.9	2.8
RB	7.6	5.4	13.1	27.9	1.4	0.9	4.7
RC	6.3	10.8	15.3	31.6	0.0	6.6	4.2
RD	7.8	9.1	11.8	35.0	1.2	4.9	1.1
RE	4.8	6.7	15.9	22.4	3.7	10.5	4.7
RF	4.0	6.1	14.9	26.9	3.2	8.8	2.7
RG	4.4	6.8	14.0	24.6	3.1	10.6	5.1
RH	3.7	7.1	14.3	28.0	4.7	6.8	3.3
RI	2.3	10.7	12.6	22.9	5.3	0.8	6.1

E.5 PALLISER BAY TUFF SAMPLES

This section tabulates the number per gram of sediment of various components of the fraction $>54\mu$ for samples above and below the tuff in the Palliser Bay Section.

The following abbreviations are used:

SAM : sample number.

POS : stratigraphic distance from the base of the tuff (cm).

BEN : number of benthic forams per gram of sediment.

PLK : number of planktic forams per gram of sediment.

SPC : number of sponge spicules per gram of sediment.

RAD : number of radiolarians per gram of sediment.

SHR : number of glass shards per gram of sediment.

SAM	POS	BEN	PLK	SPC	RAD	SHR
PTY	320	702	121	477	1179	442
PTX	270	1355	240	156	1139	720
PTW	210	597	157	162	754	722
PTV	170	505	312	187	601	550
PTU	130	1505	226	336	1376	614
PTT	110	1734	371	159	781	2091
PTS	80	1064	294	509	633	4850
PTR	60	1209	212	233	594	15591
PTQ	40	779	269	150	479	28806
PTG	-20	971	158	172	475	730
PTH	-40	827	73	345	827	1466
PTI	-60	467	16	561	751	419
PTJ	-80	475	67	218	615	380
PTK	-100	444	39	283	1088	509
PTL	-120	877	115	108	793	531
PTM	-140	925	182	288	735	273
PTN	-160	298	69	346	941	1059
PTO	-180	338	93	344	1045	423
PTP	-200	490	16	253	371	498

Plates of Radiolaria

PLATE 1 (opposite)

1. ? *Oropelex* sp. : x90 : RM02 : AA4/2
2. *Collosphaera* sp. A : x360 : MO09 : AA4/6
3. *Collosphaera* sp. aff. *huxleyi* Muller : x250 : PB11 : 167/7
4. *Collosphaera* sp. aff. *huxleyi* Muller : x290 : TM14 : AA2/7
5. *Acrosphaera spinosa echinoides* (Haeckel) : x350 : SMR1 : AA4/8
6. *Acrosphaera spinosa spinosa* (Haeckel) : x320 : SCV1 : AA4/10
7. *Actinomma antarcticum* (Haeckel) : x170 : TM23 : AA1/1
8. *Actinomma antarcticum* (Haeckel) : x410 : LT03 : AA7/4
medullary only
9. *Actinomma antarcticum* (Haeckel) : x130 : TM23 : AA1/1
double cortical shell
10. *Actinomma antarcticum* (Haeckel) : x140 : MO05 : AA4/7
11. *Actinomma* cf. *medianum* Nigrini : x220 : MS15 : AA3/6
12. *Actinomma leptodermum* (Jorgensen) : x310 : WA02 : AA8/3
13. *Actinomma leptodermum* (Jorgensen) : x250 : WA02 : AA8/3

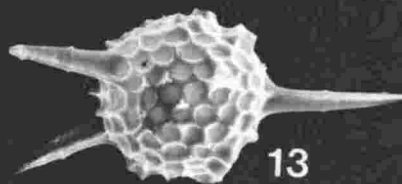
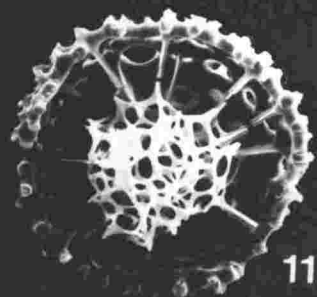
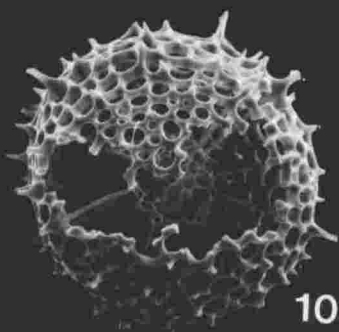
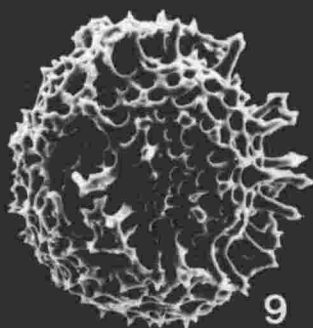
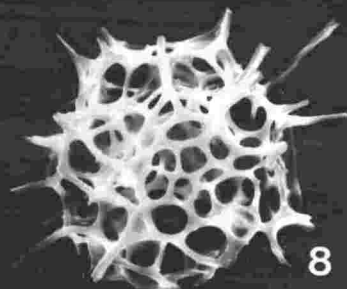
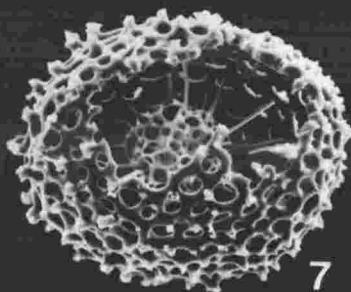
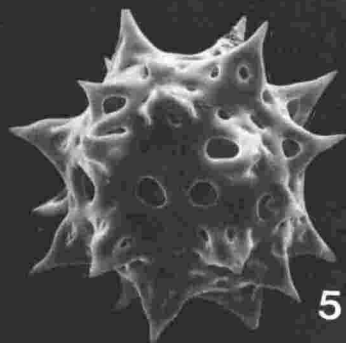
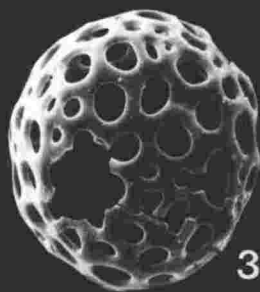
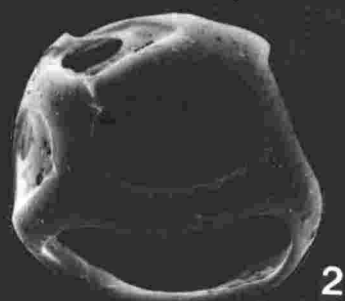
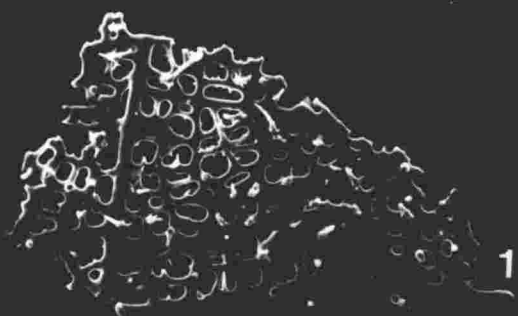
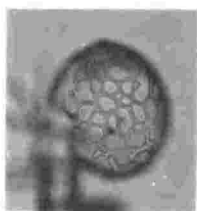
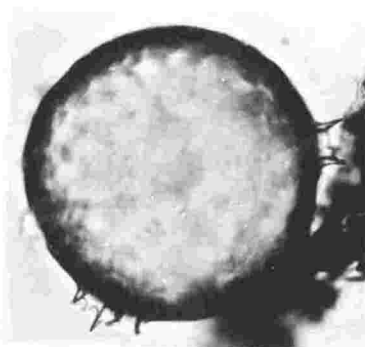


PLATE 2 (opposite)

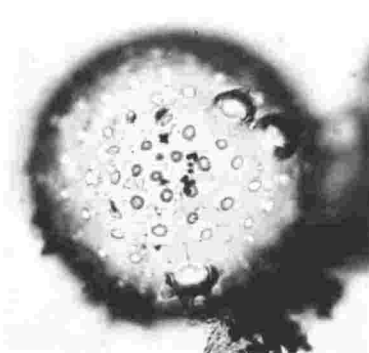
1. *Collosphaera* cf. *polygona* Haeckel : x123 : RM05 : M38/4
2. *Siphonosphaera polysiphonia* Haeckel : x403 : WA16 : L37/4
 - A. focused on circumference
 - B. focused on surface of same specimen
3. *Acrosphaera spinosa echinoides* (Haeckel) : x413 : WA01 : L28/3
 - A. focused on surface
 - B. focused on circumference of same specimen
4. *Otosphaera polymorpha* Haeckel : x397 : MO13 : O13/2
5. *Collosphaera* sp. aff. *huxleyi* Muller : x401 : SMA3 : P27/1
6. *Actinomma antarcticum* (Haeckel) : x306 : MO02 : U38/3
medullary only
7. *Actinomma* cf. *medianum* Nigrini : x250 : MO11 : K24/4
8. *Actinomma polycanthum* (Muller) group : x412 : TM20 : RIO
 - A. focused on internals
 - B. focused on surface of same specimen



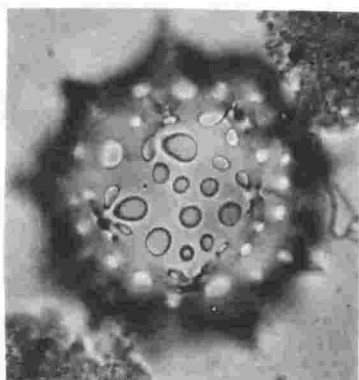
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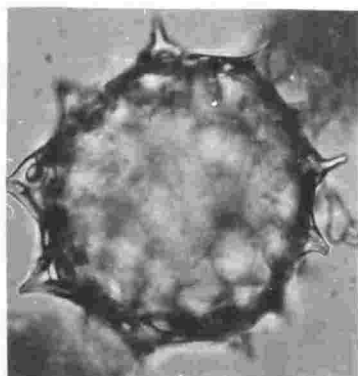
2A



B



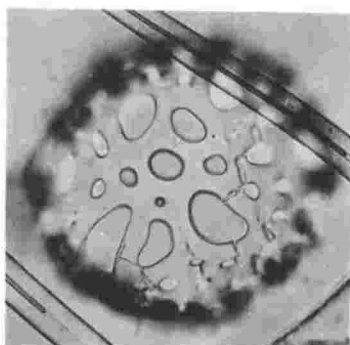
3A



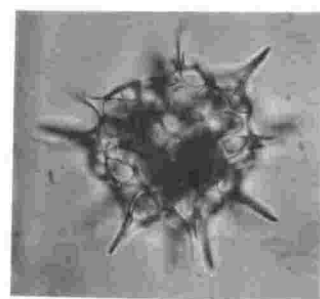
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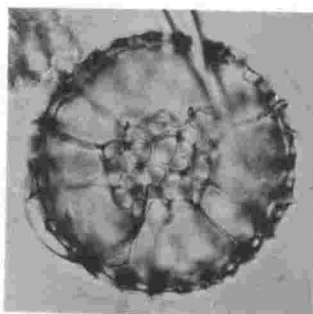
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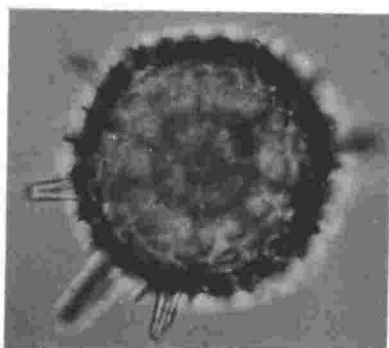
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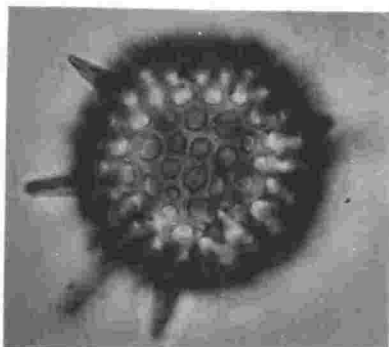
6



7



8A



B

PLATE 3 (opposite)

1. *Actinomma polycanthum* (Muller) group : x220 : RM05 : AA5/5
approximately 16 spines
2. *Actinomma polycanthum* (Muller) group : x330 : MS03 : AA2/10
"oval" form
3. *Actinomma polycanthum* (Muller) group : x210 : RM04 : MISC/5
approximately 10 spines
4. ? *Actinomma polycanthum* (Muller) group ? : x410 : SWR4 : AA4/12
medullary shell
5. *Actinomma polycanthum* (Muller) group : x320 : RM05 : AA5/5
broken specimen showing medullary shells
6. *Cladococcus dentata* (Mast) : x140 : TM20 : AA1/10
7. *Cladococcus stalactites* Haeckel : x130 : RM03 : AA4/1
8. *Cenosphaera cristata* Haeckel : x250 : MO04 : AA4/4
9. *Cenosphaera* sp. C : x270 : RM01 : AA4/2
10. *Cenosphaera* sp. A : x330 : TM16 : AA6/1
transmitted light photos of same specimen : Plate 4, figures 1a,b
11. *Acanthosphaera* sp. A : x360 : MO09 : AA4/6
"many-spined" form
12. *Acanthosphaera* sp. A : x220 : MO13 : AA4/7
"intermediate" form
13. ? *Acanthosphaera* sp. B ? : x180 : WA02 : AA8/2

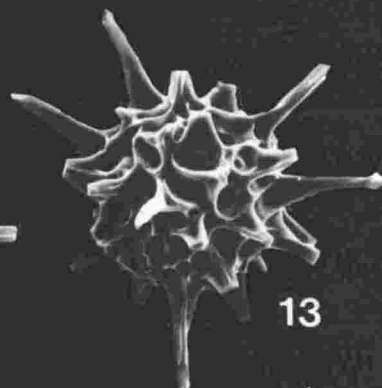
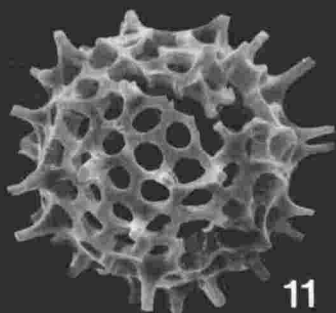
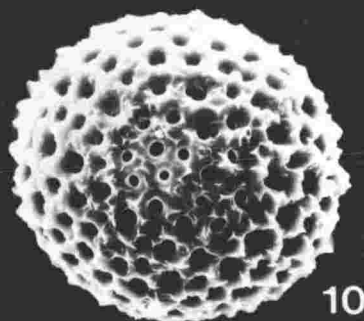
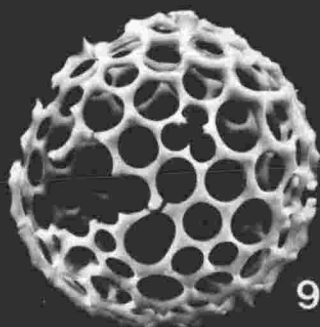
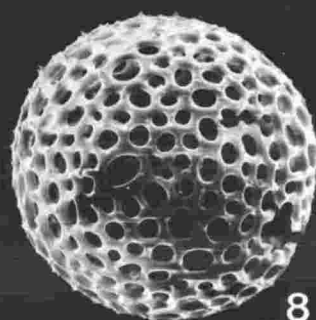
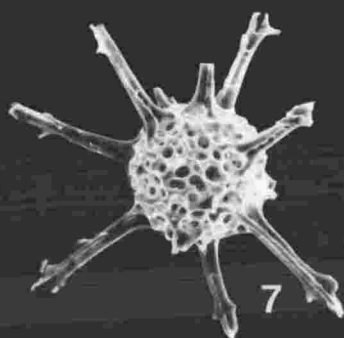
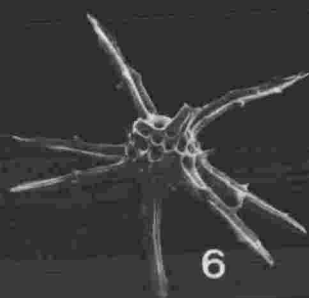
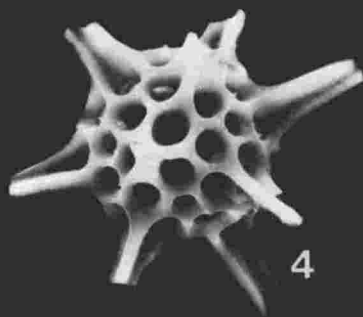
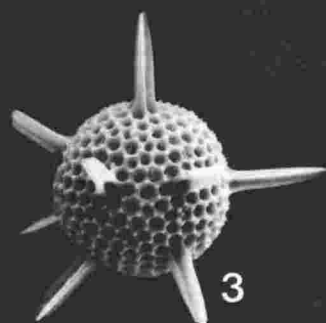
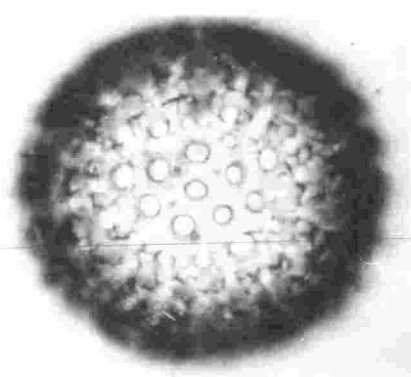
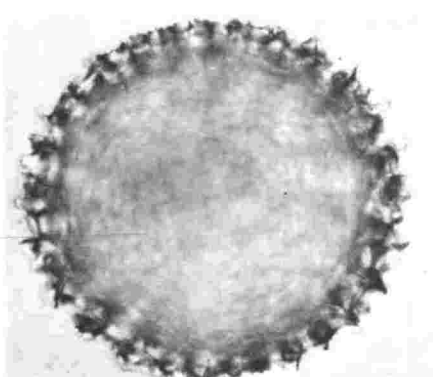


PLATE 4 (opposite)

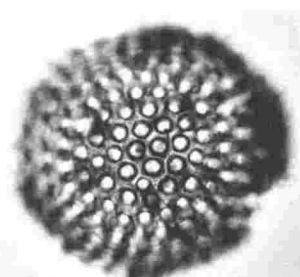
1. *Cenosphaera* sp. A : x407 : TM16 : RIO
SEM photo of same specimen : Plate 3, figure 10
A. focused on surface
B. focused on circumference of same specimen
2. *Cenosphaera* sp. B : x380 : PB02 : L39/1
A. focused on surface
B. focused on circumference of same specimen
3. *Cenosphaera* sp. D : x284 : PB11 : F33/1
A. focused on surface
B. focused on circumference of same specimen
4. *Acanthosphaera dodecastyla* Mast : x435 : LT09 : K16/3
5. *Acanthosphaera* sp. A : x422 : HRO4d : R28/1
"few-spined" form
6. *Acanthosphaera* sp. B : x294 : TM20 : RIO
7. *Hexacontium enthacanthum* Jorgensen : x264 : WA10 : W19/1
A. focused on surface
B. focused on internals of same specimen



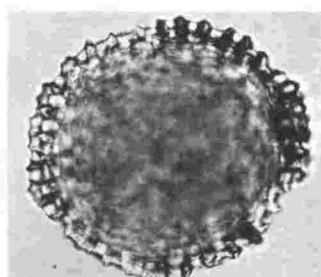
1A



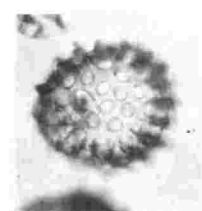
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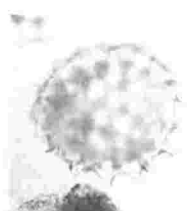
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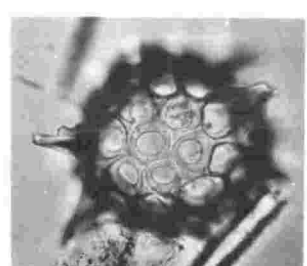
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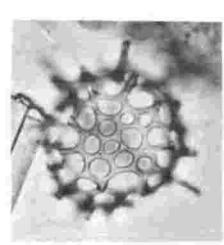
3A



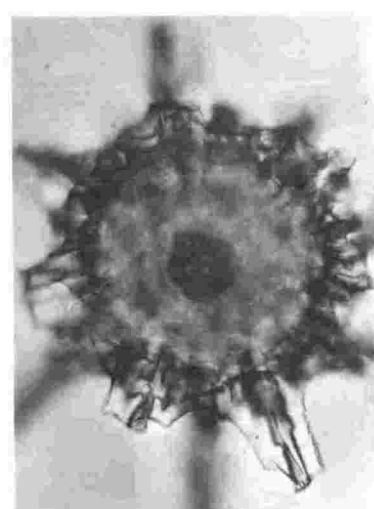
B



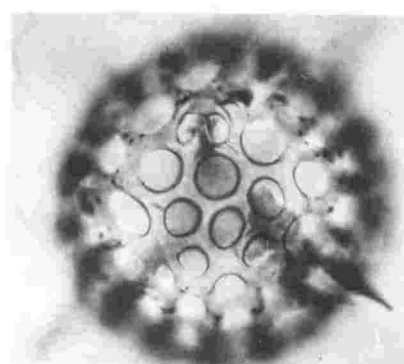
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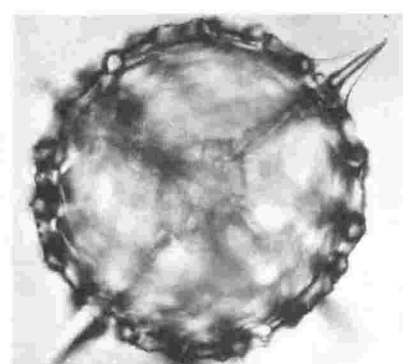
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6



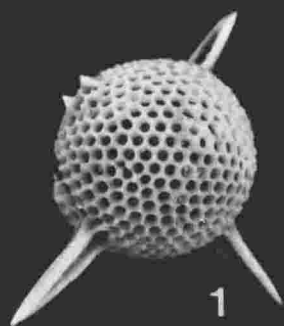
7A



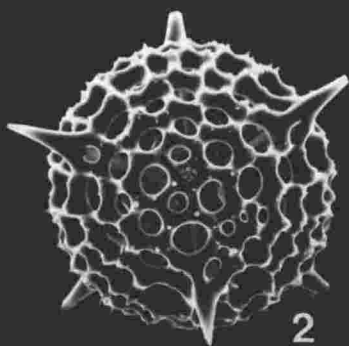
B

PLATE 5 (opposite)

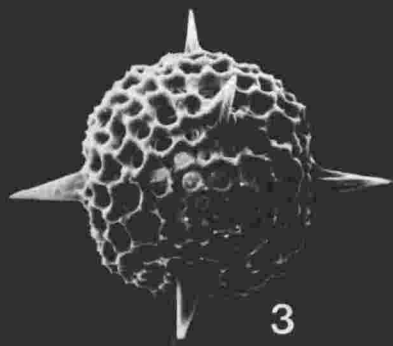
1. *Hexacontium laevigatum* Haeckel : x210 : PB04 : 158/6
"long spined" form
2. *Hexacontium enthacanthum* Jorgensen : x220 : MO04 : AA4/4
3. *Hexacontium enthacanthum* Jorgensen : x180 : RM06 : AA5/4
"quadrate" form
4. *Hexacontium enthacanthum* Jorgensen : x270 : RM01 : AA4/2
5. *Hexacontium laevigatum* Haeckel : x180 : RM02 : AA4/2
6. *Hexacontium enthacanthum* Jorgensen : x220 : TM20 : AA6/4
"oval" form
7. *Hexacontium laevigatum* Haeckel : x240 : TM14 : AA2/7
"oval" form
8. *Hexacontium laevigatum* Haeckel : x270 : PB11 : 167/8
form transitional to *H. enthacanthum*
9. *Thecosphaera* cf. *akitaensis* Nakaseko : x450 : SMA5 : AA4/12
10. ? *Thecosphaera grecoi* Vinassa de Regny group ? : x310 : PB02 : 156/2
11. *Prunulum* sp. : x380 : TM20 : AA6/6
transmitted light photo of same specimen : Plate 6, figure 2
12. *Styptosphaera stupacea* Haeckel : x180 : RM05 : AA5/5
13. *Styptosphaera spumacea* Haeckel : x270 : RM02 : AA4/1



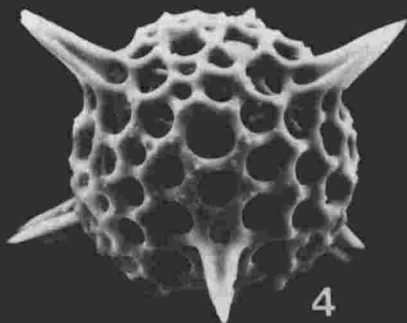
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2



3



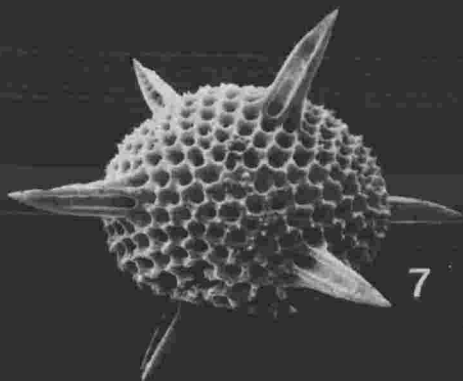
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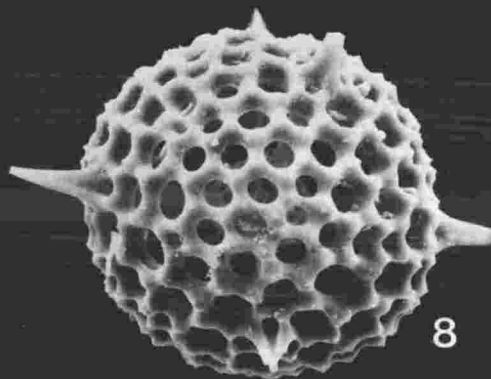
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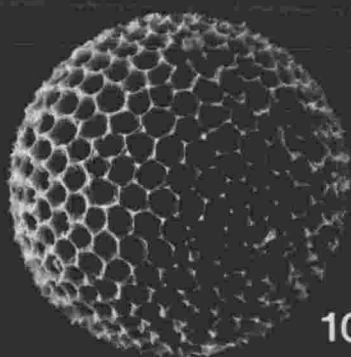
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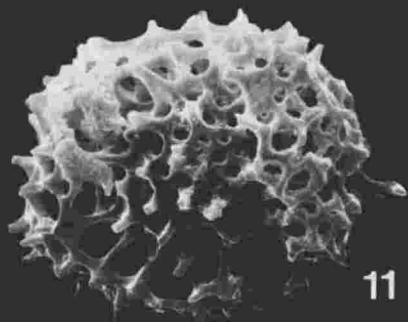
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9



10



11



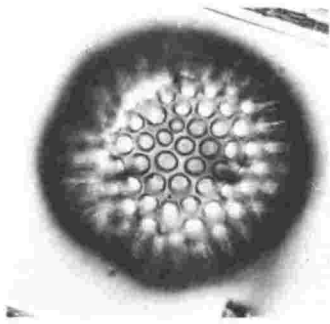
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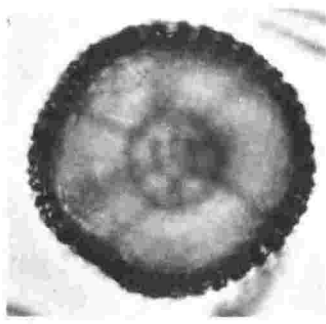
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PLATE 6 (opposite)

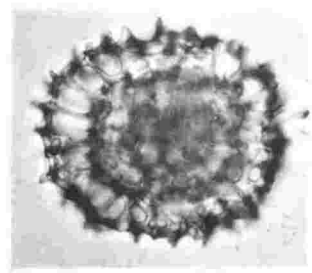
1. *Thecosphaera grecoi* Vinassa de Regny group : x411 : WH03 : W23/1
 - A. focused on surface
 - B. focused on internals of same specimen
2. *Prunulum* sp. : x294 : TM20 : RIO
SEM photo of same specimen : Plate 5, figure 11
3. *Prunulum* sp. : x407 : SMA5 : M41/2
4. *Prunulum* sp. : x292 : MS06 : G26/1
 - A. focused on surface
 - B. focused on internals of same specimen
5. "*Xiphatractus*" sp. A : x289 : PB06
form transitional to "*Stylatractus*" *universus*
 - A. focused on surface
 - B. focused on internals of same specimen
6. "*Stylatractus*" *neptunus* Haeckel *forma* large pores : x263 : PB06 : R26/4
cortical shell missing
7. "*Xiphatractus*" sp. A : x246 : MO11 : K36/2
8. "*Sphaerostylus*" sp. aff. *timmsi* Campbell and Clark : x293 : WA03 : O28/2
teratological specimen
9. "*Stylatractus*" *universus* Hays : x257 : RM06 : L21/4
 - A. focused on surface
 - B. focused on internals of same specimen
10. "*Sphaerostylus*" sp. aff. *timmsi* Campbell and Clark : x287 : PB11 : M44/3



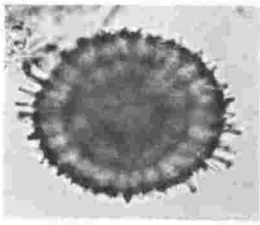
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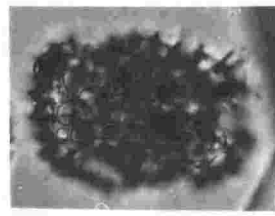
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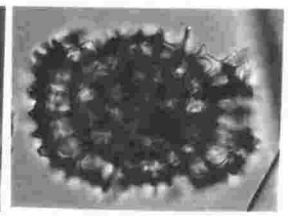
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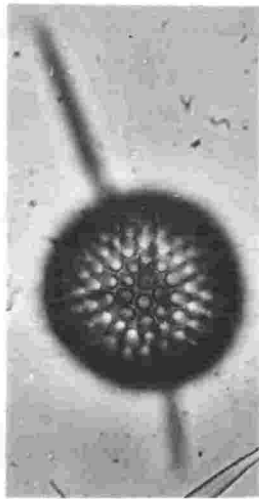
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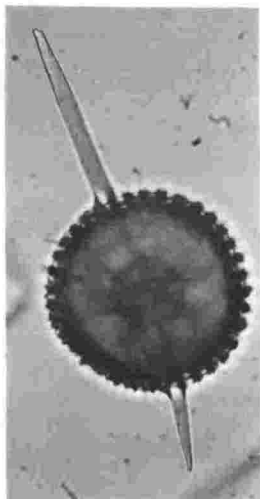
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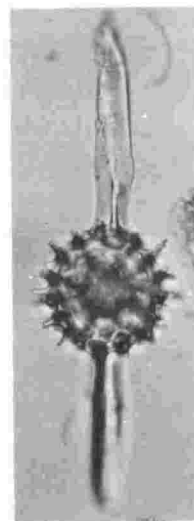
B



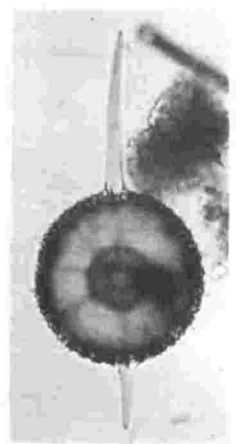
5A



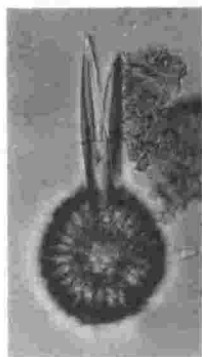
B



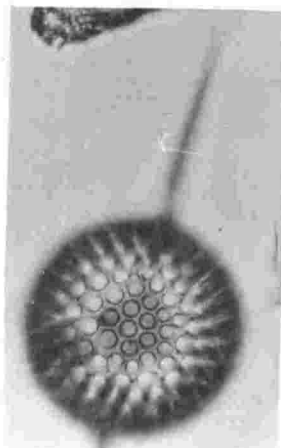
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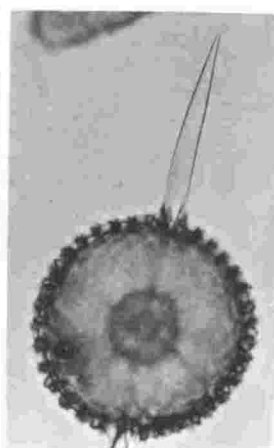
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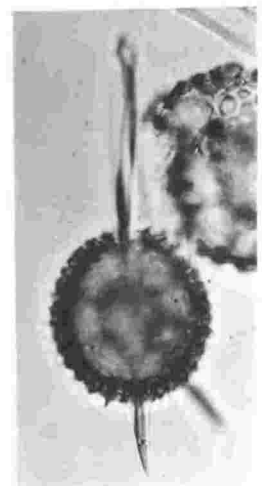
8



9A



B



10

PLATE 7 (opposite)

1. "*Stylatractus*" *neptunus* Haeckel *forma* large pores : x210 : MO02 : AA4/3
2. "*Stylatractus*" *neptunus* Haeckel *forma* large pores : x210 : TM14 : AA2/7
teratological specimen
3. "*Stylatractus*" *neptunus* Haeckel *forma* large pores : x240 : WA16 : AA9/2
cortical shell missing
4. "*Stylatractus*" *neptunus* Haeckel *forma* large pores : x400 : MS03 : AA2/10
poorly preserved specimen
5. "*Stylatractus*" *universus* Hays : x220 : RM01 : AA4/2
"large pored" form
6. "*Stylatractus*" *universus* Hays : x210 : MO07 : AA4/5
"small pored" form
7. "*Xiphatractus*" sp. A : x200 : PB07 : 161/5
8. "*Sphaerostylus*" sp. aff. *timmsi* Campbell and Clark : x300 : MO08 : AA4/5
9. "*Sphaerostylus*" sp. aff. *timmsi* Campbell and Clark : x310 : RM07 : AA5/3
10. "*Sphaerostylus*" sp. aff. *timmsi* Campbell and Clark : x270 : RM06 : AA5/4
form with thicker by-spines
11. *Prunopyle* sp. A : x280 : KB01 : AA10/4
12. Actinommid gen. et sp. indet. : x320 : RM07 : AA5/3
13. Actinommid gen. et sp. indet. : x320 : MO04 : AA4/4
14. *Prunopyle* sp. A : x400 : PB07 : 161/6
could be a member of the genus *Sphaeropyle*

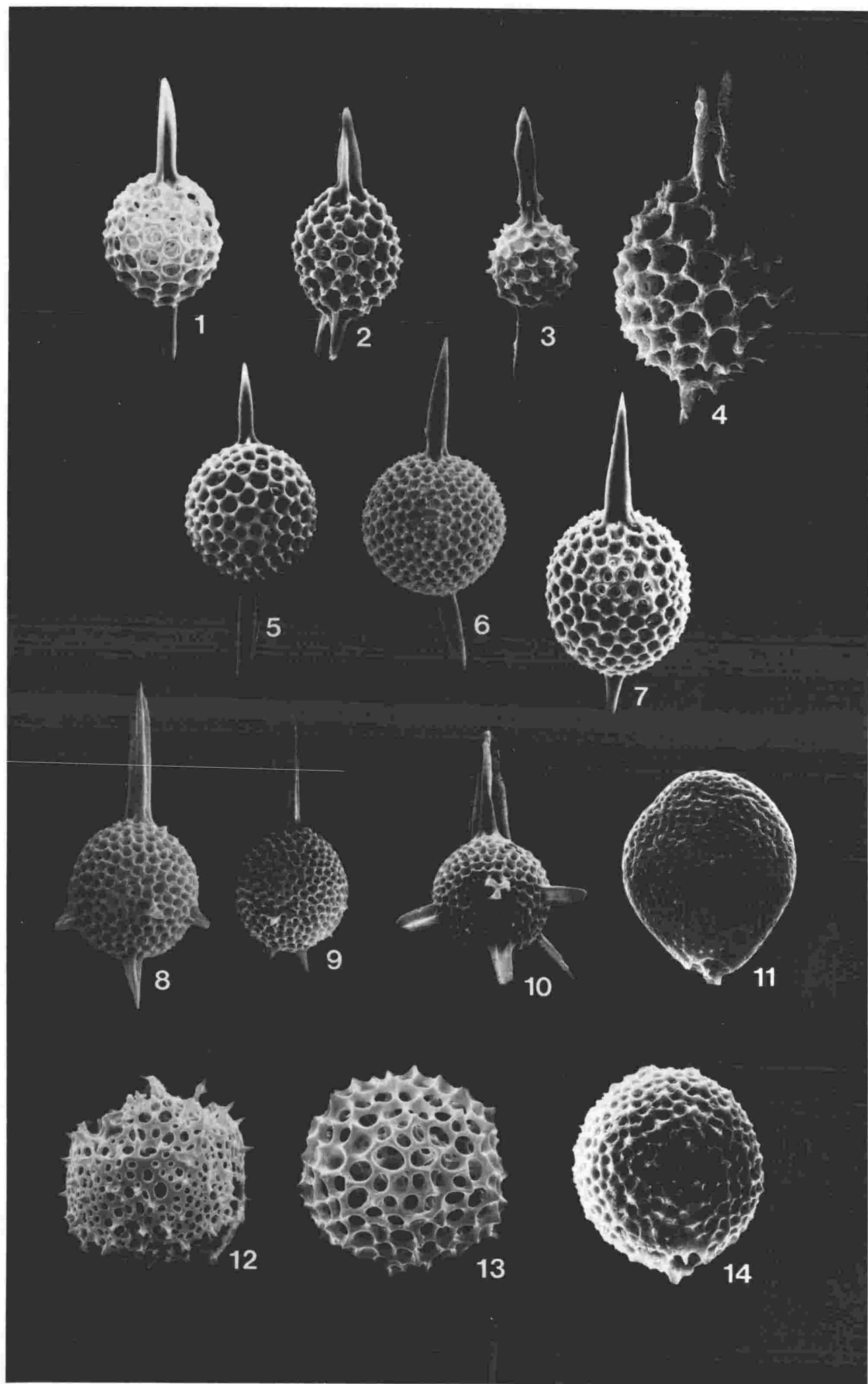
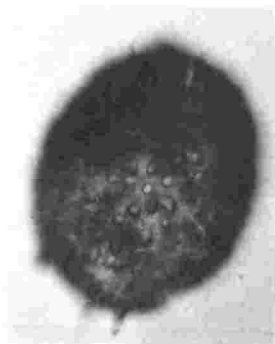
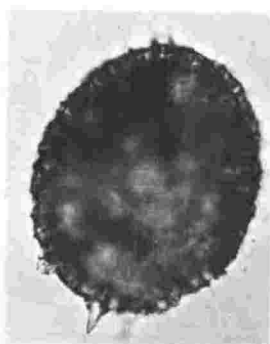


PLATE 8 (opposite)

1. *Spongurus* sp. A : x297 : TM19 : RIO
 - A. focused on surface
 - B. focused on internals of same specimen
2. *Spongurus* sp. A : x288 : TM19 : RIO
 - SEM photo of same specimen : Plate 9, figure 1
 - A. focused on surface
 - B. focused on internals of same specimen
3. *Prunopyle* sp. A : x407 : MO14 : U36/1
4. *Prunopyle* sp. A : x408 : MS13 : N17/4
5. *Spongocore puella* Haeckel : x407 : MS08 : S33/2
lattice-mantle present
6. *Spongocore puella* Haeckel : x292 : PB06 : X47/1
lattice-mantle absent
7. *Heliodiscus asteriscus* Haeckel : x257 : EC02 : N13/2
"long-spined" form
8. *Didymocyrtis virgineum* (Haeckel) : x293 : TM16 : RIO
 - A. focused on circumference
 - B. focused on surface of same specimen
9. *Heliodiscus asteriscus* Haeckel : x296 : MO14 : Q17/4
side view : focused on medullary skeleton



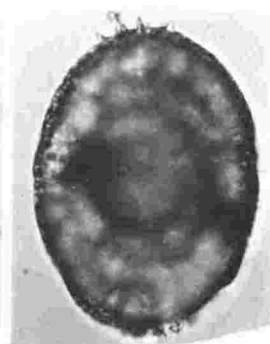
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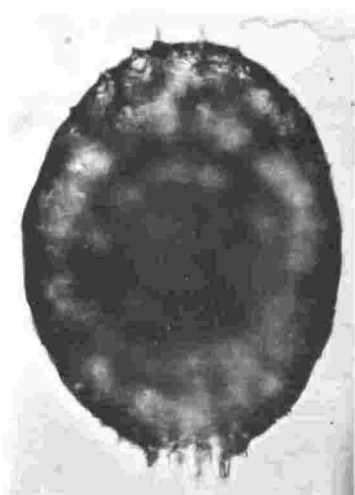
B



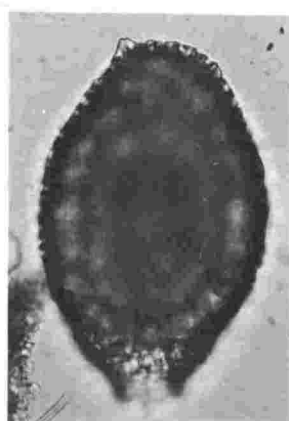
2A



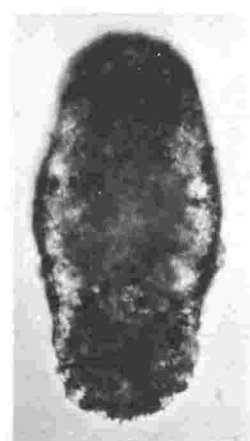
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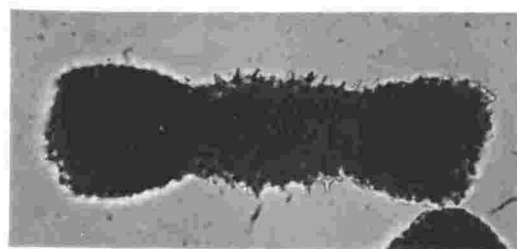
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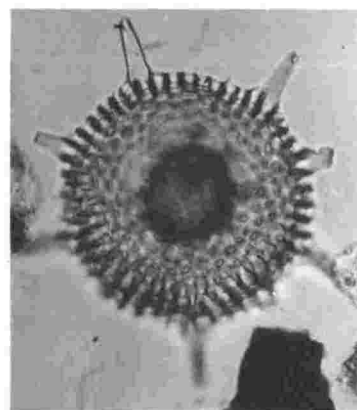
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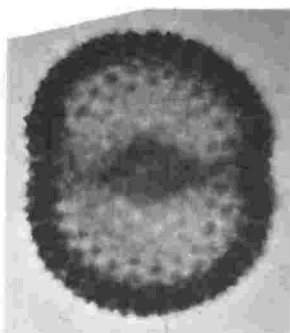
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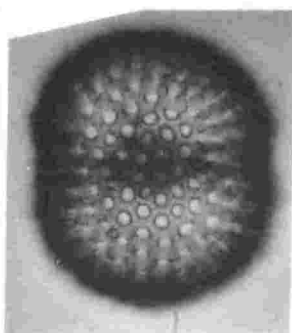
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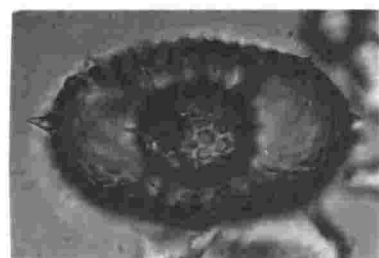
7



8A



B



9

PLATE 9 (opposite)

1. *Spongurus* sp. A : x210 : TM19 : AA6/3
transmitted light photos of same specimen : Plate 8, figures 2a,b
2. *Spongurus pylomaticus* Riedel : x340 : LT06 : AA7/2
3. *Spongurus* sp. A : x310 : PB11 : 167/7
transitional with *Prunopyle antarctica* and *Spongurus pylomaticus*
4. ? *Prunopyle antarctica* Dreyer : x250 : WA07 : AA8/6
5. ? *Spongurus pylomaticus* Riedel : x350 : SMA4 : AA4/11
inner spongy core ?
6. *Spongocore puella* Haeckel : x390 : PB08 : 164/4
abnormal bent specimen
7. *Spongocore puella* Haeckel : x310 : WA02 : AA8/2
lattice-mantle present
8. *Spongocore puella* Haeckel : x310 : MS02 : AA2/9
9. *Spongocore* sp. A : x190 : LT05 : AA7/2
10. ? *Prunopyle antarctica* Dreyer : x270 : LT01 : AA7/4
11. *Heliodiscus asteriscus* Haeckel : x420 : PB08 : 164/6
broken specimen showing medullary skeleton
12. *Heliodiscus asteriscus* Haeckel : x180 : PB02 : 156/7
"small pored" form
13. *Heliodiscus asteriscus* Haeckel : x200 : TM15 : AA2/6
"large pored" form
14. *Heliodiscus* cf. *echiniscus* Haeckel : x190 : MS15 : AA3/7
15. *Heliodiscus umbonatum* (Ehrenberg) : x150 : KB04 : AA8/1
16. *Diartus hughesi* (Campbell and Clark) group : x280 : KB01 : AA10/3
17. *Diartus hughesi* (Campbell and Clark) group : x220 : MS12 : AA3/6
form more related to *Amphymenium*

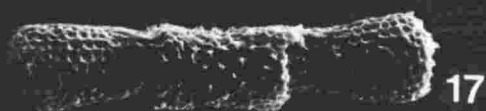
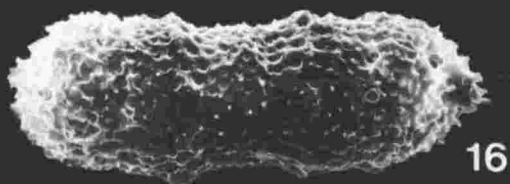
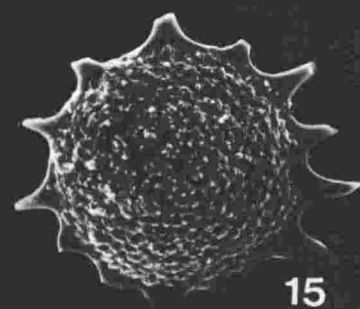
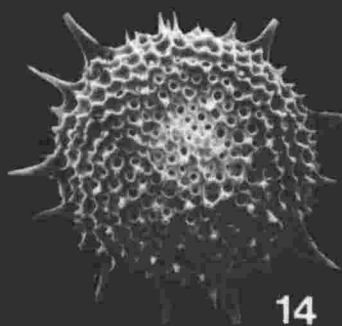
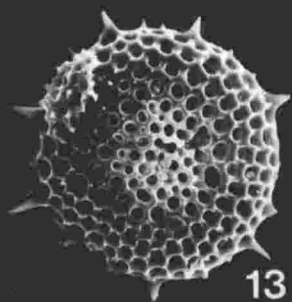
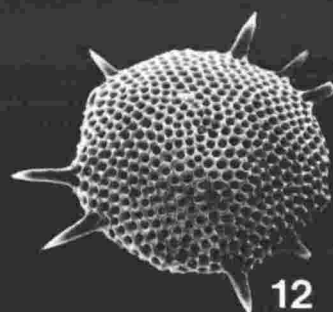
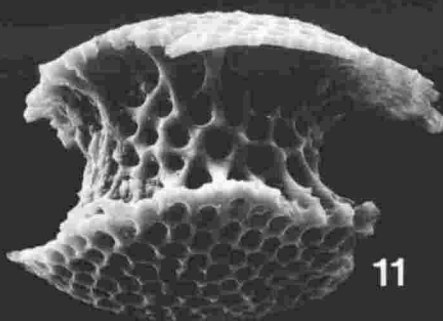
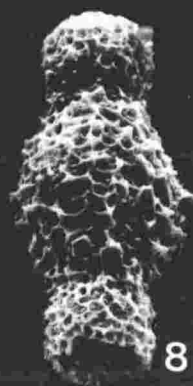
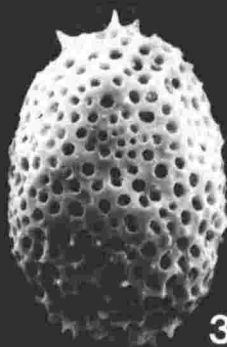
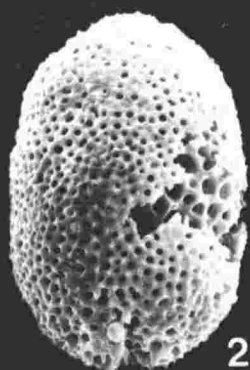
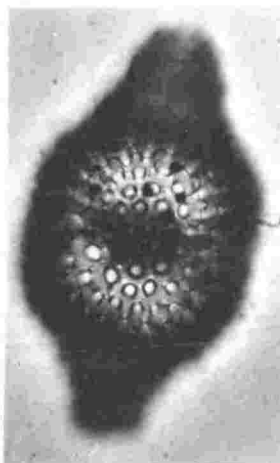


PLATE 10 (opposite)

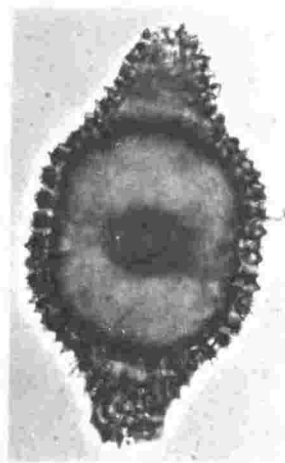
1. *Didymocyrtis laticonus* (Riedel) : x257 : MS12 : O32/2
2. *Didymocyrtis* sp. A : x302 : TM16 : RIO
 - A. focused on surface
 - B. focused on internals of same specimen
3. *Diartus hughesi* (Campbell and Clark) group : x374 : MS14 : O39/2
form more related to *Amphymenium*
4. *Didymocyrtis* sp. A : x288 : TM19 : RIO
SEM photo of same specimen : Plate 11, figure 8
5. *Didymocyrtis antepenultima* (Riedel and Sanfilippo) : x419 : SWR4 : K18/2
form close to *D. laticonus*
6. *Didymocyrtis tetralthmus tetralthmus* (Haeckel) : x413 : WA07 : O40/4
 - A. focused on cortical surface
 - B. focused on polar cap
7. *Didymocyrtis tetralthmus tetralthmus* (Haeckel) : x430 : WA07 : P39/2
form without polar cap preserved



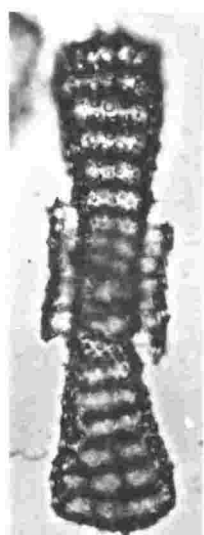
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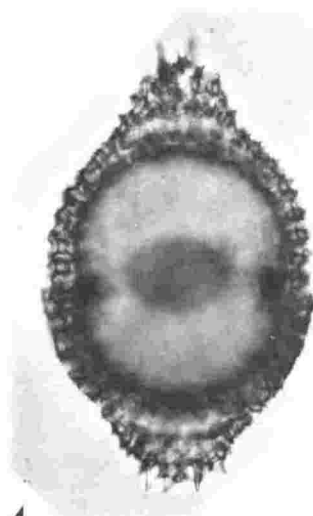
2A



B



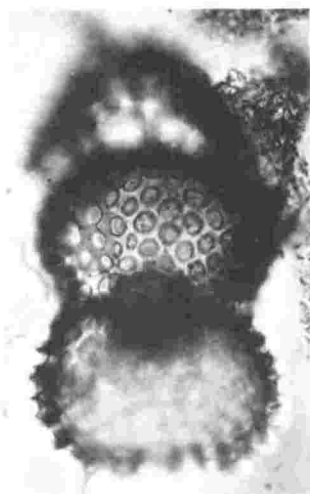
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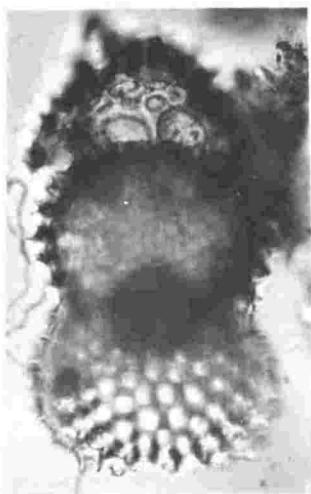
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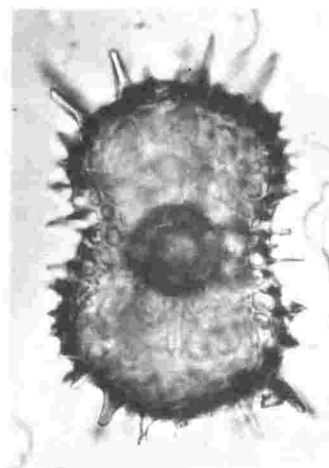
5



6A



B



7

PLATE 11 (opposite)

1. *Didymocyrtis laticonus* (Riedel) : x250 : LT07 : AA7/1
2. *Didymocyrtis* sp. A : x270 : TM07 : AA2/8
poorly preserved specimen
3. *Didymocyrtis* sp. A : x220 : MT11 : AA7/5
"spherical" form
4. *Didymocyrtis* sp. A : x250 : TM23 : AA1/2
lattice-mantle present
5. *Didymocyrtis* sp. A : x270 : MS05 : MISC/6
"non-constricted" form
6. *Didymocyrtis* sp. A : x310 : LT07 : AA7/1
"constricted" form
7. *Didymocyrtis* sp. A : x260 : LT05 : AA7/2
8. *Didymocyrtis* sp. A : x270 : TM19 : AA6/2
transmitted light photo of same specimen : Plate 10, figure 4
9. *Didymocyrtis* sp. A : x200 : MS15 : AA3/7
"narrow" form
10. *Didymocyrtis virgineum* (Haeckel) : x340 : PB07 : 161/9
"constricted" form
11. *Didymocyrtis virgineum* (Haeckel) : x280 : RM05 : AA4/1
"non-constricted" form
12. *Didymocyrtis tetrathalmus tetrathalmus* (Haeckel) : x410 : WA11 : AA8/7
no polar caps
13. ? *Didymocyrtis virgineum* (Haeckel) : x250 : WA07 : AA8/6
could be *Prunulum* sp.
14. ? *Didymocyrtis virgineum* (Haeckel) : x310 : PB08 : 164/5
could be *Prunulum* sp.

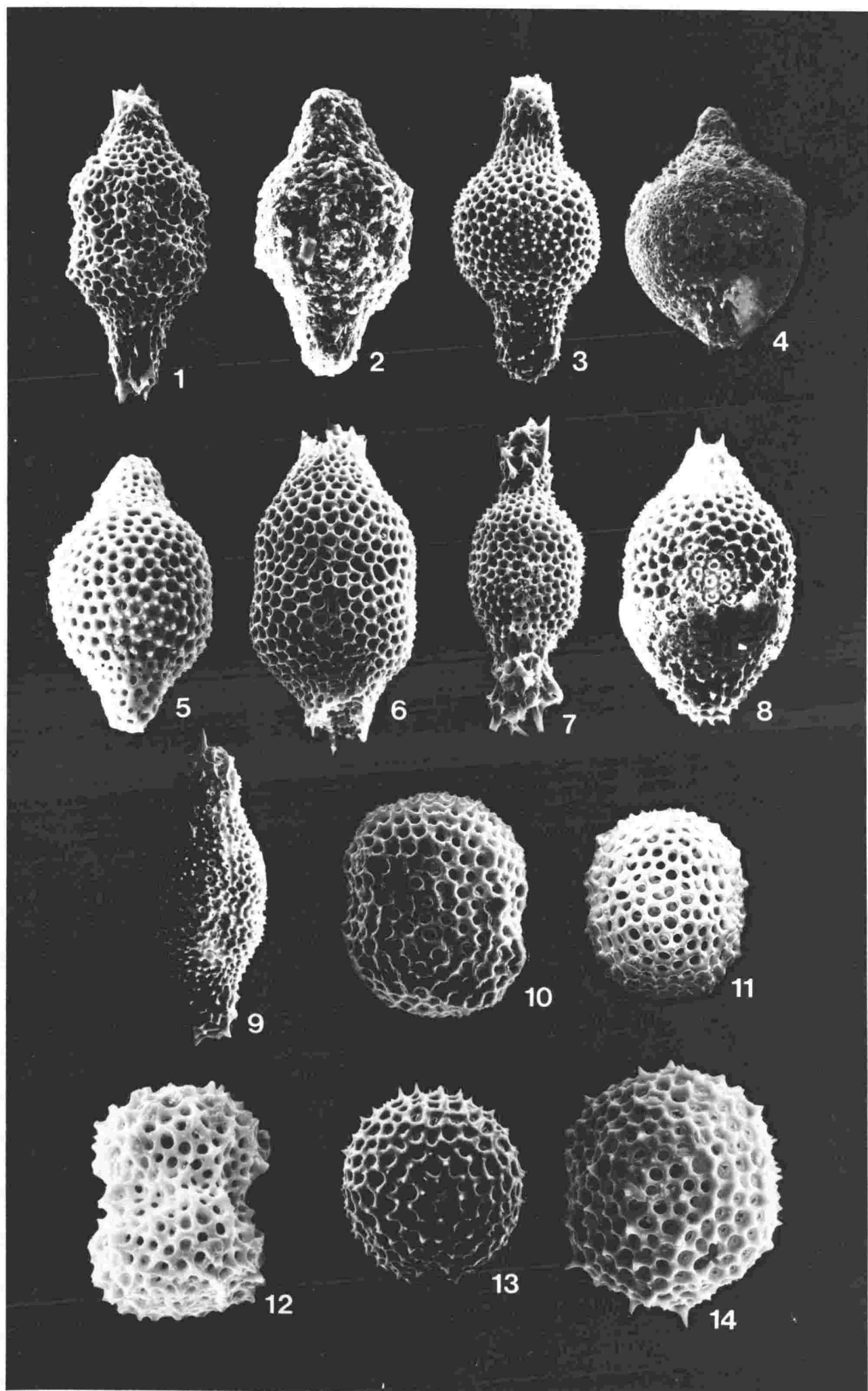
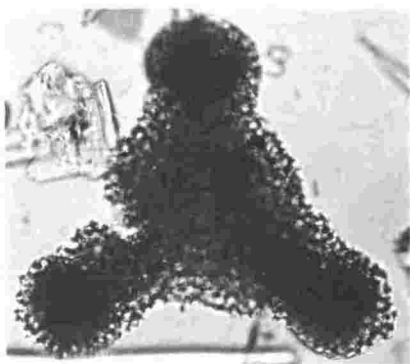


PLATE 12 (opposite)

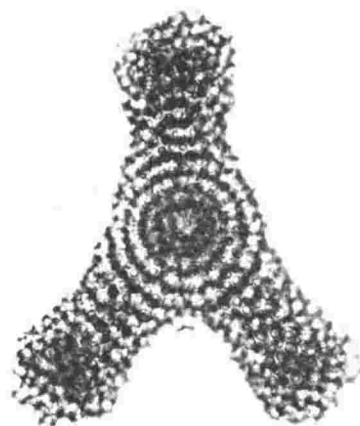
1. *Dictyocoryne profunda* Ehrenberg : x212 : LT05 : Q30/3
patagium present
2. *Dictyocoryne profunda* Ehrenberg : x129 : PB05 : W32/1
patagium absent
3. *Hymeniastrum* cf. *euclidis* Haeckel : x261 : WA19 : L26/3
4. *Hymeniastrum euclidis* Haeckel : x262 : MT10 : S27/2
5. *Amphirhopalum* cf. *ypsilon* Haeckel : x258 : WH06 : E21/2
one side of forked-arm broken
6. *Stylodictya validispina* Jorgensen : x333 : HR02 : G33/4
"quadrate" form
7. *Stylodictya cornuspira* Campbell and Clark : x411 : SPA1 : R47/4
8. *Stylodictya validispina* Jorgensen : x406 : RM06 : N16/3
"heavily spined" form
9. *Stylodictya validispina* Jorgensen : x287 : PB06 : P46/4



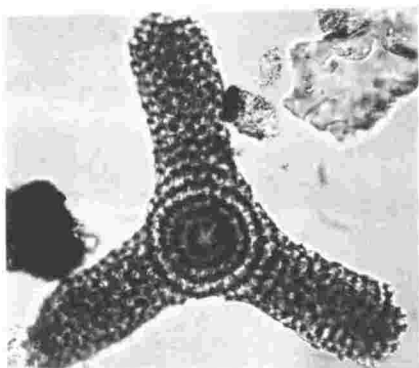
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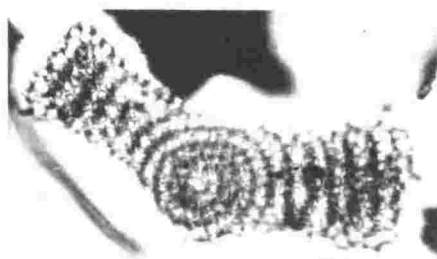
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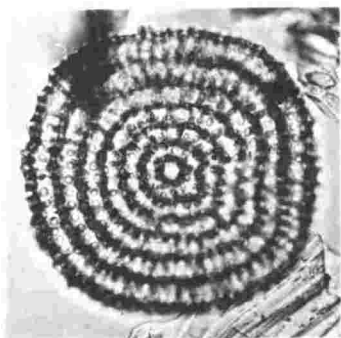
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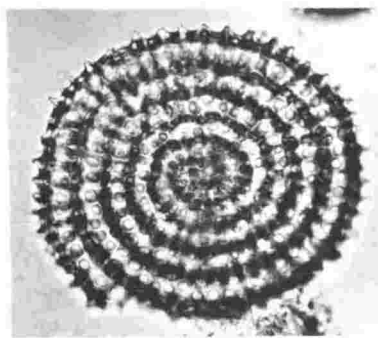
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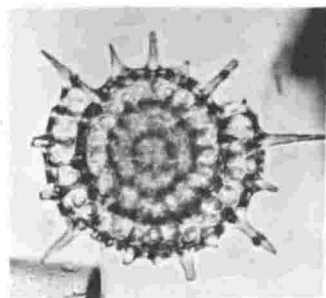
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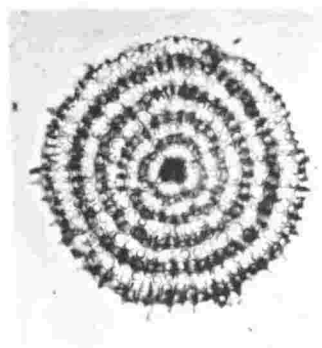
6



7



8



9

PLATE 13 (opposite)

1. *Dictyocoryne profunda* Ehrenberg : x180 : LT06 : AA7/2
patagium present
2. *Dictyocoryne profunda* Ehrenberg : x160 : TM23 : AA1/2
partial patagium present
3. *Dictyocoryne profunda* Ehrenberg : x170 : PB10 : 166/2
patagium absent
4. *Dictyocoryne profunda* Ehrenberg : x200 : WA17 : AA9/3
partial patagium present
5. ? *Hymeniastrum euclidis* Haeckel : x210 : PB06 : 160/3
6. *Spongaster pentas* Riedel and Sanfilippo : x180 : HR01 : AA9/4
7. *Larnacilla typus* Haeckel : x240 : LT06 : AA7/2
8. *Cubotholus rhombicus* Haeckel : x330 : WA11 : AA8/7
9. *Tetrapyle octacantha* Muller group : x410 : SMR1 : AA4/8
10. *Tetrapyle octacantha* Muller group : x350 : MO09 : AA4/6
cortical skeleton poorly developed
11. *Tetrapyle octacantha* Muller group : x310 : RM02 : AA4/1
"spinose" form
12. *Tetrapyle octacantha* Muller group : x400 : MO09 : AA4/6
13. *Tetrapyle octacantha* Muller group : x380 : MO09 : AA4/6
cortical skeleton poorly developed
14. ? *Lithelius minor* Jorgensen : x470 : SMR1 : AA4/9
15. ? *Lithelius minor* Jorgensen : x470 : SMR1 : AA4/9

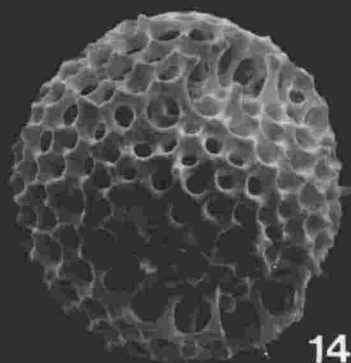
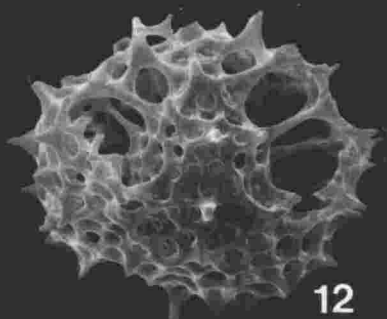
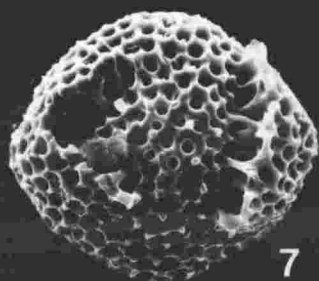
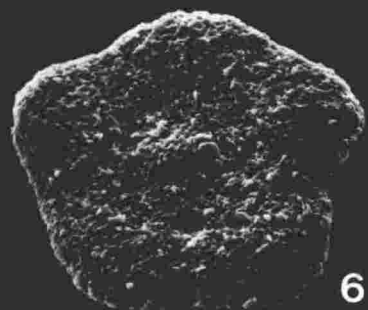
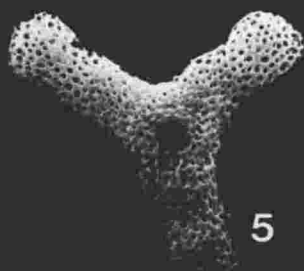
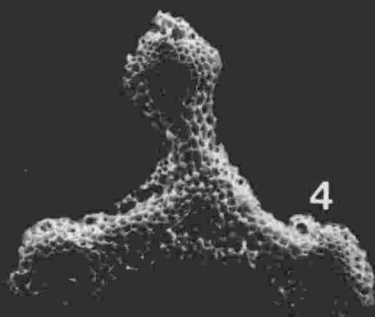
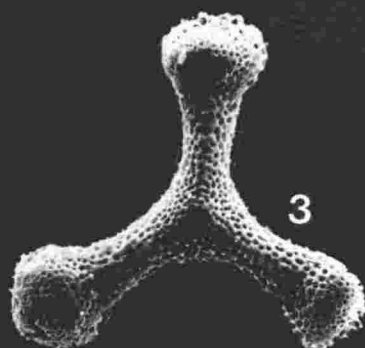
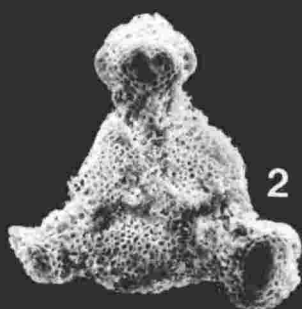
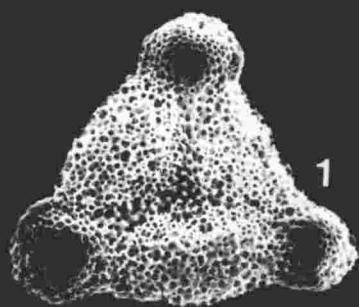


PLATE 14 (opposite)

1. *Porodiscus* sp. A : x296 : TM20 : RIO

SEM photo of same specimen : Plate 15, figure 3

2. *Porodiscus* sp. A : x279 : TM20 : RIO

3. *Porodiscus* sp. B : x116 : TM19 : RIO

4. *Porodiscus* sp. B : x120 : TM19 : RIO

SEM photo of same specimen : Plate 15, figure 6

5. *Stylochlamydidium asteriscus* Haeckel : x334 : MO11d : N15/3

6. *Spongostrochus glacialis* Popofsky : x118 : TM20 : RIO

7. *Spongostrochus glacialis* Popofsky : x119 : TM19 : RIO

8. *Spongostrochus glacialis* Popofsky : x284 : TM19 : RIO

spines present

9. *Spongostrochus glacialis* Popofsky : x115 : TM19 : RIO

SEM photo of same specimen : Plate 15, figure 7

lattice-mantle present

10. *Tetrapyle octacantha* Muller group : x305 : MO10 : T43/2

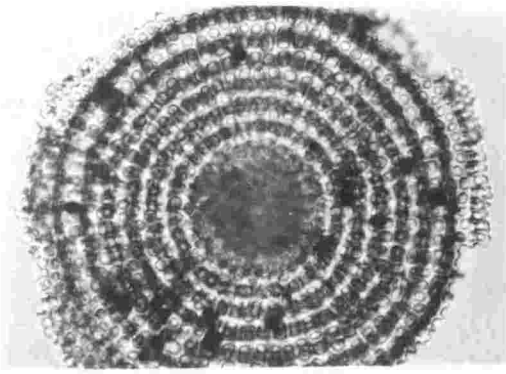
11. *Hexapyle* cf. *dodecantha* Haeckel : x421 : MO11 : M43/4

12. *Tetrapyle octacantha* Muller group : x252 : WA01 : U33/1

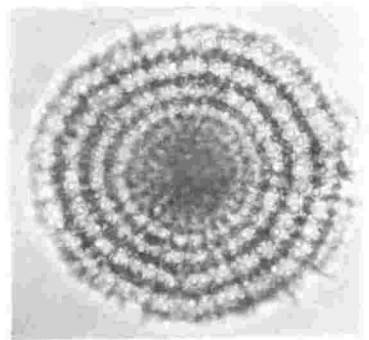
third girdle present

A. focused on surface

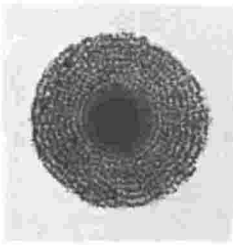
B. focused on internals of same specimen



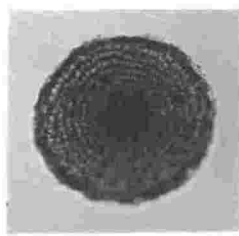
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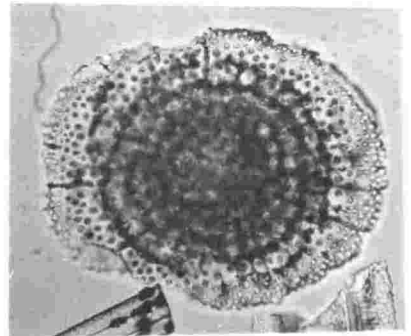
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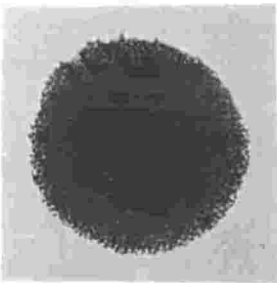
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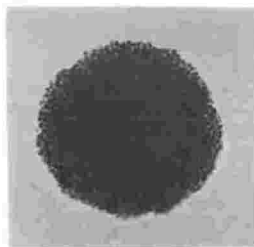
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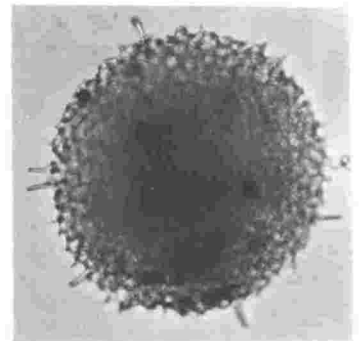
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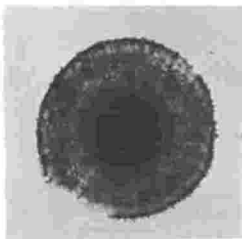
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7



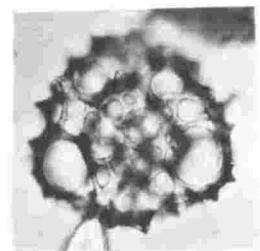
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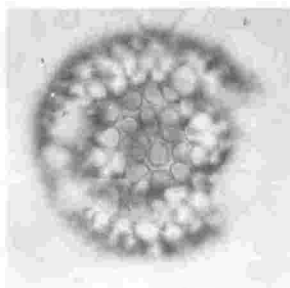
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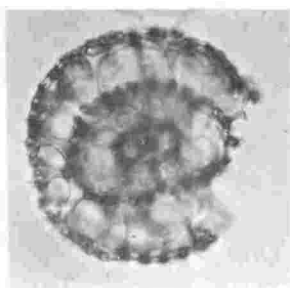
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11



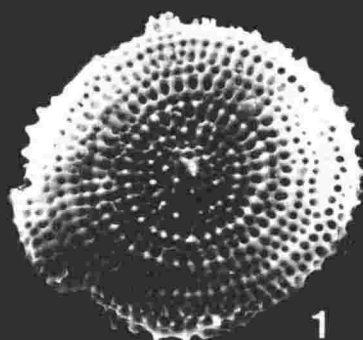
12A



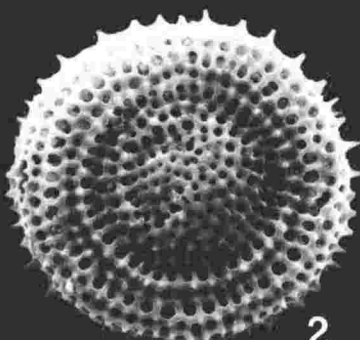
B

PLATE 15 (opposite)

1. *Stylodictya validispina* Jorgensen : x310 : PB07 : 161/3
2. *Porodiscus* sp. A : x370 : PB11 : 167/9
3. *Porodiscus* sp. A : x190 : TM20 : AA6/6
transmitted light photo of same specimen : Plate 14, figure 1
4. *Porodiscus* sp. B : x170 : SMA4 : AA4/11
5. ? *Porodiscus* sp. B ? : x240 : PB02 : 156/4
poorly preserved specimen
6. *Porodiscus* sp. B : x190 : TM20 : AA6/4
transmitted light photo of same specimen : Plate 14, figure 4
lattice-mantle ? present
7. *Spongotrochus glacialis* Popofsky : x180 : TM19 : AA6/2
transmitted light photo of same specimen : Plate 14, figure 9
lattice-mantle present
8. *Spongotrochus glacialis* Popofsky : x180 : RM04 : AA5/6
spines present
9. *Spongotrochus glacialis* Popofsky : x260 : PB11 : 167/8
partial spines present
10. *Spongotrochus glacialis* Popofsky : x150 : LT05 : AA7/2
11. *Spongotrochus glacialis* Popofsky : x170 : SMA4 : AA4/11
poorly preserved specimen
12. *Desmospyris* sp. aff. *rhodospyroides* Petrushevskaya : x350 : LT05 : AA7/2
13. ? *Gorgospyris* sp. aff. *perizostra* Sanfilippo and Riedel : x350 : LT06 : AA7/2
14. *Desmospyris rhodospyroides* Petrushevskaya : x410 : RM05 : AA5/5



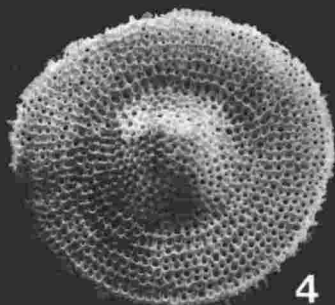
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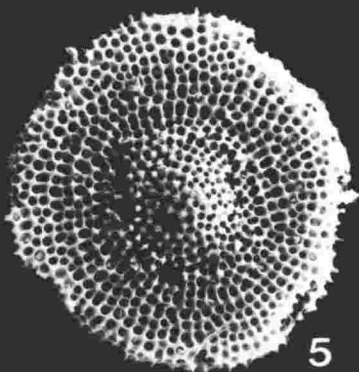
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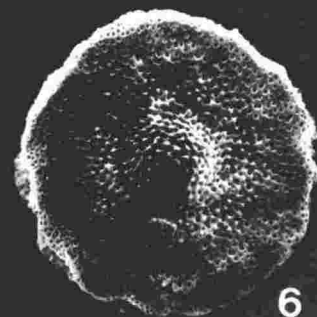
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4



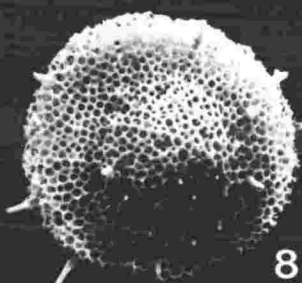
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6



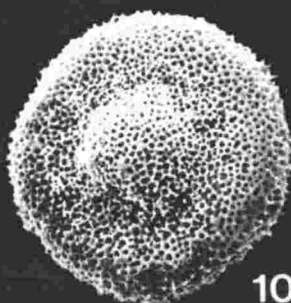
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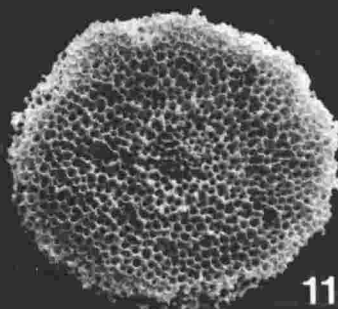
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9



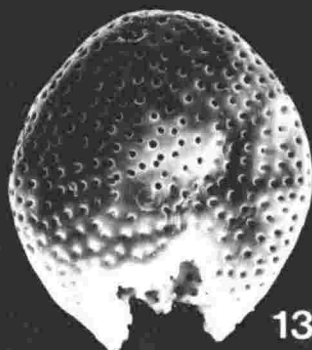
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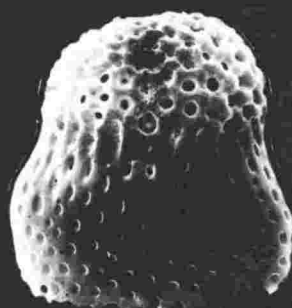
11



12



13



14

PLATE 16 (opposite)

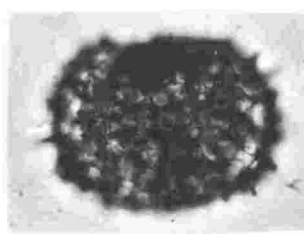
1. *Lithelius nautiloides* Popofsky : x282 : PB04 : S39/1
 - A. focused on surface
 - B. focused on internals of same specimen
2. *Pylospira octopyle* Haeckel : x283 : PB06 : S45/4
 - A. focused on surface
 - B. focused on internals of same specimen
3. *Lithelius* sp. A : x275 : PB11 : M44/3
"Larcospira" type
4. *Lithelius* sp. B : x288 : TM20 : RIO
5. *Lithelius minor* Jorgensen : x288 : PB06 : ????
double spiral visible
6. *Lithelius nautiloides* Popofsky : x384 : SPA1 : R24/2
double spiral visible
7. *Antarctissa antedenticulata* Chen : x383 : WA03 : Q37/4
8. *Antarctissa conradae* Chen : x413 : MO11 : S28/2
9. *Antarctissa antedenticulata* Chen : x416 : WA02 : V42/2
transitional with *A. longa*
10. *Antarctissa longa* (Popofsky) : x415 : WA02 : S31/2
11. *Antarctissa antedenticulata* Chen : x406 : WH06 : T16/3
 - A. focused on surface
 - B. focused on circumference of same specimen
12. *Lophophaena* cf. *macrencephala* Clark and Campbell : x301 : MO13 : O25/3



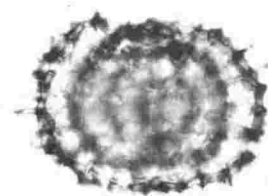
1A



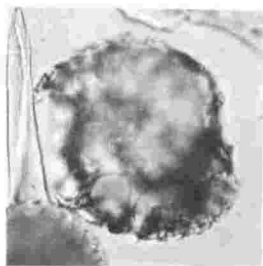
B



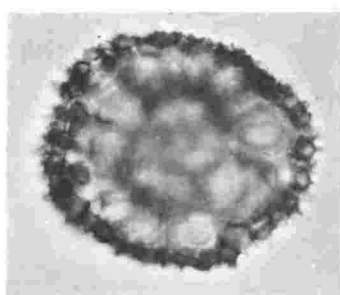
2A



B



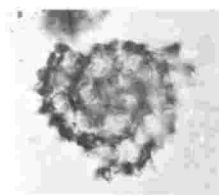
3



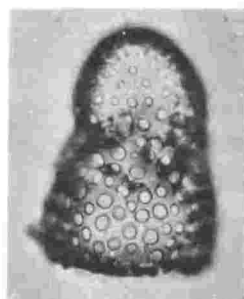
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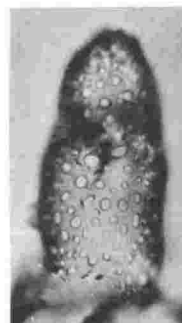
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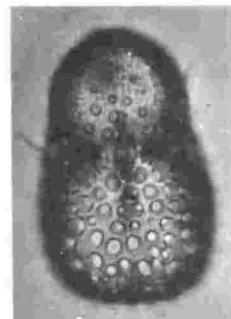
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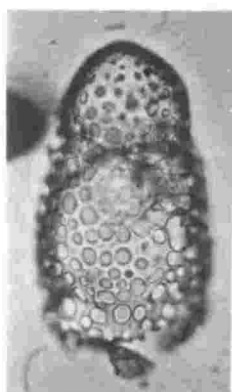
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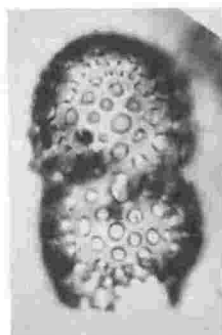
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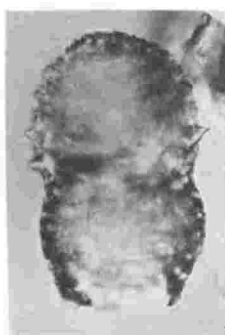
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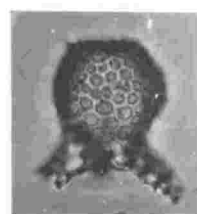
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11A



B



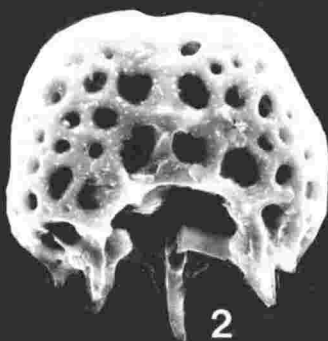
12

PLATE 17 (opposite)

1. *Phormospyris stabilis* (Goll) *antarctica* (Haecker) group : x490 : LT05 : AA7/3
front view
2. *Phormospyris stabilis* (Goll) *antarctica* (Haecker) group : x640 : TM23 : AA1/4
back view
3. *Carpocanistrum* sp. A : x470 : PB02 : 156/8
form with larger mouth
4. *Cystophormis* sp. B : x430 : TM19 : AA2/2
5. *Carpocanistrum* sp. A : x450 : SMA4 : AA4/11
form with very constricted mouth
6. *Cystophormis* sp. A : x430 : PB07 : 161/9
7. *Cystophormis* sp. A : x400 : PB07 : 161/8
form with relatively wide mouth
8. *Carpocanistrum* sp. A : x400 : LT05 : AA7/2
transitional with *Cystophormis* sp. A
9. *Cystophormis* sp. A : x470 : TM21 : AA1/9
form with prominent terminal teeth
10. *Cornutella profunda* Ehrenberg : x330 : MS03 : AA2/11
"three-pored" form
11. *Cornutella profunda* Ehrenberg : x380 : WA17 : AA9/3
"six-pored" form
12. *Plectopyramis dodecomma* Haeckel : x180 : RM05 : AA5/5
"flared" form
13. *Plectopyramis dodecomma* Haeckel : x250 : PB07 : 161/5
"tapering" form



1



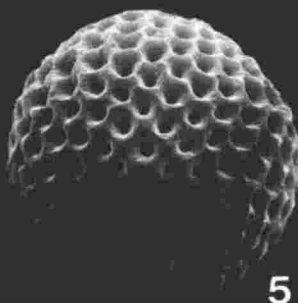
2



3



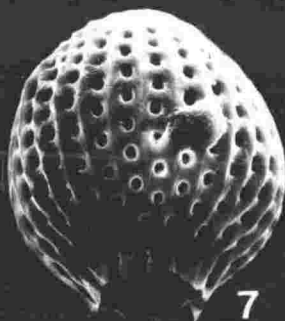
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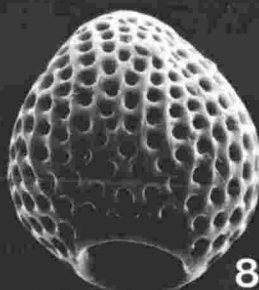
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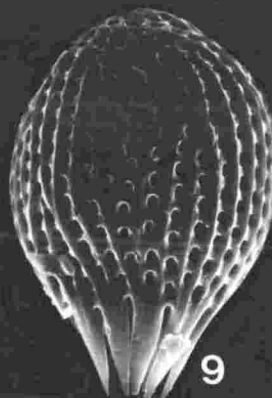
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7



8



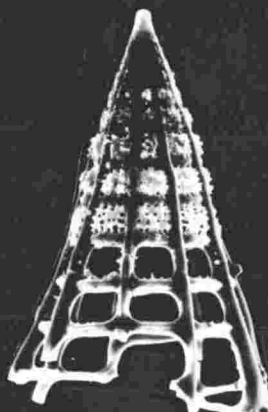
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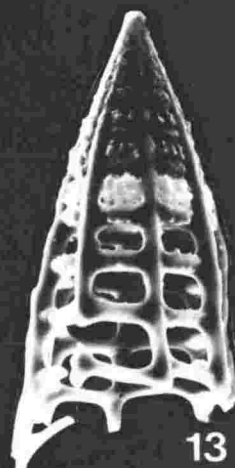
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11



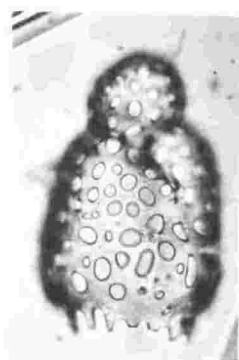
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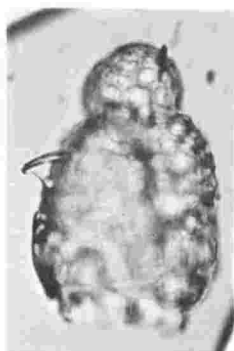
13

PLATE 18 (opposite)

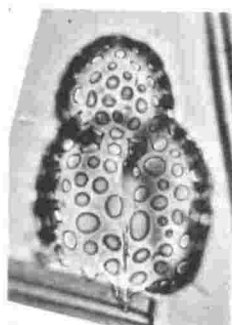
1. ? *Lithomelissa setosa* Jorgensen : x416 : RM07 : L12/3
transitional with *Antarctissa strelkovi*
A. focused on surface
B. focused on circumference of same specimen
2. ? *Lithomelissa setosa* Jorgensen : x429 : MS15 : N13/2
form with feet developed
3. ? *Lithomelissa setosa* Jorgensen : x407 : HR04 : J36/4
form with feet developed
4. *Desmospyris rhodospyroides* Petrushevskaya : x298 : TM22 : U15/3
5. *Desmospyris rhodospyroides* Petrushevskaya : x310 : MO06 : H30/1
6. *Gorgospyris* sp. aff. *perizostra* Sanfilippo and Riedel : x402 : MO11 : O20/3
A. focused on circumference
B. focused on surface of same specimen
7. *Desmospyris* (?) sp. A : x433 : SCV1 : V30/3
8. *Desmospyris* (?) sp. A : x293 : TM23 : F31/1
9. *Phormospyris stabilis* (Goll) *antarctica* (Haecker) group : x297 : RM05 : P29/2
A. and B. Two focus levels on the same specimen
10. *Phormospyris stabilis* (Goll) *scaphipes* (Haeckel) group : x412 : WA23 : N44/4
11. *Phormospyris stabilis* (Goll) *antarctica* (Haecker) group : x421 : WA17 : J47/4
A. focused on back surface
B. focused on front surface of same specimen
12. *Phormospyris stabilis* (Goll) *scaphipes* (Haeckel) group : x433 : LT05 : L27/1
transitional with *P. stabilis antarctica*
A. focused on front surface
B. focused on back surface of same specimen
13. *Spyrid* gen. et sp. indet. : x416 : MS06 : S32/1



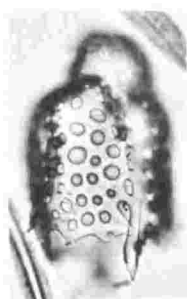
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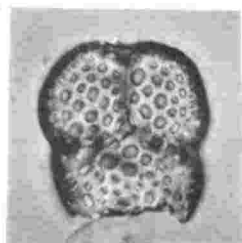
B



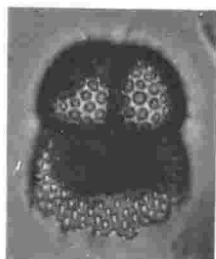
2



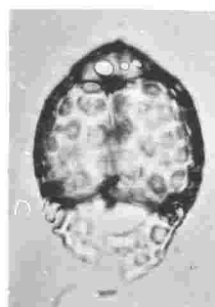
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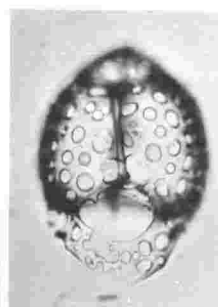
4



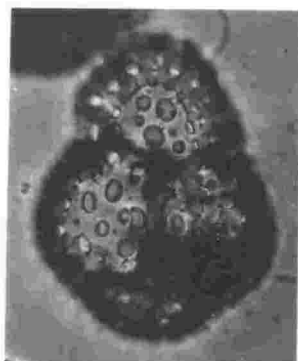
5



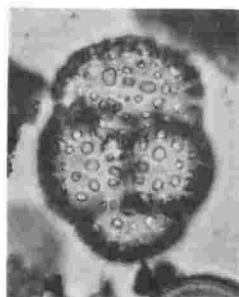
6A



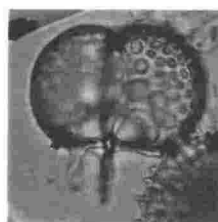
B



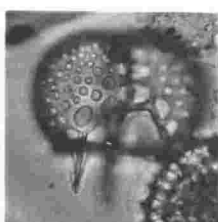
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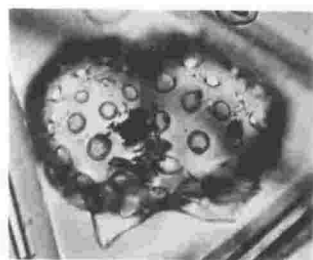
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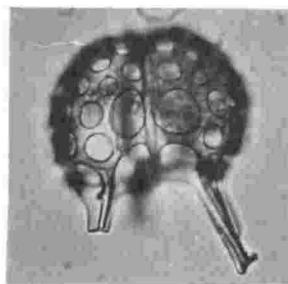
9A



B



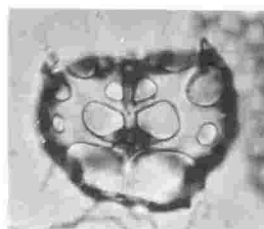
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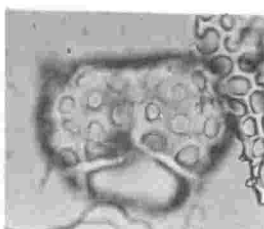
11A



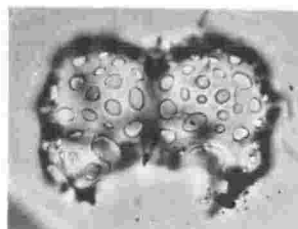
B



12A



B



13

PLATE 19 (opposite)

1. *Dictyophimus hirundo* (Haeckel) group : x260 : MO04 : AA4/4
2. *Dictyophimus hirundo* (Haeckel) group : x280 : LT07 : AA7/1
3. *Lychnocanium* sp. aff. *grande* (Campbell and Clark) : x210 : MO04 : AA4/4
4. *Lychnocanium* sp. aff. *grande* (Campbell and Clark) : x210 : MO07 : AA4/5
5. *Lychnocanium* sp. aff. *grande* (Campbell and Clark) : x310 : SMA2 : AA4/9
6. *Lychnocanella conicum* (Clark and Campbell) : x340 : LT05 : AA7/3
7. *Lampromitra tiara* Dumitrica : x260 : RM04 : AA5/6
"flaring" form
8. *Theocalyptra davisiana davisiana* (Ehrenberg) : x270 : MS03 : AA2/10
9. ? *Theocampe* cf. *mongolfieri* (Ehrenberg) : x290 : MS05 : MISC/6
10. *Cyrtocapsella tetrapera* (Haeckel) : x350 : PB06 : 160/11
"constricted" form
11. *Stichophormis cornutella* Haeckel : x220 : LT03 : AA7/4
12. *Cyrtocapsella japonica* (Nakaseko) : x500 : PB10 : 166/4
conical fourth segment
13. *Cyrtocapsella tetrapera* (Haeckel) : x460 : PB03 : 157/3
inverted fifth segment

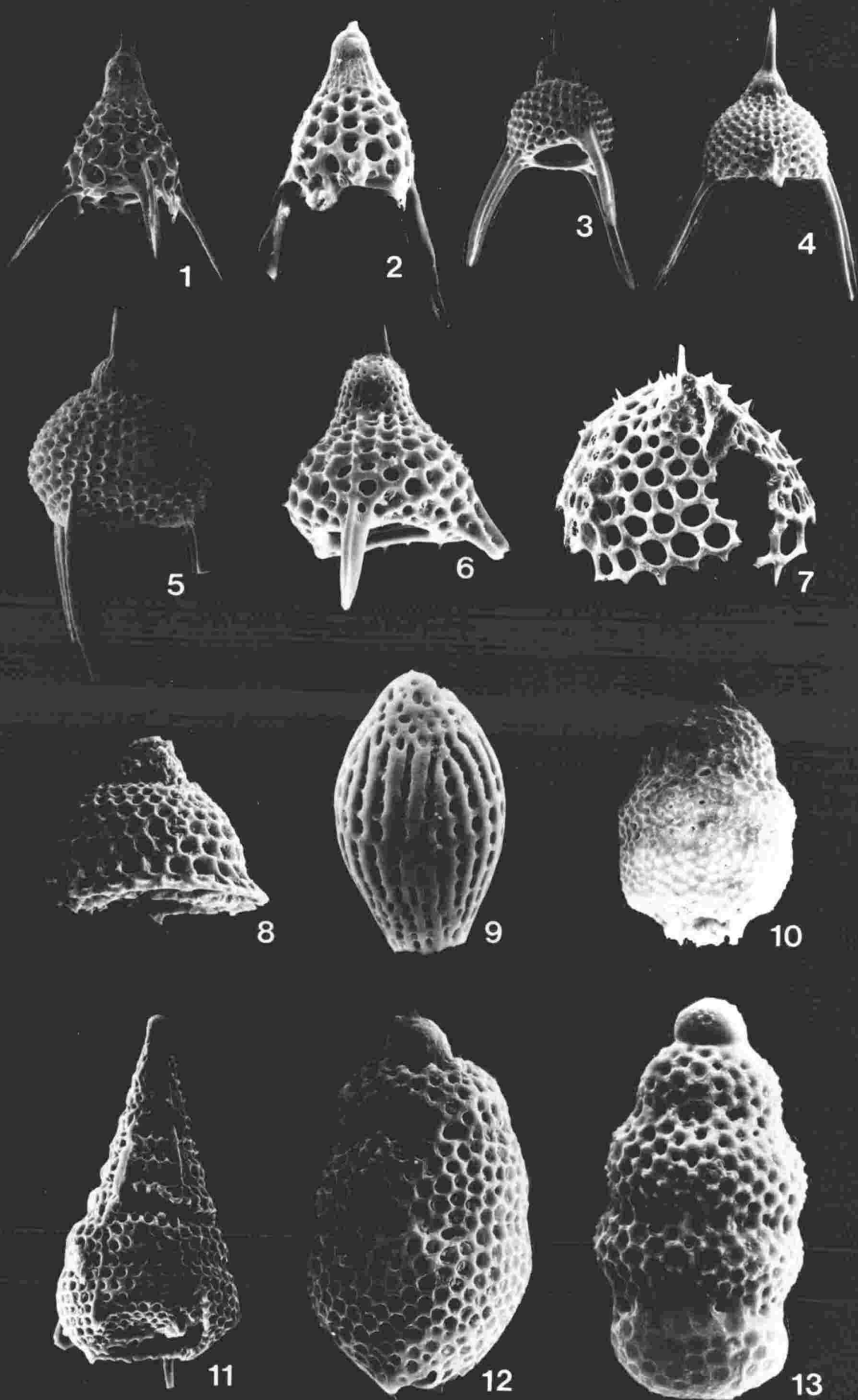
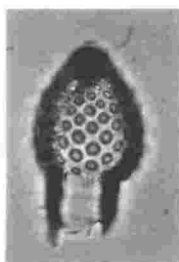
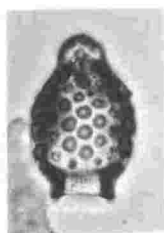


PLATE 20 (opposite)

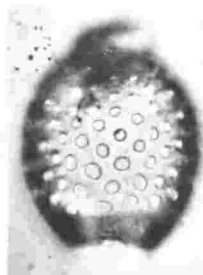
1. *Carpocanarium papillosum* (Ehrenberg) : x306 : MO06 : F33/1
2. *Carpocanarium papillosum* (Ehrenberg) : x288 : TM22 : M29/2
3. *Carpocanarium* sp. A : x403 : MS11 : L18/1
 - A. focused on surface
 - B. focused on circumference of same specimen
4. *Cystophormis* sp. A : x296 : HR05 : L27/4
 - A. focused on surface
 - B. focused on circumference of same specimen
5. *Carpocanistrum* sp. A : x223 : PB05 : Q43/1
form transitional with *Cystophormis* sp. A
 - A. focused on surface
 - B. focused on circumference of same specimen
6. *Cornutella profunda* Ehrenberg : x291 : PB11 : K45/1
7. *Plectopyramis dodecomma* Haeckel : x285 : PB11 : F13/1
8. *Plectopyramis dodecomma* Haeckel : x406 : MO11d : Q16/1
secondary meshwork visible
9. *Lampromitra tiara* Dumitrica : x403 : WA19 : J30/4
10. *Dictyophimus hirundo* (Haeckel) group : x411 : RM06 : Q28/4
11. *Dictyophimus hirundo* (Haeckel) group : x289 : MS04 : N36/1
? small portion of abdomen preserved
12. *Dictyophimus hirundo* (Haeckel) group : x113 : RM06 : O35/2
abnormally long apical horn



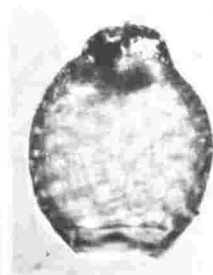
1



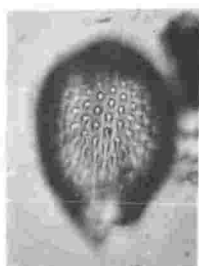
2



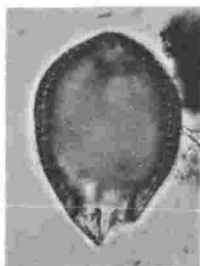
3A



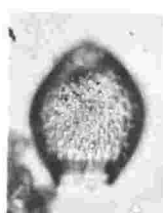
B



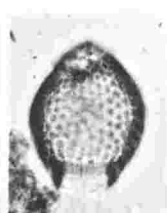
4A



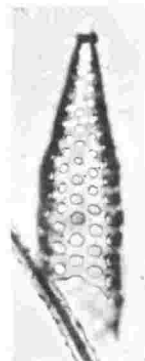
B



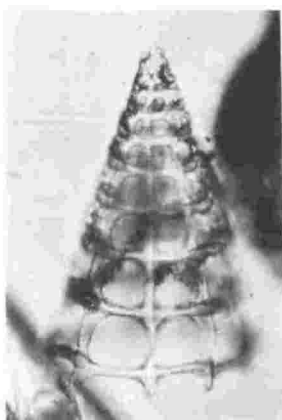
5A



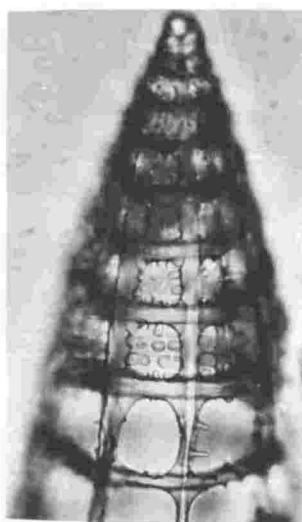
B



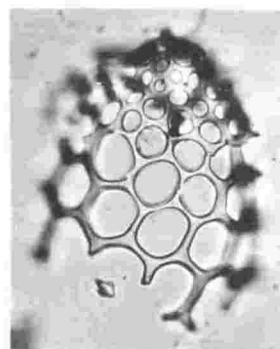
6



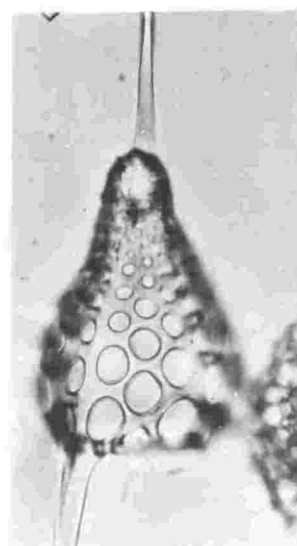
7



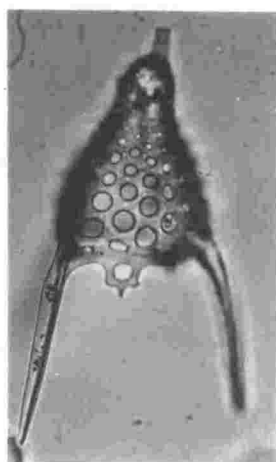
8



9



10



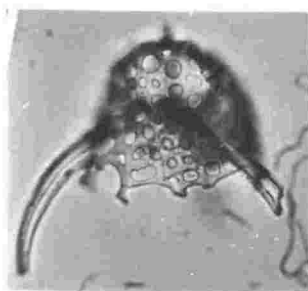
11



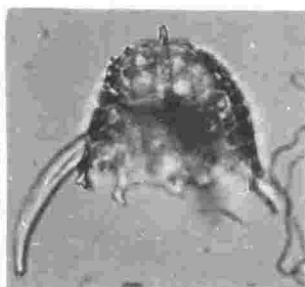
12

PLATE 21 (opposite)

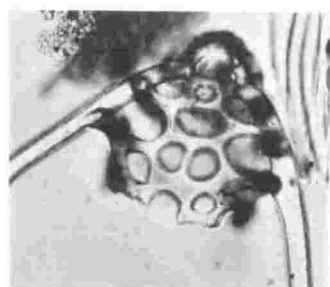
1. *Pseudodictyophimus gracilipes* (Bailey) : x384 : TM19 : S17/2
 - A. focused on surface of cephalis and thorax
 - B. focused on circumference of lattice mantle
2. *Archipilium macropus* (Haeckel) : x404 : WT05 : J40/3
3. *Lychnocanium* sp. aff. *grande* (Campbell and Clark) : x212 : MO11d : K40/1
4. *Lychnocanium* sp. aff. *grande* (Campbell and Clark) : x285 : PB11 : L42/4
 - A. focused on surface
 - B. focused on circumference of same specimen
5. *Lychnocanella conicum* (Clark and Campbell) : x394 : TM20 : T14/4
 - A. focused on surface
 - B. focused on circumference of same specimen
6. *Cyrtocapsella japonica* (Nakaseko) : x402 : MO11 : K34/3
conical fourth segment
7. *Cyrtocapsella tetrapera* (Haeckel) : x287 : HR05 : T40/2
8. *Cyrtocapsella japonica* (Nakaseko) : x371 : MO11d : J36/3
 - A. focused on surface
 - B. focused on circumference of same specimen
9. *Cyrtocapsella tetrapera* (Haeckel) : x292 : PB11 : L36/1
conical fifth segment
 - A. focused on surface
 - B. focused on circumference of same specimen



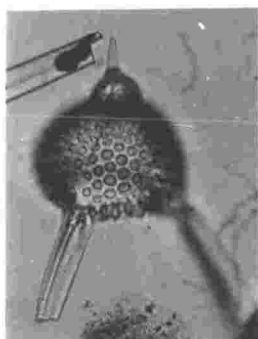
1A



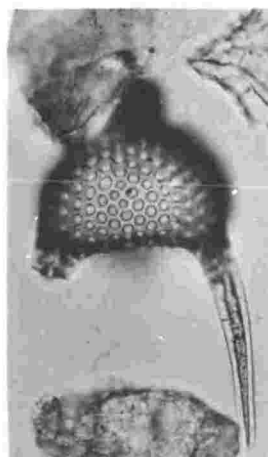
B



2



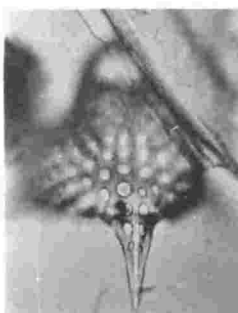
3



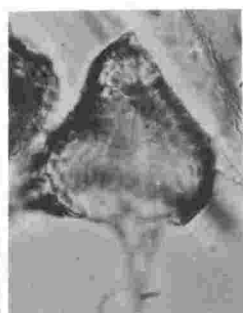
4A



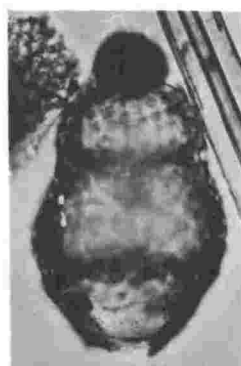
B



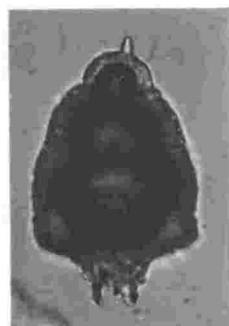
5A



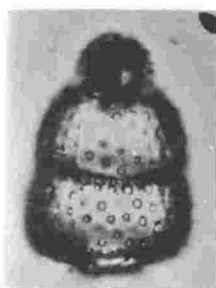
B



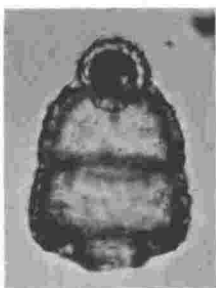
6



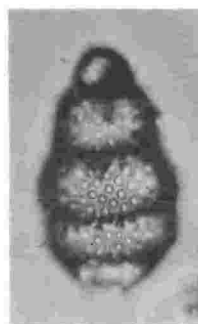
7



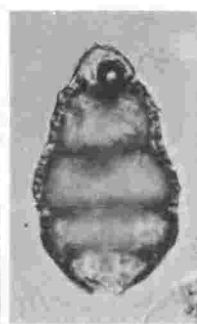
8A



B



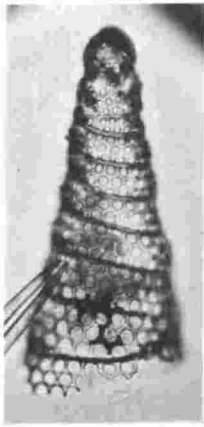
9A



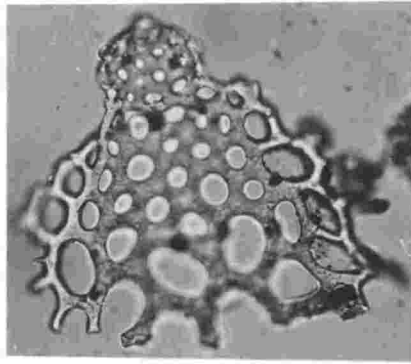
B

PLATE 22 (opposite)

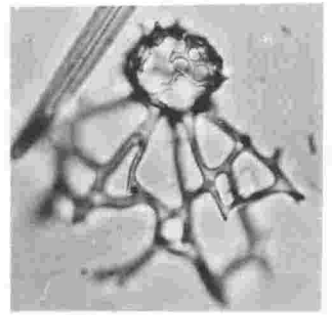
1. *Cyrtolagena laguncula* Haeckel : x410 : RM07 : L27/3
"spiralling" form
2. *Lampromitra erosa* Cleve : x410 : MS14 : O14/2
3. *Lampromitra butschlii* (Haeckel) : x417 : WA03 : H36/2
4. *Theocalyptra bicornis* (Popofsky) : x296 : MO13 : N26/2
5. *Theocalyptra davisiana davisiana* (Ehrenberg) : x294 : WA03 : J22/1
6. *Theocalyptra davisiana davisiana* (Ehrenberg) : x403 : WA07 : O28/4
7. *Eucyrtidium* sp. A : x402 : WA01 : T32/3
A. focused on surface
B. focused on circumference of same specimen
8. *Eucyrtidium vincentense* (Campbell and Clark) : x404 : MS14 : O19/4
9. *Eucyrtidium* cf. *montiparum* Ehrenberg : x415 : TM15 : O30/3
10. *Eucyrtidium calvertense* Martin : x413 : PB11 : D22/3
form transitional with *E. inflatum*
A. focused on surface
B. focused on circumference of same specimen
11. *Eucyrtidium inflatum* Kling : x343 : PB05 : Y13/2



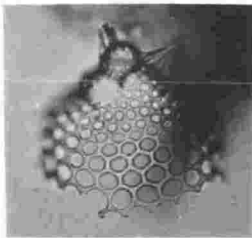
1



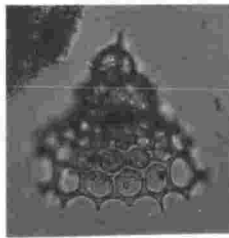
2



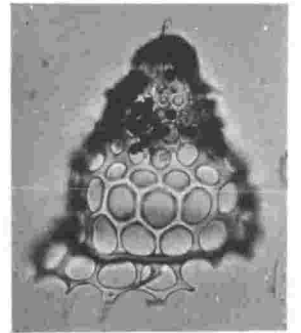
3



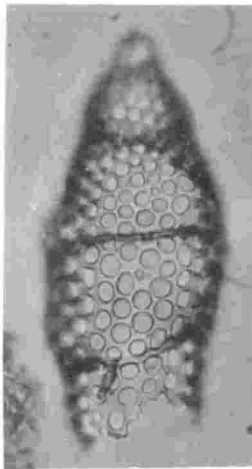
4



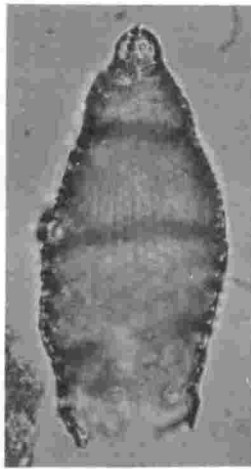
5



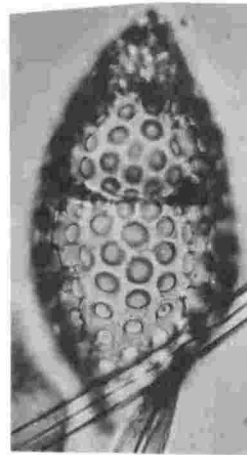
6



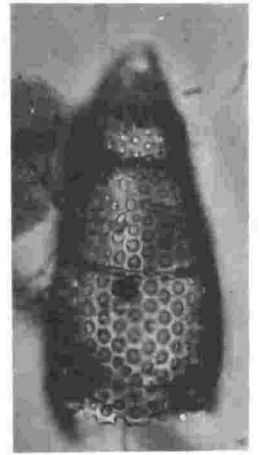
7A



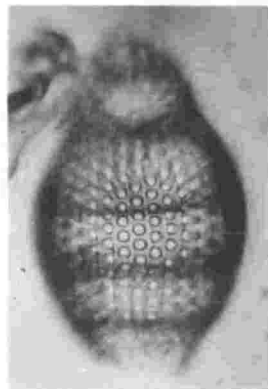
B



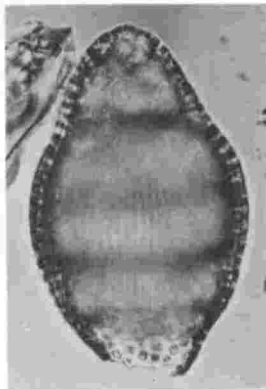
8



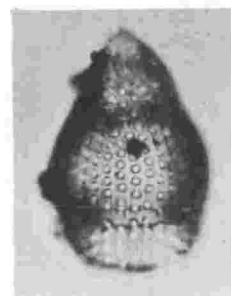
9



10A



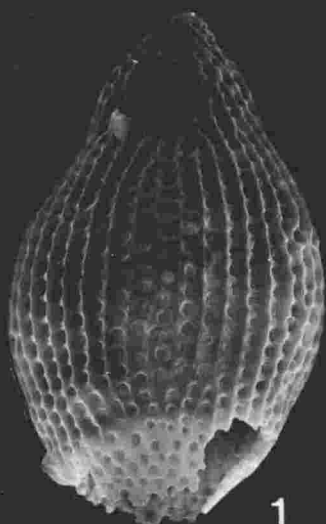
B



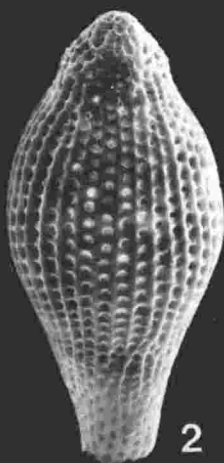
11

PLATE 23 (opposite)

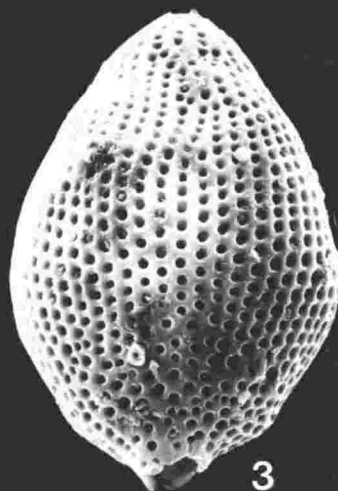
1. ? *Eucyrtidium calvertense* Martin : x440 : PB08 : 164/6
2. *Eucyrtidium calvertense* Martin : x280 : WA02 : AA8/3
3. *Eucyrtidium acuminatum* (Ehrenberg) : x410 : LT08 : AA7/1
4. *Eucyrtidium cienkowskii* Haeckel group : x360 : KB01 : AA10/3
5. *Eucyrtidium cienkowskii* Haeckel group : x410 : PB07 : 161/4
6. *Eucyrtidium cienkowskii* Haeckel group : x350 : KB01 : AA10/3
7. *Eucyrtidium acuminatum* (Ehrenberg) : x310 : JAA420 : MISC/3
lateral wing highlighted
8. *Eucyrtidium inflatum* Kling : x320 : PB07 : 161/8
9. *Eucyrtidium acuminatum* (Ehrenberg) : x280 : TM23 : AA1/3
10. *Eucyrtidium hexagonatum* Haeckel : x330 : TM14 : AA2/8
11. *Eucyrtidium punctatum* (Ehrenberg) group : x350 : WA07 : AA8/6
form transitional with *E. cienkowskii*
12. *Eucyrtidium cienkowskii* Haeckel group : x320 : LT01 : AA7/4
13. *Eucyrtidium punctatum* (Ehrenberg) group : x370 : TM19 : AA2/2
14. *Eucyrtidium punctatum* (Ehrenberg) group : x380 : RM07 : AA5/3



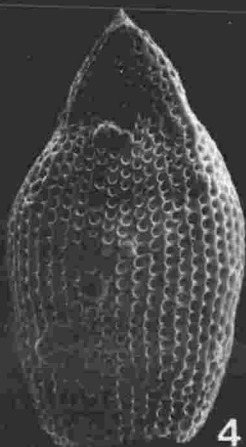
1



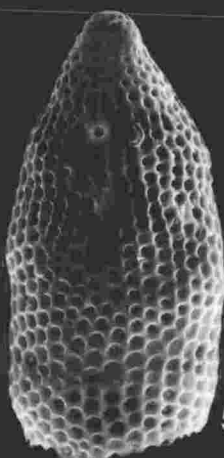
2



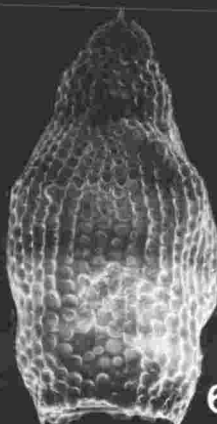
3



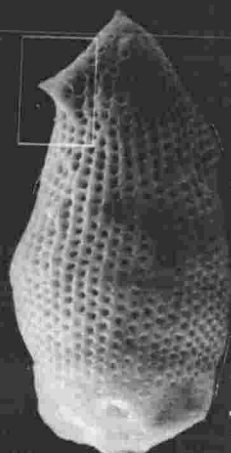
4



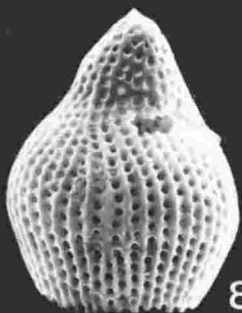
5



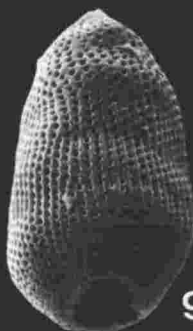
6



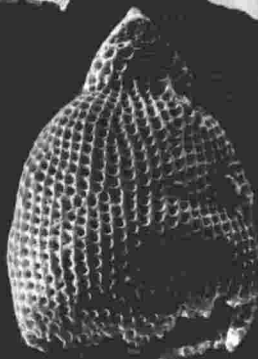
7



8



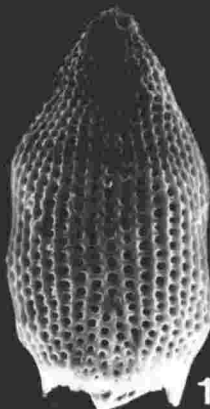
9



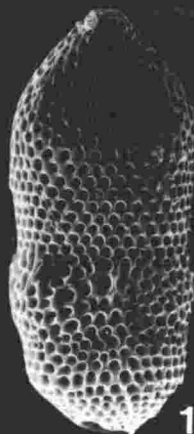
10



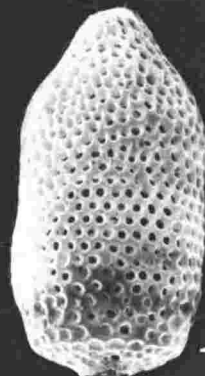
11



12



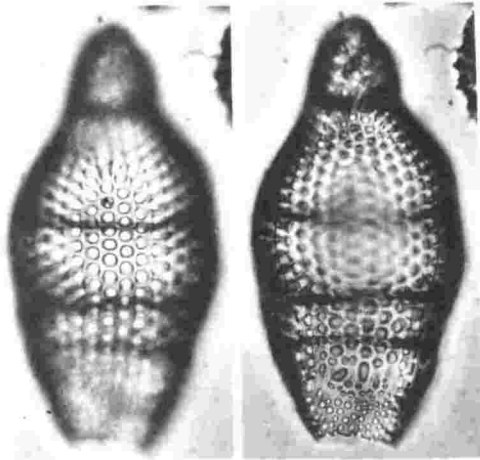
13



14

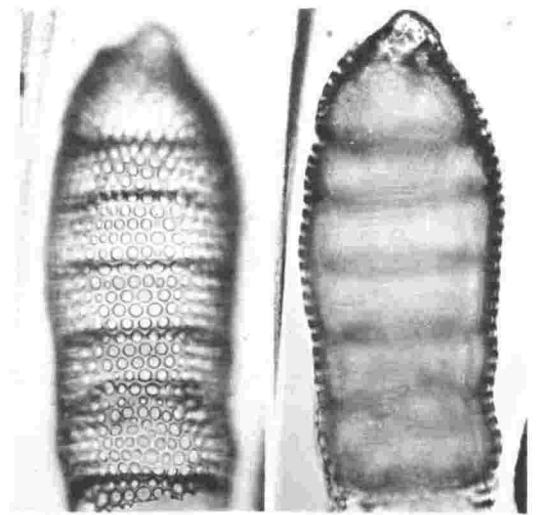
PLATE 24 (opposite)

1. *Eucyrtidium calvertense* Martin : x339 : SWR1 : U15/4
form transitional with *E. inflatum*
A. focused on surface
B. focused on circumference of same specimen
2. *Eucyrtidium punctatum* (Ehrenberg) group : x404 : RM06 : Q18/3
form transitional with *E. cienkowskii*
A. focused on surface
B. focused on circumference of same specimen
3. *Eucyrtidium punctatum* (Ehrenberg) group : x413 : HR06 : P31/3
A. focused on surface
B. focused on circumference of same specimen
4. *Eucyrtidium punctatum* (Ehrenberg) group : x415 : WH06 : R34/1
A. focused on surface
B. focused on circumference of same specimen
5. *Eucyrtidium cienkowskii* Haeckel group : x403 : HR05 : O12/2
A. focused on surface
B. focused on circumference of same specimen
6. *Eucyrtidium cienkowskii* Haeckel group : x257 : SMA4 : M27/2
A. focused on surface
B. focused on circumference of same specimen



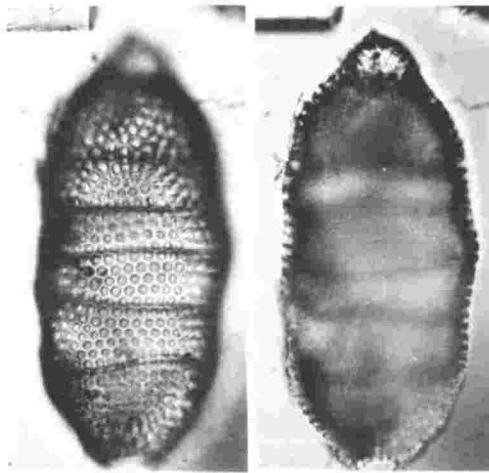
1A

B



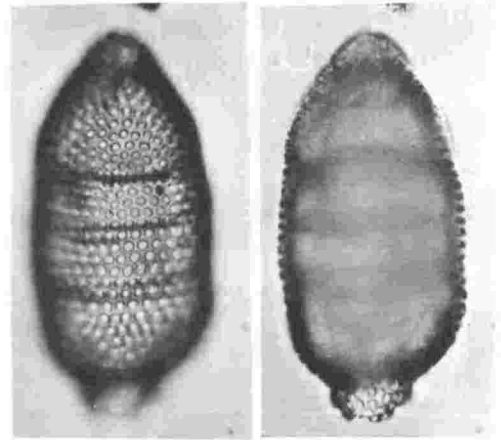
2A

B



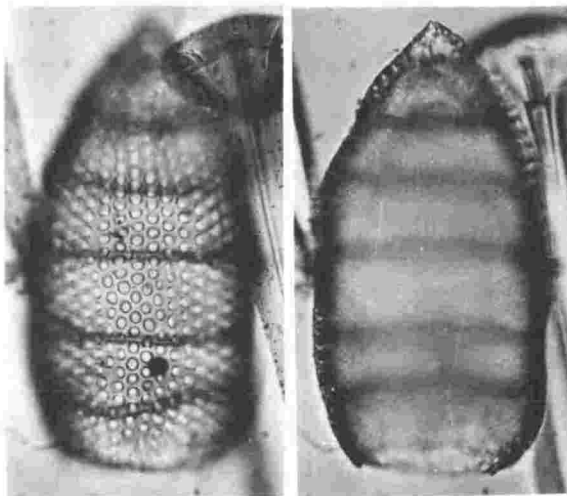
3A

B



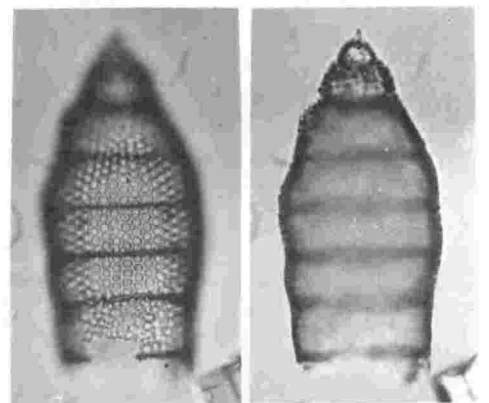
4A

B



5A

B



6A

B

PLATE 25 (opposite)

1. *Stichocorys delmontensis* (Campbell and Clark) : x360 : PB03 : 157/4
2. *Stichocorys peregrina* (Riedel) : x320 : PB11 : 167/8
3. *Stichocorys peregrina* (Riedel) : x300 : PB10 : 166/8
4. *Stichocorys peregrina* (Riedel) : x260 : MS08 : AA3/5
5. *Stichocorys peregrina* (Riedel) : x380 : MT05 : AA7/5
6. *Stichocorys delmontensis* (Campbell and Clark) : x400 : PB04 : 158/8
7. *Stichocorys peregrina* (Riedel) : x350 : SMA4 : AA4/11
8. *Stichocorys delmontensis* (Campbell and Clark) : x310 : TM16 : AA2/5
form transitional with *S. peregrina*
9. *Eucyrtidium* cf. *vincentense* (Campbell and Clark) : x330 : TM23 : AA1/3
10. *Anthocyrtidium* (?) sp. A : x320 : MO04 : AA4/4
11. *Anthocyrtidium* (?) sp. A : x350 : LT05 : AA7/3
form transitional with *A. ehrenbergi pliocenica*
12. *Anthocyrtidium ehrenbergi* (Stohr) *pliocenica* (Seguenza) : x320 : RMO6 : AA5/4
13. *Anthocyrtidium zanguebaricum* (Ehrenberg) : x320 : PB08 : 164/1
14. *Anthocyrtidium zanguebaricum* (Ehrenberg) : x320 : TM16 : AA2/5
15. *Eucyrtidium* sp. A : x310 : WA03 : AA8/4

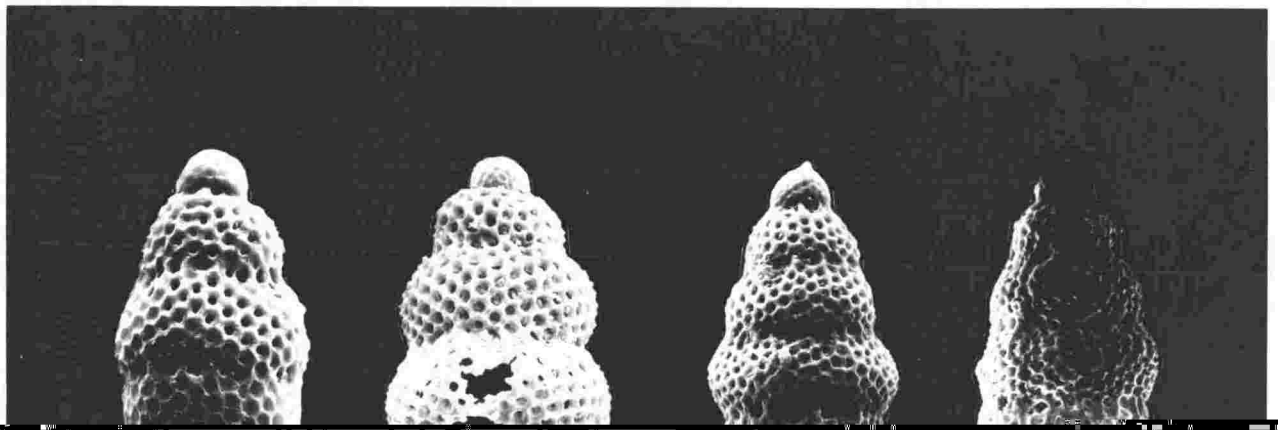
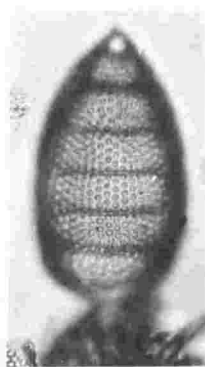
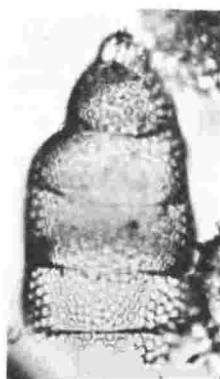


PLATE 26 (opposite)

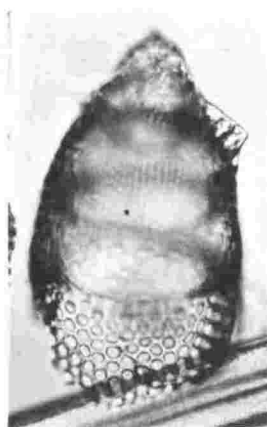
1. *Eucyrtidium acuminatum* (Ehrenberg) : x226 : TM22 : P36/3
2. *Eucyrtidium* cf. *montiparum* Ehrenberg : x413 : RM06 : Q18/4
3. *Eucyrtidium hexagonatum* Haeckel : x413 : RM06 : Q18/3
form with lateral wing
4. *Stichocorys peregrina* (Riedel) : x270 : SWR1 : N30/2
5. *Stichocorys delmontensis* (Campbell and Clark) : x406 : HR04d : T24/4
A. focused on surface
B. focused on circumference of same specimen
6. *Stichocorys peregrina* (Riedel) : x289 : PB11 : V35/2
7. *Stichocorys* sp. A : x257 : RK04 : W21/2
8. *Stichocorys peregrina* (Riedel) : x159 : RM05 : P29/3
9. *Gondwanaria dogeli* (Petrushevskaya) group : x398 : MO11 : K17/3
10. *Anthocyrtidium ehrenbergi* (Stohr) *pliocenica* (Seguenza) : x408 : MO11 : P45/1
11. *Anthocyrtidium* (?) sp. A : x305 : PB06 : X42/1



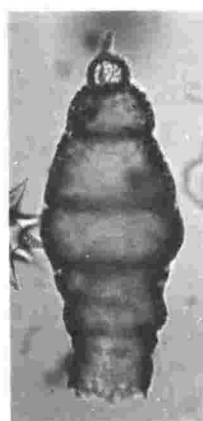
1



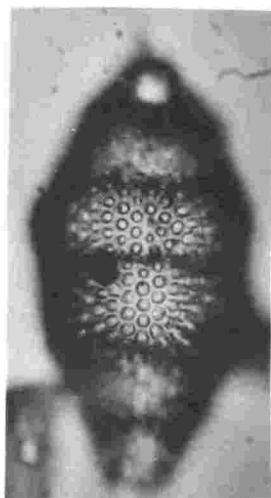
2



3



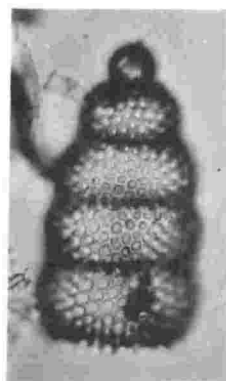
4



5A



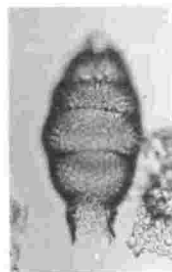
B



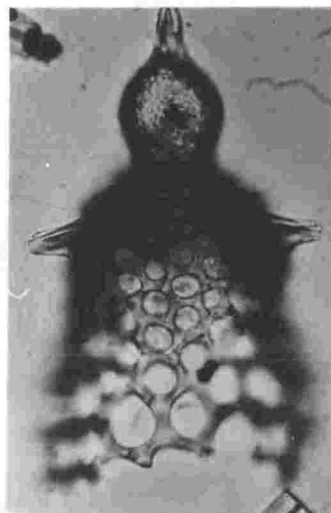
6



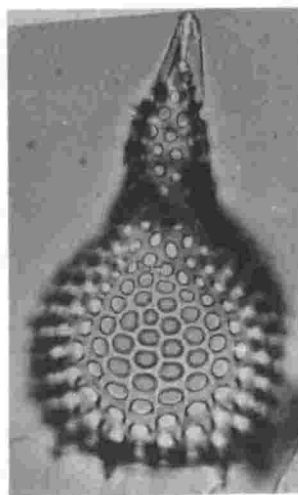
7



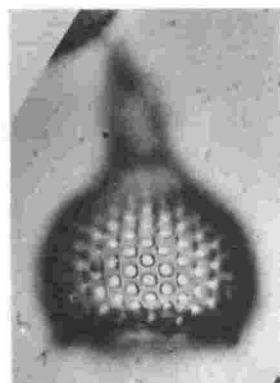
8



9



10



11

PLATE 27 (opposite)

1. *Lamprocyclas gamphonycha* (Jorgensen) : x250 : WA03 : AA8/4
form transitional with *Lamprocyrtis heteroporos*
2. *Lamprocyclas* cf. *maritalis* Haeckel : x220 : CR03 : AA7/4
3. *Lamprocyclas maritalis* Haeckel : x240 : WA17 : AA9/3
4. *Lamprocyclas* (?) sp. A : x280 : MO10 : AA4/7
5. *Lamprocyclas* sp. B : x330 : PB11 : 167/5
6. *Lamprocyclas* sp. B : x220 : PB11 : 167/5
7. *Lamprocyclas* sp. E : x250 : SWR4 : AA4/12
8. *Lamprocyclas* (?) sp. A : x270 : SMA4 : AA4/11
abnormal irregular pored form
9. *Lamprocyrtis* (?) *junonis* (Haeckel) : x320 : MO09 : AA4/7
10. *Lamprocyrtis hannai* (Campbell and Clark) : x250 : RM07 : AA5/3
11. *Lamprocyrtis* (?) *apollinis* (Haeckel) : x220 : WT05 : AA4/8
12. *Lamprocyclas* sp. D : x400 : PB08 : 164/4
13. *Lamprocyrtis* cf. *junonis* (Haeckel) : x300 : MO09 : AA4/6
14. *Lamprocyclas* sp. D : x310 : PB08 : 164/1

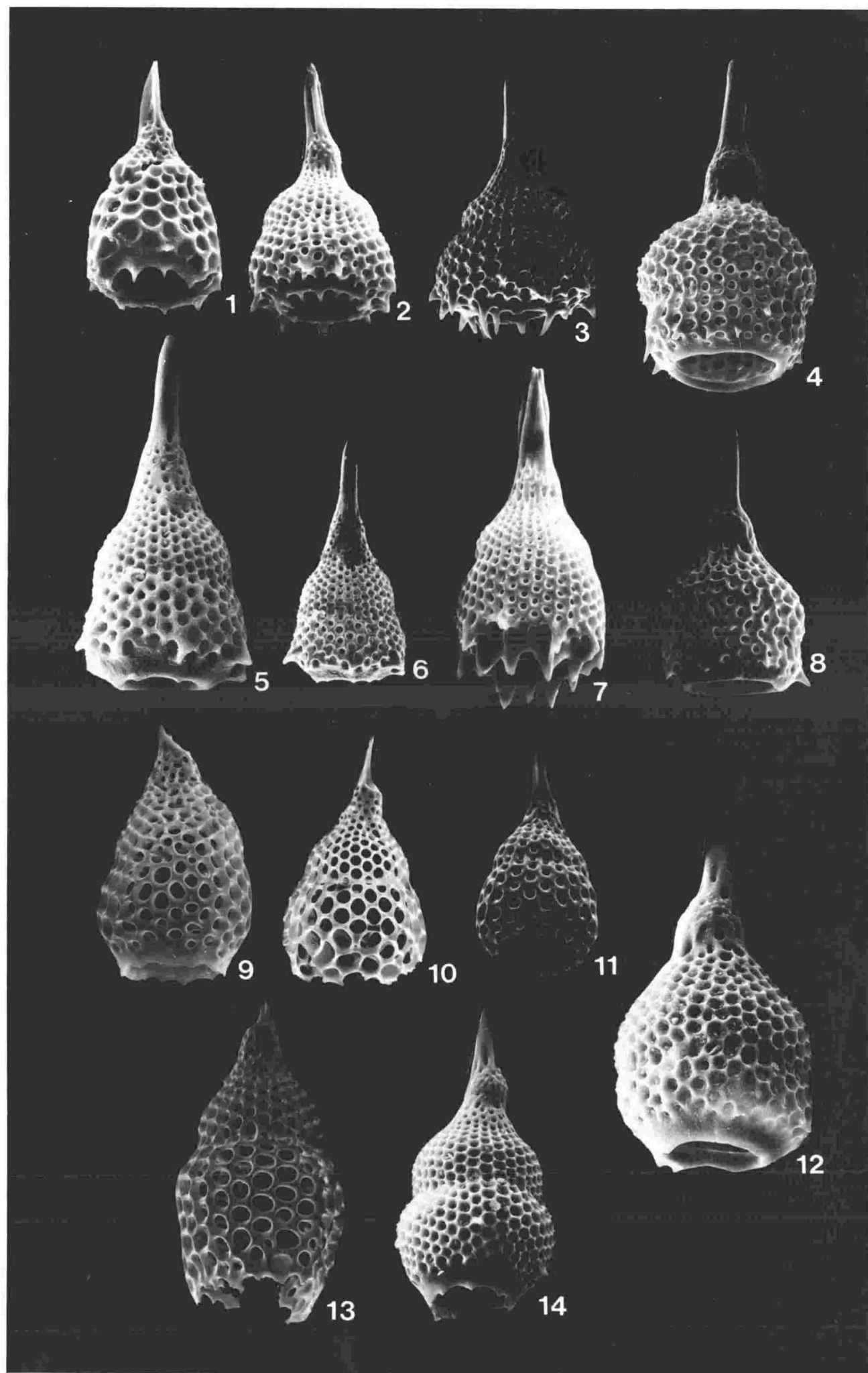
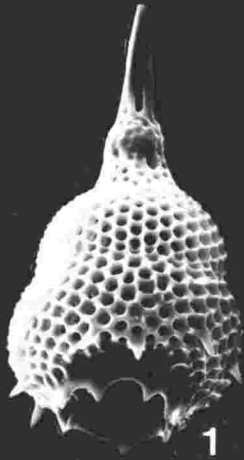
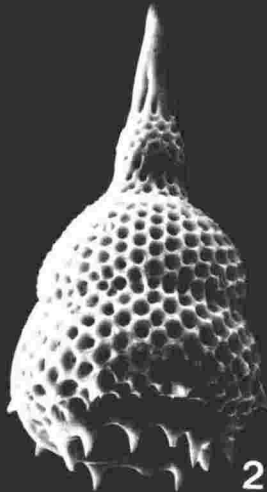


PLATE 28 (opposite)

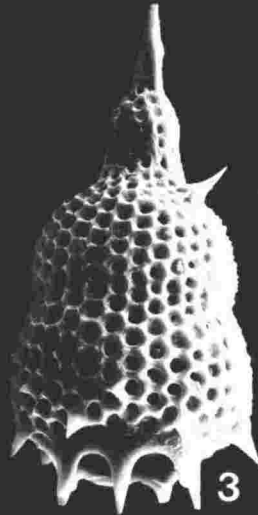
1. *Lamprocyclas* sp. C : x240 : RM02 : AA4/1
2. *Lamprocyclas* sp. C : x300 : PB02 : 156/4
3. *Lamprocyclas* sp. C : x310 : PB02 : 156/5
thoracic wing present
4. *Lamprocyclas* sp. C : x290 : PB02 : 156/2
thoracic wing present
5. *Lamprocyclas* sp. C : x330 : PB02 : 156/5
broken specimen showing internal septal ring
6. *Lamprocyclas* sp. C : x210 : PB08 : 164/3
7. *Lamprocyclas* sp. C : x300 : PB08 : 164/6
abnormal specimen with poor subterminal teeth
form transitional with *Lamprocyclas* sp. D
8. *Siphocampe nodosaria* (Haeckel) : x440 : PB11 : 167/8
9. *Siphocampe lineata* (Ehrenberg) group : x430 : LT05 : AA7/3
10. *Siphocampe lineata* (Ehrenberg) group : x410 : RM04 : AA5/6
form with distinct lumbar stricture
11. *Siphocampe lineata* (Ehrenberg) group : x400 : TM23 : AA1/4
form with distinct lumbar stricture
12. *Siphocampe arachnea* (Ehrenberg) group : x510 : KB01 : AA10/3



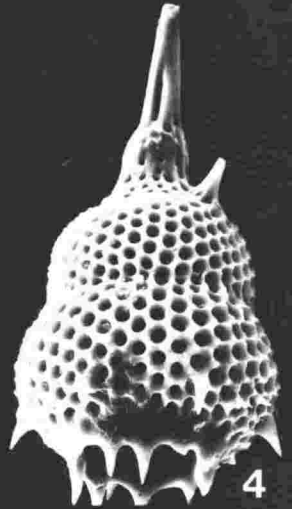
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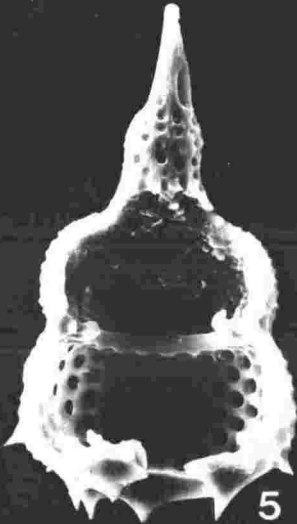
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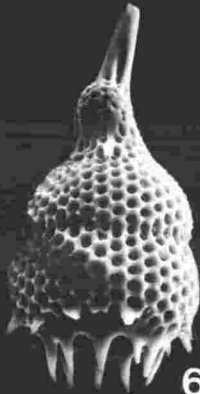
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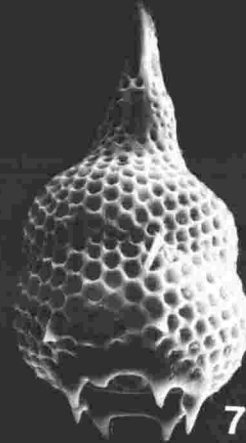
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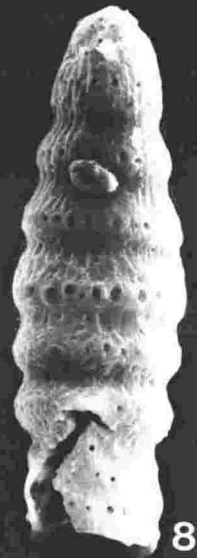
5



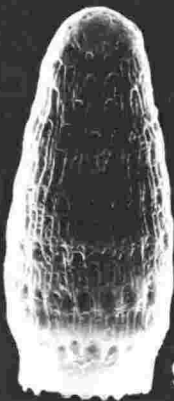
6



7



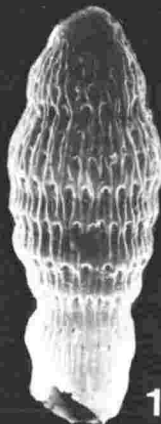
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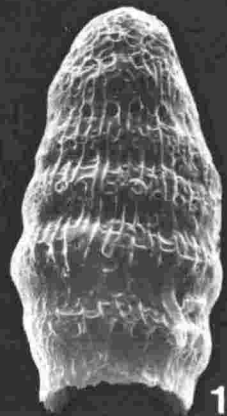
9



10



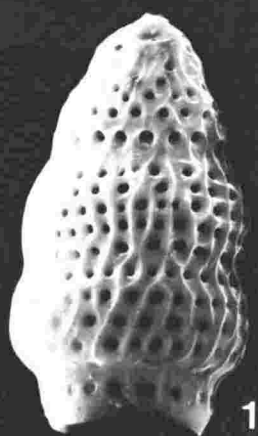
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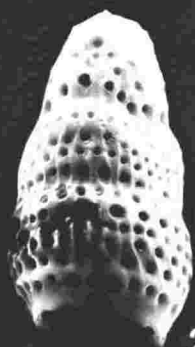
12

PLATE 29 (opposite)

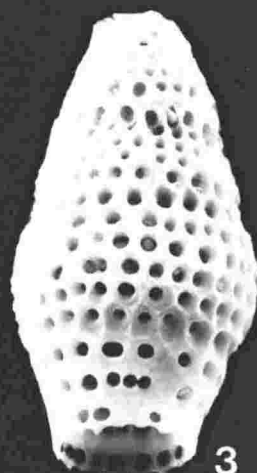
1. *Phormostichoartus* sp. A : x580 : MO04 : AA4/3
2. *Phormostichoartus* sp. A : x470 : MO04 : AA4/3
3. *Botryostrobus aquilonaris* (Bailey) : x520 : RM04 : MISC/5
4. *Phormostichoartus fistula* Nigrini : x510 : TM20 : AA1/10
5. *Siphostichartus corona* (Haeckel) : x360 : TM23 : AA1/3
6. *Botryostrobus bramlettei* (Campbell and Clark) : x450 : RM07 : AA5/3
7. *Spirocyrtis subscalaris* Nigrini : x400 : MO09 : AA4/6
8. *Spirocyrtis subscalaris* Nigrini : x400 : WA17 : AA9/3
etched specimen
9. *Botryostrobus auritus-australis* (Ehrenberg) group : x360 : TM15 : AA2/6



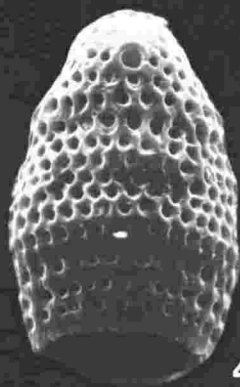
1



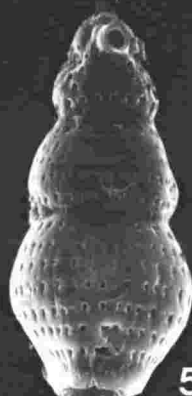
2



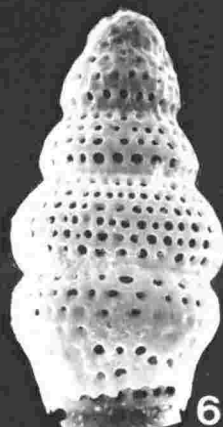
3



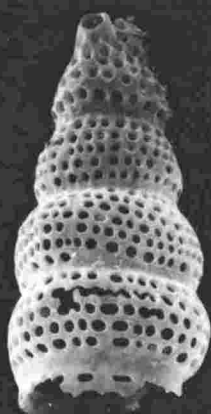
4



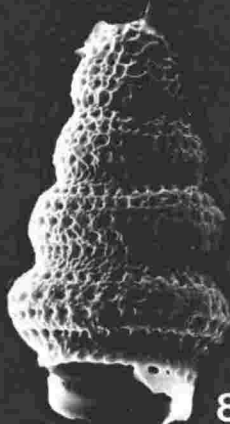
5



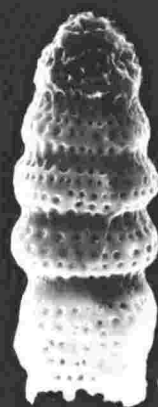
6



7



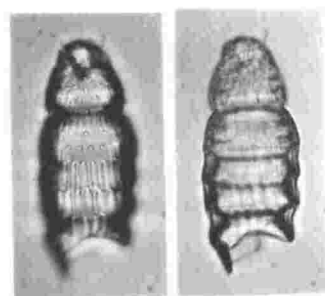
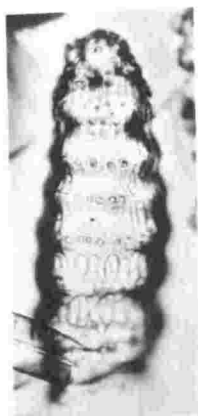
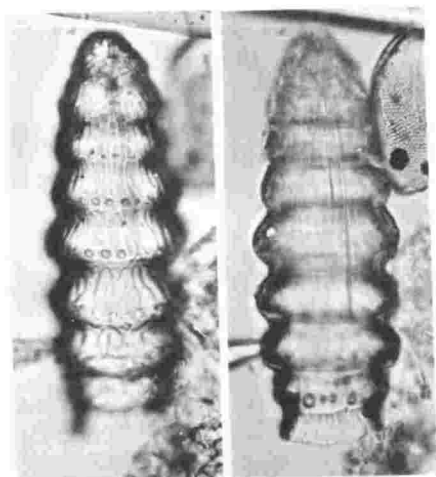
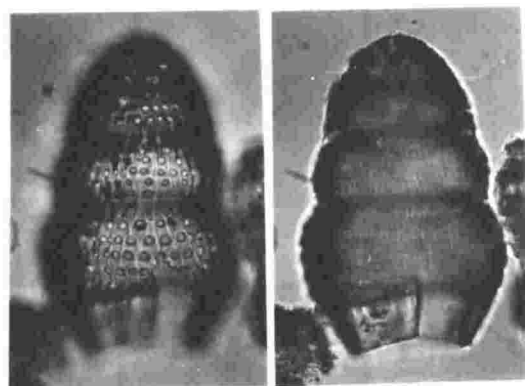
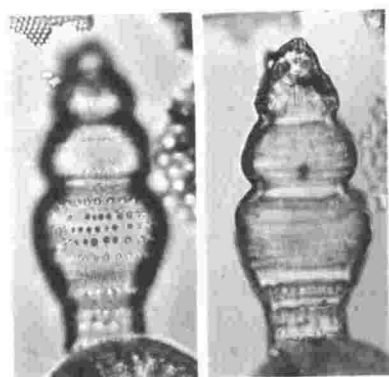
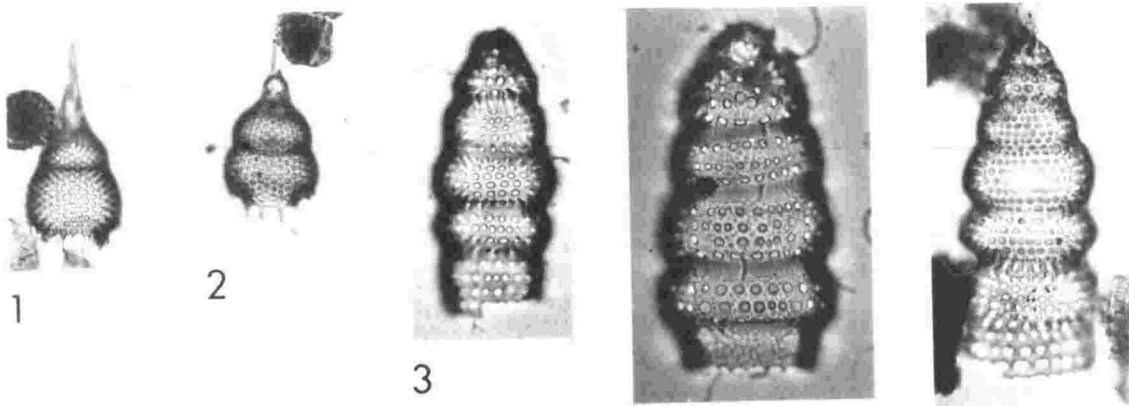
8



9

PLATE 30 (opposite)

1. *Lamprocyclas* sp. E : x119 : PB06 : E47/1
2. *Lamprocyclas* sp. C : x114 : PB06 : X45/4
transitional with *Lamprocyclas* sp. D
3. *Botryostrobus bramlettei* (Campbell and Clark) : x289 : PB06 : U37/3
4. *Botryostrobus auritus-australis* (Ehrenberg) group : x419 : WA02 : V42/2
5. *Botryostrobus bramlettei* (Campbell and Clark) : x283 : WA07 : J40/2
"long skirted" form
6. *Siphostichartus corona* (Haeckel) : x287 : TM22 : Q42/3
A. focused on surface
B. focused on circumference of same specimen
7. *Phormostichoartus* sp. A : x411 : PB09 : V22/3
A. focused on surface
B. focused on circumference of same specimen
8. *Siphocampe nodosaria* (Haeckel) : x406 : TM22 : N35/3
A. focused on surface
B. focused on circumference of same specimen
9. *Siphocampe arachnea* (Ehrenberg) group : x392 : HR04 : Q47/4
10. *Siphocampe lineata* (Ehrenberg) group : x296 : MO02 : P40/3
form with distinct lumbar stricture
A. focused on surface
B. focused on circumference of same specimen
11. *Spirocyrtis subscalaris* Nigrini : x293 : TM20 : J46/4
12. *Botryopyle dictyocephalus* Haeckel group : x419 : SMA3 : M43/1
form with a large eucephalic lobe
13. *Botryopyle dictyocephalus* Haeckel group : x288 : HR04 : R44/3
14. *Botryopyle dictyocephalus* Haeckel group : x311 : MO13 : O26/2
form with a large eucephalic lobe
15. "*Artostrobus*" *pretabulatus* Petrushevskaya : x410 : WT05 : L42/3

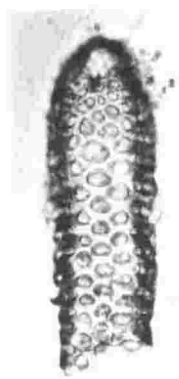
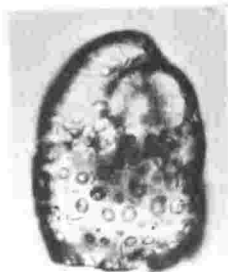


8A B

9

10A

B



11

12

13

14

15