NEOGENE PLANKTONIC FORAMINIFERA:
STUDIES ON INDO-PACIFIC OCEANIC SECTIONS

by

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SUMMARY

Neogene planktonic foraminiferal assemblages from three calcareous sections on the Ninetyeast Ridge, eastern Indian Ocean, and one section from the Ontong Java Plateau, western equatorial Pacific Ocean, have been studied in terms of biostratigraphy and systematics.

The more important of these biostratigraphic conclusions are as follows: The basal, non-evolutionary occurrence of *Globigerinoides* spp. overlaps *Neogloboquadrina kugleri s.l.* and correlates with the Oligocene/Miocene boundary stratotype. In the Middle Miocene, coiling changes in the *Globorotalia fohsi* lineage allow 'local' subdivision of the N.12-N.13 zonal interval. The extinction of *Globorotalia fohsi s.l.* correlates with the Zone N.13/N.14 boundary, the base occurrence of *Globigerina nepenthes* being allochronous. Lower Zone N.14 is characterised by a distinct right-coiled peak of *Globorotalia cultrata s.l.* In the Late Miocene *Globoquadrina dehiscens* has a disjunct range, disappearing near the Zone N.15/N.16 boundary, reappearing briefly in latest Zone N.17 before disappearing just below the Zone N.17/N.18 boundary. Rapid and distinct changes in coiling direction of *Neogloboquadrina* spp. and *Globorotalia cultrata s.l.- tumida s.l.* correlate with the Zone N.16/N.17 boundary and with radiolarian and calcareous nannofossil events within later Zone N.17. Late Miocene *Globoquadrina venezuelana s.l.* assemblages show quantitative changes in morphology that correlate with these Late Miocene coiling events. The Pliocene to Recent *Pulleniatina* spp. coiling trend and its biostratigraphic significance is confirmed. Similarly, the coiling histories of *Globorotalia tumida s.l.*, *Globorotalia cultrata s.l.- multicamerata* and *Neogloboquadrina* spp. show trends of stratigraphic significance. Quantitative changes in relative abundances of *Globigerinoides ruber*/*Globigerinoides obliquus s.l.*, *Sphaeroidinella* spp./*Sphaeroidinellopsis* spp. and *Globoquadrina altispira* are correlated to the standard Pliocene zonations and are of biostratigraphic significance. The abundance top of *Globigerinoides quadrilobatus fistulosus* is bracketed below by the evolu-

tionary appearance of *Globorotalia truncatulinoides* and *Pulleniatina obliquiloculata finalis* and correlates with the Pliocene/Pleistocene boundary stratotype.

Improved biostratigraphic resolution of the Late Miocene interval, in particular, is possible using both quantitative and qualitative changes in assemblages, in sections where the Late Miocene index species of Blow (1969) are absent or poorly developed. These rapid, coeval changes of different microfossil assemblages invite speculation on Late Miocene climatic trends.

Morphological investigations lead to an interpretation of evolutionary relationships of Neogene and selected Paleogene planktonic foraminifera. An evolutionary classification is outlined based on these phyletic relationships and several genera and higher taxa are revised. The nature of the surface wall texture, together with the presence or absence of spines, emerge through taxonomic analysis as having greater diagnostic analysis than the nature of the chamber periphery, apertural position and presence or absence of bulla(e).

In summary the bulk of the Neogene radiation is parceled among four families. The finely perforate *Globorotalia* is the only genus in the Family Globorotaliidae. The Family Catapsydracidae includes the non-spinose and cancellate-walled *Globoquadrina*, *Catapsydrax* and *Globorotaloides*. The Genus *Neogloboquadrina*, also included in this family, is expanded to include the Paleogene *opima* group and the *kugleri* evolutionary offshoot that parallels the truncate chambered turborotaliids. The family includes *Pulleniatina* whose cancellate and non-spinose wall is 'secondarily' covered by a smooth, almost imperforate, calcite layer. The Family Orbulinidae contains the spine-bearing 'spinose' to cancellate-walled genera *Beella*, *Globigerinella*, *Globigerina*, *Sphaeroidinella*, *Sphaeroidinellopsis*, *Globigerinoides*, *Praeorbulina* and *Orbulina*. The Family Candeinidae includes the microperforate-walled, non-spine bearing, genera *Candeina*, *Globigerinatella*, *Globigerinita* and *Tenuitella*.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University; nor, to the best of my knowledge and belief, does the thesis contain any material previously published or written by another person, except where due reference is made in the text of the thesis.

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INTRODUCTION

Interest in Neogene planktonic foraminiferal biostratigraphy developed rapidly over the 1950's when detailed stratigraphic resolution was required for oil exploration in the Caribbean. The careful analysis of planktonic forms published by Loeblich *et al.* (1957) represented an important step in providing an Early Neogene zonation which was applied by other authors, with differing degrees of success, elsewhere on the globe. Several zonations, of varying geographic validity, were later produced during the 1960's to expand the stratigraphic cover into the latest Cainozoic.

Over the past decade much information on Neogene planktonic foraminifera has accumulated in the Deep Sea Drilling Project. They have emerged as an important tool for solving problems of age determination of marine sediments and thereby providing a time-framework for unravelling aspects of Earth history. This has resulted in greater insight into the palaeo-geography, palaeo-oceanography and palaeo-climate of the past 24 million years. An integrated approach to Neogene Earth history is now emerging, with the interrelationships between tectonics, transgression/regression and climate receiving closer attention.

As this foraminiferal information has amassed over the past twenty or so years, there has been a growing awareness of problems associated with international correlation of Late Cainozoic marine sequences. Zonations established on tropically restricted species are often inadequate for tropical-extratropical correlation, while problems of selective preservation of planktonic foraminifera have also been recognised. Similarly the selective inshore weeding out of the planktonics has impared recognition of zonations, based on deep-sea assemblages, in neritic sequences. In response to the problems of selective preservation, Jenkins and Orr (1971) produced a zonation based on solution-resistant species at the expense of reduced biostratigraphic resolution. Problems of 'provincialism' include both latitudinal and longitudinal changes in assemblages. Tropical to extratropical Neogene correlation in the southwest Pacific has been examined by Kennett (1973) who erected separate zonations for warm and cool subtropical watermasses. Other analyses of coeval assemblages from mid to low-latitude waters reveal differences attributed to varying degrees of watermass isolation. Examples include the Late Miocene 'isolation' of the Mediterranean and the effects of the emergence of the Isthmus of Panama during the Pliocene.

While great advances in Neogene biostratigraphy have already been made much remains to be done in the way of confirmation and possible refinement of the current ideas. Thus the Indo-Pacific DSDP sites examined in this thesis were selected because of their low latitude aspect, oceanic biofacies, relatively good preservation and relatively 'complete' calcareous assemblages throughout the Late Cainozoic. In addition, particular emphasis is placed on Site 214, Ninetyeast Ridge, because it contains probably the best preserved Indian Ocean assemblages and is close to the tropics. This site also forms a comparative reference section for nearby Australasia with its relatively sporadic Neogene record. Vincent (1977) recently reinforced the biostratigraphic significance of this site which was initially outlined by McGowran (1974) and Berggren, Lohmann and Poore (1974). The western equatorial Pacific Site 289, situated on the Ontong Java Plateau, is examined as a reference section for comparison of Indian and Pacific Ocean foraminiferal assemblages. This site is also close to Papua New Guinea which has a Neogene record of complex tectonism and extremes of sedimentation rates. Since the radiolaria and calcareous nannofossils have already been examined from these sites, an important opportunity is presented to check and possibly refine correlation of the various planktonic microfossil biostratigraphies. Incorporation of these results with the latest palaeomagnetic-reversal time-scale should lead to an upgrading of the integrated planktonic microfossil time-scale.

The excellent biohistorical record of the Late Cainozoic planktonic foraminifera provides a solid foundation for an interpretation of foraminiferal evolution and classification. Improvement of their classification has lagged far behind the available phylogenetic information over the past decade.

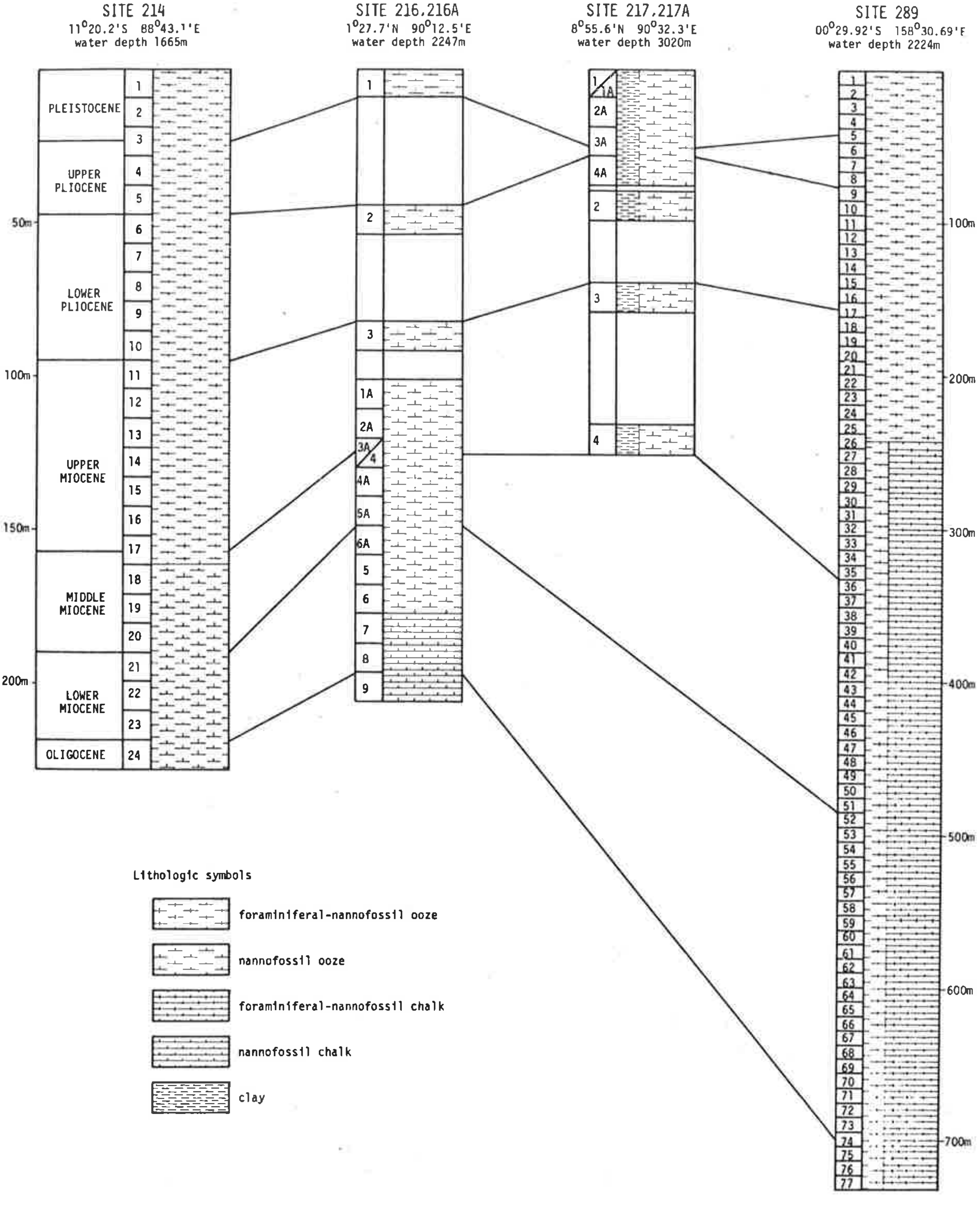

FIGURE 2. Stratigraphic column of Deep Sea Drilling Project Sites discussed showing lithologies and core positions versus depth (data from Von der Borch *et al.* 1974 and Andrews *et al.* 1975) and age. Note change of depth-scale between Site 289 and the other sites.

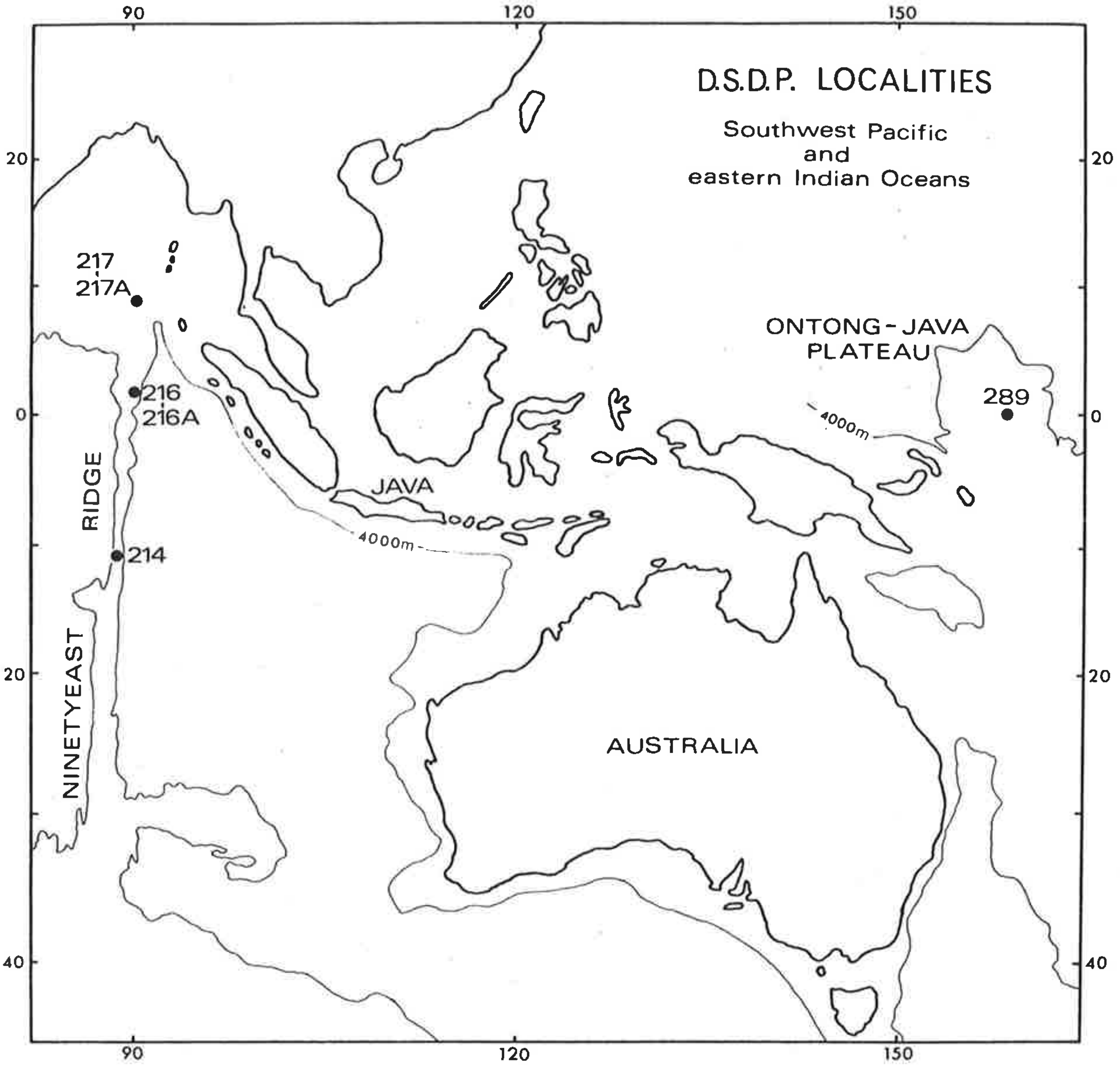

FIGURE 1. Localities of Deep Sea Drilling Sites, eastern Indian and southwest Pacific Ocean regions, discussed. Oceanic topography outlined by 4000 metre isobath.

This data has accumulated rapidly due largely to technical advances in the field of electron microscopy, enabling detailed morphological investigations. The generally well preserved assemblages at hand offer considerable scope for comparative morphology as the basis for a study of phylogeny and the evolutionary classification of Neogene and selected Paleogene forms.

The thesis is divided into two parts. The first part documents Indo-Pacific Neogene planktonic foraminiferal biostratigraphy while the second is mainly taxonomic. Chapter 1 details the Miocene to Recent biostratigraphy of the eastern Indian Ocean DSDP Sites 214, 216/216A and 217/217A, and the western equatorial Pacific Site 289. Biostratigraphic conclusions are discussed in Chapter 2, providing the biostratigraphic framework for a discussion and analysis of various Neogene planktonic foraminiferal zonations in Chapter 3. The integration of this planktonic foraminiferal data with the published radiolarian and calcareous nannofossil biostratigraphies leads to a consideration of the Late Cainozoic planktonic microfossil time-scale. This is presented in Chapter 4. In Chapter 5 (Part 2) an analysis of the evolutionary relationships between Neogene and selected Paleogene planktonic foraminifera is attempted, based on personal observations and discussions in the literature. These morphological groupings and evolutionary phenomena are related to the classification of the planktonic foraminifera, providing the basis for the systematic checklist of foraminiferal species recognised contained in Chapter 6.

MATERIALS AND METHODS

Samples from the eastern Indian Ocean Deep Sea Drilling Project Sites 214, 216/216A, 217/217A and the western equatorial Pacific Site 289 were examined. The locality of each site is shown on Figure 1 and the lithologies of intervals examined are shown on Figure 2.

Of the Indian Ocean sites, 214 was continuously cored throughout the Neogene while Sites 216/216A and 217/217A were discontinuously cored. Site 289 was continuously cored throughout the Neogene.

A list of samples examined is contained in the range charts compiled for each site.

Sample nomenclature. This is in accordance with standard DSDP procedure, set out for example, in Kennett, Houtz *et al.* 1975. In summary, 9.5 metre cores, numbered from 1 downwards, are cut into 1.5 metre long sections numbered from 1 at the top of the core down to a maximum of 6. The symbol cc refers to the core-catcher sample located at the bottom of each core.

Therefore a sample numbered 214-5-1 5-7cm indicates the following:

214 = Site number
5 = Core number
1 = Section number
5-7cm - position below the top of the section, measured in centimetres, where the sample was obtained.

Methods of investigation. The DSDP samples, generally 10cc. in volume, were disaggregated and washed over a 63 micron sieve, using standard laboratory procedures.

Planktonic foraminifera from the greater than 63 micron fraction were examined using both a Leitz stereobinocular microscope and a Siemens Autoscan scanning electron microscope (SEM).

Preparation for SEM work involved placing selected specimens onto a gum tragacanth-coated glass-slide which were already mounted onto an aluminium stub. The specimens were then coated with gold using a sputter-coater, and photographed in the SEM using Kodak Panatomic X fine-grained film.

Quantitative work involved the counting of 500 specimens taken from the fraction greater than 150 microns. Specimens to be counted were selected at random using a disposable splitter made from large filter paper. The filter paper is folded to make a series of radially arranged flutes over which the sample is slowly poured via a filter paper funnel. Each flute collects a percentage of the total sample depending on the number of flutes constructed. Data on the coiling preferences of selected taxa was obtained by counting the first fifty specimens, generally taken from the greater than 150 micron size fraction in order to avoid problems associated with identification of juveniles.

Sample repository. Assemblage and species slides (accession number 721-) are held in the micropalaeontology collection, Department of Geology and Mineralogy, University of Adelaide.

CHAPTER 1

INDO-PACIFIC NEOGENE BIOSTRATIGRAPHY

INTRODUCTION

The Neogene, as used in this thesis, represents the interval from the Oligocene/Miocene boundary to the present. An attempt is made to analyse as many assemblage characteristics as time permits in Sites 214, 216/216A, 217/217A and 289. Accordingly species ranges, evolutionary development, abundance and coiling trends (for selected taxa) are recorded. The synthesis of this stratigraphic data enables an estimate of the reliability of selected zone-defining events and of zonal synchroneity. An additional reason for a close examination of coiling trends is to document biogeographic patterns in coiling which may reflect palaeo-oceanographic and tectonic events as exemplified by Saito's (1976) study of the *Pulleniatina* spp. coiling history.

OLIGOCENE/MIOCENE BOUNDARY

At Sites 214, 216 and 289 the basal, non-evolutionary, occurrence of *Globigerinoides* spp. occurs within the range of *Neogloboquadrina kugleri s.l.* and just above the first, upsection, appearance of the latter taxon. Therefore, the base of *Globigerinoides* spp. in these oceanic sections is approximately coeval with the base of Zone N.4 as recognised by Blow (1969) in the lectostratotype Aquitanian of France. However, recent studies show *Globigerinoides quadrilobatus primordius* to range well below this level in more complete sections in the Aquitane Basin (Eames, 1970; Anglada, 1971). The distinction between Zones N.3 and N.4 of Blow (1969) in these neritic sections is therefore questionable. The timing of the first appearance of *Globigerinoides* spp. has similarly been questioned by Belford (1972), Lamb and Stainforth (1976), Steininger *et al.* (1975) and Shafik and Chaproniere (1978) amongst others.

In these Indo-Pacific oceanic sections the base of *Globigerinoides* spp. lies just above the extinction of the nannofossil *Sphenolithus ciperoensis* as recorded by Bukry (1974a), Gartner (1974) and Shafik (1975). This extinction correlates with the NP.25/NN.1 nannofossil zonal boundary of Martini and Worsley (1970). Also, the base of *Globigerinoides* spp. is associated with the radiolarian *Lychnocanoma elongata* in Sites 216 and 289 and is below the base of the radiolarian *Calocycletta virginis* at Site 289 (Johnson, 1974; Holdsworth, 1975). Accordingly the base of *Globigerinoides* spp. lies within the *Lychnocanoma elongata* Zone of Riedel and Sanfilippo (1970, 1971).

Van Couvering and Berggren (1977) argue that the base of the Aquitanian stratotype equals the base of the Miocene and that this occurs within Zone N.4 (as Blow (1969) defined in evolutionary terms). They show this to be close to the NP.25/NN.1 nannofossil zone boundary which is considered by Theyer and Hammond (1974b) to lie within the *Lychnocanoma elongata* Zone.

In this biostratigraphic framework the basal, non-evolutionary, occurrence of *Globigerinoides* spp. at Sites 214, 216 and 289 correlates with the Oligocene/Miocene boundary stratotype because it lies just above the NP.25/NN.1 nannofossil boundary and within the *Lychnocanoma elongata* radiolarian Zone. This supports the suggestion of Shafik and Chaproniere (1978) that the first, upsection, appearance of *Globigerinoides quadrilobatus primordius* occurs later in oceanic sections than in shallower marine environments where Zones N.3 and N.4 of Blow (1969) are not distinguishable as defined. More importantly, the base of *Globigerinoides* spp. in these Indo-Pacific sites correlates with the Oligocene/Miocene boundary as determined by both radiolarian and nannofossil biostratigraphy. Though Zone N.4 of Blow (1969) cannot be recognised as defined the overlap of *Globigerinoides* spp. and *Neogloboquadrina kugleri s.s.* permits recognition of an interval of time, valid for these oceanic sites, informally designated here as Zone 'N.4'.

The *Lychnocanoma elongata* Zone, which brackets the Oligocene/Miocene boundary stratotype, is correlated to within Palaeomagnetic Epoch 21 by Theyer, Mato and Hammond (1978) which in turn is dated at 23 to 25 Ma (mega-annum) by Van Couvering and Berggren (1977) or 21 to 21.75 Ma by La Brecque *et al.* (1977).

FIGURE 4. Early Miocene range chart, Site 214.

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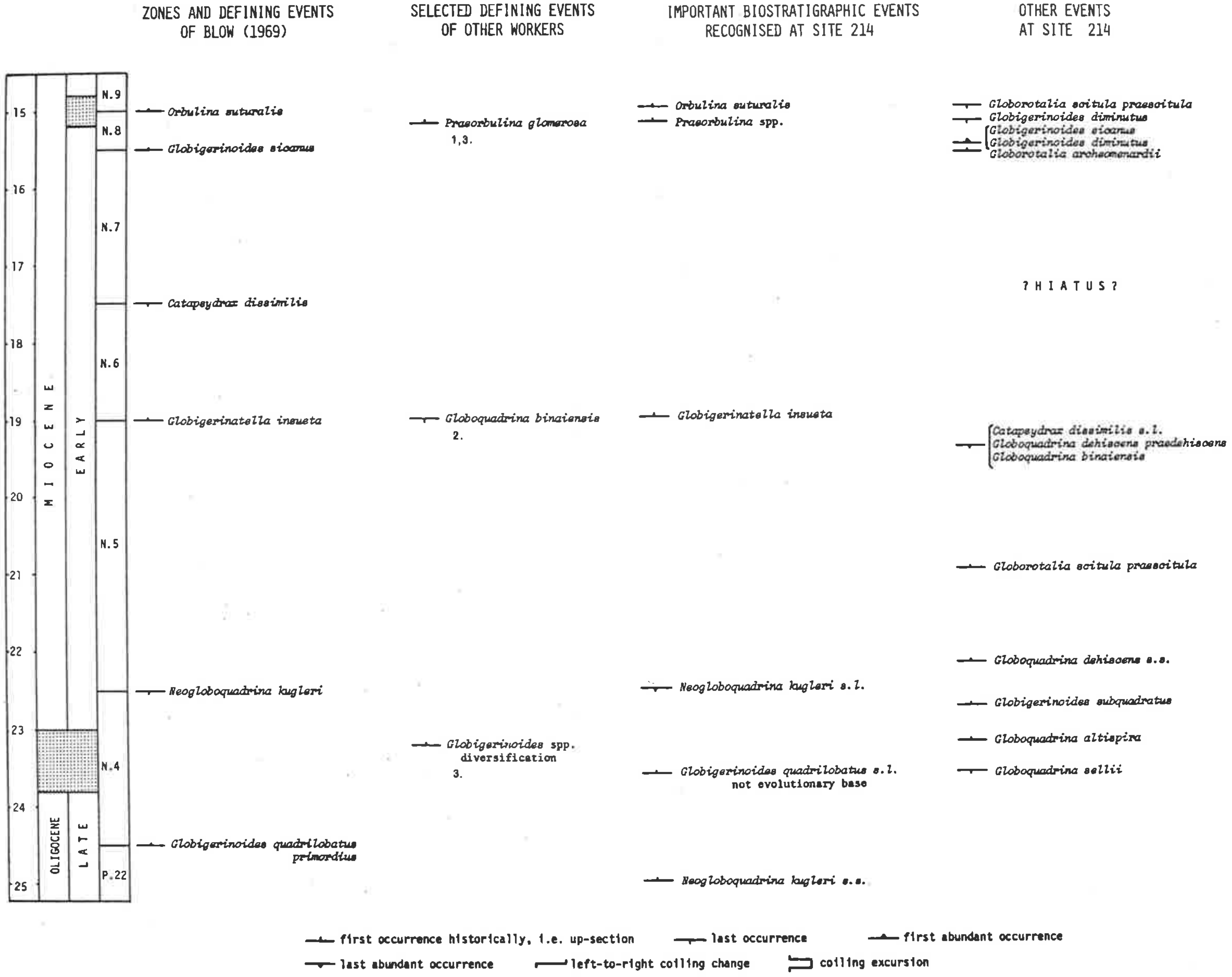

FIGURE 3. Early Miocene planktonic foraminiferal biostratigraphy, Site 214.
1. Postuma 1971; Jenkins & Orr, 1972 2. Haak & Postuma, 1975 3. Stainforth *et al.* 1975.

EARLY MIOCENE

Various planktonic foraminiferal zonal schemes have been suggested for the Early Miocene, including those of Bolli (1957), Blow (1969), Jenkins and Orr (1972), Postuma (1971) and Stainforth *et al.* (1975). Most of these schemes employ essentially the same zonal species in the same relative chronological order as indicated by Blow (1969). Figure 3 outlines the zones and defining events of Blow for the Early Miocene against which several defining events of other authors are correlated. Within this framework the base and top occurrences of selected taxa are also figured. In this and all subsequent (relevant) text-figures the vertical dimension is drawn to scale after the estimated duration of Zones N.4 to N.21 as indicated by Van Couvering and Berggren (1977).

SITE 214

The planktonic foraminiferal events used to subdivide the Early Miocene of Site 214 are outlined on Figure 3 and the occurrences of all planktonic foraminiferal species identified from the Early Miocene of this site are shown on Figure 4.

Preservation of tests is fair to moderate over this 'continuously cored' interval. Robust *Globoquadrina* spp. dominate the assemblages though the thin-walled genera *Globigerinita* and *Cassigerinella* are also present throughout.

Biostratigraphic subdivision of the older part of the Early Miocene at Site 214 is based on the sequential extinction of *Neogloboquadrina kugleri s.l.* and the evolutionary appearance of *Globigerinatella insueta*. Blow (1969) uses these events to define the boundaries between his Zones N.4/N.5 and N.5/N.6 respectively.

Globoquadrina dehiscens s.s. first appears in sample 214-22-cc after the extinction of *N. kugleri* at Site 214, contrary to the observations of McGowran (1974) who records an overlap of ranges of these species. *G. dehiscens s.l.* in Zones N.4 and N.5 is dominated by the *praedehiscens* form which

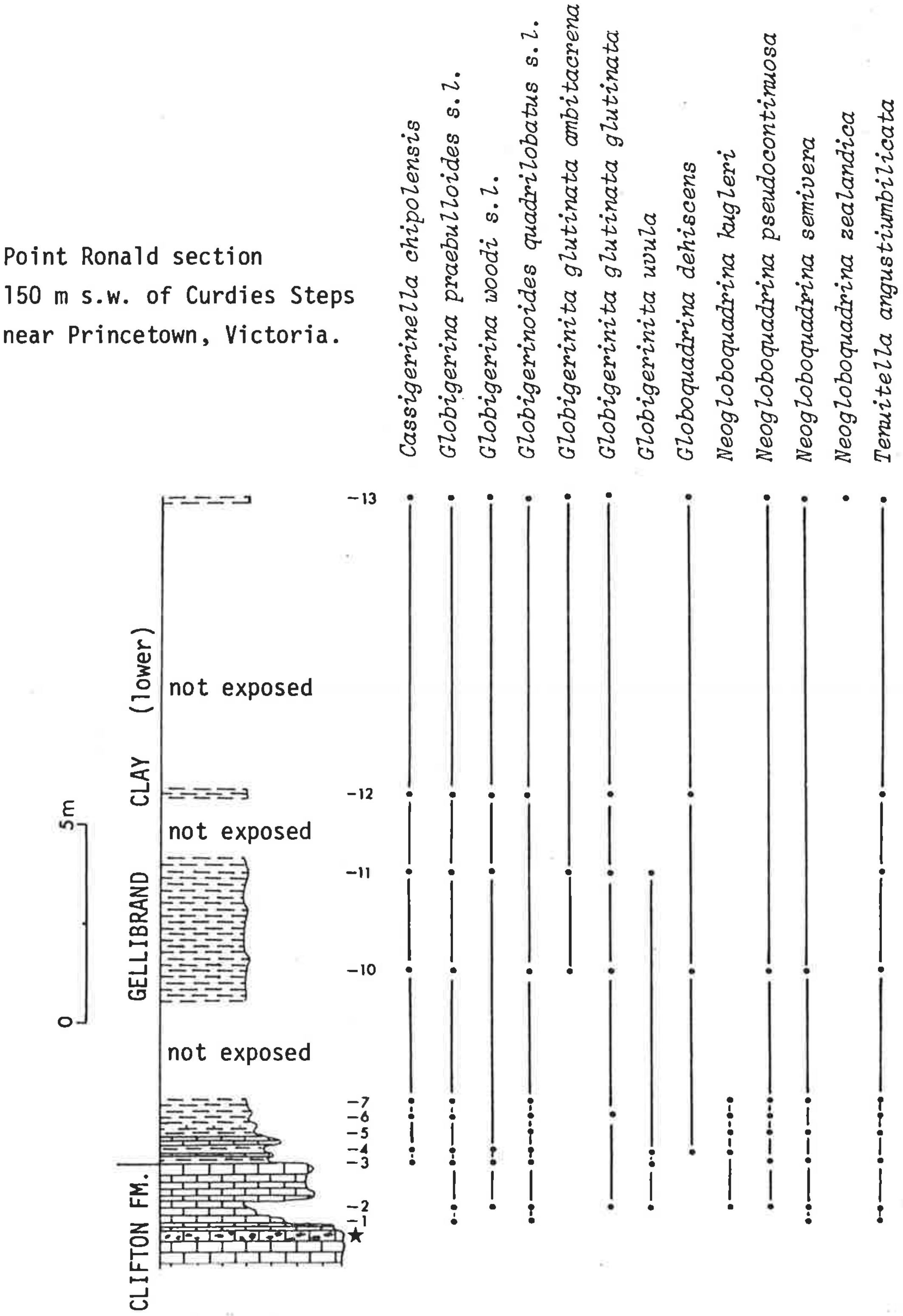

FIGURE 5. Planktonic foraminiferal biostratigraphy of the upper part of the Clifton Formation and lower Gellibrand Clay sampled about 150 metres southwest of Curdies Steps near Princetown, Victoria. ★phosphate-nodule bed.

is typically of large size compared to *dehiscens s.s.* The first occurrence of *G. dehiscens s.l.* is within sample 214-23-cc, assigned to Zone 'N.4'. Berggren and Amdurer (1973 p.28) record that "the development of *Globoquadrina dehiscens* from *G. praedehiscens* occurs somewhat subsequent to the initial appearance of the genus *Globigerinoides*". This is yet another example of the biostratigraphic inconsistencies generated by the variable first appearance of *Globigerinoides* spp.

The basal occurrence of *Globoquadrina dehiscens* is reported within the range of *N. kugleri* in southern Australia (Lindsay and McGowran, 1971) and below the first occurrence of *N. kugleri* in New Zealand (Jenkins, 1971). Jenkins (1960) regards the first occurrence of *G. dehiscens* in the Lakes Entrance Oil Shaft, Victoria, as correlating with pre-*N. kugleri* sections in Trinidad. However, my examination of material from the B.M.R. Lakes Entrance well produced one specimen referable to *N. kugleri* from a sample taken at 1176 feet some 32 feet below the first appearance of *G. dehiscens* as recorded by Jenkins (1960). *G. dehiscens* first appears in the Gellibrand Clay (Point Ronald, Victoria) within the range of *N. kugleri* and *Globigerinoides* spp. (Figure 5), although it occurs in greater abundance and in greater stratigraphic continuity above the disappearance of *N. kugleri*. In summary the basal occurrence of *G. dehiscens s.s.* is allochronous appearing first within Zone 'N.4', although in few numbers, before its subsequent and more obvious 'appearance' within the lower part of Zone N.5.

The highest occurrence of both *Globoquadrina binaiensis* and *Catapsydrax dissimilis s.l.* is sample 214-22-3 5-7cm. The next higher sample, 214-22-2 5-7cm, contains specimens intermediate between *Globigerinatella insueta* and *Globigerinita glutinata ambitacrena* indicating an early Zone N.6 age. In the south Atlantic DSDP Site 18 Blow (1970a, p.654) records "*Globigerinatella* cf. *insueta* (phylogenetically very primative)" from sample 18-2-2 75-77cm and assigned a Zone N.6 age. *Globoquadrina binaiensis* is also recorded from sample 18-2-2 by Berggren and Amdurer (1973, p.17). Thus the disappearance of *G. binaiensis* provides a close approximation to the Zone N.5/N.6 boundary in both Indian and south Atlantic deep-sea cores. Haak and Postuma (1975) use this event, correlated to the Zone N.5/N.6 boundary, to formally define the boundary between their (Indo-Pacific) *Globoquadrina binaiensis* and *Catapsydrax stainforthi* Subzones. In view of the distinctive morphology of *G. binaiensis*, its widespread distribution and probable high resistance to calcite-solution, further use of this event as a significant bio-horizon is supported.

The Zone N.5/N.6 boundary is also approximated by the extinction of *Globoquadrina dehiscens praedehiscens* in Site 214 (Figure 3) and the south Atlantic DSDP Site 18 (Berggren and Amdurer, 1973 p.17). This species ranges above the top occurrence of *Globoquadrina binaiensis* at Site 216. The absence of *Globigerinatella insueta* in core 5 of Site 216 prevents assessment of the position of top *G. dehiscens praedehiscens* and *G. binaiensis* relative to the Zone N.5/N.6 boundary.

The extinction of *Catapsydrax dissimilis s.l.*, occurring above the first appearance of *Globigerinatella insueta* and below the first occurrence of *Globigerinoides sicanus*, defines the Zone N.6/N.7 boundary of Blow (1969). *C. dissimilis* is the most abundant Early Miocene *Catapsydrax* species at Site 214 and disappears within Zone N.5 (contrary to McGowran, 1974), so that Zone N.7 cannot be recognised.

Blow (1969) indicates that *Catapsydrax unicavus* becomes extinct immediately below the base of Zone N.7 and thereby aids the recognition of that zone. However, Brönnimann and Resig (1971) report *C. unicavus* overlapping the N.8 zonal species *Globigerinoides sicanus* at DSDP Site 64.1, Ontong Java Plateau, while Srinivasan (1977) reports *Globigerinoides* aff. *bisphericus* (= aff. *sicanus*) overlapping *Catapsydrax dissimilis* in the Andaman-Nicobar Islands. At Site 214 specimens of *G. sicanus* and *Globigerinoides diminutus*, typical of Blow's Zone N.8, occur extremely rarely in sample 214-22-1 5-7cm associated with specimens referable to *C.* cf. *unicavus*. A positive identification is not apparent for these specimens in view of their rarity and the writer's lack of faith in the taxonomic weight given to the nature of the

Catapsydrax bulla particularly when measured against its biostratigraphic consequences.

The abrupt increase in abundance of both *Globigerinoides sicanus* and *Globigerinoides diminutus* above the base of *Globigerinatella insueta*, and of top of rare *Catapsydrax* cf. *unicavus*, and before the base of *Praeorbulina* spp. (Figure 3), provides an easily recognisable event at sample 214-21-5 5-7cm. The older occurrences of *G. sicanus* are extremely rare at Site 214 so that the abundance increase event is regarded as greater potential biostratigraphic value than the first occurrence of this species in view of its post-*C. unicavus* first appearance recorded elsewhere. Similarly, Blow (1969, p.230) recognises that *G. diminutus* reaches its acme within Zone N.8, and that "the frequent occurrence of *G. diminutus* forms a useful guide to the recognition of Zone N.8 in the absence of other, more direct evidence". This species is abundant only from sample 214-21-5 5-7cm to sample 214-21-2 30-32cm. The oldest occurrence of *Globorotalia archeomenardii*, restricted to horizons from within Zone N.8 to early Zone N.10 (Blow, 1969), is within sample 214-21-cc. The base of Zone N.8 is therefore tentatively recognised at 214-21-cc.

The extinction of *Catapsydrax stainforthi* is often used to approximate the Zone N.7/N.8 boundary. Blow (1969) records its extinction within the later part of Zone N.7 while Brönnimann and Resig (1971) record an overlap of *C. stainforthi* with *Globigerinoides sicanus*, the Zone N.8 index species, at Site 64.1. *C. stainforthi* is present in only one sample, 214-22-5 5-7cm, assigned to Zone N.5 and therefore precludes any refinement of the N.7-N.8 zonal interval based on this taxon. Ingle (1973) records an overlap of *C. stainforthi* with *Praeorbulina* spp. in DSDP Site 173 implying that *C. stainforthi* may range as high as the later part of Zone N.8.

The abundance of several taxa rapidly change across the core 21/22 boundary. In particular the microperforate *Tenuitella grata-clemenciae* group ranges in abundance in core 21 and is rare in core 22 while *Globorotalia peripheroronda* is very rare in uppermost core 22 and abundant in the basal part of core 21. That is, there are changes across the boundary between cores 22 and 21 in terms of relative abundances and presences/absences of index species. The evidence, therefore, suggests either a very condensed middle Early Miocene section or a hiatus covering later Zone N.6, N.7 to early Zone N.8. Using the time-scale of Van Couvering and Berggren (1977) this interval represents a time-span of approximately 2.5 Ma.

An additional factor to be considered is that significantly more zone boundaries lie between adjacent cores than would be expected by chance alone suggesting that DSDP 'continuous' coring does not in fact recover the complete stratigraphic sequence (Moore, 1972). Accordingly the significance of this between-core hiatus at Site 214 is uncertain.

The first appearance of *Praeorbulina* spp. offers a welcome adjunct to biostratigraphic resolution in the later Early Miocene, allowing recognition of an 'upper' and 'lower' Zone N.8 at Site 214. Although specimens of *Praeorbulina* are rare, the distinctiveness of this genus adds to its utility as a biostratigraphic marker as is stressed in New Zealand by Jenkins (1970) and in the Central Paratethys by Steininger *et al.* (1975).

Other biostratigraphic events of significance. The initial occurrence of *Globigerinoides subquadratus* within latest Zone 'N.4' is lower than the middle to later Zone N.5 record of Blow (1969) and correlates with Zone N.4 *Globigerinoides subquadratus* in the Aquitaine Basin as documented by Pujol (1970 = his *G. ruber*). Site 214 Zone 'N.4' specimens of this taxon stratigraphically overlap the earliest specimens of *Globigerinoides quadrilobatus* aff. *altiapertura*, their suggested ancestor (Cordey, 1967). The earliest specimens of *G. subquadratus* all have thick calcite-crusts that obscure the nature of the supplementary apertures. Forms with only a single (observable) supplementary aperture per chamber first appear in earliest Zone N.5 while advanced forms with two supplementary apertures associated with the last chamber range from within upper Zone N.5.

Cassigerinella martinezpicoi ranges from 214-21-3 12-14cm (within Zone N.8) and represents the first record of this species from the Indian Ocean.

FIGURE 7. Neogene range chart, Site 216/216A

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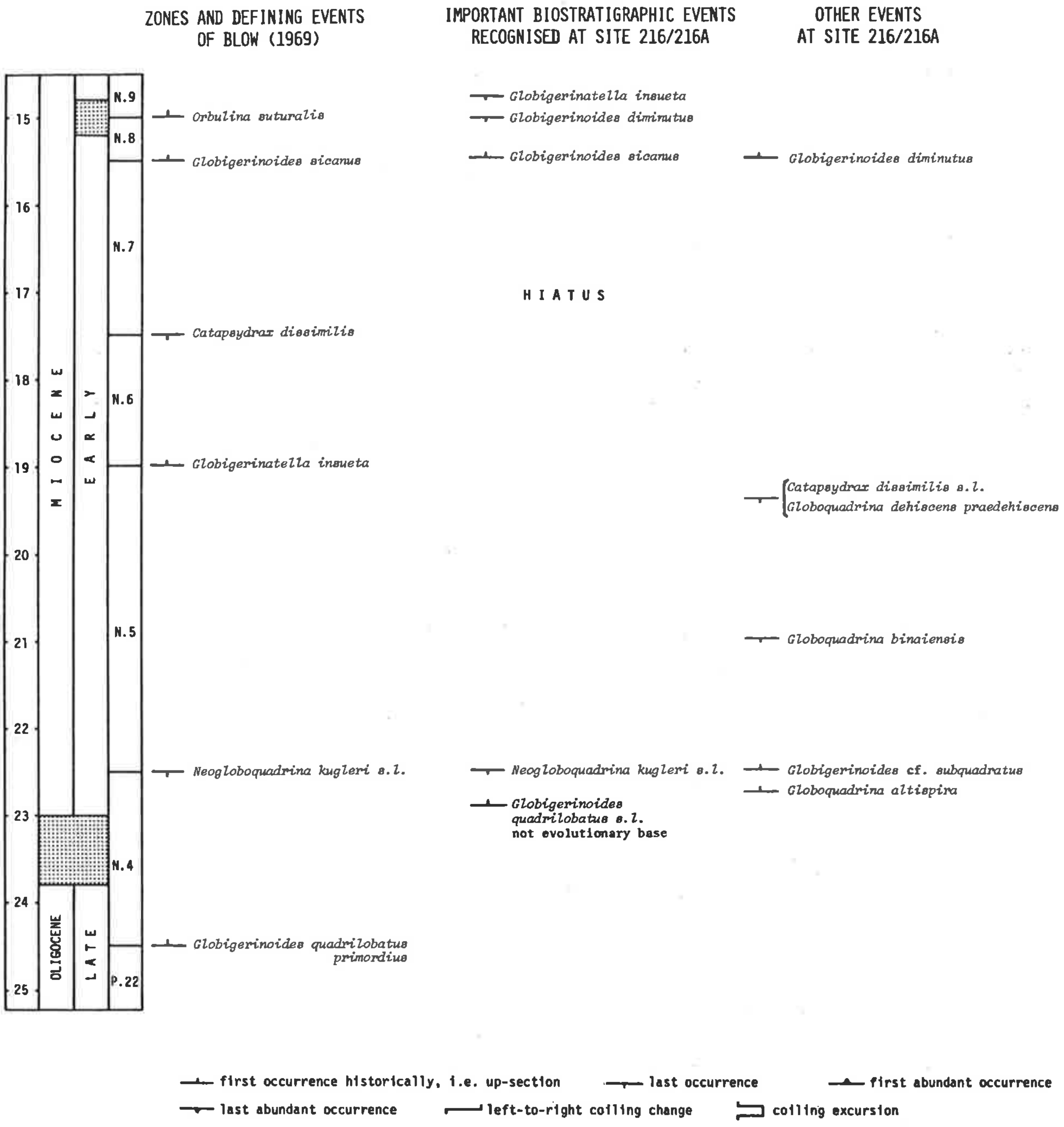

FIGURE 6. Early Miocene planktonic foraminiferal biostratigraphy, Site 216/216A.

The earliest occurrence of *Streptochilus latum* is recorded from early Zone N.5 representing a considerable downward extension of its range from within Zone N.16 as recorded by Brönnimann and Resig (1971).

Globigerinoides diminutus ranges from within Zone N.7 to early Zone N.9 becoming abundant only within intervals overlying Zone N.7 (Blow, 1969). Postuma (1971) reports an earlier appearance of *G. diminutus* from the base of his *Globigerinatella insueta* Zone (equivalent to the Zone N.5/N.6 boundary) and ranging into the lowermost part of his *Globorotalia peripheroronda* Zone correlated to just above the Zone N.8/N.9 boundary. In the Capricorn Basin, Queensland, *G. diminutus* ranges from the basal occurrence of *Globigerinoides sicanus* (basal Zone N.8) to just before the Zone N.8/N.9 boundary (Palmieri, 1975). A Zone N.9 disappearance occurs in Java where Kadar (1975) records an overlap in ranges of *G. diminutus* and *Orbulina suturalis*.

In Site 214 *Globigerinoides diminutus* is present in abundance and ranges from the base of Zone N.8 to just prior to the Zone N.8/N.9 boundary (Figure 3). The balance of evidence supports a correlation of the extinction of *G. diminutus* near the Early/Middle Miocene boundary. To its credit as a guide fossil *G. diminutus* is surprisingly solution-resistant since it is present in abundance in the later Early Miocene of Site 216A when other so-called solution-susceptible species of *Globigerinoides* and *Globigerinatella insueta* are either rare or absent.

SITE 216/216A

This discontinuously cored site contains poorly preserved assemblages of Early Miocene planktonic foraminifera. Significant biostratigraphic events are outlined on Figure 6 based upon the ranges of species documented on Figure 7.

Zones N.4 and N.5 (part) are present within cores 5 and 6 of Site 216 while Zone N.8 (part) is represented by core 6 of Site 216A. According to the site reports the base of core 6 of Site 216A is at the same depth as the top of core 5 of Site 216, yet Zones N.5 (part), N.6, N.7 and N.8 (part) are missing. This time-gap represents about 3.5 to 4 Ma using the time-scale of

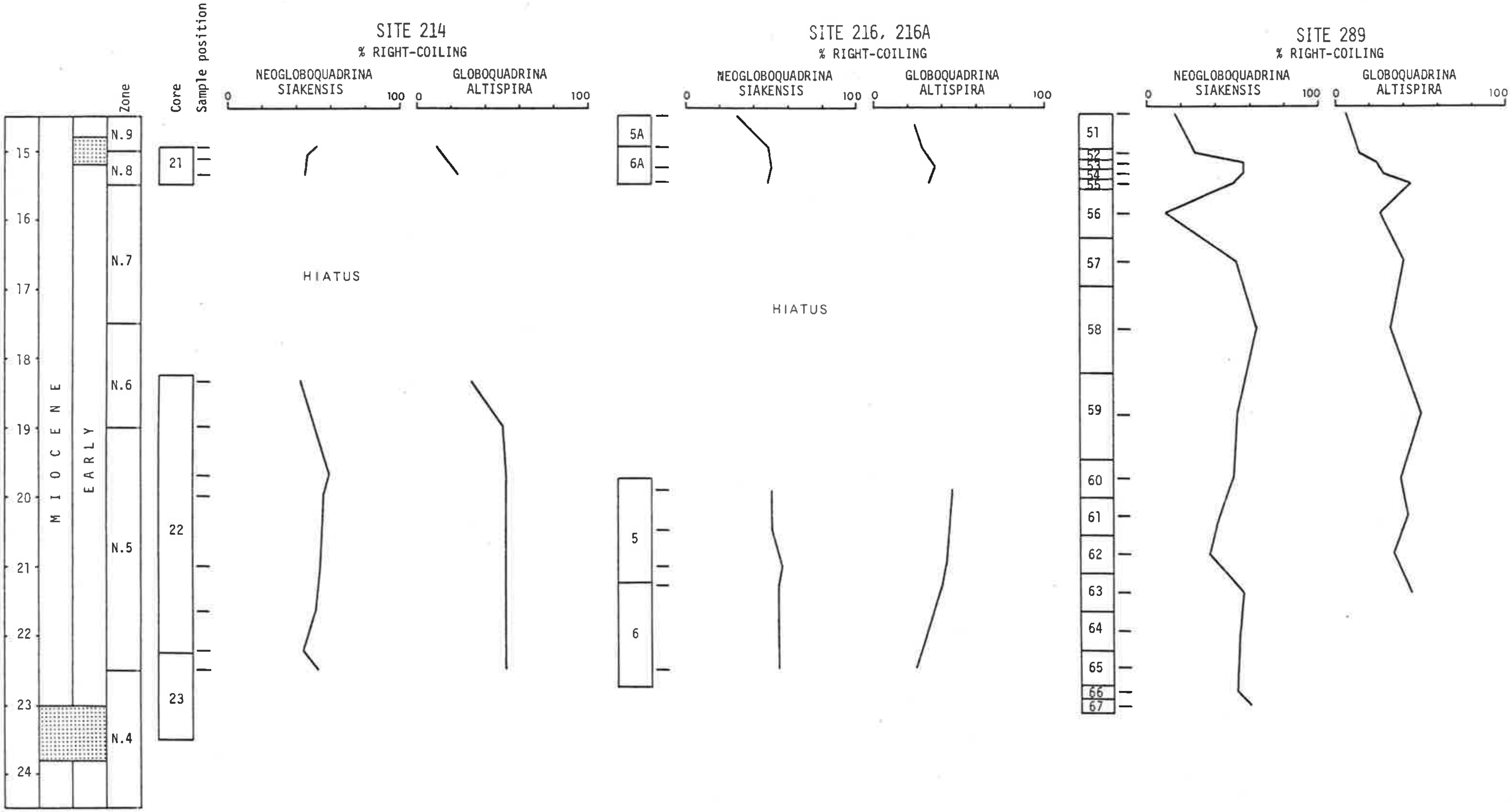

FIGURE 10. Early Miocene coiling trends of *Neogloboquadrina siakensis* and *Globoquadrina altispira* in D.S.D.P. Sites 214, 216/216A and 289.

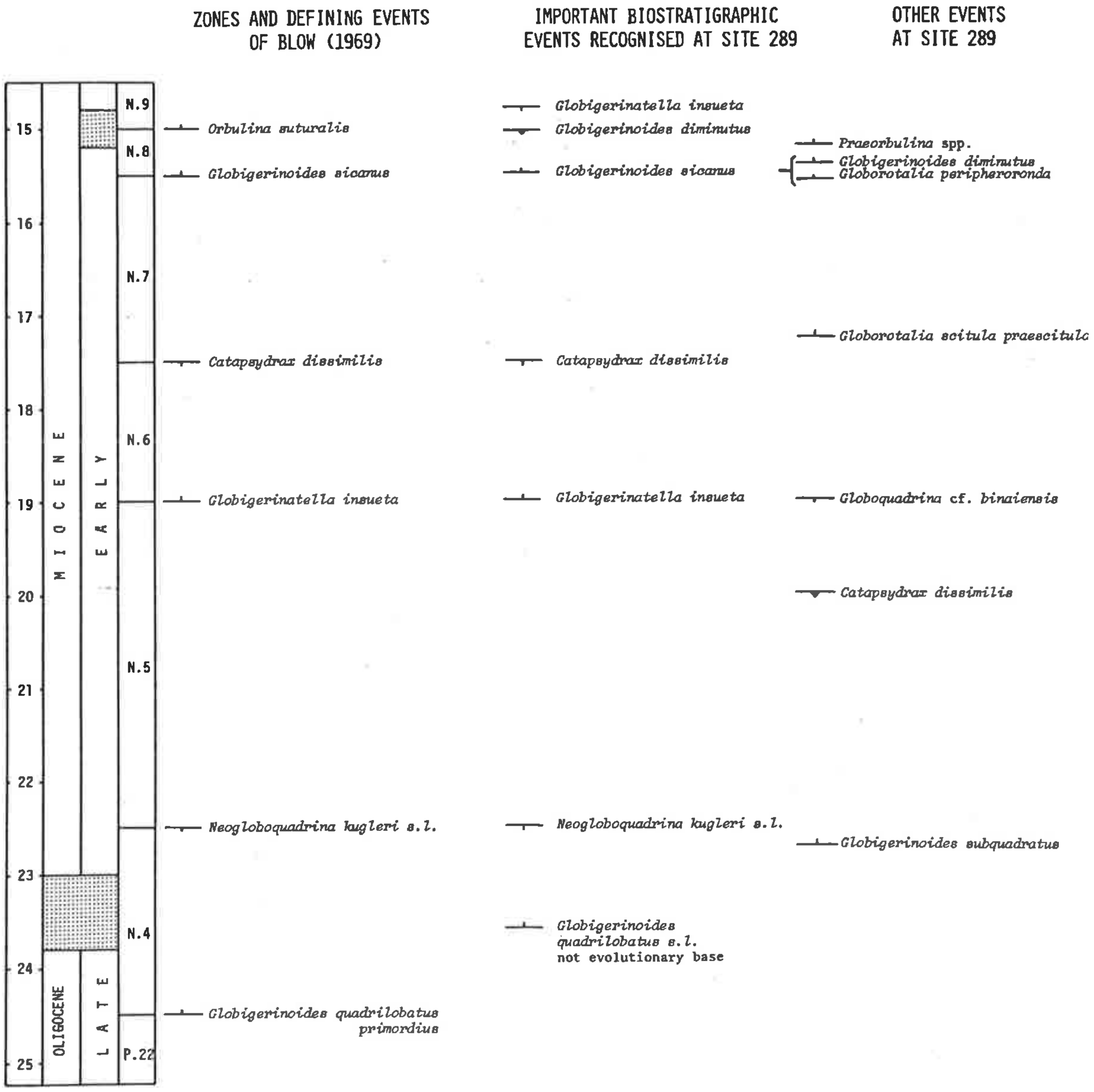

FIGURE 9. Early Miocene planktonic foraminiferal biostratigraphy, Site 289.

FIGURE 8. Early and Middle Miocene range chart, Site 289.

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Van Couvering and Berggren (1977) and matches the middle Early Miocene 'hiatus' at Site 214 as well as the generally condensed interval from Zone N.4 to Zone N.8 in most low- and mid-latitude Indian Ocean sites (Vincent, 1977).

Other biostratigraphically significant aspects of this site includes the overlap in range of *Globigerinoides subquadratus* and *Neogloboquadrina kugleri s.l.*, as noted also in Site 214, and the persistence of *Globoquadrina binaiensis* and *Globoquadrina dehiscens praedehiscens* to within Zone N.5.

SITE 289

The Early Miocene of Site 289 is represented by the interval between cores 74 and 52. Continuous coring recovered moderately preserved assemblages of planktonic foraminifera representing uninterrupted sedimentation. The occurrence of species identified versus samples examined is documented on Figure 8. All of Blow's (1969) Early Miocene zones are recognised. The more important biostratigraphic events (Figure 9) include the following: *Globigerinoides subquadratus* ranges from within Zone 'N.4' as noted in Sites 214 and 216; although *Catapsydrax dissimilis* ranges above *Globigerinatella insueta* it rapidly decreases in abundance within the upper part of Zone N.5 matching its later Zone N.5 disappearance in Site 214; the disappearance of *Globoquadrina* cf. *binaiensis* at the basal occurrence of *Globigerinatella insueta* confirms its value as a guide to the Zone N.5/N.6 boundary and the range of *Globigerinoides diminutus* is confined to Zone N.8 as noted in Sites 214 and 216A.

EARLY MIOCENE COILING TRENDS

The Early Miocene coiling histories of *Neogloboquadrina siakensis* and *Globoquadrina altispira* (Figure 10) are examined to determine their biostratigraphic potential. The significant changes in coiling direction of these species within latest Early Miocene times, as outlined by Bolli (1971) suggests a means of increasing resolution in this interval particularly as these species often dominate Early Miocene deep-sea assemblages that have been subjected to intense calcite-solution with consequent removal of some of the less solution-resistant index species.

Bolli (1971) shows *G. altispira* gradually changing upsection from randomly coiled to dominantly left-coiled over the interval from the base of *Praeorbulina* spp. (within Zone N.8) to near the extinction of *Globorotalia fohsi* (within Zone N.13). At Site 289, with the most 'complete' Early-Middle Miocene record, this trend occurs within the limits of Zone N.8 (Figure 10) and so over a much shorter time interval. In spite of the poor stratigraphic record at Sites 214 and 216A some support for this rapid change can be inferred from within Zone N.8 (Figure 10). The rapidity of this coiling transition within Zone N.8 of such a solution-resistant species has obvious biostratigraphic significance sufficient to encourage further study in other sections.

Neogloboquadrina siakensis changes rapidly from randomly coiled (during the Oligocene and Early Miocene) to dominantly left-coiled (Middle Miocene to mid-Pliocene times) the transition occurring during the interval of the *Globorotalia fohsi barisanensis* Zone (Bolli, 1971). This should occur from within Zone N.9 according to the zonal correlation of Blow (1969), however at Site 289 this random to left-coiling trend commences earlier within Zone N.8 (Figure 10). Site 216A (Figure 10) presents a more complicated picture of random coiling up till latest Zone N.11 while the trend at Site 214 remains randomly coiled throughout the Early Miocene. The coiling history of this species is not as clear as implied by Bolli (1971) and no improvements to Early Miocene biostratigraphic resolution using these coiling trends are suggested. The areal and stratigraphic significance of a left-coiled *Neogloboquadrina siakensis* peak within Zone N.7 at Site 289 is unknown at this stage, this interval being absent at Sites 214 and 216/216A.

MIDDLE MIOCENE

Sites 214, 216A and 289 were continuously cored over the Middle Miocene while Site 216 was discontinuously cored. Preservation is usually poor with assemblages dominated by robust species such as *Globoquadrina altispira*,

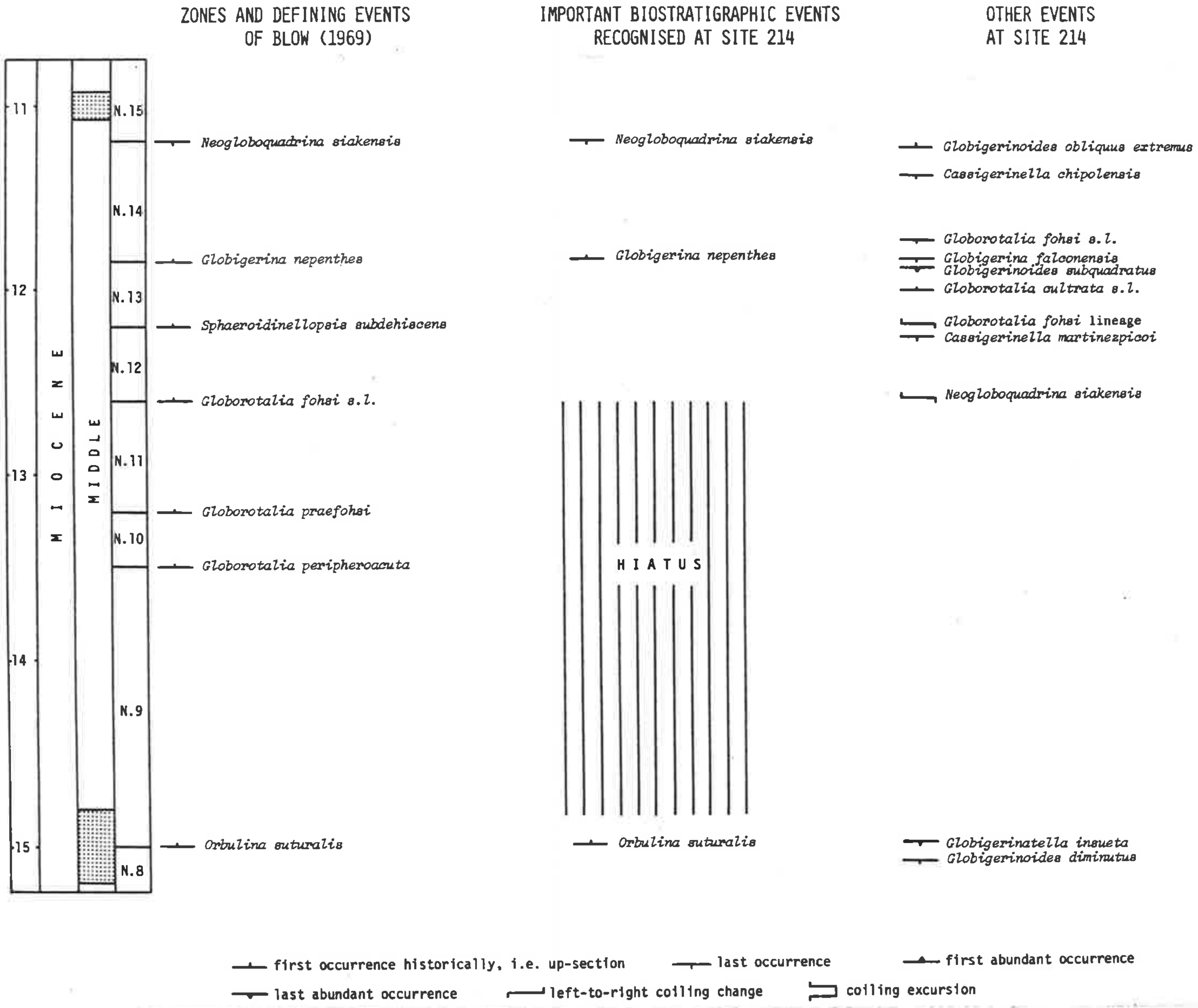

FIGURE 12. Middle Miocene planktonic foraminiferal biostratigraphy, Site 214.

FIGURE 11. Middle and Late Miocene range chart, Site 214.

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Globoquadrina venezuelana and *Neogloboquadrina siakensis*. Specimens of the biostratigraphically important *Globorotalia peripheroronda* - *fohsi* lineage generally show signs of lamellar exfoliation and wall-surface etching, features attributed to solution by carbonate-poor waters.

The evolutionary appearance of *Orbulina suturalis*, the *Orbulina* Datum, defines the boundary between Zones N.8 and N.9 of Blow (1969) and correlates with the Early/Middle Miocene boundary. The evolutionary development of *Globorotalia fohsi* from *Globorotalia peripheroronda* provides the basis of several post-*Orbulina* Datum zones. Differing morphological groupings for members of this lineage results in the non-synchroneity of two widely used schemes as outlined by Blow (1969) and Stainforth *et al.* (1975). Blow's scheme is used here for this morphological continuum.

SITE 214

The occurrences of species recognised and samples examined for the Site 214 Middle Miocene are shown on Figure 11. The Middle Miocene zones and defining events of Blow (1969) recognised at this site are shown on Figure 12.

The lowest occurrence of *Orbulina suturalis* is within sample 214-21-1 Top and is associated with *Globigerinatella insueta* and *Praeorbulina glomerosa s.l.* which are known to range to within the early part of Zone N.9 and to the basal part of Zone N.9 respectively (Blow 1969). The Early/Middle Miocene boundary is drawn at this level and is bracketed below, by the disappearance of *Globigerinoides diminutus*, and above by the disappearance of *Globigerinatella insueta*.

Contamination of the top three sections of core 21 is indicated by the concurrence of *Globorotalia peripheroacuta* (rare), *Globorotalia fohsi s.s.* (rare), *Sphaeroidinellopsis subdehiscens* (rare), *Globigerinoides sicanus* and *Globigerinatella insueta*. Even if the occurrence of *Orbulina suturalis* in 214-21-1 Top is regarded as a contaminant, the top of core 21 has an age restricted to later Zone N.8 to basal Zone N.9 as indicated by the restricted ranges of *Globigerinatella insueta, Globigerinoides sicanus* and *Praeorbulina glomerosa s.s.*

The next stratigraphically younger sample, 214-20-cc, contains *Globorotalia peripheroronda, peripheroacuta, praefohsi, fohsi s.s.* and *Sphaeroidinellopsis subdehiscens.* The overlap in ranges of *S. subdehiscens* and *G. peripheroronda*, in particular, suggests either that a re-appraisal of stratigraphic ranges is required or that downhole contamination has occurred since the ranges of these two species, as recorded by Blow (1969), do not overlap.

Since *Globorotalia fohsi* is present as a contaminant in the Early Miocene core 21 and there is some evidence that core 20 may also be contaminated by Zone N.12-N.13 material, the discussion in the section on Middle Miocene coiling trends outlines evidence in support of an age assignment of basal Zone N.12 for the base of core 20. This assessment of the age of the top of core 21 and the base of core 20 indicates that Zones N.9 (part), N.10, N.11 and N.12 (part) are missing. The time span represented by this hiatus is approximately 1.5 to 2 Ma. Similarly, because the Zone N.13 index species *Sphaeroidinellopsis subdehiscens* occurs within Zone N.8, the extinction of *Globorotalia peripheroacuta* in sample 214-20-1 6-8cm is used to approximate the Zone N.12/N.13 boundary. Blow (1969) records this species as ranging to within Zone N.12, (?) Zone N.13.

The evolution of *Globigerina nepenthes* from *Globigerina druryi*, defining the base of Zone N.14, is placed at 214-18-cc, notwithstanding the transitional nature of this event. *Neogloboquadrina siakensis* is last recorded in 214-17-cc enabling Zones N.14 and N.15 to be recognised as defined. The Middle/Late Miocene boundary is placed within Zone N.15 as suggested by Blow (1969).

Other biostratigraphic events of significance. At this site *Cassigerinella chipolensis* ranges until the middle of Zone N.14, although in very small numbers. A similar overlap of *C. chipolensis* and *Globigerina nepenthes* is indicated by Postuma (1971) while Blow (1969) records

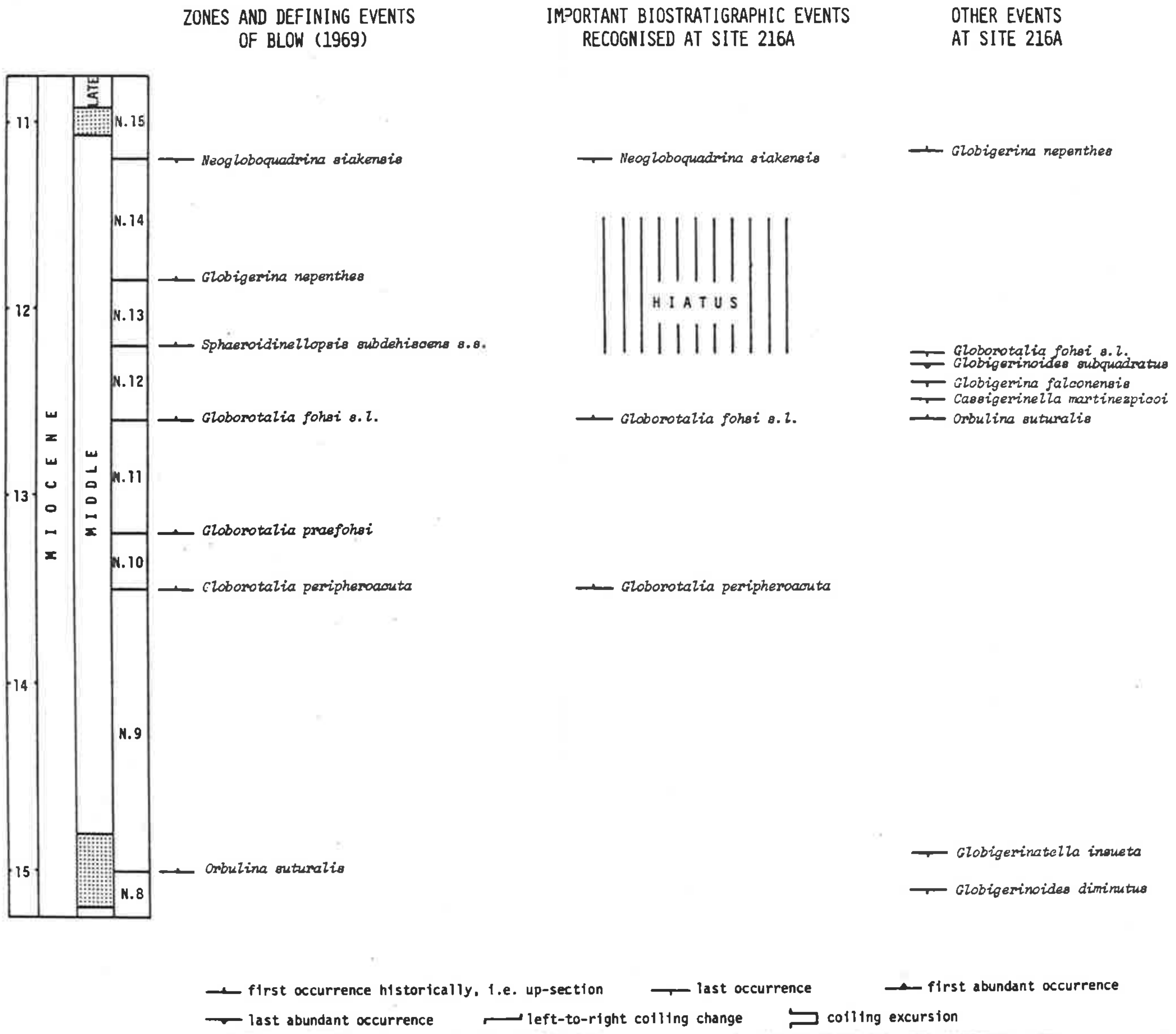

FIGURE 13. Middle Miocene planktonic foraminiferal biostratigraphy, Site 216A.

C. chipolensis as ranging to within later Zone N.13, (?) early Zone N.14.

In the Indian Ocean the highest occurrence of *Globorotalia fohsi s.l.* overlaps the lowest occurrence of *Globigerina nepenthes* in sample 214-18-cc contrary to the reports of McGowran (1974), Berggren *et al.* (1974) and Vincent (1977). The relationship of these events to other planktonic microfossil events and their biostratigraphic significance, is discussed at greater length in the following biostratigraphic conclusions chapter when evidence from Sites 216/216A and 289 is discussed.

The extinction of *Globorotalia peripheroronda* is cited to occur within Zone N.11 (?N.12) by Blow (1969) and within Zone N.10 (Postuma, 1971). At Site 214 *G. peripheroronda* disappears above sample 214-20-3 5-7cm, supporting a range that extends to at least Zone N.12.

At Site 214 the topmost occurrence of abundant *Globigerinoides subquadratus* is within sample 214-19-1 94-96cm, that is, just below the Zone N.13/N.14 boundary (Figure 12). Very rare specimens referable to *G.* cf. *subquadratus* range into Zone N.16. The last occurrence of *Globigerina falconensis* coincides with the last occurrence of *G. fohsi s.l.*, just above the *G. nepenthes* Datum.

The first, upsection occurrence of *Globigerinoides obliquus extremus* is used by Takayanagi and Oda (1976) to approximate the Zone N.15/N.16 boundary in Site 317B and by D'Onofrio *et al.* (1975) to recognise a zone younger than Zone N.16 in the Mediterranean region; which would agree with its range reported by Blow (1969) as early Zone N.16. However, in Site 214 *G. obliquus extremus* ranges from within Zone N.14.

SITE 216A

Selected planktonic foraminiferal events recognised at this site are shown on Figure 13. Ranges of species and samples examined are documented on Figure 7.

The first occurrence of (rare) *Orbulina suturalis* is above the base of *Globorotalia peripheroacuta* so that the Zone N.8/N.9 boundary cannot be recognised as defined. Preservational difficulties prevent recognition of the

Globorotalia peripheroacuta-praefohsi transition and therefore the Zone N.10/N.11 boundary. In the absence of *Orbulina suturalis* the Early/Middle Miocene boundary is placed at the level between the extinction horizons of *Globigerinoides diminutus* and *Globigerinatella insueta*, that is, between cores 5 and 6. This relationship of events is observed at Site 214 (see Figure 12). Berggren *et al.* (1974) record an overlap in ranges of *"Hastigerinella" bermudezi* and *Globigerinatella insueta* in the basal part of core 5 and topmost part of core 6 (Site 216A). The overlap of these species is regarded as confirmation of the placement of the Early/Middle Miocene boundary between these two cores.

Zone N.13 cannot be recognised as defined. The early occurrence of *Sphaeroidinellopsis subdehiscens* within sample 216A-5-2 6-8cm may require either an earlier extension of its range or a review of my identification. *Globigerina nepenthes* ranges from above the extinction level of *Neogloboquadrina siakensis* so that Zone N.14 is not recognised as defined. However, the presence of *N. siakensis, Globorotalia cultrata s.l.* and the absence of *Globorotalia fohsi s.l.*, in lower core 3, correlates with Zone N.14 at Site 214 and 289. Quantitative evidence discussed later indicates lower core 3 correlates with the upper part of Zone N.14. Zone N.15 is represented by the upper part of core 3.

The geographic range of *Cassigerinella martinezpicoi* is extended to Site 216A where it occurs within assemblages dated as Zone N.12. This species is also present in a sample of the type sample of the *Globorotalia fohsi barisanensis* Zone of Bolli (1957) from the M.F. Glaessner, University of Adelaide, micropalaeontological collection.

SITE 216

This site contains one core of Middle Miocene age. The distribution of taxa and samples from this core 4 is shown on Figure 7. This core contains rare *Globigerina nepenthes* which are confined to the top two core-sections and are associated with *Neogloboquadrina siakensis* indicating an age of Zone N.14. Lower in the core *Globorotalia fohsi* disappears at the

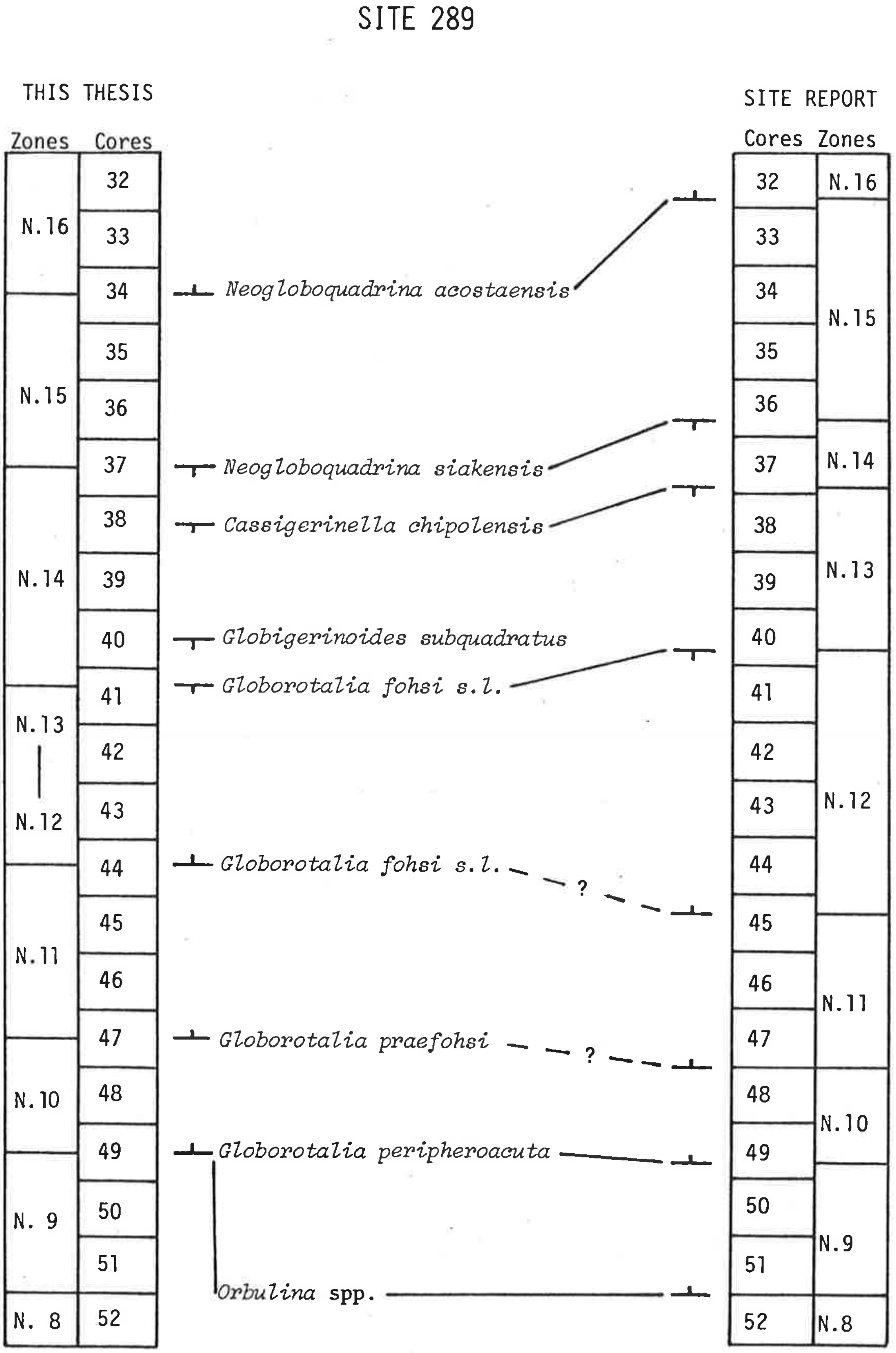

FIGURE 15. Comparison of Deep Sea Drilling Project Site 289, Ontong Java Plateau, Middle Miocene zonal assessment in the Site report (Andrews *et al.* 1975) and this thesis.

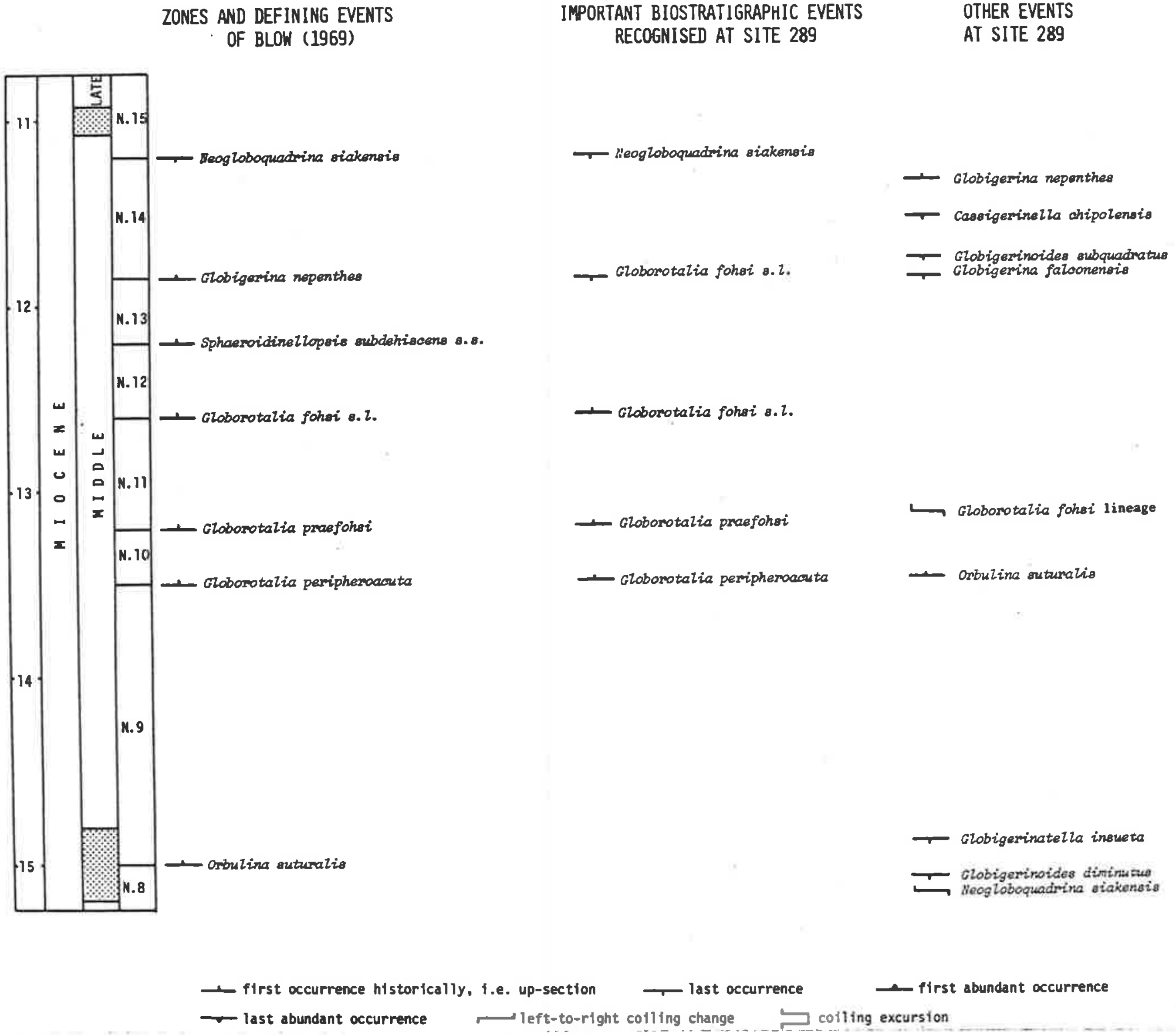

FIGURE 14. Middle Miocene planktonic foraminiferal biostratigraphy, Site 289.

same level as the abundance top of *Globigerinoides subquadratus*. Correlation of these and quantitative events, outlined in the following section on Middle Miocene coiling trends, with similar events at Site 214 indicate that base *G. nepenthes* (at Site 216) occurs within the upper part of Zone N.14 and that the extinction of *G. fohsi* more closely approximates the Zone N.13/N.14 boundary. The citation of *G. nepenthes* throughout this core by Vincent (1977) is not substantiated by either this study or her original data source of Berggren *et al.* (1974).

SITE 289

The ranges of all planktonic foraminifera found in the Middle Miocene of this site are documented on Figure 8. Biostratigraphically significant events are shown on Figure 14.

The Middle Miocene Zones N.10, N.11 and N.15 are recognised as defined by Blow (1969). Zones N.9, N.13 and N.14 could not be recognised as defined due to the rarity or absence of the zonal index species. *Globigerina nepenthes*, the evolutionary appearance of which defines the Zone N.13/N.14 boundary, occurs only very rarely in the later part of the Middle Miocene. Even though it overlaps the earliest occurrence of *Neogloboquadrina siakensis* its first, upsection, occurrence is not its evolutionary appearance and is shown on page 59 not to be synchronous with the evolutionary base of *G. nepenthes* in Site 214. The occurrence of *Sphaeroidinellopsis subdehiscens* in Zone N.10 (core 49) is anomalous in view of its range reported by Blow (1969). Specimens are typically poorly preserved and the possibility of identification confusion cannot be totally ruled out. However, at face value this range supports its Zone N.10-N.11 occurrence in Site 216A, the Zone N.8 occurrence in Site 214 being conservatively regarded as contamination.

The lowest occurrence of *Orbulina* spp. at Site 289 is reported by Andrews *et al.* (1975) to lie at the base of core 51 (Figure 15), however this taxon was not found in these samples below core 49 despite an intensive search. In the absence of *Orbulina* spp. the Zone N.8/N.9 boundary, and therefore the

Early/Middle Miocene boundary, is approximated by the interval between the successive disappearances of *Globigerinoides diminutus* (core 52) and *Globigerinatella insueta* (core 51). The basis for this correlation is outlined in the discussion of the Site 214 and 216A Middle Miocene.

The initial planktonic foraminiferal biostratigraphic assessment of the Site 289 Neogene by Andrews *et al.* (1975) report biostratigraphic events with greater resolution than is possible with my sample density. For the Middle Miocene they recognise Zones N.9 to N.16 inclusively, identifying the foraminiferal events except those delimiting the Zone N.10/N.11 and N.11/N.12 boundaries. They use the zonal scheme of Blow (1969) for this interval and it is therefore assumed that the Zone N.10/N.11 boundary is located at the evolutionary appearance of *Globorotalia praefohsi* and the Zone N.11/N.12 boundary at the evolutionary appearance of *Globorotalia fohsi s.s.*

On this basis the sequence of foraminiferal events established by Andrews *et al.* (1975) is confirmed by this study and is outlined on Figure 15. Minor differences are attributed to sample density with the most obvious difference being the base of *Neogloboquadrina acostaensis s.s.* which they place in lower core 32 and I record as low as core 34. This inconsistency has yet to be resolved.

Significant differences, however, involve the age assessment of several important events. Firstly, the extinction of *Globorotalia fohsi s.l.* (and *Globigerina falconensis*) correlates with the Zone N.13/N.14 boundary not with the N.12/N.13 boundary as indicated by Andrews *et al.* (1975) and secondly, *Cassigerinella chipolensis* ranges to within Zone N.14 and not to the base of that zone. The basis of my assessment involves correlation of this sequence of events, together with quantitative evidence (to be outlined below), with Sites 214 and 216A. This suggests that although *Globigerina nepenthes* overlaps *Neogloboquadrina siakensis* its basal (non-evolutionary occurrence) is of later Zone N.14 age.

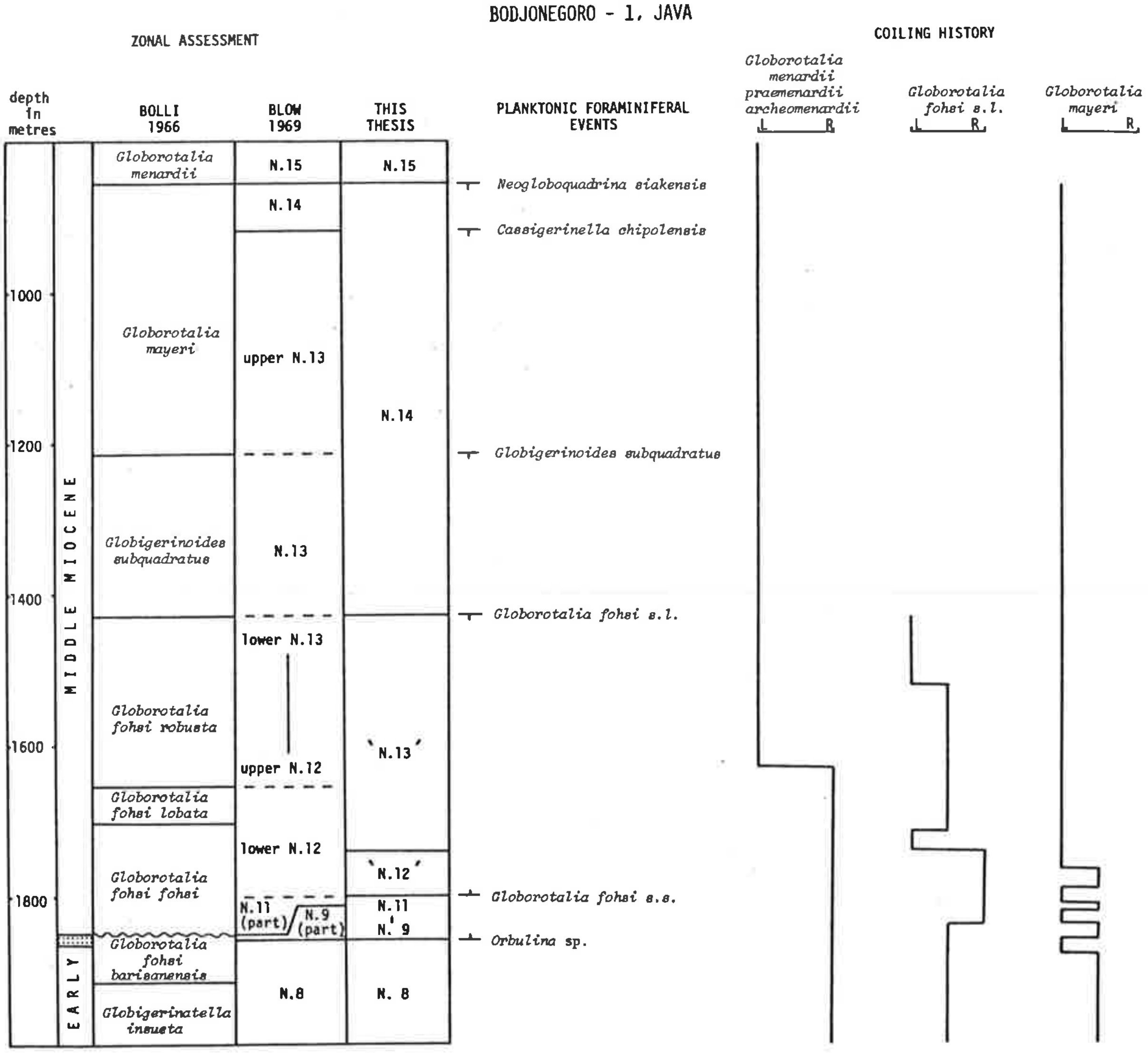

FIGURE 17. Assessment of the Middle Miocene planktonic foraminiferal biostratigraphy of Bodjonegoro-1, Java (after Bolli, 1966b), by Bolli (1966b), Blow (1969) and this thesis.

FIGURE 16. Middle Miocene coiling trends of *Globorotalia cultrata s.l.*, *Globorotalia fohsi* lineage and *Neogloboquadrina siakensis* in Sites 214, 216/216A and 289.

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MIDDLE MIOCENE COILING TRENDS

The coiling histories of *Globorotalia cultrata s.l.*, *Globorotalia fohsi s.l.*, and *Neogloboquadrina siakensis* at Sites 214, 216/216A and 289 are compared with those in the Java section of Bolli (1966b). These coiling histories in the DSDP sites and Java are shown on Figures 16 and 17 respectively.

Trends in the *N. siakensis* group at Site 214 show some similarity to those of Bodjonegoro-1, Java. In both sections the group is dominantly left-coiled (stratigraphically downwards from its extinction horizon) becoming randomly coiled within the range of *Globorotalia fohsi s.s.* It is unlikely that this would result from down-hole contamination since such contamination would dampen rather than accentuate such a trend as all younger *N. siakensis* are at least 80% left-coiled. That is, a dominantly left-coiled succession of *N. siakensis* occurs from within and above Zone N.12. In Site 214 *N. siakensis* is dominantly left-coiled throughout cores 18 to 20, with a slight shift towards random coiling in the lower part of core 20. *N. siakensis* is randomly coiled in core 21, assigned to lower part of Zone N.9 and N.8. The absence of randomly-coiled *Neogloboquadrina siakensis* at the bottom of core 20 (Site 214) is cited as additional evidence for an age assessment, of this core, of within Zone N.12.

At Site 216A *Neogloboquadrina siakensis* is randomly coiled within Zone N.8 passing upwards to an interval of fluctuating trends within Zones N.9, N.10-N.11 before becoming dominantly left-coiled within cores 4 and 3. This Zone N.11-N.12 trend is similar to the Zone N.11 (part) - lower N.12 trend in Bodjonegoro-1 (Figure 17) thereby supporting the Zone N.12 age for core 20 in Site 214.

At Site 289 the upsection trend from random to dominantly left-coiled *Neogloboquadrina siakensis* takes place across the Early/Middle Miocene boundary and is completed in the later part of Zone N.9. Therefore the trend in *N. siakensis* from randomly- to dominantly left-coiled is allochronous occurring in the lower part of Zone N.12 in the Indian Ocean and across the

Zone N.8/N.9 boundary in the Pacific Ocean.

The coiling history of the *Globorotalia fohsi* lineage at Site 214 shows trends similar to those documented in Bodjonegoro-1 by Bolli (1966b) (Figure 17) where the first downhole occurrence of dominantly right coiled *G. fohsi* occurs in his *Globorotalia fohsi fohsi* Zone which is correlated to within Zone N.12 by Blow (1969). *G. fohsi* then reverts downhole to random coiling during the interval represented by a hiatus in Bolli's section, where Zone N.9 (part), N.10, N.11 and N.12 (part) are missing (Blow, 1969). At Site 214 *Globorotalia fohsi* is dominantly left-coiled within core 19 becoming dominantly right-coiled across the core 19/20 boundary. As in the Java section, this coiling event occurs within assemblages containing fully-keeled members of *G. fohsi*, and therefore within Zone N.12-N.13. Towards the base of core 20 there is a trend towards random-coiling.

The *G. fohsi* lineage in Site 216A shows an upsection coiling trend from random to mainly right-coiled in cores 5 and 4 and to that extent is similar to the trend observed in core 20 of Site 214. No rapid change towards left-coiling is observed as anticipated from observations from Site 214 and Bodjonegoro-1. Such a trend in Site 216A suggests that either these trends are not synchronous or that if synchronous the difference is due to a hiatus that spans the interval of time represented by parts of cores 19 and 20 in Site 214. Evidence discussed from Site 216 is critical to this problem and supports the suggestion that there is a hiatus (of(?) mechanical origin) in the Middle Miocene of Site 216A.

In core 4, Site 216, *G. fohsi* occurs in very small numbers (1 to 11 specimens per sample all of which are left-coiled) below a right-coiling excursion of *Globorotalia cultrata s.l.* A similar *G. cultrata s.l.* excursion lies within the lower part of Zone N.14 at Site 214.

The *Globorotalia fohsi* lineage at Site 289 shows the dominantly left-coiling to right-coiling downsection trend (as noted in Site 214 and Bodjonegoro-1), the transition occurring between cores 46 and 47 (Figure 16) below the base of *G. fohsi s.l.* and towards the base of Zone N.11. Therefore the timing of this coiling event in the Indian and Pacific Oceans is not synchronous.

As mentioned earlier the coiling history of *Globorotalia cultrata s.l.* shows a distinct right-coiling excursion within the lower part of Zone N.14 at Site 214 (Figure 16). *G. cultrata s.l.* remains dominantly left-coiled from upper Zone N.14 to the Zone N.16/N.17 boundary. Noticeably at Site 216A the pre-Zone N.15 occurrences of *G. cultrata s.l.* are dominantly left-coiled while core 4 of Site 216 and Site 289 show the *G. cultrata s.l.* excursion just above the extinction of *Globorotalia fohsi s.l.* and within the range of *Neogloboquadrina siakensis*. This trend is not documented in Bodjonegoro-1.

Thus the sequence of events at Site 214 provide a standard for assessing Sites 216/216A, 289, and Bodjonegoro-1 (Figure 17). At Site 214 the sequence of suggested biostratigraphically significant events is as follows: a random to dominantly left-coiled transition in the *Globorotalia fohsi* lineage occurs within the Zone N.12-N.13 interval; the extinction of (dominantly left-coiled) *G. fohsi s.l.* and *Globigerina falconensis* overlaps the earliest occurrence of *Globigerina nepenthes*; the lower part of Zone N.14 is characterised by a short-lived right-coiling excursion of *Globorotalia cultrata s.l.* The *G. fohsi s.l.* coiling transition is used to informally subdivide the Zone N.12-N.13 interval into Zone 'N.12' and Zone 'N.13'. These zones are valid only in the tropical Indian Ocean, the same quantitative event occurring significantly earlier (in Zone N.11) in the Pacific Ocean.

Accordingly, by comparison with Site 214, a hiatus is recognised between cores 3 and 4 of Site 216A, the missing time-interval being represented by core 19 (part) and core 20 (part) of Site 214 and of about 0.75 Ma duration on the Van Couvering and Berggren (1977) time-scale. Cores 3 and 4 of Site 216A are reported by Von der Borch *et al.* (1974) as being continuously cored yet core 4 of Site 216A contains much of the missing interval at Site 216A. This evidence reinforces the statements of Moore (1972) concerning the 'completeness' of DSDP continuous coring and underscores the difficulty in assessing the origin of the between-core hiatus's within the Early and Middle Miocene of Site 214 and 216/216A.

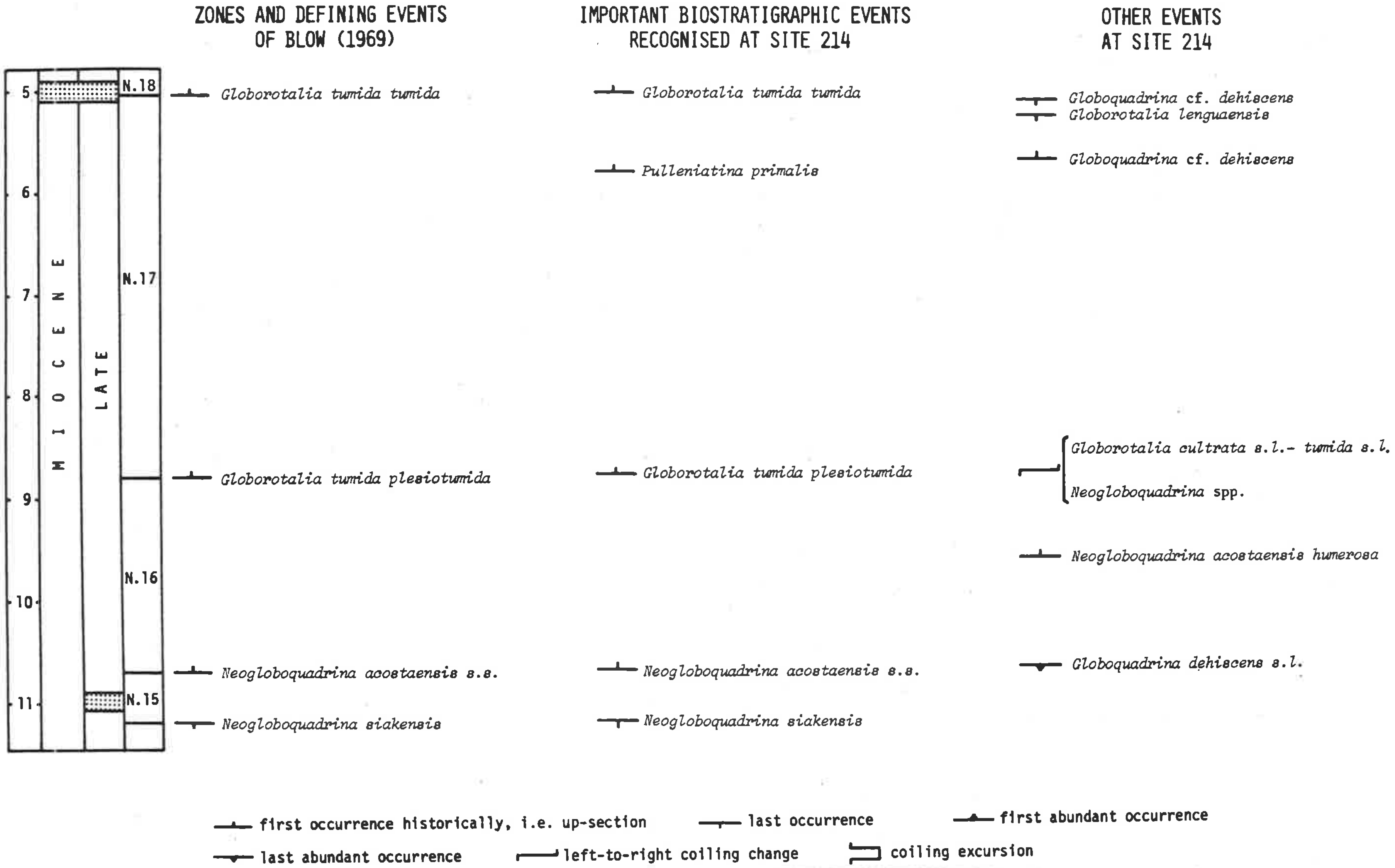

FIGURE 18. Late Miocene planktonic foraminiferal biostratigraphy, Site 214.

LATE MIOCENE

Correlation of Late Miocene sediments is considerably less certain than for the Middle Miocene and Pliocene. The three planktonic foraminiferal zones erected by Blow (1969) provide poor resolution for this 6 m.y. interval. Regression on the margins of Indo-Pacific and other land-masses, with consequent lack of sedimentary record (Adams *et al.* 1977) is typical, while palaeotemperature trends show a distinct post-later Middle Miocene cooling, culminating in the New Zealand Kapitean regression/cooling episode and the Mediterranean Messinian phase of evaporite deposition.

The Late Miocene is, therefore, an interval of distinct climatic change. Because of the frustrating lack of an adequate chronological framework for the assessment of this interval, the present investigation sought fresh evidence for biostratigraphic markers.

SITE 214

The ranges of planktonic foraminifera within the Late Miocene at Site 214 are shown on Figure 11. The Middle/Late Miocene boundary is placed within Zone N.15 as suggested by Blow (1969). The extinction of *Neogloboquadrina siakensis* marks the base of Zone N.15 and occurs near the base of core 17 while the first appearance of *Neogloboquadrina acostaensis*, within latest core 17, marks the base of Zone N.16. The successional first appearances of *N. acostaensis s.s.*, *N. acostaensis humerosa*, *Globorotalia tumida plesiotumida*, *Sphaeroidinellopsis subdehiscens paenedehiscens*, *Pulleniatina primalis* and *Globorotalia tumida s.s.* are in the same relative chronological order as indicated by Blow (1969) and permit recognition of his Late Miocene zones. Figure 18 outlines these Late Miocene zones and events at Site 214.

An important refinement to Late Miocene planktonic foraminiferal biostratigraphy is marked by the evolutionary development of *Pulleniatina primalis* from *Neogloboquadrina acostaensis* as discussed by Banner and Blow (1967). This transition is observable at Site 214 and occurs immediately above a left-coiling excursion of *N. acostaensis*; an interesting phenomenon

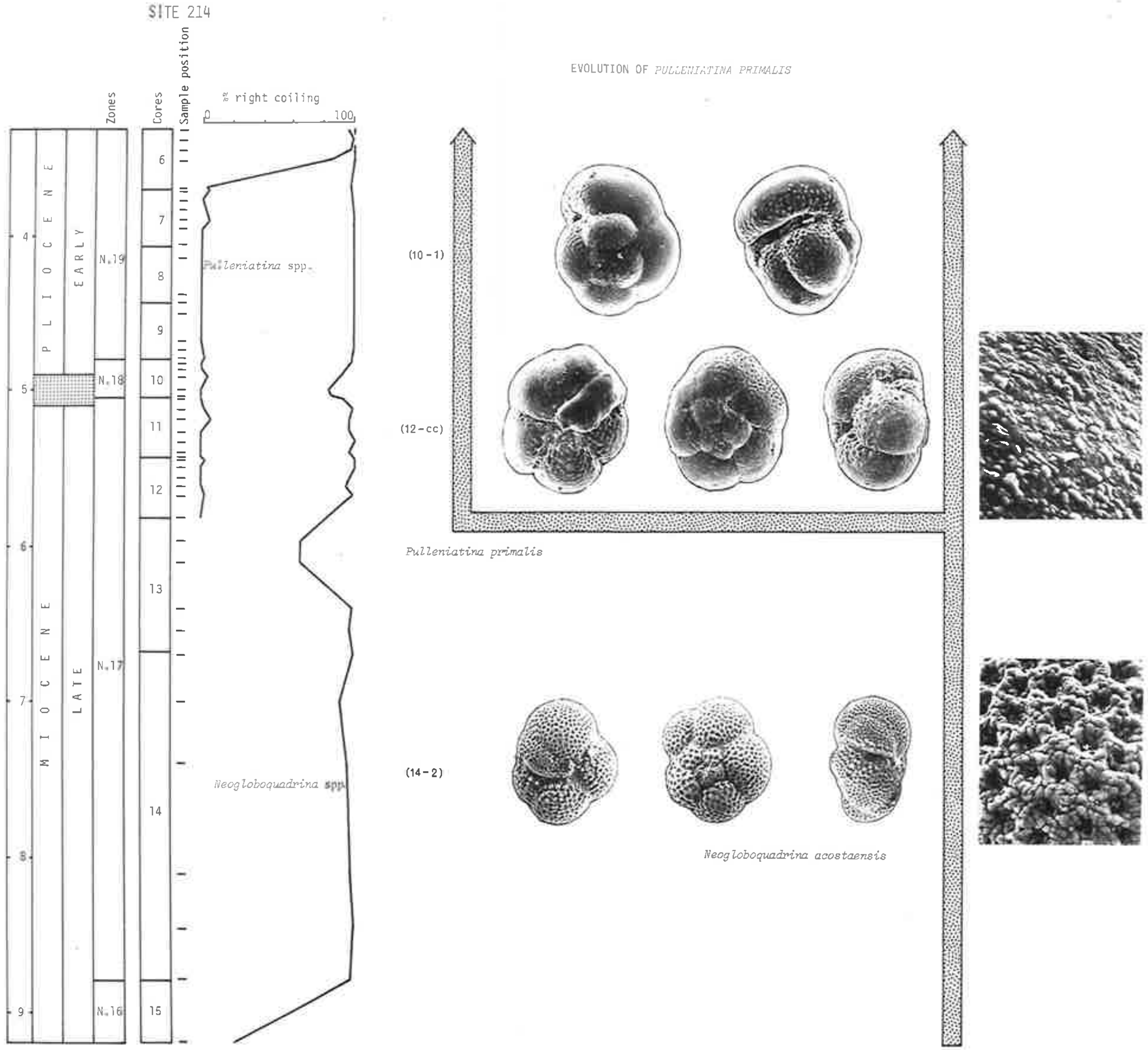

FIGURE 19. Evolutionary development of *Pulleniatina primalis* from *Neogloboquadrina acostaensis* in the Late Miocene of Site 214, including Late Miocene and Early Pliocene coiling trends of *Pulleniatina* spp. and *Neogloboquadrina* spp.

since the earliest *P. primalis* specimens are dominantly left-coiling and are, in effect, a left-coiling cancellate walled *acostaensis* with a microperforate 'skin' (see Figure 19). The stratigraphic relationship between coiling trends (and morphological development at Site 214) is shown by Saito *et al.* (1975) to occur in the Equatorial Pacific deep-sea core RC12-66, within the basal normal magnetic event of Palaeomagnetic Epoch 5, dated at 5.8 Ma.

Biostratigraphic significance of Late Miocene *Globoquadrina dehiscens* and *Globoquadrina venezuelana*. The disappearance of *Globoquadrina dehiscens* is reported to be extremely variable, ranging to the mid-Late Miocene (Bolli, 1957; 1966b) or as high as the Early Pliocene (Kennett and Srinivasan, 1975). Much of this evidence is conveniently summarised by Vincent (1977). The biostratigraphic significance attached to the last occurrence of *G. dehiscens* is also variable. That is, this event is regarded as diachronous within New Zealand (Kennett and Watkins, 1974) and in the North Pacific (Vincent, 1975). On the other hand the disappearance of *G. dehiscens* is regarded with importance as a guide to the Miocene/Pliocene boundary in the Atlantic Ocean (Berggren, 1973; 1977b).

At Site 214 the range of *Globoquadrina dehiscens* morphotypes is markedly disjunct, ranging, in abundance, to within Zone N.16, then 'locally disappearing' only to reappear (rarely) within the later part of Zone N.17 before its final occurrence immediately prior to the evolutionary appearance of *Globorotalia tumida s.s.* These latest Miocene forms are typically more loosely coiled, with consequently more open umbilicus and less quadrate equatorial profile, than the earlier occurrences of *G. dehiscens* and are accordingly recorded as *G.* cf. *dehiscens*. Of particular interest in the basal Zone N.17 to later Zone N.17 interval without *Globoquadrina dehiscens* is the appearance of large specimens of *Globoquadrina* with distinctly flattened apertural faces that superficially resemble *Globoquadrina dehiscens praedehiscens*. Progressive dissection of these specimens reveals juvenile stages referable to *Globoquadrina venezuelana* and not to *Globoquadrina*

FIGURE 21. Correlation of selected Late Miocene microfossil phyletic and non-phyletic events, Sites 214, 216/216A, 217 and 289.

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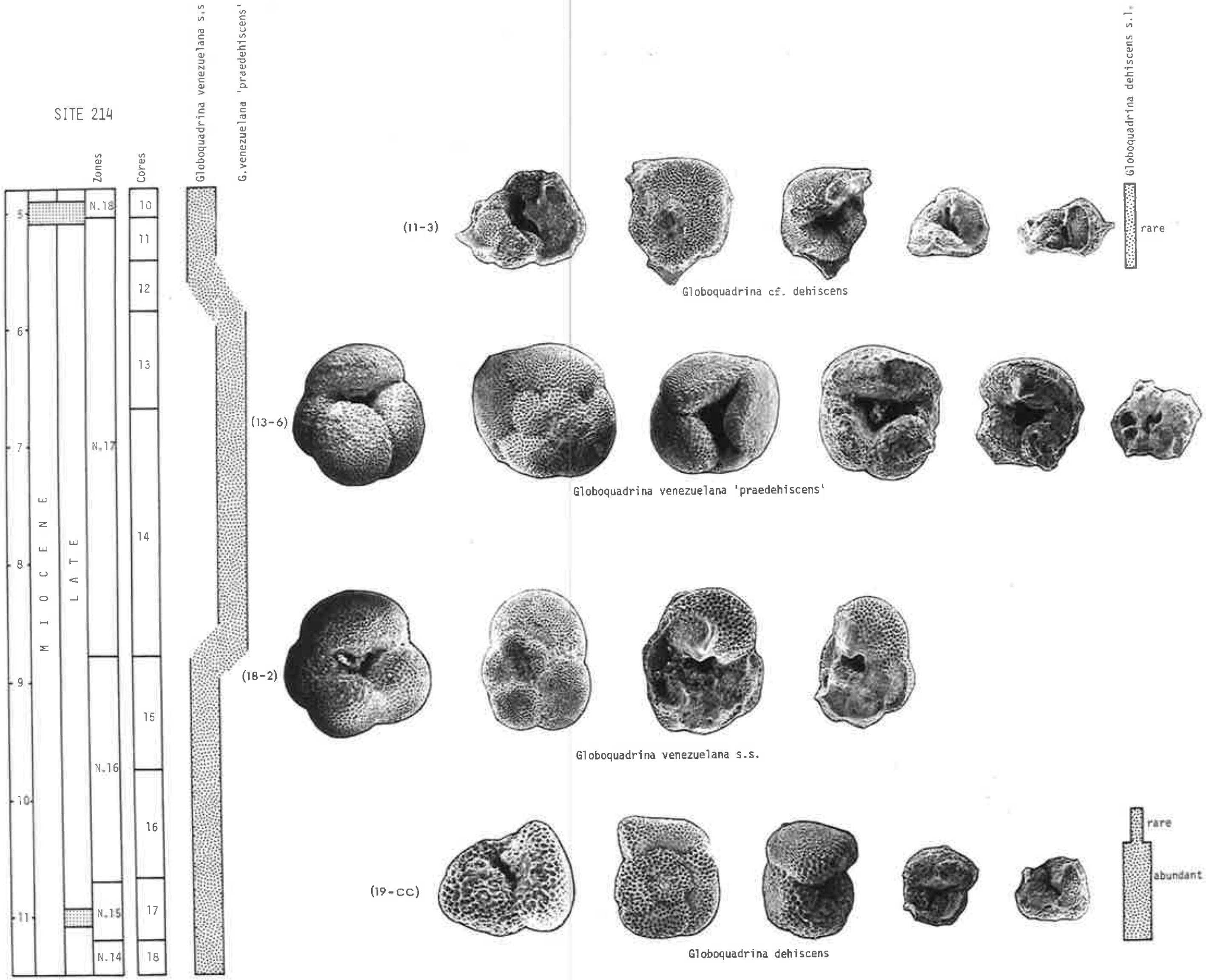

FIGURE 20. Late ontogenetic convergence, at Site 214, between Late Miocene samples of *Globoquadrina venezuelana s.l.* and *Globoquadrina dehiscens* (with disjunct range).

dehiscens s.l. The stratigraphic distribution of the Late Miocene *Globoquadrina venezuelana-dehiscens* complex at Site 214 is outlined on Figure 20. The detailed comparative morphological study is outlined in the systematics chapter.

In summary, at Site 214 *Globoquadrina venezuelana* comprises a broad spectrum of adult morphotypes ranging from those with subglobular chambers to those with laterally compressed chambers bearing distinctly flattened apertural faces. This latter group is informally named *G. venezuelana 'praedehiscens'*. It is noteworthy that this morphological variant occurs during the absence of *G. dehiscens*. Although laterally compressed forms of *G. venezuelana* are present in samples containing *G. dehiscens*, the extreme forms of *G. venezuelana* with flattened apertural faces in the adult stages are distinctly abundant, and the subglobular form virtually absent, only during the absence of *G. dehiscens* (Figure 20).

A similar pattern of *Globoquadrina dehiscens* disjunct range and *Globoquadrina venezuelana* morphotypes is present in Sites 216/216A and 289 and is shown later to correlate with other planktonic microfossil events (Figure 21).

<u>Selected Late Miocene non-phyletic trends at Site 214</u>. Several Late Miocene non-phyletic planktonic foraminiferal events from Site 214 and their relationship to the radiolarian biostratigraphy, and hence to the palaeomagnetic reversal sequence, are shown on Figure 21. The method of construction of this figure is outlined below.

The radiolarian zonation of Site 214 (Johnson, 1974) is calibrated to the palaeomagnetic reversal sequence following Theyer and Hammond (1974a). This reversal sequence is then calibrated to the radiometric dates of Van Couvering and Berggren (1977). The planktonic foraminiferal zonation, of the present study, is correlated to the radiolarian zonation of Johnson (1974). Consequently the cores are shown in terms of their duration rather than in terms of their standard length.

The correlation indicates the following synchronous events:

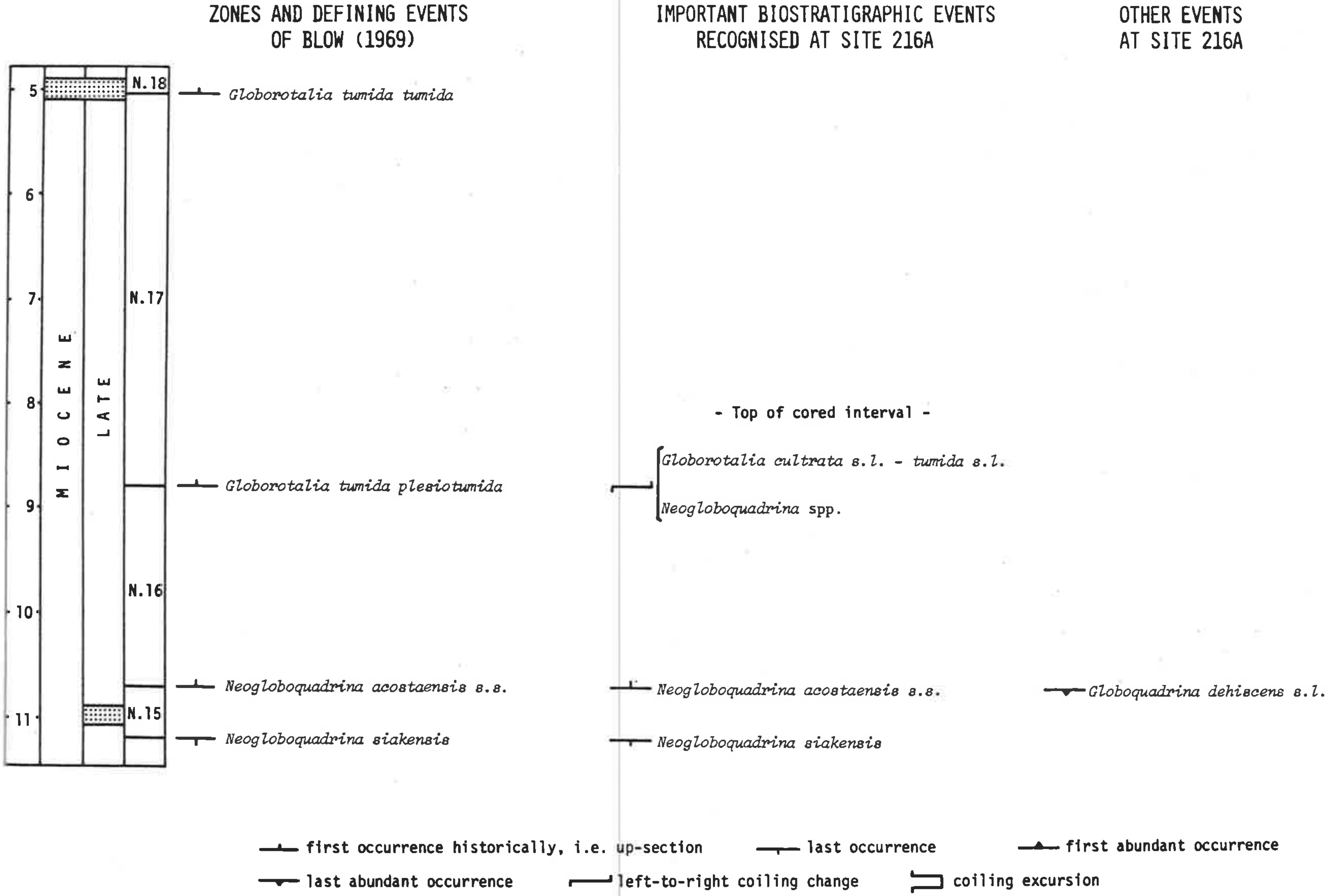

FIGURE 22. Late Miocene planktonic foraminiferal biostratigraphy, Site 216A.

1. The abundance decrease of *Globoquadrina dehiscens* at the N.15/N.16 and *Cannartus petterssoni/Ommatartus antepenultimus* zonal boundaries; the re-appearance of *G. dehiscens* (as *G.* cf. *dehiscens*), restricted to latest Zone N.17, within the radiolarian *Stichocorys peregrina* Zone.

2. *Globoquadrina venezuelana s.l.* is abundant in all cores examined; the development of the *G. venezuelana 'praedehiscens'* morphotype occurs at the expense of *G. venezuelana s.s.* in the interval of time from the base of Zone N.17 (= *Ommatartus antepenultimus/Ommatartus penultimus* boundary) to latest N.17 (to within the *Stichocorys peregrina* Zone).

3. Rapid changes in coiling direction of the *Neogloboquadrina* spp. group and the *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* group. A rapid left-to-right change of coiling in both groups coincides with the Zone N.16/N.17 boundary, while the latter group shows a rapid right-to-left coiling change near the base of the *Stichocorys peregrina* Zone and near the base of the nannofossil *Ceratolithus tricorniculatus*.

SITE 216A

The distribution of species within the samples examined is shown on Figure 7. Phyletic events of biostratigraphic significance are rare in this interval (Figure 22) and of Blow's (1969) Late Miocene zones only the base of Zone N.16 is recognised. Specimens that could be confidently identified as *Globorotalia tumida plesiotumida* are extremely rare contrary to the shore laboratory report of Berggren *et al.* (1974). They record this species as ranging from section 5 of core 2, a level which I would place within Zone N.16.

The topmost occurrence of consistently abundant *Globoquadrina dehiscens* lies just below the Zone N.15/N.16 boundary as at Site 214. The Zone N.16/N.17 boundary is placed between cores 1 and 2 based on the correlation of timing and direction of coiling trends, of *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* and the *Neogloboquadrina* spp. group, with Site 214 (Figure 21). Support for this assessment is provided by the morphological transition of *Globoquadrina venezuelana s.s.* to *Globoquadrina venezuelana*

FIGURE 23. Neogene range chart, Site 217/217A.

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'praedehiscens' across the same cored interval and the correlation with the radiolarian *Ommatartus antepenultimus/Ommatartus penultimus* zonal boundary of Johnson (1974) (Figure 21). The evolutionary appearance of *Discoaster berggrenii* occurs in 216A-1-cc correlating with its first occurrence in sample 214-14-cc (Shafik, written communication 18-9-78). The top of the cored interval, core 1, is placed within the lower part of Zone N.17 on the basis of the absence of *Pulleniatina primalis* and the presence of the typical lower Zone N.17 coiling trends as shown on Figure 21, and is supported by the presence of *Ommatartus penultimus* (Johnson, 1974).

Late Miocene assemblages of planktonic foraminifera are present in core 3 of Site 216 and cores 3 and 4 of Site 217. No evolutionary events of biostratigraphic significance are observed within any of these cores, although an age assignment, based on both qualitative and quantitative aspects of their planktonic foraminiferal assemblages, in conjunction with the radiolarian biostratigraphic report of Johnson (1974) is presented in Figure 21.

SITE 216

Site 216 core 3 contains left-coiled *Pulleniatina primalis*, right-coiled *Neogloboquadrina* spp. and the radiolarian *Stichocorys peregrina* (Johnson, 1974) indicating an age, by correlation with Site 214, within the later part of Zone N.17. The morphological transition from *Globoquadrina venezuelana 'praedehiscens'* to *Globoquadrina venezuelana s.s.* occurs within this core, adding support for an age approximating the middle of Palaeomagnetic Epoch 5, dated at 5.8 Ma.

SITE 217

The distribution of species within samples examined is shown on Figure 23.

Site 217 core 3 is of late Late Miocene age on the basis of the radiolarian assemblage (Johnson, 1974). The absence of *Pulleniatina primalis* and *Globoquadrina venezuelana s.s.*, the presence of *Globoquadrina venezuelana 'praedehiscens'* and *Globoquadrina* cf. *dehiscens*, together with right-coiled

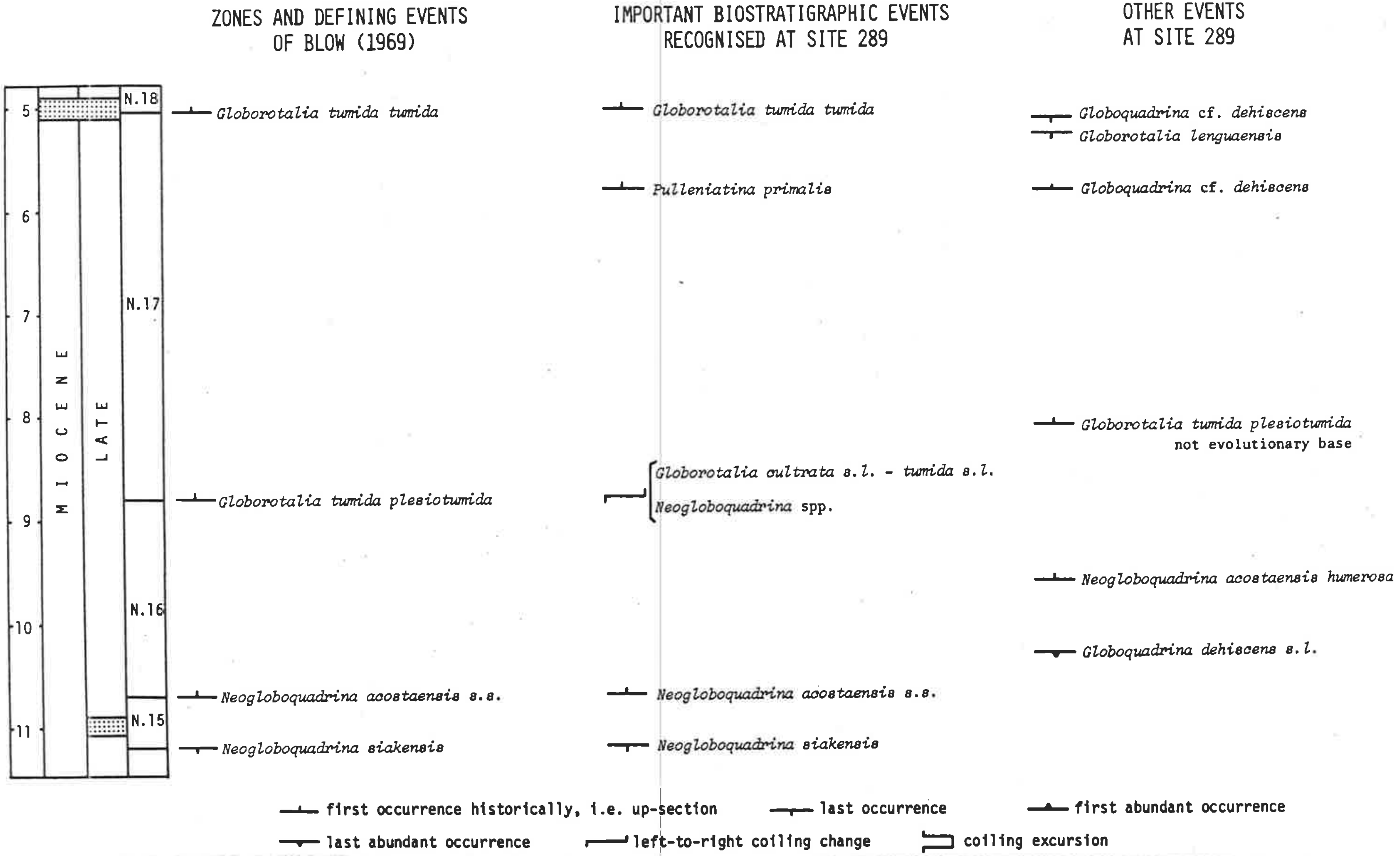

FIGURE 25. Late Miocene planktonic foraminiferal biostratigraphy, Site 289.

FIGURE 24. Late Miocene - Pleistocene range chart, Site 289.

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Neogloboquadrina spp. and the left-coiled *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* group, support an age correlative with the base of the *Stichocorys peregrina* radiolarian zone as established at Site 214 (Figure 21).

Site 217 core 4 lies within Zone N.16 on the basis of the presence of *Neogloboquadrina acostaensis s.s.* and the absence of *Globorotalia tumida plesiotumida.* Although, as has been seen in several other sites, the absence of *G. tumida plesiotumida* is not necessarily good 'negative' evidence. An independent age assessment for Zone N.16 is provided by the presence of *Globoquadrina venezuelana s.s.* and the absence of *Globoquadrina venezuelana 'praedehiscens'*; and the presence of both left-coiled *Neogloboquadrina* spp. and the *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* group. That this core lies within the radiolarian *Ommatartus antepenultimus* Zone (Johnson, 1974) is cited as additional confirmation for this age assessment.

SITE 289

The distribution of species recognised in the samples examined from this site is shown on Figure 24. The Late Miocene zones and their defining events, recognised at Site 289, are outlined in Figure 25. Zonal boundaries N.15/N.16 and N.17/N.18 are confidently recognised. The Zone N.16/N.17 boundary, defined by the evolutionary development of *Globorotalia tumida plesiotumida* from *Globorotalia merotumida*, is not confidently recognised due to the rarity of these species and problems of intergradation. This boundary is approximated using multiple criteria of both a quantitative and qualitative nature. *Globoquadrina dehiscens* has a disjunct range in the Late Miocene similar to that noted in Site 214.

Quantitatively, coiling changes in *Neogloboquadrina* spp. and *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* are almost synchronous in the middle Late Miocene cores 27 and 28. In Sites 214 this event occurs at the evolutionary appearance of *G. tumida plesiotumida*, that is, at the Zone N.16/N.17 boundary (Figure 21). Qualitatively, *Globoquadrina venezuelana s.s.* gives rise to *Globoquadrina venezuelana 'praedehiscens'* across the Zone N.16/N.17 boundary at Sites 214 and 216A (Figure 21). The same morphological transition is found between cores 27 and 28 at Site 289. Accordingly the Zone N.16/N.17 boundary is placed between these cores.

The oldest occurrence of *Pulleniatina primalis* within my samples is 289-21-2 141-143cm in which the *P. primalis* form is well established. One specimen only was found in 289-22-2 144-146cm, referable to *P.* cf. *primalis*. Andrews *et al.* (1975) record the base of *Pulleniatina* as 289-22-1 65-67cm. In view of the importance of the *Pulleniatina* Datum for correlation of Late Miocene sequences, particularly when sedimentation rates in the deep-sea are relatively high compared to the earlier Late Miocene, the position of the *Pulleniatina* Datum of Andrews *et al.* (1975) is used for Figure (21).

For the eastern Indian Ocean sites, the correlation of the planktonic foraminiferal events to the palaeomagnetic reversal sequence, via the radiolarian biostratigraphy, is on relatively safe grounds. However, the radiolarian biostratigraphy is poorly developed at Site 289 (Holdsworth, 1975) since the *Ommatartus penultimus* Zone cannot be recognised and the base of the *Stichocorys peregrina* Zone corresponds to the base of *Pulleniatina primalis*. The radiolarian *S. peregrina* is known elsewhere to range from below the base of *P. primalis*.

Between the base of *Globorotalia tumida s.s.* (in core 17) and the base of *Pulleniatina primalis* (in core 22), a high sedimentation rate of approximately 9.5cm/1000 years is indicated in comparison with approximately 1.9cm/1000 years for the earlier part of Zone N.17. In order to avoid a criticism of *a priorism* the age of cores of latest Miocene times becomes critical to either expand or compress the coiling ratio curves and therefore to establish their correlation with those documented for the eastern Indian Ocean sites.

In the absence of well developed radiolaria in the vicinity of the *Pulleniatina primalis* Datum, and the possible 'artificial' effects of poor resolution on the timing of the documented quantitative events, an independent age assessment is necessary.

The occurrence of the nannofossil *Ceratolithus tricorniculatus* offers a solution to this problem since the base of this species lies near to the base of the *Stichocorys peregrina* radiolarian zone in the eastern Indian Ocean Site 214 (data of Gartner, 1974; Johnson, 1974) and in the western equatorial Pacific Ocean Site 62.1 (data of Gartner, 1971; Riedel and Sanfilippo, 1971). The first occurrence of *Ceratolithus primus* is regarded as equivalent to the basal occurrence of *Ceratolithus tricorniculatus* (Shafik, 1975) and is reported by him to lie within the upper part of core 25 at Site 289. In view of the relationship between *C. tricorniculatus* and the base of the *Stichocorys peregrina* Zone in Sites 214 and 62.1, which is situated in equatorial Pacific waters to the northwest of Site 289, the upper part of core 25 of Site 289 is correlated to the middle of Palaeomagnetic Epoch 6 (Figure 21), the level corresponding to the base of the *Stichocorys peregrina* Zone. This correlation is supported by right-to-left coiling trend of *G. cultrata s.l.* - *G. tumida s.l.* between cores 24 and 25 (Figure 21).

Across cores 23 and 24 there appears to be a morphological gradation between *Globoquadrina venezuelana 'praedehiscens'* and *Globoquadrina* cf. *dehiscens*. As in Site 214 these 'homeomorphic' forms generally have a more open umbilicus with, consequently, about one more chamber per whorl than *Globoquadrina dehiscens s.s.* While this difference in itself does not necessitate the erection of a new species, the fact that, at Site 289, pre-Zone N.16 *G. dehiscens s.s.* are dominantly left-coiled and that *G.* cf. *dehiscens* are randomly coiled, as are *G. venezuelana 'praedehiscens'*, is suggestive of convergence.

MIOCENE/PLIOCENE BOUNDARY

Blow (1969) suggests that, in tropical sequences, the Miocene/Pliocene boundary is approximated by the evolutionary appearance of *Sphaeroidinella dehiscens immatura* from its ancestor *Sphaeroidinellopsis subdehiscens paenedehiscens*. Problems of latitude restriction, species identification and differing concepts of the *Sphaeroidinella* Datum have led to some confusion.

Two '*Sphaeroidinella* Datums' are generally recognised (Berggren and

FIGURE 26. Pliocene planktonic foraminiferal biostratigraphy, Site 214.

Van Couvering, 1974; Taylor and Deighton, 1978). The evolutionary appearance of *S. dehiscens immatura*, at about 4.8 Ma, is the earlier datum and the appearance of *S. dehiscens s.s.* (with flange), in the mid-Pliocene, is the other datum. This younger datum is shown later in this thesis to represent the abundance base of *S. dehiscens s.s.* at about 3.3 Ma in the Indo-Pacific which is about 0.3 Ma earlier than the base of *S. dehiscens* (with flange) in the Atlantic Ocean as shown by Berggren and Van Couvering (1974).

Several workers, including Stainforth *et al.* (1975), use the basal occurrence of *Globorotalia margaritae* to recognise the Miocene/Pliocene boundary. At Site 214 the first appearance of *G. margaritae* is cryptic (non-evolutionary) and is approximately coeval with the evolutionary appearance of *S. dehiscens immatura* (Figure 26). *G. margaritae* is reported as ranging from below the base of *S. dehiscens s.l.* and *Globorotalia tumida s.s.* by Saito *et al.* (1975), and thus from within Zone N.17, in agreement with the range data of Blow (1969). In the Andaman and Nicobar Islands, Bay of Bengal, the initial appearance of *G. margaritae* is subsequent to the appearance of *S. dehiscens* (Srinivasan and Srivastava, 1974) yet is above the base of *Globigerinoides quadrilobatus fistulosus* (Vincent, 1977 figure 21) and is probably of latest Zone N.19 age. Similarly, the initial appearance of *G. margaritae* in Bodjonegoro-1 well in Java (Bolli, 1966b) is within the range of *S. dehiscens*, well above the extinction horizon of *Globigerina nepenthes* and coeval with the distinctive mid-Pliocene coiling change of *Globorotalia tumida s.s.* and *Pulleniatina* spp. which is of latest Zone N.19 age. *G. margaritae* is also reported from within Zone N.16 in the western Atlantic DSDP Site 102 by Poag (1972) while Blow (1969) records its evolutionary appearance from within his Zone N.16.

At the Miocene/Pliocene boundary stratotype, in the Mediterranean, *G. margaritae* ranges from just above the golden spike and from just below the first appearance of *S. dehiscens immatura* (Cita and Gartner, 1973) and provides a 'good' datum for recognising the base of the Pliocene within the Mediterranean. However, even at the boundary-stratotype the first occurrence of *G. margaritae* is cryptic and not uniquely evolutionary.

FIGURE 27. Pliocene-Pleistocene range chart, Site 214.

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G. margaritae is known to be readily susceptible to calcite-solution which may account for many discrepancies in its recorded range. At Site 214 *G. margaritae* is consistently present throughout its range although generally in small numbers and often showing signs of solution effects. Cryptic facies changes and/or a hiatus in the Andaman Islands and Java regions may similarly reflect the variable first appearance horizon of this taxon. Accordingly, the biostratigraphic significance of the first appearance of *G. margaritae* is treated with caution.

Other planktonic foraminiferal events suggested as Miocene/Pliocene boundary markers include the extinction of *Globoquadrina dehiscens* and the evolutionary appearance of *Globorotalia tumida s.s.* (Berggren, 1977b). These events are almost synchronous at Site 214; however, the former event is considered to be of less value in view of its rarity and disjunct range as discussed earlier. The evolutionary appearance of *G. tumida s.s.* is taken as the Miocene/Pliocene boundary for Sites 214 and 289 in view of its distinctive evolutionary appearance and the problems associated with *Sphaeroidinella dehiscens* as a biostratigraphic indicator. The resistance of *G. tumida s.s.* to calcite-solution, as evidenced by its consistent occurrence in the deeper water Sites 216 and 217, adds to its reliability as a biostratigraphic marker.

PLIOCENE

Site 214 contains an essentially complete sequence with well preserved planktonic foraminifera. Site 216 and 217 were discontinuously cored over the Pliocene interval and are generally less well preserved. The Pacific Site 289 provides an excellent section.

SITE 214

Figure 26 outlines the Pliocene zones and defining events of Blow (1969) and those zones recognised at Site 214. Samples versus species ranges are shown on Figure 27.

The evolutionary appearance of *Sphaeroidinella dehiscens immatura* at 214-10-1 5-7cm, described by Berggren and Poore (1974), is regarded as a useful datum only in well preserved tropical sequences. Identification of this taxon can be obscured by the tendency of members to lose part of all of their outer cortex by calcite-solution; also, it is rare within early Zone N.19 sediments.

The evolutionary appearance of *Neogloboquadrina acostaensis pseudopima*, defining the base of Zone N.20, is not conclusively determined at this site due to its rarity. Occurrences of *N. acostaensis pseudopima* from near the base of Zone N.18 are reported by Brönnimann and Resig (1971 p.1248) casting doubt on the validity of this species as a biostratigraphic marker.

The extinction of *Globorotalia margaritae* approximates the Zone N.19/N.20 boundary (Brönnimann and Resig, 1971; Berggren, 1977b). Hays *et al.* (1969) correlate this event with the Gilbert/Gauss Palaeomagnetic boundary in their Indo-Pacific deep-sea cores that show no evidence of calcite-solution. Cita (1975) similarly records the extinction of *G. margaritae* in the Mediterranean at the Gilbert/Gauss boundary. At Site 214, although specimens show signs of calcite-solution, the last occurrence of *G. margaritae* in 214-6-1 7-9cm is regarded as synchronous with this magnetic event in view of the close parallelism of planktonic foraminiferal events between Site 214 and the palaeomagnetically assessed core V20-163 (Hays *et al.*, 1969; Bandy, 1973) situated approximately 6° south of Site 214 on the Ninetyeast Ridge. Vincent *et al.* (1974) report inconsistent and scarce occurrences of *G. margaritae* in all DSDP Leg 24 sites of the western Indian Ocean indicating that, in that region, it is an unreliable stratigraphic indicator. The evolutionary sequence of *G. margaritae* morphotypes postulated by Cita (1973) is not apparent at Site 214.

Blow (1969) recognises the first appearance of *Globigerina rubescens s.s.* at the Zone N.19/N.20 boundary. At Site 214 this event is below the boundary but above the horizon of extinction of *Globigerina nepenthes*.

The evolutionary development of *Globorotalia tosaensis* from *Globorotalia crassaformis* defines the base of Blow's (1969) Zone N.21. The lowest occurrence of *G. tosaensis*, in sample 214-5-4 5-7cm, is in the same relative order of Pliocene planktonic events as outlined by Blow (1969) and Hays *et al.* (1969), marking the base of Zone N.21 in spite of the absence of morphotypes transitional to *G. crassaformis*.

Other biostratigraphic events of significance. The first occurrence of *Pulleniatina obliquiloculata s.s.* is within mid Zone N.19 at this site, not in Zone N.21 as reported by McGowran (1974). However, it is rare until early Zone N.21.

The extinction of *Globigerina nepenthes* within Zone N.19 at Site 214 is consistent with Blow's (1969) sequence of events and occurs at the top of the Gilbert "a" Palaeomagnetic Event in both the Indo-Pacific and Atlantic Oceans (Saito *et al.*, 1975), at approximately 3.7 Ma (Berggren, 1977b). However, even in closely spaced palaeomagnetically assessed deep-sea cores V24-59 and RC12-66 (Saito *et al.*, 1975) the top occurrence of *G. nepenthes* varies from just below the Gilbert "a" to between the Gilbert "b" and "c" palaeomagnetic events, a time difference of about 0.5 Ma. Calcite-solution may be responsible since the range of *Globorotalia margaritae* is similarly truncated in these cores. However, the suggestion of Hays *et al.* (1969) that *Globigerina nepenthes* is a particularly solution-susceptible species is not supported by the consistent occurrence of well preserved *nepenthes*, although in small numbers, throughout its range at Site 214. This assessment is in agreement with the findings of Berger and Von Rad (1972 p.799) and Vincent (1975 p.783). Parker (1969) records an overlap in the ranges of *G. nepenthes* and *Globorotalia tosaensis*. The writer has not yet encountered any additional evidence that supports this record.

In summary, the biostratigraphic significance of the base of *Pulleniatina obliquiloculata s.s.* and extinction of *Globigerina nepenthes* is clouded by problems of rarity and varying extinction levels such that the absence of these taxa does not necessarily provide good negative evidence for Early Pliocene biostratigraphic resolution.

The extinctions of *Globoquadrina altispira* and *Sphaeroidinellopsis* spp. are recorded from within the lower part of Zone N.21 supporting the observations of Blow (1969). The significance of the *G. altispira* disappearance is dis-

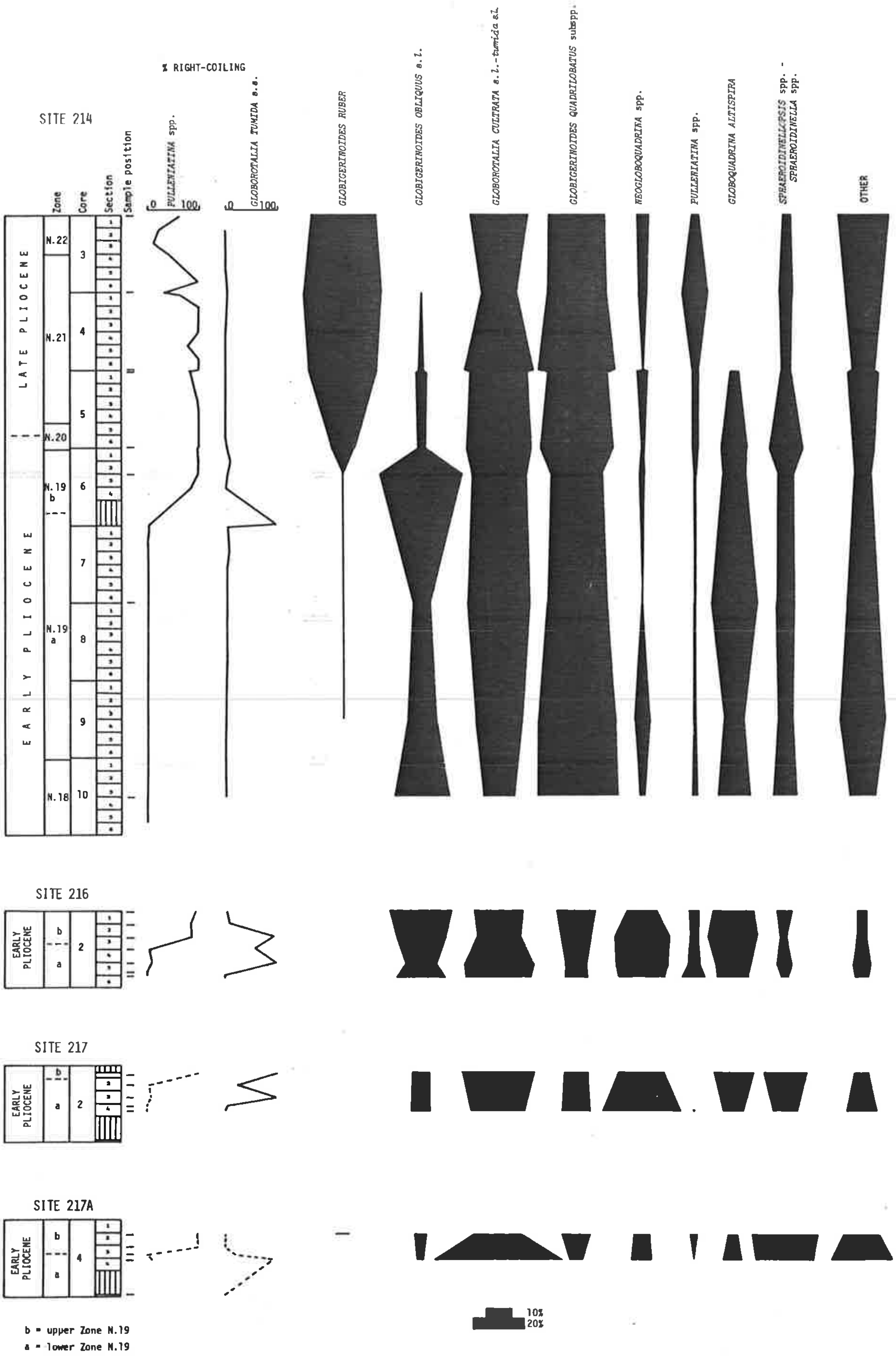

FIGURE 29. Pliocene relative abundance trends, based on counts of 500 specimens per sample, and coiling trends of *Pulleniatina* spp. and *Globorotalia tumida s.s.* in Sites 214, 216, 217/217A.

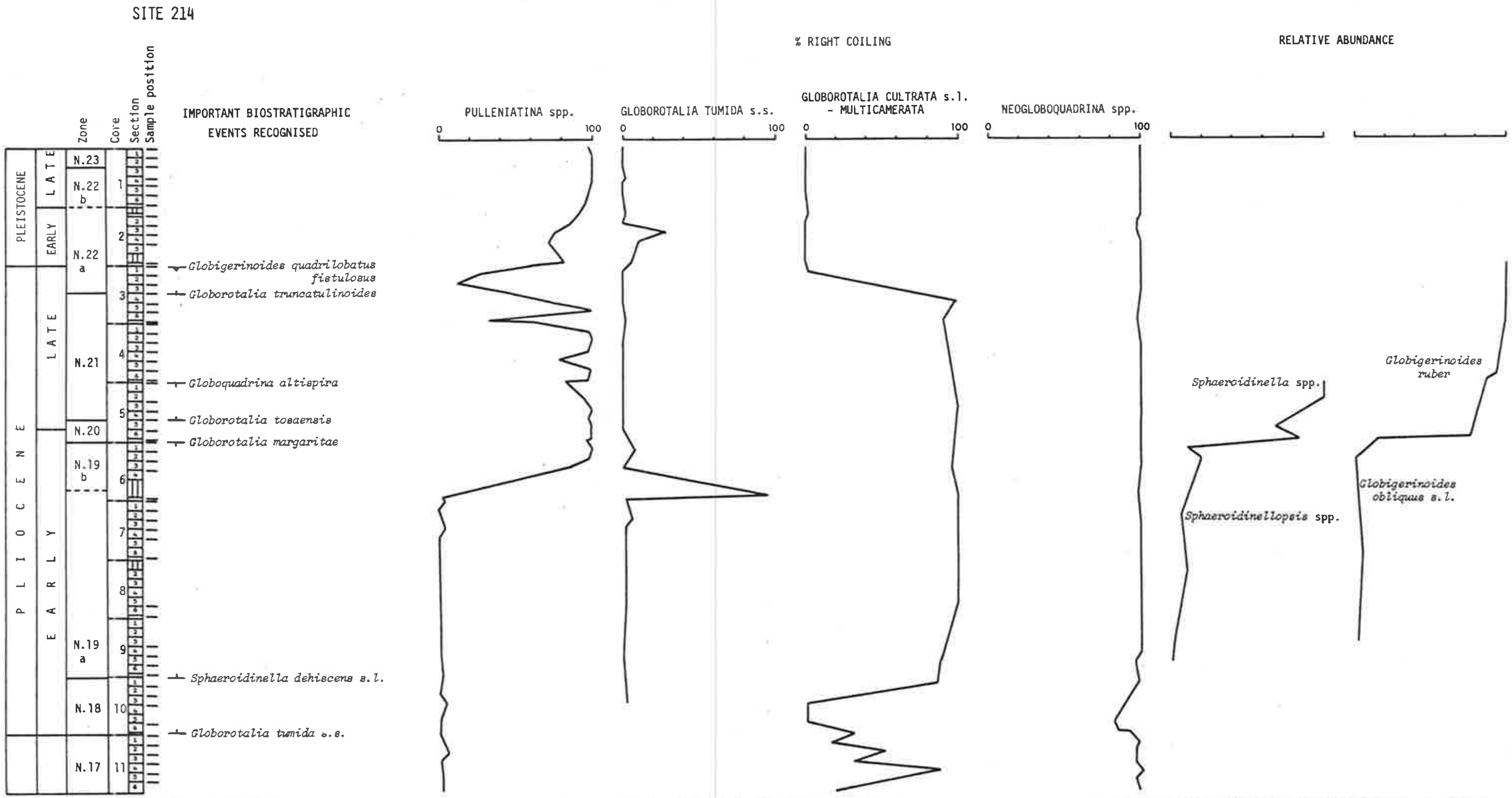

FIGURE 28. Pliocene-Pleistocene coiling trends of *Pulleniatina* spp., *Globorotalia tumida s.s. Globorotalia cultrata s.l.-multicamerata* and *Neogloboquadrina* spp. and relative abundance trends of *Sphaeroidinella* spp./*Sphaeroidinellopsis* spp. and *Globigerinoides ruber*/*Globigerinoides obliquus s.l.* at Site 214.

cussed in the following chapter.

The disappearance of *Globorotalia multicamerata* is reported by Berggren (1977b) to coincide with the disappearance of *Globoquadrina altispira*. At Site 214, *G. multicamerata* ranges until just below the base of Zone N.22. This relationship is used to provide an assessment of the Pliocene/Pleistocene boundary at Site 217A.

Lamb and Beard (1972, Table 2) show overlapping ranges of *Globorotalia tosaensis* and *Globorotalia margaritae*. The writer has not yet encountered any confirmation of this situation and considers the occurrence cited as possibly the result of a drafting error as this overlap is not documented in their later contribution contained in Stainforth *et al.* (1975).

Streptochilus globigerum ranges to within Zone N.21 at Site 214, representing an extension of its youngest occurrence from lower Zone N.19 as recorded by Brönnimann and Resig (1971).

Several quantitative and qualitative aspects of the Pliocene at Site 214 are shown on Figures 28 and 29.

The coiling history of *Pulleniatina* spp. is well documented by Saito (1976) for Indo-Pacific and Atlantic-Caribbean deep-sea cores. Consistent and synchronous changes in coiling preference are observed and are correlated with the palaeomagnetic reversal sequence (Saito, 1976). A quantitative 'standard' for correlation of Site 214 *Pulleniatina* spp. is therefore available.

Within the Pliocene of Site 214 the most pronounced left-to-right coiling change occurs within later Zone N.19 (Figure 28). The same relationship is noted by Hays *et al.* (1969) in core V20-163 just above the Gilbert "a" Palaeomagnetic Event, dated at approximately 3.7 Ma (Saito, 1976). Zones N.20 and N.21 contain mainly right-coiled *Pulleniatina* spp. with left-coiled forms becoming more common towards the Pliocene/Pleistocene boundary.

One significant right-coiling excursion of *Globorotalia tumida*, within an otherwise consistently left-coiled mode, is evident. This occurs within 214-6-cc, just below the first, upsection, occurrence of right-coiled

Pulleniatina. The same temporal relationship is recorded in Java by Bolli (1966b), in the Ninetyeast Ridge core V20-163 and in Sites 216, 217 and 217A. *Globorotalia tumida* coiling trend fluctuations, in the equatorial Pacific, are figured by Saito *et al.* (1975) for the palaeomagnetically assessed cores V24-59 and RC12-66 where they occur at the top of the Gilbert "a" Event. This *G. tumida* trend is most prominent in the former core and less so in the latter.

The *G. cultrata s.l.* - *G. multicamerata* group of the Site 214 Pliocene is dominated by right-coiled morphotypes in contrast to Late Miocene and Pleistocene assemblages. Bolli (1971) recognises essentially the same trend, while Ericson *et al.* (1963) use the right-to-left coiling trend to recognise the Pliocene/Pleistocene boundary in deep-sea cores. Pliocene "*Globorotalia menardii*" complex coiling trends have occasionally been reported. Such trends, outlined by Asano *et al.* (1975), for example, are not particularly useful since if *Globorotalia tumida* and *Globorotalia multicamerata/limbata* are included in the "complex" then the resulting coiling percentage for the Pliocene, at least, will essentially be a measure of the relative percentage of either of these two taxa since *G. tumida* is dominantly left-coiled and *G. multicamerata/limbata* is dominantly right-coiled throughout their Pliocene stratigraphic range.

The coiling history of *Neogloboquadrina* spp. (mainly *acostaensis s.l.* and *dutertrei*) is relatively simple throughout the Pliocene and Pleistocene. The only coiling excursion away from dominantly right-coiled is a short-lived trend within Zone N.18 just above the base of *Globorotalia tumida s.s.* A similar relationship is documented later for Site 289. There is little published documentation of the coiling history of this group, either as individual species or as a group. Saito *et al.* (1975) plot a *G. acostaensis* coiling trend for the mid-equatorial Pacific Ocean core RC12-66 which does not show any Pliocene-Pleistocene variation away from approximately 100% right-coiled. Bolli (1966b) also shows a *G. acostaensis* coiling trend for Bodjonegoro-1 well, Java, however a hiatus in that well, represented by latest Zone N.18 (?)part Zone N.19, prevents correlation of the Zone N.18 coiling excursion. The basis of this interpretation of the Bodjonegoro-1 Pliocene is presented in Chapter 3.

Rapid and distinct changes in coiling direction preferences of *Pulleniatina* spp. and *Globorotalia tumida s.s.* which precede the extinction of *Globorotalia margaritae* are associated with a rapid abundance increase of *Sphaeroidinella* spp. at the expense of *Sphaeroidinellopsis* spp. (Figure 28). Similarly, *Globigerinoides ruber* (rare below upper core 6) rapidly increases in abundance near the top of core 6 becoming abundant in 214-5-cc. *Globigerinoides obliquus s.l.* rapidly decreases in abundance over the same interval (Figures 28 and 29). A similar distribution pattern for *G. ruber* is recorded in Site 219 (Fleisher, 1974) and in DSDP Leg 24 sites (E. Vincent pers. comm. in Fleisher, 1974) while the base range of *G. ruber* in Bolli's (1966b) Javan sequence correlates with this abundance event, taxonomic differences notwithstanding. This assemblage overturn in Site 214 occurs just above the extinction of *G. margaritae* which is correlated to the Gilbert/Gauss Palaeomagnetic boundary and dated at approximately 3.3 Ma (Berggren, 1977b). A rapid decrease in abundance of *Globigerinoides obliquus extremus* is recognised in the Mediterranean, although this event is of early Matuyama Palaeomagnetic age (Cita, 1975).

SITES 216, 217/217A

Ranges of species and samples examined are documented in Figures 7 and 23, while coiling ratio and abundance trends are shown on Figure 29. Each site was discontinuously cored in the Pliocene-Pleistocene with only one core intersecting Early Pliocene sediments in each case. No zone-defining evolutionary events are recognised so that the age assessment is based on assemblage characteristics.

Core 2 of Site 216 contains moderately well preserved planktonic foraminifera. The presence of *Globorotalia margaritae* and *Sphaeroidinella dehiscens* (rare) throughout indicates a Zone N.19 age. A latest Zone N.19 age is indicated by the presence of a *Globorotalia tumida* right-coiling peak which immediately precedes a left-to-right *Pulleniatina* spp. coiling trend. The lower part of this core can therefore be correlated to near the top of the Gilbert "a" Palaeomagnetic Event.

The presence of abundant *Globigerinoides obliquus s.l.* and rare *Globigerinoides ruber* together with abundant *Sphaeroidinellopsis* spp. and rare *Sphaeroidinella* spp. (Figure 29), support a latest Zone N.19 age.

The foraminifera of core 2 of Site 217 are poorly preserved as shown by the high degree of fragmentary remains, lamellar exfoliation, wall-surface etching and abundant, isolated, *Globorotalia* spp. keels. In spite of the poor preservation, *Globorotalia margaritae* is present together with *Sphaeroidinella dehiscens s.l.* indicating a Zone N.19 age. Right-coiled *Globorotalia tumida* occurs immediately below the left-to-right *Pulleniatina* spp. coiling trend; *Globigerinoides obliquus s.l.* is abundant and *Globigerinoides ruber* is rare while *Sphaeroidinellopsis* spp. is abundant and *Sphaeroidinella* spp. is rare. These events correlate with the mid-Pliocene of Site 214 and a latest Zone N.19 age is indicated. Site 217 differs from Sites 214 and 216 in that it contains *Beella nicobarensis* and *Beella digitata* which is attributed to the more northerly position of Site 217. *B. nicobarensis* has previously only been reported from the Andaman-Nicobar Islands by Srinivasan and Kennett (1975).

The foraminiferal assemblages of Site 217A core 4 are very poorly preserved as indicated by the very abundant isolated *Globorotalia* keels and dominance of fragments over whole tests. Quantitative trends suggest an age slightly younger than core 2 of Sites 216 and 217. Towards the top of this core *Sphaeroidinella* spp. numerically dominate *Sphaeroidinellopsis* spp.; *Globigerinoides ruber* is present with *Globigerinoides obliquus s.l.* in approximately equal numbers; *Pulleniatina* spp. are right-coiled and *Globorotalia tumida s.s.* has reversed back to left-coiling from a basal core 4 right-coiling peak (Figure 29). In the absence of relevant index species the age of this core is assessed on the combination of these quantitative assemblage features which are consistent with a late Zone N.19-N.20 age. *Globorotalia margaritae* is only tentatively recorded from section 4 of core 4. Sample 4-cc, examined for *G. margaritae*, shows common *G. ruber*, common *G. obliquus*, abundant *Sphaeroidinella* spp. and right-coiled *Pulleniatina* spp. No *G. margaritae* was found. All these features suggest an age younger than core 4

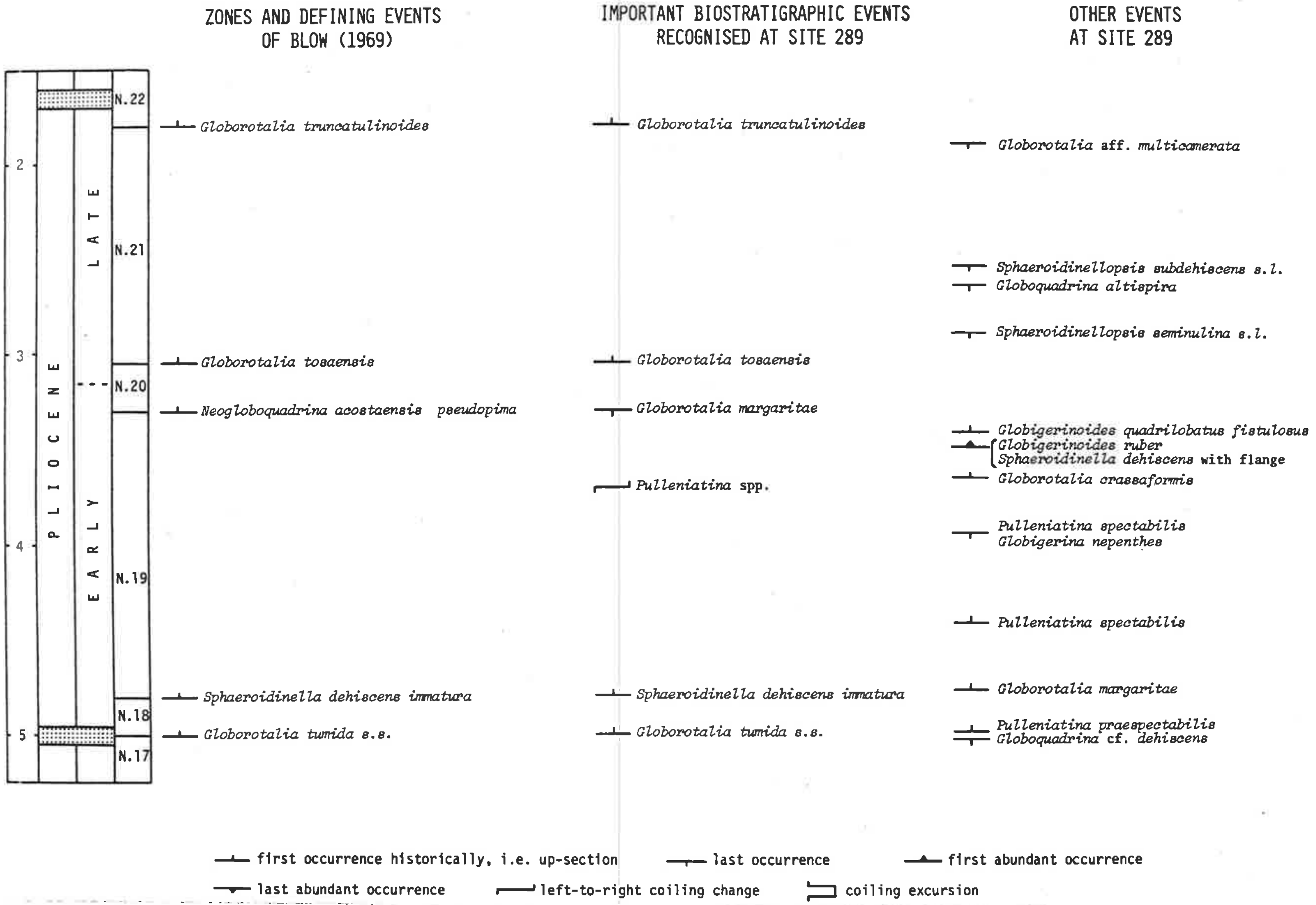

FIGURE 30. Pliocene planktonic foraminiferal biostratigraphy, Site 289.

section 2; mechanical contamination is a likely cause.

SITE 289

Species recognised and samples examined for the Pliocene of the western equatorial Pacific Site 289 are shown on Figure 24. Assemblages are well preserved apart from minor occurrences of isolated *Globorotalia* keels and lamellar exfoliation indicative of calcite-solution below the lysocline. Samples are analysed both qualitatively and quantitatively and provide an excellent reference section for comparing Indo-Pacific Pliocene planktonic foraminiferal biostratigraphy.

The Pliocene planktonic foraminiferal zones and defining events of Blow (1969) together with events of biostratigraphic significance at Site 289 are shown on Figure 30.

Zones N.18, N.19, N.20 and N.21 are recognised on the same criteria as at Site 214. The basal occurrence of *G. margaritae* corresponds to the base of *Sphaeroidinella dehiscens immatura*, as at Site 214, adding support for its (cautious) use as a marker for the Miocene/Pliocene boundary in Indo-Pacific tropical deep-sea sections. As at Site 214 the evolutionary appearance of *G. margaritae* is not represented.

Other biostratigraphic events of significance. At Site 289 *Globigerina nepenthes* disappears below the *Pulleniatina* spp. and *Globorotalia tumida s.s.* coiling events. *G. nepenthes* is reported by Saito *et al.* (1975) to range to just below these coiling events in the equatorial Pacific deep-sea core RC12-66.

The *Pulleniatina primalis-spectabilis* lineage is represented in the Early Pliocene of Site 289. Within the limits of resolution imposed by sample spacing, the basal occurrence of *P. praespectabilis* appears at the Zone N.17/N.18 boundary where it forms a morphological continuum with *P. primalis*. *P. praespectabilis* ranges from approximately latest Zone N.17 at Site 62.1, western equatorial Pacific, in my assessment of the published biostratigraphy of that site. The first, upsection, occurrence of *P. praespectabilis* is therefore an additional guide to the Miocene/Pliocene boundary in deep-sea sediments. The continued morphologic trend towards angular chambers results in the development of a peripheral thickening along the equatorial periphery (a carina); this evolutionary stage is represented by *Pulleniatina spectabilis*. At Site 289 this trend is terminated at the occurrence of only partially carinate specimens (*P.* cf. *spectabilis*) which are found over a short stratigraphic range from 289-14-3 142cm to 289-13-1 146-148cm. Brönnimann and Resig (1971) also report a short range of *P. spectabilis* within Zone N.19 at Site 62.1.

The evolutionary development of *Pulleniatina spectabilis* from *Pulleniatina praespectabilis* is a potentially useful biostratigraphic marker within the Early Pliocene, if only within the tropical Pacific region, particularly in view of the relative lack of other phyletic and non-phyletic events of significance within the early part of Zone N.19. The youngest occurrence of *Pulleniatina spectabilis* is recorded by Parker (1967) in the central equatorial Pacific deep-sea core CAP38BP where *P. spectabilis (s.l.)* overlaps the basal occurrence of *Globorotalia tosaensis*. Most subsequent records show *P. spectabilis* as terminating just below the *Pulleniatina* spp. and *Globorotalia tumida s.s.* coiling events of latest Zone N.19 age. The extinction of *Pulleniatina spectabilis* coincides with the extinction of *Globigerina nepenthes* at 289-13-1 146-148cm; both are known to range as high as these coiling events in the deep-sea core RC12-66 (Saito *et al.* 1975). In the absence of palaeomagnetic stratigraphy at Site 289, and at the resolution of current radiolarian and calcareous nannofossil biostratigraphic schemes, it cannot be determined whether the stratigraphic gap between these coeval extinctions and the coiling events is the result of foreshortened ranges or a high sedimentation rate.

The basal occurrence of *Globigerinoides quadrilobatus fistulosus* overlaps the topmost occurrence of *Globorotalia margaritae* at Site 289 in the same manner as in Site 214 and CAP38BP (Parker, 1967). This relationship does not apply everywhere throughout the tropical Indo-Pacific since Jenkins and Orr (1972) report *G. quadrilobatus fistulosus* as ranging from above the extinction of *G. margaritae* and below the first, upsection, occurrence of *Globorotalia tosaensis*. The first occurrence of this taxon therefore varies in the order of 0.2 Ma either side of the *G. margaritae* event. The overlap of *G. quadrilobatus fistulosus* with *Globigerina nepenthes* in an outcrop sample of the Suva Marl, Fiji, by Parker (1967) is considered doubtful because of the lack of confirmation of this relationship from other sections and the rarity of *G. nepenthes* as well as the possibility of confusion of *G. nepenthes* with members of the *Globigerina rubescens decoraperta* group.

Within the Late Pliocene Zone N.21 the disappearance of *Sphaeroidinellopsis seminulina, S. subdehiscens* and *Globoquadrina altispira* are clustered together with *S. seminulina* disappearing prior to *G. altispira* in the same relative order as at Site 214.

The disappearance of *Globoquadrina altispira* at Site 289 is represented by the last occurrence of abundant specimens in 289-8-1 143-145cm and no specimens in 289-7-6 113-115cm.

Specimens referable to *Globorotalia* aff. *multicamerata* range until just below the base of *Globorotalia truncatulinoides* in the same manner as at Site 214. Selected quantitative aspects of the Pliocene at Site 289 are shown on Figure 31 for comparison with Site 214 (Figure 28).

The coiling trends of *Pulleniatina* spp. determined for Site 289 are consistent with those outlined by Saito (1976). As at Site 214, the most obvious left-to-right trend within Zone N.19 provides a tie to just above the Gilbert "a" Palaeomagnetic Event, dated at approximately 3.7 Ma (Saito, 1976; Berggren, 1977b). Comparison of the *Pulleniatina* spp. coiling trends of Site 289 (Figure 31) with those of Site 214 (Figure 28) shows that four main coiling regimes are recognisable; late Zone N.17, N.18 to late N.19 - dominantly left-coiled; latest Zone N.19, N.20 to early N.21 - dominantly right-coiled; later Zone N.21 to mid Pleistocene - widely fluctuating; late Pleistocene to Recent - dominantly right-coiled. Within the later Zone N.21 to early Zone N.22 interval a close correlation of coiling trends between Sites 289 and 214 is not immediately obvious, apart from a broad left-coiled peak at the base of

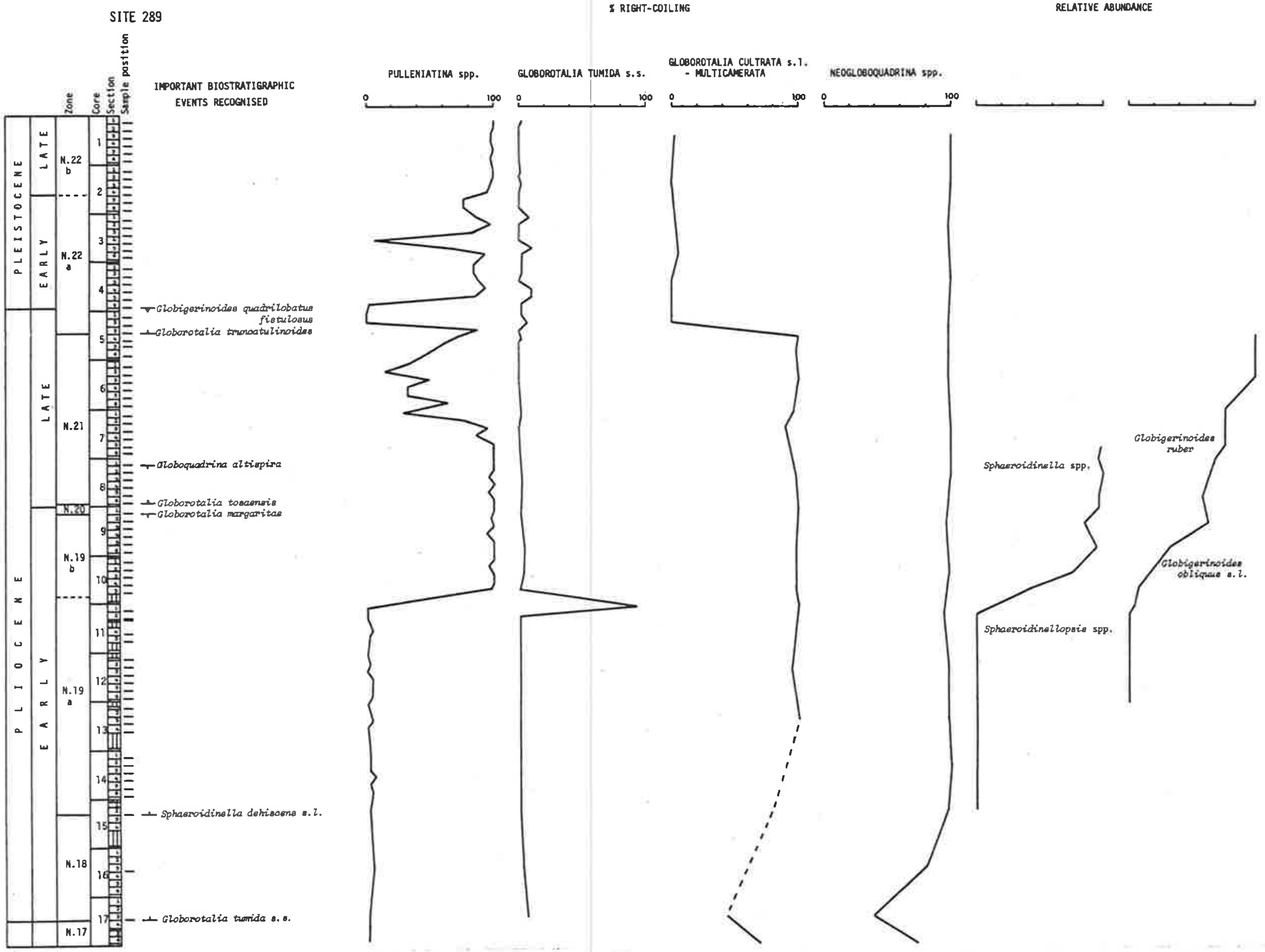

FIGURE 31. Pliocene-Pleistocene coiling trends of *Pulleniatina* spp., *Globorotalia tumida s.s. Globorotalia cultrata s.l.-multicamerata* and *Neogloboquadrina* spp. and relative abundance trends of *Sphaeroidinella* spp./*Sphaeroidinellopsis* spp. and *Globigerinoides ruber*/*Globigerinoides obliquus s.l.* at Site 289.

Globorotalia truncatulinoides near the Pliocene/Pleistocene boundary. The Site 289 trend is very similar to the generalised *Pulleniatina* spp. coiling trend outlined by Saito (1976). This is not surprising since most of his data comes from Pacific cores, and his only Indian Ocean core did not span later Zone N.21 to Recent. Site 214 therefore represents an initial standard for the *Pulleniatina* spp. coiling trend in the Indian Ocean and differences in coiling history testify to a degree of watermass isolation between the Indian and Pacific Oceans.

One right-coiling excursion of *Globorotalia tumida s.s.* is present, within an otherwise dominantly left-coiled trend, immediately below the *Pulleniatina* spp. left-to-right coiling event (Figure 31). This correlates with the trends in the Indian Ocean Site 214, 216, 217 and 217A as well as in Java (Bolli, 1966b). An early Zone N.22 right-coiling trend as documented for Site 214 is not present in the Pacific Ocean Site 289.

There is a close similarity in coiling trends of *Globorotalia cultrata s.l. - multicamerata* between Site 289 (Figure 31) and Site 214 (Figure 28). In particular, an upsection, rapid, right-to-left trend occurs at the base of *Globorotalia truncatulinoides* providing additional *a posteriori* evidence for the value of this event as marking the Pliocene/Pleistocene boundary as suggested by Ericson *et al.* (1963). Zone N.18 to early N.19 occurrences of *Globorotalia* spp. are generally small in size such that consistent separation of this group from *G. tumida* is not possible. However, Figure 31 shows latest Zone N.17 left-coiled and early Zone N.19 right-coiled *G. cultrata s.l.*-aff. *multicamerata* which is broadly to the same interval in Site 214.

Apart from a trend towards left-coiling within Zone N.18, the remainder of the Pliocene and Pleistocene *Neogloboquadrina* spp. are almost 100 per cent right-coiled. The occurrence of left-coiled *Neogloboquadrina* spp. in association with *Globorotalia tumida s.s.* in Sites 289 (Figure 31) and Site 214 (Figure 28) may provide a guide to the Zone N.18 interval in view of the variability of the first, upsection, occurrence of the Zone N.18/N.19 boun-

FIGURE 32. Pleistocene planktonic foraminiferal biostratigraphy of Sites 214, 217A and 289, including coiling trends of *Pulleniatina* spp., *Globorotalia tumida* and *Globorotalia crassaformis*.

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dary index species, *Sphaeroidinella dehiscens immatura.*

At this site the relative percentage of *Globigerinoides ruber* and *obliquus s.l.* is determined by the percentage of *G. ruber* of a total of 50 specimens of *G. ruber* and *G. obliquus,* selected at random. The same procedure is employed for the *Sphaeroidinella/Sphaeroidinellopsis* change.

The upsection assemblage change from dominantly *Sphaeroidinellopsis* spp. to dominantly *Sphaeroidinella* spp. is coeval with the upsection 'replacement' of *G. obliquus s.l.* by *G. ruber*, and occurs above the later Zone N.19 *Pulleniatina* spp. coiling event and below the extinction of *Globorotalia margaritae.* The *G. ruber* abundance base at Site 289 is therefore earlier than its Zone N.20 base at Site 214. However, at that site the base of abundant *G. ruber* is at the base of a core and the abundance transition with *G. obliquus s.l.* very rapid. These facts, in conjunction with the evidence of common *G. ruber* in latest Zone N.19 in the Indian Ocean Site 217 (Figure 29) implies that the Indo-Pacific *G. ruber* abundance-base offset between Sites 289 and 214 may be an artifact of 'incomplete' coring (*sensu* Moore, 1972).

PLIOCENE/PLEISTOCENE BOUNDARY

Planktonic foraminiferal events covering the Pliocene/Pleistocene boundary to the Recent, at Sites 214, 217A and 289, are shown on Figure 32. In this figure cores are plotted in terms of their standard length rather than their estimated time-duration as is the case in previous figures. This method avoids *a priori* compression or stretching of the relative spacing of many events of potential biostratigraphic significance over such a short time interval.

In the well preserved assemblages of Site 214 and 289 the evolutionary base of *Globorotalia truncatulinoides* is bracketed below by the extinction of *Globorotalia multicamerata* and above by the base of *Pulleniatina obliquiloculata finalis* and the abundance top of *Globigerinoides quadrilobatus fistulosus.* *G. truncatulinoides* is distinguished by the presence of a keel (*sensu* Scott, 1973) whether wholly or only partially present on one or more chambers. Thus the Zone N.21/N.22 boundary of Blow (1969), the *G. truncatulinoides* Datum, is placed at sample 214-3-4 5-6cm and 289-5-3 142-144cm.

Recent investigation by Haq *et al.* (1977) of the calcareous microfossil biostratigraphy of the Pliocene/Pleistocene boundary stratotype refine the biostratigraphic basis for the recognition of this boundary in extra-Mediterranean areas. Criticism of this work by Jenkins (1978) is solidly rebuffed by the reply of Haq *et al.* (1978). Their study shows the boundary, at Le Castella (Italy), to be coeval with, or slightly younger than, the top of the Olduvai Palaeomagnetic Event (Gilsa Event of Cox, 1969), dated at approximately 1.6 Ma. In calcareous nannofossil terms, the top of the Olduvai Event is above the extinction of *Discoaster brouweri* and bracketed by the sequential appearance of *Gephyrocapsa caribbeanica* and *Gephyrocapsa oceanica*. In terms of the planktonic foraminiferal biostratigraphy of some North Atlantic deep-sea cores, the top of the Olduvai Event is approximated by the disappearance of both *Globigerinoides obliquus* and *Globigerinoides quadrilobatus fistulosus*, while the base of the Olduvai Event is preceded by the first appearance of *G. truncatulinoides*. The *G. truncatulinoides* Datum is dated at about 1.85 Ma (Haq *et al.* 1977), some 0.25 Ma older than the top of the Olduvai Event and thus the Pliocene/Pleistocene boundary.

The planktonic foraminiferal events that correlate with the Pliocene/Pleistocene boundary in the Atlantic and Mediterranean are not synchronous, however, with the same events in the Indo-Pacific. That is, in the Atlantic the disappearance of *G. obliquus* is recorded variously as occurring below the base of *G. truncatulinoides* (Parker, 1973), contemporaneous with the base of *G. truncatulinoides* (Berggren, 1977b) or just above this datum (Haq *et al.* 1977). At Site 214 *G. obliquus* ranges as high as 214-1-5 Top which is correlated to within the Brunhes Palaeomagnetic Epoch on the basis of *Pulleniatina* spp. coiling trends to be outlined later. *G. obliquus* is also reported in Recent sediments by Boltovskoy and Watanabe (1975). Similarly, the disappearance of *G. quadrilobatus fistulosus* occurs close to the top of the Olduvai Event in the Atlantic, as mentioned above, yet Bielak and Briskin

(1978) record a 1.3 Ma extinction for this taxon. The last occurrence of *G. quadrilobatus fistulosus* in Site 289 is correlated to within the Brunhes Palaeomagnetic Epoch on the basis of *Pulleniatina* spp. coiling trends to be outlined later. A similar disappearance level near the base of the Brunhes Epoch, dated at about 0.7 Ma (Saito *et al.* 1975), is evident at Site 214. Significantly, however, at Site 289 *G. quadrilobatus fistulosus* rapidly decreases in abundance just above the base of *G. truncatulinoides*, near the top occurrence of *Discoaster brouweri* and below the base of *Gephyrocapsa caribbeanica* (Shafik, 1975). This nannofossil configuration correlates near to the top of the Olduvai Event in the south east Equatorial Pacific core RC11-220 and the south central North Atlantic core CH61-171 (Haq *et al.* 1977). Thus the abundance top of *G. quadrilobatus fistulosus* at Site 289 is coeval with its supposed 'extinction' in the Atlantic, and correlates with the Pliocene/Pleistocene boundary stratotype.

Additional foraminiferal events have been suggested to correlate with the 'Pliocene/Pleistocene' boundary, including the top occurrence of *Globorotalia limbata* and *Globigerina rubescens decoraperta* and the first appearance of *Globigerina tenellus*. Vincent *et al.* (1974) report that many of these events are either contemporaneous with, or slightly older than, the lowest common occurrence of *G. truncatulinoides* (= their boundary indicator), however, the sequence of events is not consistent. Ericson *et al.* (1963) recognise the Pliocene/Pleistocene boundary on the basis of a coiling change in the *Globorotalia menardii* complex. At Sites 214 and 289 a distinct right-to-left coiling change of *G. cultrata s.l.* (= their *menardii*) occurs at the base of *G. truncatulinoides* (Figures 28 and 31 respectively). Changes in the relative abundance of taxa across this datum are relatively minor at Site 214 in comparison with the mid-Pliocene assemblage changes (Figure 29).

PLEISTOCENE

SITE 214

Significant Pleistocene events at Site 214 are outlined on Figure 32. The term Holocene, postglacial Pleistocene, is regarded as biostratigraphically indistinct in terms of planktonic foraminiferal biostratigraphy and unworthy of recognition as a separate Series. The term Recent is used in an informal sense of extant. The occurrence of species recognised and samples examined at this site are shown on Figure 27.

Blow (1969) informally recognises two subdivisions of the post-Pliocene, Zones N.22 and N.23, although most workers have not been able to consistently recognise these zones. At Site 214 *Sphaeroidinella dehiscens excavata*, confined to Zone N.23 according to Blow (1969), is found as low as earliest Zone N.22, (?)late Zone N.21. *Globigerina calida s.s.* is present as low as 214-1-3 Top.

Brönnimann and Resig (1971) formally define the Zone N.22/N.23 boundary on the basis of the evolutionary appearance of *Globigerinella adamsi*. At Site 214 adult specimens of this taxon are recorded only within the topmost sample and several juvenile specimens are noted as low as 214-1-3 Top. The base of Zone N.23 at this site is therefore drawn tentatively, in view of the cryptic appearance and rarity of *G. adamsi*.

Other biostratigraphic events of significance. As mentioned in the discussion of the Pliocene/Pleistocene boundary, *Globigerinoides quadrilobatus fistulosus* ranges in abundance to within the lower part of Zone N.22 although rare specimens range into the upper part of Zone N.22. This abundance top at Site 214 correlates with a similar trend at Site 289 where the calcareous nannofossil evidence (as discussed earlier) suggest a correlation with the top of the Olduvai Palaeomagnetic Event. Thus this abundance top correlates with its 'extinction' level in the Atlantic cores and several Pacific cores outlined by Haq *et al.* (1977) and also correlates with Datum 3 of Hays *et al.*

(1969). The last occurrence of (rare) *G. quadrilobatus fistulosus* at Site 214 occurs just below the base of dominantly right-coiled *Pulleniatina* spp. (dated at about 0.85 Ma by Saito *et al.* 1975), (Figure 32), which is correlated to the upper part of the Matuyama Palaeomagnetic Epoch and thus dated at approximately 1.0 Ma.

The last occurrence of this taxon is allochronous as Bielak and Briskin (1978) record a 1.3 Ma age for its disappearance in the equatorial Pacific core RC11-220 while data from Site 289 suggests an 'extinction' younger than 0.9 Ma.

The last appearance of *Globorotalia tosaensis* within the Pleistocene is also variable, ranging from just above the Olduvai (1.6 Ma) to within the Brunhes Palaeomagnetic Event (0.7 Ma) (references in Bielak and Briskin, 1978). *G. tosaensis* last occurs in 214-2-2 Top, judged to be at about 0.9 Ma on the basis of multiple quantitative events and their correlation to the palaeomagnetic time-scale, as outlined later.

The evolution of *Pulleniatina obliquiloculata finalis* from *Pulleniatina obliquiloculata s.s.* occurs above the *G. truncatulinoides* Datum and below the abundance top of *G. quadrilobatus fistulosus* and is therefore a guide to the Pliocene/Pleistocene boundary.

Selected quantitative aspects extracted from the Pleistocene assemblages of Site 214 include the coiling histories of *Pulleniatina* spp., *Globorotalia tumida s.s.*, *Globorotalia cultrata s.l.*, *Globorotalia crassaformis* and *Neogloboquadrina* spp. and the relative abundances of selected taxa which are based on counts of 500 specimens.

At Site 214 (Figure 32) there is a broad left-coiling peak of *Pulleniatina* spp. at the base of *Globorotalia truncatulinoides* followed by a return to right-coiling, interrupted later in the Early Pleistocene by a minor left-coiling excursion. The Pleistocene trends of the western Indian Ocean core RC12-327, documented by Saito (1976), show a similar trend to Site 214, differing mainly in the amount of 'noise' generated by a closer sampling density. From his core, the first downhole occurrence of less than 95% right-coiled *Pulleniatina* spp. occurs between the base of the Brunhes Normal Epoch and the top of the Jaramillo Event of the Matuyama Reversed Epoch, dated at approximately 0.8 Ma. The timing of this coiling event is virtually synchronous throughout the equatorial Indo-Pacific (Saito, 1976). Thus core 1 of Site 214 lies within the Brunhes Epoch and cores 2 and 3 (part) lie within the Matuyama Epoch.

Figure 32 shows a right-coiling excursion of *Globorotalia tumida s.s.*, within the mid-Pleistocene of Site 214, away from a dominance of left-coiled specimens. This distinctive trend occurs just below the 0.8 Ma *Pulleniatina* spp. coiling event outlined above and is judged to be at approximately 0.9 to 1.0 Ma. Vincent *et al.* (1974) report right-coiled *Globorotalia tumida* within the Pleistocene of several Gulf of Aden DSDP sites after allowance is made for their Pliocene/Pleistocene boundary definition. At these sites this coiling event occurs above the extinction of *Globorotalia limbata* and below the base of the common occurrence of *Globorotalia truncatulinoides*. A similar coiling peak is outlined later in the Pleistocene of Site 217A.

Of the few Pleistocene samples examined all contain dominantly left-coiled *Globorotalia cultrata s.l.* (Figure 28). A much closer sample spacing is required in order to resolve the coiling fluctuations observed by Kierstead *et al.* (1969) for the Pleistocene in several equatorial Pacific deep-sea cores.

The Site 214 coiling history of *Globorotalia crassaformis* is shown on Figure 32. This species is rare from the base of *G. truncatulinoides* to the top of core 2 and becomes (relatively) more abundant within core 1. In this core it is dominantly left-coiled becoming dominantly right-coiled in the top two core-sections within Zone N.23 and the calcareous nannofossil *Emiliania huxleyi* Zone (Gartner, 1974). A similar trend is noted in several cores from the central equatorial Indian Ocean documented by Oba (1969) and in core 7 of Site 262, situated in the Timor Trough (Rögl, 1974), the transition also occurring within the *E. huxleyi* Zone (Proto Decima, 1974).

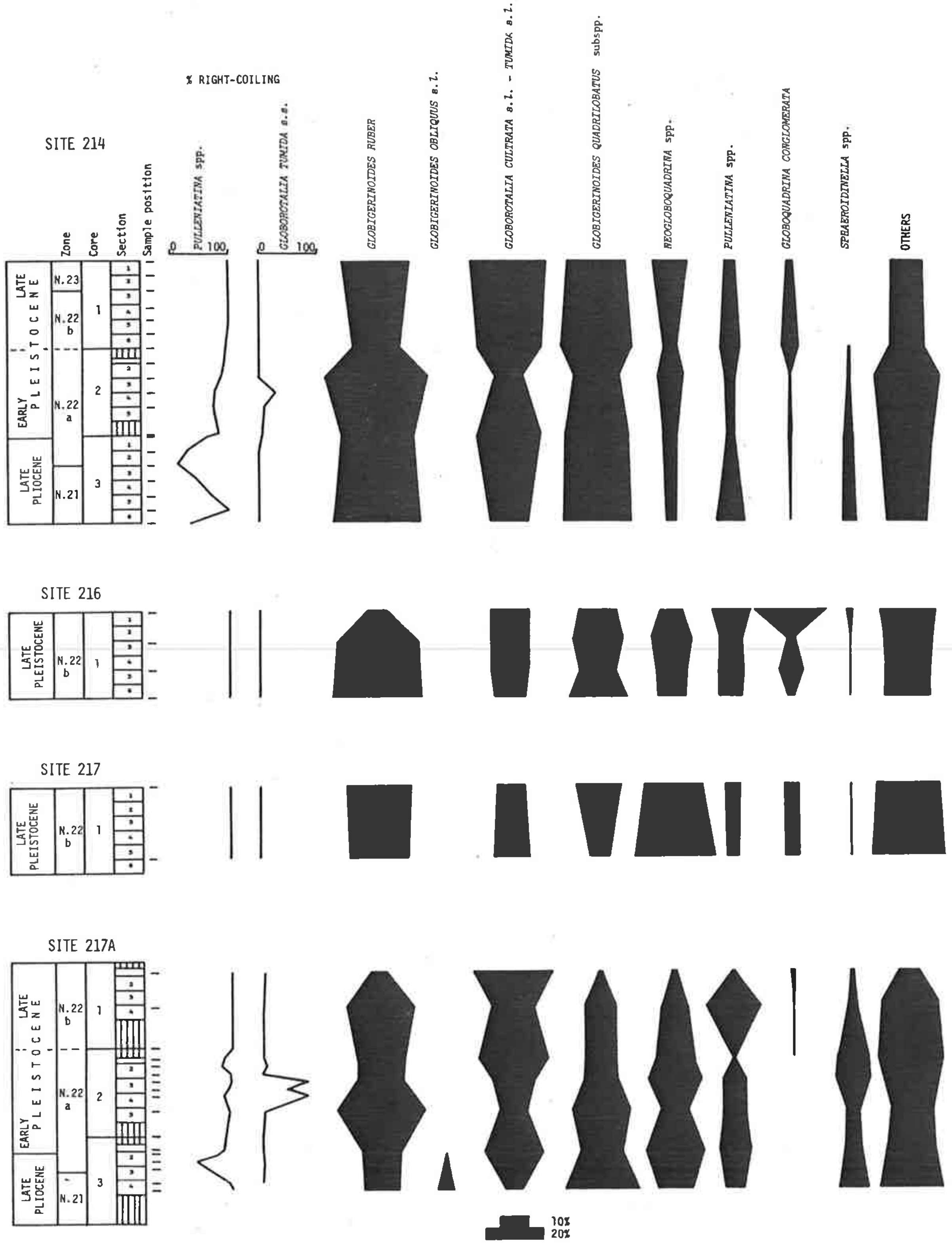

FIGURE 33. Pleistocene relative abundance trends, based on counts of 500 specimens per sample, and coiling trends of *Pulleniatina* spp. and *Globorotalia tumida s.s.* at Sites 214, 216, 217/217A.

All Pleistocene samples contain almost 100% right-coiled *Neogloboquadrina* spp. with no indication of variation from this theme expressed within the limits of my sampling and counting.

Within the mid-Pleistocene a number of other quantitative trends of potential biostratigraphic significance have been described, some of which are present in Site 214. In particular, a reduction in abundance of *Sphaeroidinella dehiscens s.l.*, associated with the base of the Brunhes Normal Epoch, is recognised by Glass *et al.* (1967), Hays *et al.* (1969) and Berggren and Van Couvering (1974). The investigations of Saito (1976) reveals an essentially synchronous coiling change from left-to-right in *Pulleniatina* spp., between the top of the Jaramillo Normal Event and the base of the Brunhes Normal Epoch as outlined earlier. A similar trend is also reported by Hays *et al.* (1969). A reduction in the abundance of *Pulleniatina* spp. is noted by Berggren (1968b) at the top of the Jaramillo Event in a North Atlantic deep-sea core while Kaneps (1973) records a reduction in the abundance of *Pulleniatina* spp. at the same stratigraphic level as the distinctive coiling change from left-to-right in *Pulleniatina* spp. in several eastern equatorial Pacific DSDP sites. At Site 214 the reduction in abundance of *Sphaeroidinella dehiscens s.l.* occurs over the same interval as the coiling change in *Pulleniatina* spp., that is, near the top of core 2 to the base of core 1 (Figure 33) and, together, are regarded as synchronous in terms of the samples analysed quantitatively to date and within the limits of planktonic foraminiferal biostratigraphic resolution. The essential synchroneity of these combined events provides a useful subdivision of the Quaternary at Site 214 enabling recognition of an informal 'upper' Zone N.22 and 'lower' Zone N.22. In addition to the assemblage changes outlined above both *Globorotalia crassaformis* and *Globoquadrina conglomerata* become more abundant in 'upper' Zone N.22 than in the 'lower' Zone N.22.

Berggren and Van Couvering (1974) show the Zone N.22/N.23 boundary to correlate with the reduction in abundance of *Sphaeroidinella dehiscens s.l.*

At Site 214 the bases of *Sphaeroidinella dehiscens excavata* and *Globigerina calida s.s.*, which define the base of Blow's (1969) informal Zone N.23, do not correspond with this horizon nor does the base of *Globigerinella adamsi* which is the basis for the recognition of the base of Zone N.23 as redefined by Brönnimann and Resig (1971). The base of *G. adamsi* is well above this *Pulleniatina* spp. coiling horizon in the southwest Pacific DSDP sites examined by Brönnimann and Resig (1971). Therefore the base of Zone N.23, as recognised by Blow (1969), Berggren and Van Couvering (1974) and Brönnimann and Resig (1971), is not synchronous.

SITES 216, 217/217A

Sites 216, 217 and 217A were drilled further north along the Ninetyeast Ridge in deeper water than Site 214. The planktonic foraminiferal assemblages reflect both the deeper water aspect and the more equatorial locality. The abundance of isolated *Globorotalia* spp. keels and the relatively greater abundance of fragmentary tests testifies to the deep-water biofacies while the more tropical aspect is exemplified by the presence of *Beella digitata* and the rarity of *Globorotalia truncatulinoides*.

Site 216, drilled in a water depth of 2247 metres, recovered only one core of Pleistocene age, as indicated by the presence of (rare) *Globorotalia truncatulinoides*. The coiling trends of *Pulleniatina* spp., *Globorotalia tumida s.s.* (Figure 33), *Globorotalia cultrata s.l.* and *Neogloboquadrina* spp., together with rare *Sphaeroidinella dehiscens* and abundant *Globoquadrina conglomerata* (Figure 33) indicate a maximum age of 'upper' Zone N.22. *Globorotalia crassaformis* is common throughout and is dominantly left-coiled except in section 1 which contains randomly coiled specimens. *Globigerinella adamsi* is only tentatively recognised supporting a Late Pleistocene age. In terms of nannofossil biostratigraphy, Gartner (1974) records the extinction of *Pseudoemiliania lacunosa* at the base of core 1 and the basal occurrence of *Emiliania huxleyi* in the upper half of the core. These events are dated at 0.458 Ma and 0.268 Ma, respectively, by Thierstein *et al.* (1977).

Site 217, drilled in a water depth of 3020 metres on the eastern flank of the Ninetyeast Ridge, recovered one core of Pleistocene age. The presence of well-preserved *Globigerinoides ruber*, one of the most solution-susceptible species (Berger, 1968), in association with isolated *Globorotalia* spp. keels suggests the possibility of a 'mixed' assemblage although other evidence of faunal reworking is not evident. An age of 'upper' Zone N.22 is indicated by the dominantly right-coiled trend of *Pulleniatina* spp., the rarity of *Sphaeroidinella dehiscens* and the abundance of *Globoquadrina conglomerata* (Figure 33). *Globorotalia crassaformis* is relatively common and dominantly left-coiled throughout this core. The presence of the nannofossil *Pseudoemiliania lacunosa* as high as section 4 (Gartner, 1974) provides an approximate minimum age of 0.5 Ma for the base of the core. The presence of *Emiliania huxleyi* in section 1 (Gartner, 1974) and the absence of right-coiled *G. crassaformis* suggest that the top of this core is probably no younger than about 0.25 Ma.

Site 217A was 'continuously' cored throughout the Pleistocene. Important biostratigraphic events for this site are shown on Figures 32 and 33. Planktonic foraminifera from section 1 of core 1 are very poorly preserved as shown by the abundance of *Globorotalia* spp. keels; a low planktonic/benthonic ratio of 218/96 together with lower diversity and greater dominance of planktonic foraminiferal species than in other sections (Figure 33). *Globorotalia truncatulinoides* is rare to absent throughout most of the Site 217A Pleistocene so that the Zone N.21/N.22 boundary was determined by several independent criteria that cluster around the *G. truncatulinoides* Datum in the more complete section at Site 214. At Site 217A the extinction of *Globorotalia multicamerata* occurs just below the basal occurrence of *Pulleniatina obliquiloculata finalis* and the last occurrence of *Globigerinoides quadrilobatus fistulosus* (Figure 32) bracketing an interval within sections 2 and 3 of core 3. The *G. truncatulinoides* Datum is bracketed by these events at Site 214. Also at Site 214 (and Site 289), this datum lies just below a broad left-coiled peak of *Pulleniatina* spp., below an interval of dominantly right-coiled *Pulleniatina* spp. A similar coiling pattern is apparent at Site 217A

(Figure 32) supporting correlation of the *G. truncatulinoides* Datum to within sections 2 and 3 of core 3.

In terms of the radiolarian zonation, the extinction of *Pterocanium prismatium* occurs above the base of *G. truncatulinoides* (Hays *et al.* 1969). Johnson (1974) records this radiolarian extinction between sections 2 and 3 of core 3 at Site 217A. The extinction of *Discoaster* spp. also approximates this zone boundary in Site 214, at Site 217A however, *Discoaster* spp. are present as high as sample 217A-1-1 131-133 cm (personal observation) indicating reworking. Neither Gartner (1974) or Bukry (1974a) discuss the nannofossils from this site.

The last occurrence of *Globigerinoides quadrilobatus fistulosus* is coeval with the base of *Pulleniatina obliquiloculata finalis* and is just above the distinctive *Pulleniatina* spp. left-coiling excursion which correlates with 'lower' Zone N.22 at Site 214. Therefore, the last occurrence of *G. quadrilobatus fistulosus* in Site 217A correlates with its abundance top in Site 214 and thus with the Pliocene/Pleistocene boundary.

Within the Pleistocene *Globorotalia tumida s.s.* is dominantly left-coiled except for a major right-coiling excursion just below the relative reduction in abundance of *Sphaeroidinella dehiscens* and the basal occurrence of dominantly right-coiled *Pulleniatina* spp. (Figure 32). These events are in the same relative order as in Site 214. It is suggested that since the *G. tumida s.s.* right-coiling peak is present within 'lower' Zone N.22 in both Sites 214 and 217A it may provide a basis for further biostratigraphic resolution within this zonal interval. Encouragement is provided by Vincent *et al.* (1974) who report an interval of right-coiled *Globorotalia tumida s.s.* from several Gulf of Aden DSDP sites.

SITE 289

Planktonic foraminifera of Pleistocene age are present from within the middle of core 5 to the top of core 1 at Site 289, where they are generally well preserved. Species recognised versus samples examined are shown on Figure 24. Events of biostratigraphic significance are outlined on Figure 32.

As at Sites 214 and 217A, the Pliocene/Pleistocene boundary is taken at the abundance top/disappearance of *Globigerinoides quadrilobatus fistulosus*. At Site 289 this event occurs at 289-4-6 142-144cm and is above the evolutionary appearance of *Globorotalia truncatulinoides* which occurs between samples 289-5-4 143-145cm and 289-5-3 142-144cm. Rare, weakly fistulose, specimens of *G. quadrilobatus fistulosus* range as high as 289-2-1 143-145cm. The disappearance of this taxon reported by Andrews *et al.* (1975) for this site at 289-3-5 60-62cm is not regarded as biostratigraphically significant. *Globigerinella adamsi*, the Zone N.23 index species, is not present within the samples examined.

Within the Pleistocene 'upper' and 'lower' Zone N.22 are recognised as at Sites 214 and 217A. The boundary between these informal subdivisions is placed at the base of dominantly right-coiled *Pulleniatina* spp. which is correlated to just below the Brunhes Palaeomagnetic Epoch and above the Jaramillo Palaeomagnetic Event, judged to be at 0.8 Ma. The relative abundance of *Sphaeroidinella dehiscens s.l.* decreases throughout the Pleistocene with occasional rapid drops. Although this is not quantified it appears to follow the two-step abundance reduction as noted by Bielak and Briskin (1978) in their Pacific deep-sea core. This mode of abundance reduction is in contrast to the one-step reduction seen in Sites 214 and 217A and may represent a degree of watermass isolation between the Indian and Pacific Oceans during the Pleistocene.

The *Pulleniatina* spp. coiling histories in Sites 289 and Site 214 (Figure 32) show broad similarities although they are not comparable in detail in some instances. In both sites there is a broad left-coiling peak just above the basal occurrence of *Globorotalia truncatulinoides*, followed by an Early Pleistocene fluctuating trend which becomes dominantly right-coiled in the Late Pleistocene. The basal occurrence of the dominantly right-coiled *Pulleniatina* spp. is present within several Indo-Pacific deep-sea cores and is correlated to the palaeomagnetic time-scale, dated at approximately 0.8 Ma (Saito, 1976). This coiling event occurs between sections 4 and 5 of core 2 and provides an important Pleistocene time-marker.

The Pleistocene of Site 289 is dominated by left-coiled *G. tumida s.s.* (Figure 32) and does not show the distinctive mid-Pleistocene right-coiling excursion as seen in the Indian Ocean Sites 214 and 217A. A degree of water-mass isolation within the Pleistocene of the Indo-Pacific is suggested by this non-parallelism of coiling trends.

A coiling change in *Globorotalia cultrata s.l.* from right (below) to left (above) occurs at the base of *Globorotalia truncatulinoides* at Site 289 (Figure 31) in the same fashion as at Site 214. The value of this event lies in its independent assessment of the proximity of the Pliocene/Pleistocene boundary in the absence of *G. truncatulinoides,* as is often the case in tropical sections.

As at Site 214, *Globorotalia crassaformis* is rare in 'lower' Zone N.22 and relatively abundant in 'upper' Zone N.22 where it is dominantly left-coiled. No trend towards right-coiling is noted at this site, even within the nannofossil *Emiliania huxleyi* Zone as determined by Shafik (1975), or in the DSDP Site 208, Lord Howe Rise, as documented by Irvine (1978).

CHAPTER 2

BIOSTRATIGRAPHIC CONCLUSIONS

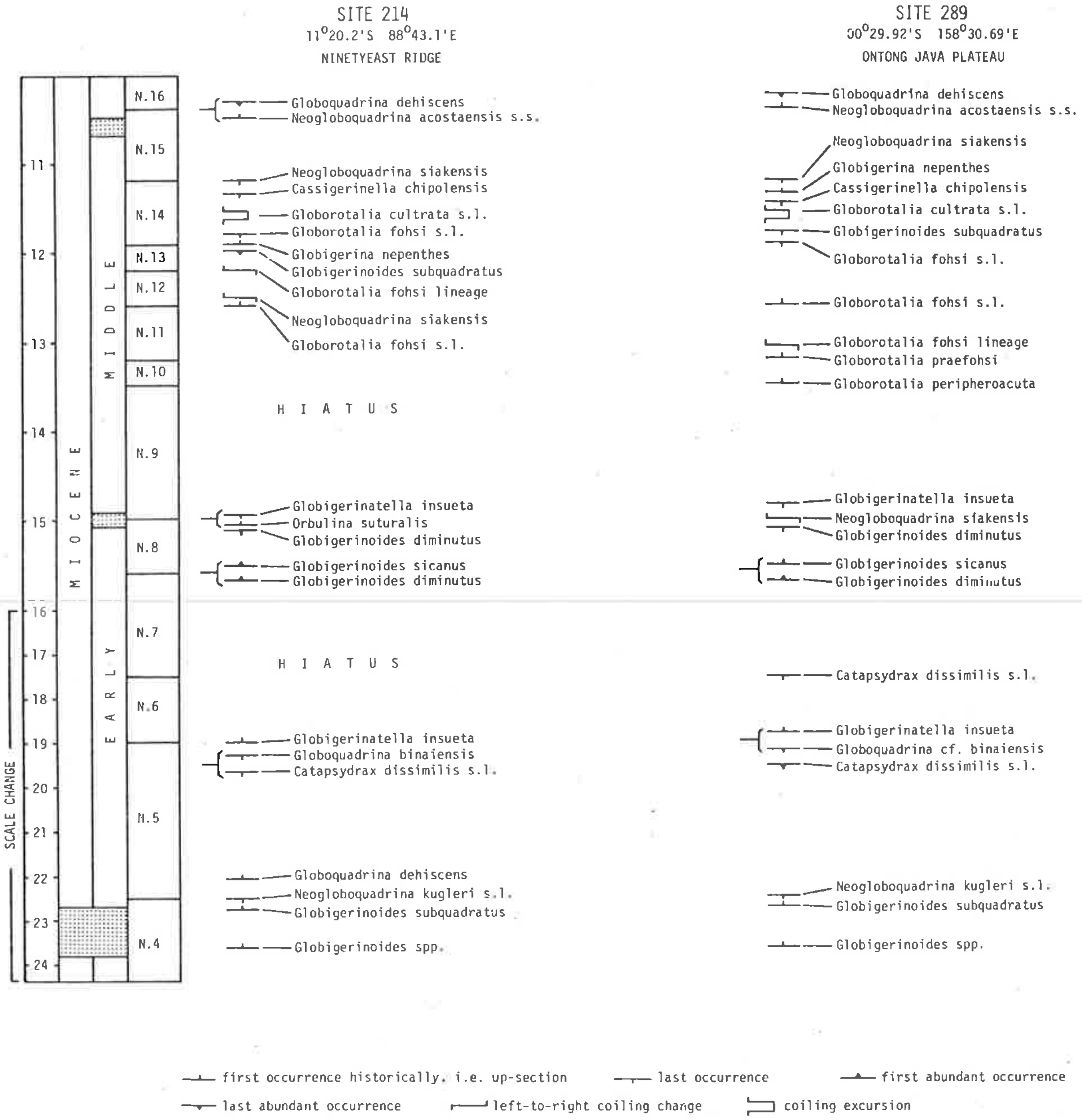

FIGURE 34. Correlation of Indo-Pacific Early Neogene planktonic foraminiferal events calibrated to the time-scale of Van Couvering and Berggren (1977).

OLIGOCENE/MIOCENE BOUNDARY

The basal, non-evolutionary, occurrence of *Globigerinoides* spp. overlaps *Neogloboquadrina kugleri s.l.* and correlates with selected radiolarian and calcareous nannofossil biostratigraphic events which in turn permit a correlation to the Oligocene/Miocene boundary stratotype.

MIOCENE

EARLY MIOCENE

Ninetyeast Ridge Sites 214 and 216/216A contain an interrupted Early Miocene sequence, the interval spanning Zones N.6 (part), N.7 and N.8 (part) being either very condensed, or absent due to a hiatus, or uncored. Site 289 contains a 'complete' Early Miocene sequence. The more important biostratigraphic conclusions, shown on Figure 34, are as follows:

Although Zone N.4 of Blow (1969) cannot be recognised as defined, the overlap of *Globigerinoides* spp. and *Neogloboquadrina kugleri s.l.* permits recognition of an interval of time, valid for these oceanic sites, informally designated here as Zone 'N.4'. The basal occurrence of *Globigerinoides subquadratus* overlaps *N. kugleri s.l.* in Sites 214 and 289 and in the Mediterranean Aquitaine Basin. The late Zone N.5 disappearance of *Catapsydrax dissimilis s.l.* in the Indian Ocean correlates with its last abundant occurrence in the Pacific. The extinction horizons of *Globoquadrina binaiensis* and *Globoquadrina dehiscens praedehiscens* approximate the Zone N.5/N.6 boundary, thus supporting Haak and Postuma (1975). Only at Site 289 does (rare) *C. dissimilis s.l.* overlap *Globigerinatella insueta* and therefore permit recognition of Zone N.7.

The morphologically distinct and relatively solution-resistant *Globigerinoides diminutus* ranges from the base of Zone N.8 at Site 289 where the Early Miocene continuity of stratigraphic record is 'complete'.

MIDDLE MIOCENE

The evolutionary stages leading up to *Orbulina* are poorly preserved even in Site 214, the shallowest (1665 metres) site examined. However, the Zone N.8/N.9 boundary is bracketed below by the disappearance of *Globigerinoides diminutus* and above by the disappearance of *Globigerinatella insueta* forming a guide to the Early/Middle Miocene boundary in the absence of the index species *Orbulina suturalis*. This level is also marked in the Pacific Ocean by the downhole change in coiling of *Neogloboquadrina siakensis* from dominantly left-coiled to randomly coiled. A similar trend occurs in the Indian Ocean although significantly offset to within Zone N.12. The distinction between Blow's (1969) Zones N.12 and N.13 cannot be made in the cores studied since the index species *Sphaeroidinellopsis subdehiscens* occurs lower, within Zone N.10-N.11 at Site 216A and Zone N.10 at Site 289. An alternative means of subdividing the interval from Zone N.12 to N.14, within the eastern Indian Ocean, is provided by the distinct right-to-left coiling change of *Globorotalia fohsi s.l.* The same event is present within the (relatively) faunally impoverished Java section of Bolli (1966b). *G. fohsi s.l.* also changes from right-to-left coiling in Site 289, but within Zone N.11, thus the geographic extent and synchroneity of this event for age determination is questionable. However, on the restricted geography of the eastern Indian Ocean, including the tropical Ninetyeast Ridge and Java, this coiling event is regarded as synchronous, geologically speaking, and allows the informal subdivision of the N.12-N.13 zonal interval into Zones 'N.12' and 'N.13'. The boundary between these informal zones is placed at the level of right-to-left coiling change of *Globorotalia fohsi s.l.*

The first appearance of *Globigerina nepenthes*, defining the Zone N.13/N.14 boundary of Blow (1969), and its relationship to the extinction horizon of *Globorotalia fohsi s.l.* has received much attention recently by Vincent (1977) and Berggren and Van Couvering (1978). Both reports cite the non-overlap in ranges of *G. nepenthes* and *G. fohsi s.l.* at Site 214, as documented by McGowran (1974) and Berggren *et al.* (1974). However, my investigations show an overlap in these ranges at Site 214 supporting the same overlap in the Hut Bay Formation, Little Andaman Island in the Bay of Bengal, reported by Srinivasan (1975), in DSDP Leg 9 material of the eastern equatorial Pacific (Jenkins and Orr, 1972) and in North Atlantic oceanic sections (Berggren and Amdurer, 1973). The ranges of *G. nepenthes* and *G. fohsi s.l.* are reported as not overlapping in Java (Bolli, 1966b) and Venezuela (Blow, 1959) in addition to Sites 216/216A and 289. At these two DSDP sites *G. nepenthes* overlaps *Neogloboquadrina siakensis* but not *G. fohsi s.l.* The first occurrence of *G. nepenthes* at these sites is non-evolutionary and cryptic, thus the base of Zone N.14 (*sensu stricto*) is not recognised as defined by Blow (1969). The following discussion suggests that the base of *G. nepenthes* is allochronous and the extinction of *G. fohsi s.l.* is synchronous, geologically speaking. At Sites 214, 216/216A and 289 the following events occur in relative stratigraphic order from older to younger: extinction of left-coiled *G. fohsi s.l.*, a right-coiling excursion of *Globorotalia cultrata s.l.*, extinction of *Cassigerinella chipolensis* and the extinction of *N. siakensis*. As mentioned above, the basal occurrence of *G. nepenthes* lies just below the extinction of *N. siakensis* at Site 289 (Figure 34) and Site 216. Thus the base of *G. nepenthes* is out of phase with these three events at Sites 214, 216/216A and 289 and in view of the fact that the base of *G. nepenthes* at Sites 216/216A and 289 is non-evolutionary and cryptic the base of *G. nepenthes* is considered allochronous. The disappearance of *Globigerina falconensis* also coincides with the extinction of *G. fohsi s.l.* at both Sites 214 and 289 supporting this assessment. Accordingly the extinction of *G. fohsi s.l.* is taken to approximate the Zone N.13/N.14 boundary in those sites in which *G. nepenthes* is rare or absent in pre-Zone N.15 assemblages, while the *G. cultrata s.l.* right-coiling excursion occurs within the lower part of Zone N.14 and the extinction of *C. chipolensis* occurs within the later part of Zone N.14.

The 'last occurrence'/abundance top of *Globigerinoides subquadratus* is also allochronous within the Middle Miocene. Most reports indicate this species to range above the extinction of *G. fohsi s.l.* (Bolli and Bermúdez,

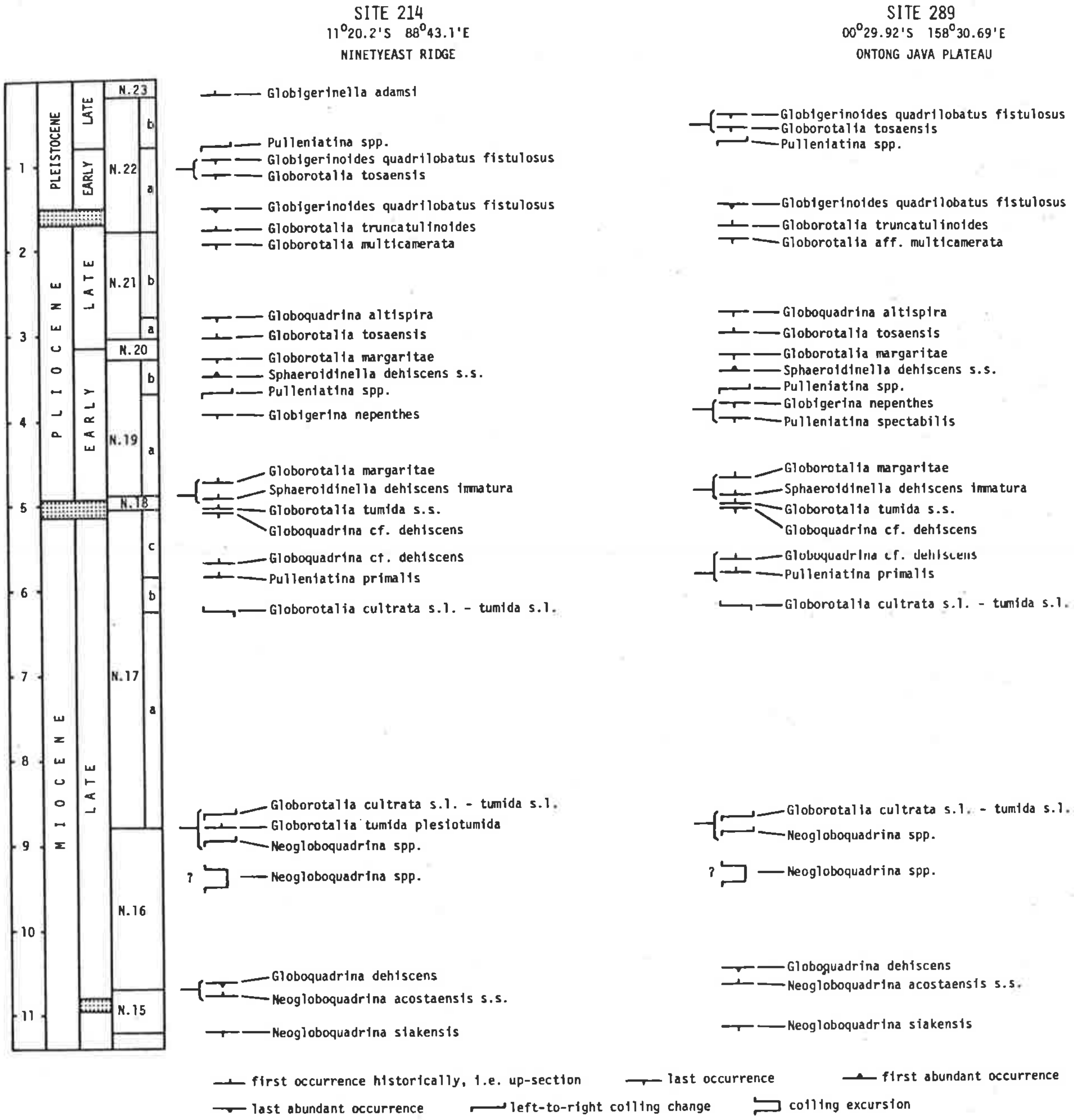

FIGURE 35. Correlation of Late Neogene planktonic foraminiferal events calibrated to the time-scale of Van Couvering and Berggren (1977).

1965; Bolli, 1966b; Haak and Postuma, 1975). At Site 214, the last abundant occurrence of *G. subquadratus* is just below the extinction of *G. fohsi s.l.* although the last occurrence of (rare) *G. subquadratus* may range as high as Zone N.16.

LATE MIOCENE

The zonal scheme of Blow (1969) is found inadequate to provide consistent biostratigraphic resolution within the middle to later part of the Late Miocene. The evolutionary appearance of *Neogloboquadrina acostaensis s.s.*, *Pulleniatina primalis* and *Globorotalia tumida s.s.* are perhaps the most useful evolutionary events that characterise this interval. Blow did not, however, use the evolution of *P. primalis* in his formalised biostratigraphic scheme.

The evolution of *Globorotalia tumida plesiotumida* from *Globorotalia merotumida* is not regarded with enthusiasm as an event of 'golden spike' significance, because of its relative rarity and difficulty in recognition, as stated by Parker (1973) and endorsed here. Other events of biostratigraphic significance within this otherwise relatively barren interval emerge from this study of Sites 214, 216/216A, 217/217A and 289.

In the eastern Indian Ocean Sites 214 and 216A, *Globoquadrina dehiscens* rapidly decreases in abundance across the Zone N.15/N.16 boundary before becoming 'locally' extinct shortly thereafter. A morphotype referred to as *Globoquadrina* cf. *dehiscens* appears in latest Zone N.17, just above the base of *Pulleniatina primalis* (Figure 35).

A disjunct range of *Globoquadrina dehiscens* is reported in the western Indian Ocean DSDP Site 236 by Vincent *et al.* (1974). At that site it disappears in the late Middle Miocene and reappears later in association with *Pulleniatina primalis* and within the nannofossil *Ceratolithus primus* Zone (Roth, 1974; Bukry, 1974c). This Late Miocene occurrence of *G. dehiscens* at Site 236 is recorded by Vincent *et al.* (1974) in Zone N.16 and early Zone N.17; however, the nannofossil evidence and presence of *P. primalis* (downhole contamination notwithstanding) is clear evidence for a latest Late Miocene age.

The disappearance of *Globoquadrina dehiscens* on land-based sections in Pakistan (Kureshy, 1977), Java (Bolli, 1966b) and Irian Jaya (Visser and Hermes, 1962) corresponds to the base of *Neogloboquadrina acostaensis* and therefore to the Zone N.15/N.16 boundary. *G. dehiscens* is not recorded as reappearing later within these sections. It will be shown later that a hiatus is present in Bolli's Java section that includes the later part of Zone N.17.

In Site 289, *Globoquadrina dehiscens* has a history similar to Site 214, disappearing near the Zone N.15/N.16 boundary (Figure 35) and reappearing in latest Zone N.17 near the base of *Pulleniatina primalis*. Further south, Palmieri (1975) shows the extinction of *G. dehiscens* occurring at the Zone N.15/N.16 boundary in the Aquarius-1 well of the Capricorn Basin, offshore eastern Australia. Kennett (1973) records *G. dehiscens* from within his Late Miocene *Globigerina nepenthes* Zone (Site 208) and his *Globorotalia continuosa* Zone (Site 207A) and as an isolated occurrence within Zone N.18 of the Coral Sea Site 210. The correlation of his Late Miocene zones to Sites 214 and 289 is not sufficiently clear to establish whether either the (early Late Miocene) top of *G. dehiscens* or his zones are allochronous. Jenkins (1971) reports a disjunct range of *G. dehiscens* in New Zealand, disappearing within his Late Miocene *G. (G.) miotumida miotumida* Zone and later reappearing, questionably, within sediments assigned to his Early Pliocene *G. (T.) inflata* Zone.

In the Atlantic Ocean, Berggren and Amdurer (1973) show *G. dehiscens* as disappearing just above the Zone N.15/N.16 boundary at Site 149. A similar relationship is reported by Miles (1977) for Leg 37 Atlantic DSDP sites.

Berggren (1977b) suggests that the extinction of *Globoquadrina dehiscens* occurs just below the evolutionary appearance of *Globorotalia tumida s.s.* and that both events can be used to recognise the Miocene/Pliocene boundary. The extinction of *G.* cf. *dehiscens* in Sites 214 and 289 (Figure 35) does indeed correspond closely to the evolutionary base of *Globorotalia tumida s.s.*, though this taxon is very rare in latest Miocene sediments. However, this extinction event is less than synchronous even in the Indian Ocean since *G. dehiscens* is reported as ranging into the Early Pliocene of the Andaman Islands as well as in the Great Australian Bight (southern Indian Ocean) (Kennett and Srinivasan, 1975; Vincent, 1977). In contrast, the extinction or local disappearance of *Globoquadrina dehiscens* near the Zone N.15/N.16 boundary is recognisable in the Indian, Pacific and Atlantic Oceans over a wide latitudinal range, and therefore assumes biostratigraphic significance. This event offers an important link in Late Miocene tropical-extratropical correlation if the same event in New Zealand is synchronous with the tropics, as is suggestive by the evidence of Jenkins (1971).

Quantitative and qualitative Late Miocene events, outlined in detail on Figure 21 and partly summarised on Figure 35, are clearly episodic and synchronous, geologically speaking, indicating that three distinct Late Miocene assemblages are recognisable. The oldest assemblage correlates with the interval of Zone N.16 and is characterised by rare to absent *Globoquadrina dehiscens*, abundant *Globoquadrina venezuelana s.s.*, rare to abundant and dominantly left-coiled *Neogloboquadrina* spp. and abundant, dominantly left-coiled *Globorotalia cultrata s.l.* - *Globorotalia tumida s.l.* Potential resolution within Zone N.16 is offered by a right-coiling excursion of *Neogloboquadrina* spp. The abrupt change to the next younger assemblage is indicated by the 'replacement' of *G. venezuelana s.s.* by *G. venezuelana 'praedehiscens'* and the rapid left-to-right coiling change of *Neogloboquadrina* spp. and *G. cultrata s.l.*-*G. tumida s.l.* This assemblage is correlated to the interval from the Zone N.16/N.17 boundary to latest Zone N.17. The third and youngest assemblage is heralded by the right-to-left coiling change of *G. cultrata s.l.*-*G. tumida s.l.*, the left-coiling excursion of *Neogloboquadrina* spp. and the return of *G. venezuelana s.s.* at the expense of *G. venezuelana 'praedehiscens'*. *G.* cf. *dehiscens* may be present.

The significance of these events is twofold. One is their biostratigraphic potential for recognising temporal subdivisions of the Late Miocene in the absence of reliable phyletic events; also they correlate consistently with the radiolarian and calcareous nannofossil biostratigraphy in well developed sections. Secondly, the synchroneity of such quantitative and qualitative changes in diverse members of the planktonic foraminiferal assemblages, and their close correlation to 'evolutionary' events in the radiolaria and calcareous nannofossils, suggest climatic/watermass fluctuations in an interval of time that is relatively poorly known in terms of climatic fluctuations.

When these quantitative and qualitative foraminiferal events are used in conjunction with phyletic events they permit Zone N.17 to be (informally) subdivided into three subzones, designated here as Zone N.17a, b, c, in ascending order (Figure 35). The bases of these zones are placed, respectively, at the evolutionary appearance of *Globorotalia tumida plesiotumida* and/or left-to-right coiling change of *Globorotalia cultrata s.l.-Globorotalia tumida s.l.* and *Neogloboquadrina* spp.; right-to-left coiling change of *Globorotalia cultrata s.l.-Globorotalia tumida s.l.* and evolutionary appearance of *Pulleniatina primalis* which occurs just above a left-coiling excursion of *Neogloboquadrina* spp.

Late Miocene climatic trends. Climatic trends preserved in the geological record may be interpreted from both biological (fossil) and physical/chemical data.

A sensitive indicator of climatic amelioration is provided by synchronous bipolar excursions of 'larger' foraminifera into extratropical regions. McGowran (in press a) recognises four such episodes in the Neogene of Australasia and Japan which are correlated with Zones N.4, N.8, N.9 (-?N.10) and N.14.

The Early to later Middle Miocene of the sites examined in this thesis all contain typical tropical species showing no distinct assemblage fluctuations that closely reflect these climatic events. Quantitatively, the synchroneity of coiling trends from random (Zone N.8) to preferred (Zone N.9) in *Globoquadrina altispira* (Sites 214, 216A, 289) and *Neogloboquadrina siakensis* (Site 289) across the Early/Middle Miocene boundary correlates with the second of these climatic peaks. Similarly, the right-coiling excursion of *Globorotalia cultrata s.l.* correlates with the Zone N.14 'larger' foraminiferal excursion.

Evidence from these sites for Late Miocene climatic fluctuations is similarly based on less than solid ground. Assemblage changes are subtle yet changes in selected components of these assemblages are often synchronous across the equatorial Indo-Pacific. I refer to the following synchronous events; abrupt decrease in abundance of *Globoquadrina dehiscens* at the Zone N.15/N.16 boundary and coiling changes of *Neogloboquadrina* spp. and *Globorotalia cultrata s.l.-tumida s.l.* at the Zone N.16/N.17 boundary at a time when *Globoquadrina venezuelana s.l.* was undergoing a change in morphological expression. These events correlate with 'evolutionary' events in the calcareous nannoplankton and the radiolaria, as outlined on Figure 21. The rapid fluctuations in coiling ratios in latest Zone N.17 correlates with evidence of major climatic perturbations as indicated by the Messinian evaporites and Kapitean glacigenic events. The occurrence of forms referable to the extra-tropical *Globorotalia miozea conoidea* within Zone N.17c at Sites 214 and 289 may also reflect the Kapitean cooling episode.

By inference, the correlation of right-coiling excursion of *Globorotalia cultrata s.l.* in Zone N.14 with a 'warm' episode and left-coiling in Zone N.17b-c with a 'cool' episode invites speculation that the rapid change towards right-coiling of *G. cultrata s.l.-G. tumida s.l.* at the Zone N.16/N.17 boundary, maintained to the base of the radiolarian *Stichocorys peregrina* Zone, suggests a Late Miocene 'warm' episode for the major part of Zone N.17, that is, Zone N.17a. Zone N.16, with left-coiled *Globorotalia cultrata s.l.-tumida s.l.*, was, therefore, a relatively cooler interval. The 'larger' foraminiferal T_{f3}-T_g boundary potentially reflects the climatic deterioration that heralded this Zone N.16 episode.

Biogeographic patterns of Miocene calcareous nannofossils from the Atlantic Ocean show several latitudinal changes in assemblages (Haq and Lohmann, 1976). They interpret these migrations as responses to major changes in ocean sea-surface temperatures indicating several 'climatic' episodes:

1.	Late Oligocene-Early Miocene	23-21.5	Ma	warming
2.	Early Miocene	19-17	Ma	cooling
3.	Early-Middle Miocene	15-13	Ma	warming
4.	Late Middle-early Late Miocene	13-9	Ma	cooling
5.	latest Miocene	8-5	Ma	warming

Warming episode 1 matches the Zone N.4 'larger' foraminiferal excursion of McGowran (in press a) while their Early-Middle Miocene warm peak corresponds broadly to the two late Early-early Middle Miocene climatic peaks that are resolvable in Australasian stratigraphic sections. The late Middle-early Late Miocene cooling trend corresponds to known climatic trends and transgressive/regressive trends in Australasia and the Central Paratethys (McGowran, in press a,b). An interesting aspect of their analysis is the recognition of a latest Miocene warm trend between 8 and 5 Ma age. This trend matches the Zone N.17a warm trend as suggested above on quantitative grounds, notwithstanding possible errors in the radiometric dates.

The most widely used physico-chemical tool used in Cainozoic palaeoclimatic analysis is that of oxygen isotope fluctuations. The significance of oxygen isotope ratios of planktonic foraminiferal tests is discussed by Shackleton and Kennett (1975a) who indicate that oxygen isotope ratios vary as a function of temperature and with respect to the amount of polar ice. Thus for the Neogene such isotope curves can probably be best interpreted as providing an indication of cooling and warming trends rather than directly indicating water temperature.

Although numerous oxygen isotope studies have appeared in the literature in recent years, most are confined to studies of Quaternary sediments. Far less studies examine Cainozoic trends, and of these only two have the prerequisites of closely spaced sample intervals with good biostratigraphic control, necessary for the close analysis of Late Miocene palaeoclimatic trends. I refer to the work on DSDP Sites 281 and 284 by Shackleton and Kennett (1975a,b) respectively. However, both these sites contain planktonic foraminifera of extratropical aspect making precise correlation between these sites and the tropics difficult.

A correlation of the Site 281 Late Miocene, with its oxygen isotope curve, to the tropical Site 214 is attempted, based mainly on radiolarian events. In the absence of significant foraminiferal datums within the Site 281 Late Miocene the extinction of the radiolarian *Ommatartus hughesi*, as determined by

Petrushevskaya (1975), is used to approximate the Zone N.16/N.17 boundary. *O. hughesi* is confined to Zone N.16 in Sites 214 and 216A (Johnson, 1974) and its extinction occurs near the top of the *Ommatartus antepenultimus* Zone (Riedel and Sanfilippo, 1971) which, in turn, correlates with the Zone N.16/N.17 boundary (Figure 21). The base of *Globorotalia conomiozea* at Site 281 is tentatively correlated to the top of Zone N.17a (the basis of this correlation is outlined on page 82). Within this framework the position of Site 281 cores were estimated and therefore the relative position of the samples analysed for their oxygen isotopes. In spite of the problems of sample density and correlation, some generalisations concerning climatic trends can be made. This reinterpreted Site 281 curve shows that the interval with *Ommatartus hughesi* is cooler relative to the Middle Miocene, that a warming trend is present within Zone N.17a and a post-*G. conomiozea* Datum cooling event. Evidence from New Zealand suggests that their local Kapitean stage, of latest Miocene age, is regressive and presumably resulted from an expansion of the Antarctic ice sheet.

In summary, both qualitative and sparse quantitative data suggests the following palaeotemperature trends; a 'warm' lower Zone N.14, a cooler Zone N.15 and N.16, a warmer Zone N.17a and a cooler Zone N.17b-c.

MIOCENE/PLIOCENE BOUNDARY

The evolution of *Globorotalia tumida s.s.* is used to recognise the Miocene/Pliocene boundary at these sites, where it is bracketed below by the last occurrence of (rare) *Globoquadrina* cf. *dehiscens* and above by the coeval appearances of *Sphaeroidinella dehiscens immatura* and *Globorotalia margaritae.* The lower part of Zone N.18 is characterised by a left-coiling excursion of *Neogloboquadrina* spp. and *Globorotalia cultrata s.l.-multicamerata* which, together, provide a guide to this zone of relatively short duration.

PLIOCENE

The extinction of *Globorotalia margaritae* is used to recognise the Zone

N.19/N.20 boundary in the effective absence of Blow's (1969) index species *Neogloboquadrina acostaensis pseudopima*. This event occurs above the distinct left-to-right *Pulleniatina* spp. coiling event, a firmly established biostratigraphic marker dated at about 3.7 Ma. This coiling event is used to informally subdivide Zone N.19 into 'upper' and 'lower' subzones designated as N.19a and N.19b respectively on the accompanying figures. To their credit as an index species, *Pulleniatina* spp. are relatively solution resistant thus providing an important datum in assemblages deposited between the lysocline and the calcium compensation depth in which the zonal index species may be removed by calcite-solution. The N.19a/N.19b boundary is straddled by a right-coiling excursion of *Globorotalia tumida s.s.*, recognisable in both the Indian and Pacific Oceans.

The mid-Pliocene has long been recognised as a time when "much that was characteristic of the Miocene planktonic foraminiferal assemblages disappears..." Blow (1969 p.256) and the assemblages develop a more 'Recent' character. Blow (1969) considers that the top of his Zone N.19 marks this faunal change; an opinion that is supported by the rapid faunal overturn, not only evolutionary but also in terms of quantitative changes in assemblages, at the various deep-sea sites discussed herein.

The most distinctive quantitative changes in mid-Pliocene Indo-Pacific assemblages are the relative abundance changes of *Globigerinoides ruber/Globigerinoides obliquus* and *Sphaeroidinellopsis* spp./*Sphaeroidinella* spp. The basal occurrence of abundant *G. ruber* occurs in Zone N.19b at Site 289 and in basal Zone N.20 at Site 214. Evidence from Sites 216/216A and 217/217A is not sufficient to determine the biostratigraphic significance of this offset as such an offset could be an artifact of incomplete coring. This is suggested at Site 214 by the abundance of *G. ruber* at the base of core 5 (= base of Zone N.20) in comparison with its relative rarity in the top of core 6 (within Zone N.19b). The base of abundant *Sphaeroidinella dehiscens s.l.* however, is within Zone N.19b in both Indo-Pacific sites (Figure 35) and significantly offset from its Zone N.21 base in the Atlantic as reported by Berggren and Van Couvering (1974).

Within early Zone N.21 *Globoquadrina altispira* rapidly disappears at

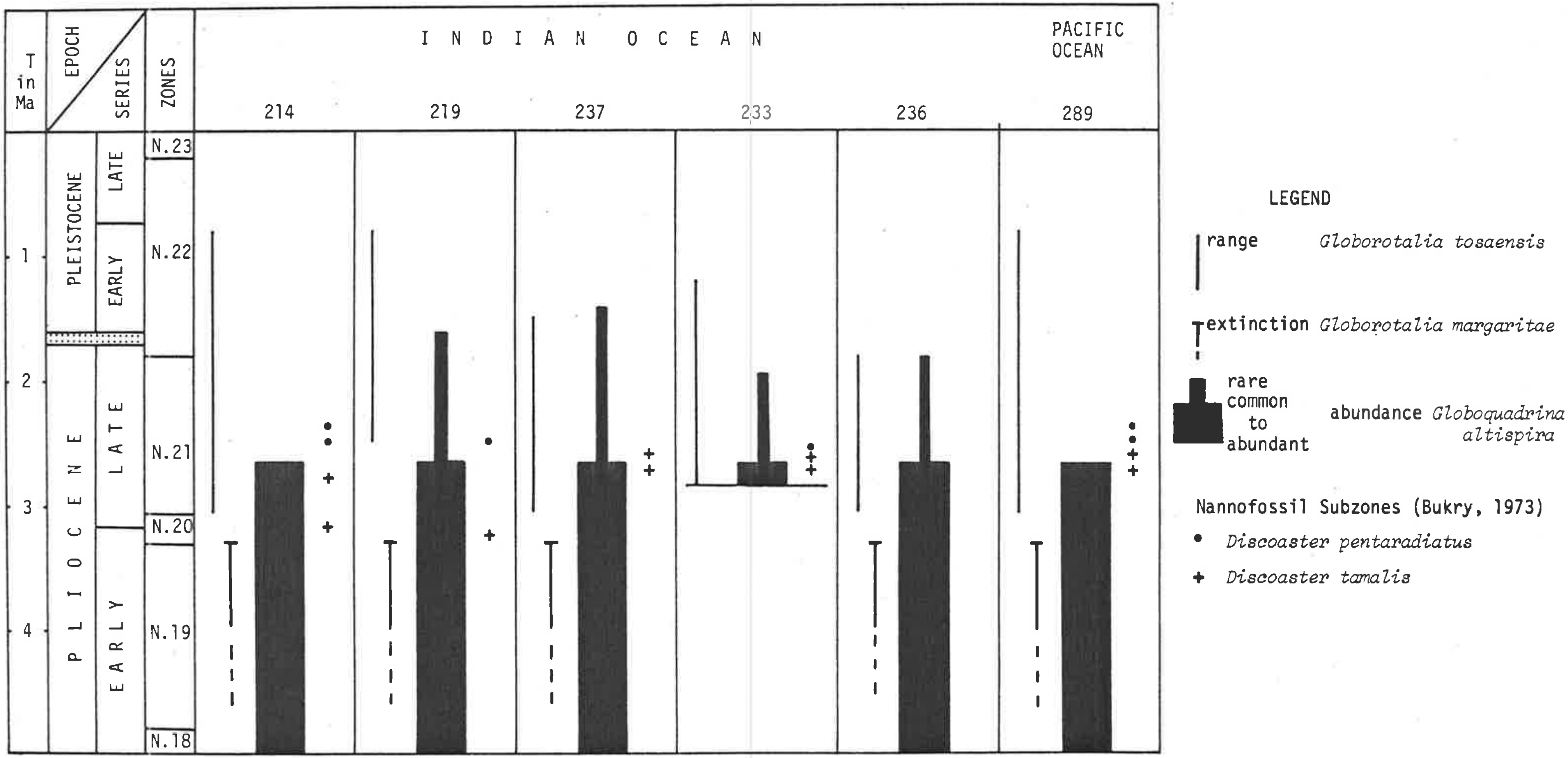

FIGURE 36. Correlation of Late Neogene occurrences, and relative abundances, of *Globoquadrina altispira* in selected Indo-Pacific Deep Sea Drilling Project Sites.

Site 214. A similar abundance decrease, overlapping the range of *Globorotalia tosaensis* and hence of Zone N.21 age, is noted in the biostratigraphic reports of the Indian Ocean DSDP Sites 233, 236 and 237 (Figure 36). At Site 219 the conjugate events, a rapid abundance decrease of *G. altipsira* and the first appearance of *G. tosaensis* are recorded but do not fit the above pattern. An independent check using the nannofossil data of Bukry (1974a,b) for Sites 214 and 219 suggests that the restricted range of *G. tosaensis* relative to the abundance decrease of *G. altispira* is, in Site 219, a function of its rarity as recorded by Fleisher (1974, p.1003). That is, the abundance-top of *G. altispira* is of early Zone N.21 age and not of Zone N.19-20 age (Table 1A of Fleisher, 1974). The final appearance of *G. altispira* is within Zone N.21 at Sites 214, 233, 236, and within Zone N.22 at Sites 219 and 237. Blow (1970b) similarly recognises the variability of the extinction horizon of *G. altispira*.

Figure 36 illustrates the abundance decrease or local extinction of *Globoquadrina altispira* in terms of planktonic foraminiferal and nannofossil events. The foraminiferal data for this figure is extracted from Fleisher (1974) and Vincent *et al.* (1974); nannofossil information is taken from Bukry (1974a,b,c) with supplementary information from Roth (1974).

In terms of the nannofossil zonal scheme of Bukry (1973) the *G. altispira* event occurs between samples assigned to the *Discoaster tamalis* Subzone and the *Discoaster pentaradiatus* Subzone in Sites 214 and 219. The same event is recorded within the *D. tamalis* Subzone at Sites 233 and 237. That is, the abundance event of *G. altispira* occurs probably within the later part of the *D. tamalis* Subzone.

It is concluded that this event is most likely synchronous within these Indian Ocean DSDP sites and also it is of greater potential biostratigraphic significance, at least within the deep-sea tropical Indian Ocean than the often distinctly variable last occurrence of *G. altispira*. *G. altispira* disappears during the middle normal-magnetic Gauss Palaeomagnetic Event in the core V20-163, at about 2.8 Ma, correlating with its extinction in the South Atlantic as documented by Berggren (1977b). The timing of the last occurrence of abundant *G. altispira* in Site 289 matches its extinction or abundance decrease in the Indian Ocean DSDP Sites as shown in Figure 36. That is, the extinction or abundance decrease occurs within Zone N.21 and towards the top of the nannofossil *Discoaster tamalis* Zone as recognised in this site by Shafik (1975). Accordingly this foraminiferal event is used to subdivide Zone N.21 into two subzones which are informally designated here as Zone N.21a and b.

Within the Indo-Pacific the relative positions of significant biostratigraphic events are internally consistent. There is, however, evidence that suggests some degree of faunal isolation between the two watermasses. That is, the Early Pliocene *Pulleniatina spectabilis* lineage is present within tropical Pacific deep-sea cores but has yet to be found in the Indian Ocean, while the Pliocene *Beella nicobarensis* is restricted to the Pliocene sediments of the northeast Indian Ocean. Another difference includes the lack of detailed correlation of the late Pliocene-Pleistocene *Pulleniatina* spp. coiling trends. Additional deep-sea sequences need to be examined in order to estimate the effects of these differences with respect to site locality and regional watermass differences.

PLIOCENE/PLEISTOCENE BOUNDARY

The Pliocene/Pleistocene boundary stratotype is judged to correlate with the top of the Olduvai Palaeomagnetic Event which is bracketed by the sequential appearance of *Gephyrocapsa caribbeanica* and *G. oceanica* (Haq *et al.* 1977). The abundance top of *Globigerinoides quadrilobatus fistulosus* in the Indo-Pacific Ocean correlates with these nannofossil events and thus with the boundary stratotype. From published data, this abundance top correlates with its 'last' occurrence in many Pacific and Atlantic deep-sea cores near the top of the Olduvai Event although rare *G. quadrilobatus fistulosus* may range as high as 0.8 Ma.

The *Globorotalia truncatulinoides* Datum, often used by convention as the boundary marker in deep-sea cores, is bracketed below by the disappearance of *Globorotalia multicamerata* (in the Indo-Pacific) and above by the abundance top of *G. quadrilobatus fistulosus* and the base of *Pulleniatina obliquiloculata finalis*. This Datum is approximately coeval with the base of a distinct left-coiling peak of *Pulleniatina* spp. and a right-to-left coiling change in *Globorotalia cultrata s.l.* The abundance top of *G. quadrilobatus fistulosus* occurs near the top of this distinctive *Pulleniatina* spp. coiling excursion.

PLEISTOCENE

Comparison of these Indo-Pacific Pleistocene deep-sea cores shows the relative position of many foraminiferal events and the synchroneity of several quantitative changes in assemblages to be broadly similar, enabling the informal subdivision of Zone N.22 into an 'upper' and 'lower' interval designated Zone N.22a and b, respectively. The boundary between these subzones is placed at the distinctive coiling change of *Pulleniatina* spp. between the Jaramillo Palaeomagnetic Event and the base of the Brunhes Palaeomagnetic Epoch, dated at 0.785 Ma by Thompson and Sciarrillo (1978). In the Indian Ocean this boundary is also marked by the abundance decrease in *Sphaeroidinella dehiscens s.l.* and abundance increase in *Globoquadrina conglomerata*. In the Pacific the abundance decrease of *S. dehiscens s.l.* is more gradual throughout Zone N.22. The geographic area over which these informal subzones can be recognised is restricted to the Indo-Pacific since in several Atlantic cores this most conspicuous mid-Pleistocene *Pulleniatina* spp. coiling trend occurs near the Olduvai Event (Saito, 1976), approximately 0.9 Ma earlier than in the Indo-Pacific.

The last occurrence of *Globorotalia tosaensis* and *Globigerinoides quadrilobatus fistulosus* is allochronous, occurring within Zone N.22a in the Indian Ocean and in Zone N.22b in the Pacific. This Zone N.22b extinction of *G. tosaensis* is noted in other Pacific deep-sea cores documented by Thompson and Sciarrillo (1978). Additional aspects in the foraminiferal assemblages that are absent or not synchronous between the Indian and Pacific Oceans suggesting a degree of watermass isolation, include the presence of a right-coiled excursion of *Globorotalia tumida s.s.* within Zone N.22a of the Indian

Ocean - this is not present at Site 289. Similarly, the coiling history of *Pulleniatina* spp. is broadly similar yet detailed differences are present in addition to the differences in abundance trends of *Sphaeroidinella dehiscens s.l.* as noted above. Also *Globorotalia crassaformis* changes from dominantly left- to dominantly right coiling within the nannofossil *Emiliania huxleyi* Zone in the Indian Ocean, yet remains left-coiled throughout this zone in Site 289.

Although the Pleistocene sequence of events suggests a degree of Indo-Pacific watermass isolation, the abundance top of *Globigerinoides quadrilobatus fistulosus* and the mid-Pleistocene *Pulleniatina* spp. coiling event emerge as important biostratigraphic markers for inter-ocean correlation. This latter event is coeval with significant assemblage changes, particularly in the Indian Ocean, that correlate with evidence for the first severe cooling episode of the classical glacial Pleistocene in the Atlantic, as documented by Berggren (1968b).

The problems associated with such a, presumably, environmentally controlled event, as discussed by Berggren and Van Couvering (1974) for example, are recognised. However, the correlation of this climatic 'overprinting' indicates the geographically widespread, essentially synchronous and hence biostratigraphic value of this event, dated at about 0.8 Ma.

CHAPTER 3

ANALYSIS OF SELECTED LATE CAINOZOIC PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHIC SCHEMES.

INTRODUCTION

In the past twenty years numerous zonations based on tropical Neogene planktonic foraminifera have been described. The interval from Early Miocene to early Late Miocene was first subdivided using planktonic foraminifera by Bolli (1957). The addition of several zones by Blow (1959) extended this zonation into latest Late Miocene times. During the early 1960's several additional zonations appeared in the literature, often of local validity only, and with virtually no improvements to biostratigraphic resolution.

The documentation of a Neogene section in Java by Bolli (1964, 1966b) was an important contribution that provided a framework of species ranges and coiling directions that could be tested against other biostratigraphic sections. This work enabled Bolli and Bermúdez (1965) to extend the system of bio-zones to cover the Pliocene. Later, in 1965, a zonation covering the entire Miocene to Recent was outlined by Banner and Blow (1965) and subsequently documented in greater detail by Blow (1969). The work of Stainforth *et al.* (1975) and Bolli and Krasheninnikov (1977) represents the most recent, authoritative, correlation of these, and other, Neogene zonations erected for the tropical Indo-Pacific and Atlantic-Caribbean regions.

The planktonic foraminiferal successions at Sites 214, 216/216A, 217/217A and 289 were checked with these and other zonations, leading to the conclusion that, for these sites, the scheme of Blow (1969) is the most appropriate of the available schemes. Even so, species ranges and assemblages were often inconsistent with those documented by Blow (1969), particularly in the Late Miocene and Pliocene.

The first chapter of this thesis analysed the sites with reference to Blow's zonation. The combination of range data and selected quantitative events supports his scheme and enables an attempt to improve biostratigraphic resolution particularly within the Late Miocene and several intervals within the Pliocene and Pleistocene, as outlined in the previous chapter.

Accordingly these sites provide an important biostratigraphic framework in which to assess some of the currently used zonation schemes. Zonations

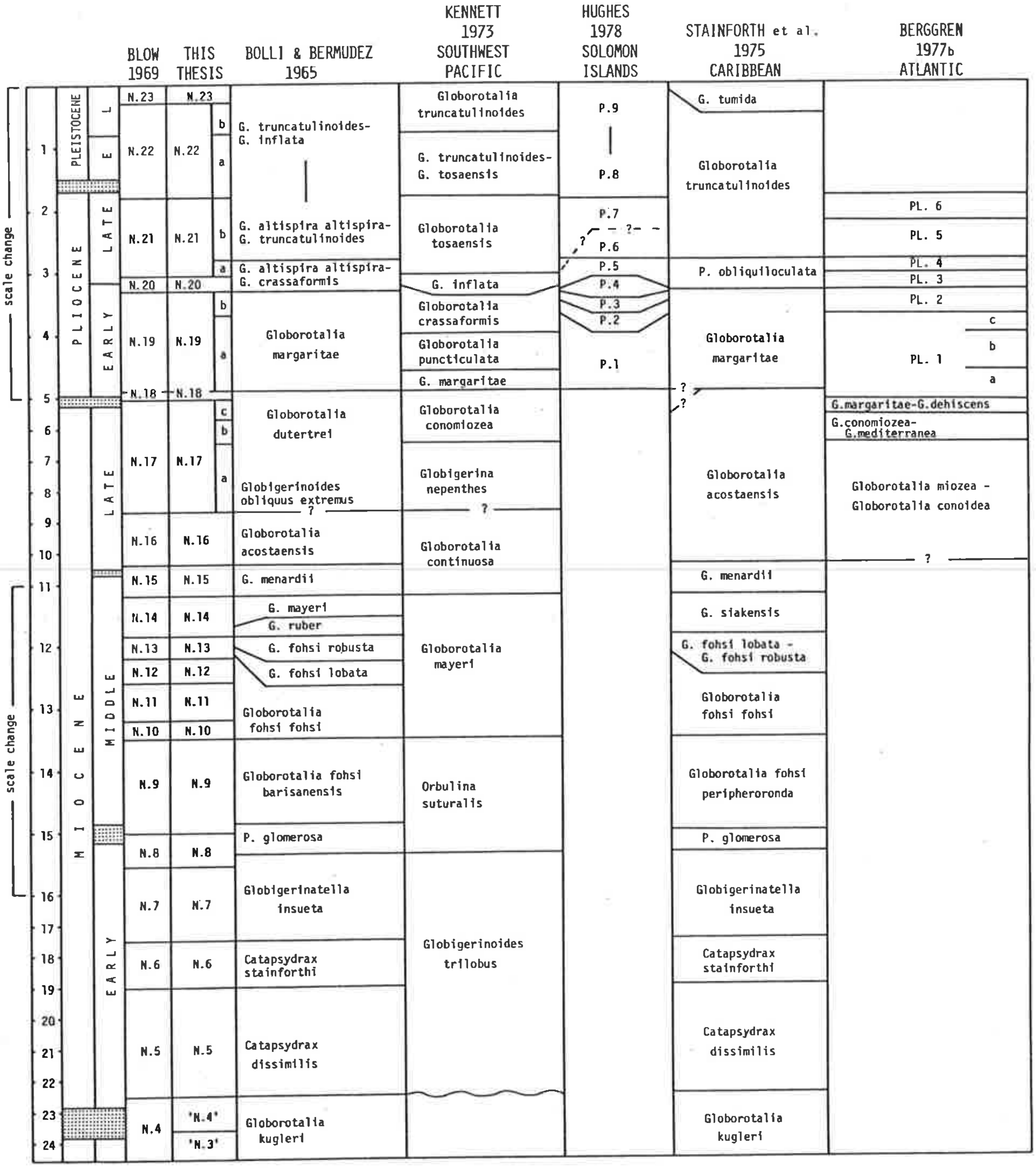

FIGURE 37. Correlation of selected Neogene planktonic foraminiferal zonation schemes.

erected for the Early to Middle Miocene (Early Neogene) are discussed separate from Late Miocene to Recent (Late Neogene) zonations. This approach is taken for the sake of convenience since Early Neogene zonations are comparatively unchanged for the past twenty years and are relatively straightforward while the Late Neogene is characterised by an abundance of zonal scheme with many discrepancies.

EARLY NEOGENE ZONATIONS

The stability of Early Neogene zonal schemes is shown by the virtual absence of significant amendments to the schemes of Bolli (1957), Bolli and Bermúdez (1965), and Blow (1969) (Figure 37). To this solid framework several other non-zone-defining events have been added as additional stratigraphic markers. Seemingly of significance is the correlation of the *Globoquadrina binaiensis* extinction with the Zone N.5/N.6 boundary by Haak and Postuma (1975). This relationship is supported at Site 214 and in the south Atlantic. The significance of the extinction of this species within (?) mid Zone N.5 at Site 216 is difficult to assess due to the state of preservation and the absence of the thin-walled Zone N.6 index species, *Globigerinatella insueta*. All of the eastern Indian Ocean Early Miocene successions examined contained either probable hiatuses or were discontinuously cored. Even so, the timing of the extinction of *Catapsydrax dissimilis/unicavus* appears questionable. This event occurs above the initial appearance of *Globigerinatella insueta* and below the first appearance of *Globigerinoides sicanus* according to many workers. In these sites *C. dissimilis/unicavus* generally disappeared within Zone N.5, that is, below the first appearance of *G. insueta*. *C. dissimilis* (rare) was present with *G. insueta* only at Site 289, while the overlap of *Globigerinoides sicanus* with *Catapsydrax* spp., as noted by Brönnimann and Resig (1971), Fleisher (1974) and Srinivasan (1977) casts doubt on the validity of the distinction between Blow's (1969) Zones N.7 and N.8 within the tropical Indo-Pacific Ocean.

The remainder of the Early Miocene to the end of the Middle Miocene is satisfactorily zoned. Differences in the two rival biostratigraphic schemes for the early Middle Miocene reflect differing morphological groupings for members of the *Globorotalia peripheroronda-Globorotalia fohsi s.l.* lineage, the evolutionary development of which provides the biostratigraphic basis for subdivision of this interval.

The biostratigraphy of Bodjonegoro-1 well, Java, forms the basis of the later part of the Middle Miocene zonation of Bolli and Bermúdez (1965) and Bolli (1966a). My assessment of this well, presented in Figure 17, indicates the following conclusions: the *Globorotalia fohsi lobata* and *Globorotalia fohsi robusta* Zones of Bolli and Bermúdez (1965) correlate with the Site 214 Zone 'N.13' and that the *Globigerinoides ruber* and *Globorotalia mayeri* Zones correlate with Zone N.14 and not with the bulk of Zone N.13 as suggested by Blow (1969). The Caribbean *G. fohsi lobata-G. fohsi robusta* Zone of Stainforth *et al.* (1975) is tentatively correlated to Zone 'N.13' (Figure 37).

LATE NEOGENE ZONATIONS

The Late Neogene is characterised by zonations, developed for numerous sections from many different geographic localities, which cannot be correlated with validity over intercontinental distances. Another feature characteristic of at least the earlier part of the Late Neogene is a decrease in stratigraphic resolution, coupled with generally conflicting age-assessments, particularly within the interval from the later Middle Miocene to the Miocene/Pliocene boundary. As a result Late Neogene zonations are discussed individually, with reference to the planktonic foraminiferal stratigraphy established at these Indo-Pacific deep-sea sites. The following section begins with an analysis of the zonation schemes of Bolli and Bermúdez (1965) and Bolli (1966a). Most subsequently described zonations generally contain elements of their scheme together with elements of the zonation of Blow (1969).

The extratropical southwest Pacific zonation of Kennett (1973) is included for the sake of completeness. The lack of extratropical elements in the sections studied in this thesis discourages a close scrutiny of his zona-

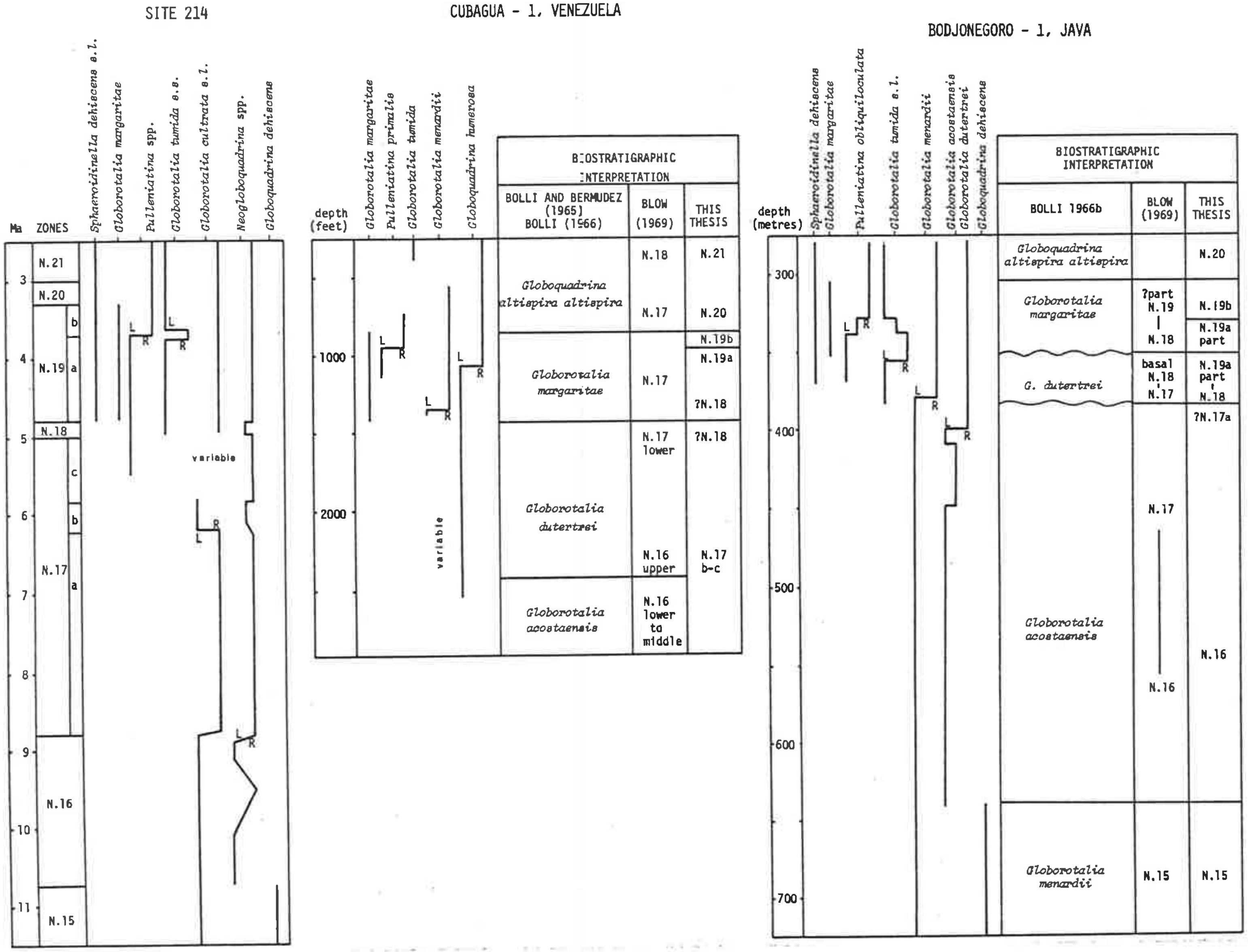

FIGURE 38. Correlation and interpretation of selected planktonic foraminiferal events at Cubagua-1, Venezuela (after Lamb and Beard, 1972), Bodjonegoro-1, Java (Bolli, 1966b) and Site 214. Wavy-line in Bodjonegoro-1 represents hiatus-bound *G. dutertrei* Zone.

tion although one problem, in particular, has emerged. As mentioned in the preceding chapter, the 'top' occurrence of *Globoquadrina dehiscens* lies near the Zone N.15/N.16 boundary and variously lies at the top of the *Globorotalia continuosa* Zone and within the *Globigerina nepenthes* Zone of Kennett. Thus it remains to be resolved whether either the (abundance) top of *G. dehiscens* or Kennett's zones are synchronous or allochronous.

THE LATE NEOGENE ZONATION OF BOLLI AND BERMÚDEZ (1965).

The biostratigraphic scheme of Bolli and Bermúdez (1965) is based on their observations in Java and the Caribbean, the Javan sequence being detailed later by Bolli (1966b). Blow (1969) found major discrepancies between his and their scheme, within their type zonal sections in both areas, suggesting that their zones are not time-equivalents. He only discussed these relationships in terms of the *Globorotalia margaritae* Zone and the *Globoquadrina altispira altispira/ Globorotalia truncatulinoides* Zone of Bolli and Bermúdez (1965) indicating that the detailed geological and palaeontological reasons for these and other discrepancies would be published later. His untimely death has so far prevented publication of these important facts.

The zonation of Bolli and Bermúdez (1965) is based, in large part, on their biostratigraphic study of the Cubagua-1 well, Venezuela, and the Bodjonegoro-1 well, Java. It is instructive to re-interpret relevant intervals of these type-sections not only in terms of their biostratigraphic zonation but also in terms of Blow's criticism of the same intervals.

The stratigraphic distribution and coiling directions of selected planktonic foraminifera from both wells, and the zonal assessment of Bolli and Bermúdez (1965), Bolli (1966b), and Blow (1969), are shown on Figure 38. For comparison, the same events at Site 214, calibrated to the time-scale of Van Couvering and Berggren (1977), are shown on the same figure. Foraminiferal data from Bodjonegoro-1 is extracted from Bolli (1964, 1966b), while data on Cubagua-1 is taken from Lamb and Beard (1972, Figure 13), as I have been unable to obtain the original range data of Bolli and Bermúdez (1965).

Blow's stratigraphic analysis of the biostratigraphy of these wells is taken from Blow (1969, Figures 16 and 31).

My biostratigraphic interpretation of these reference sections is considerably different from that of Blow (1969), although I concur with him that several of Bolli and Bermúdez' (1965) zones represent different intervals of time in different areas, but for different reasons.

The following section outlines these reasons in the discussion of each of Bolli and Bermúdez' Late Neogene zones.

Globorotalia margaritae Zone. This zone of Bolli and Bermúdez (1965) is defined by the range of the zonal marker, *Globorotalia margaritae*. Blow (1969) criticised this zone, referring it to his Zone N.17 at Cubagua-1 and to Zone N.18, ?part Zone N.19 in Bodjonegoro-1. I do not agree with Blow for the reasons given in the following discussions of the basal occurrences and extinction horizon of the nominate taxon.

At both Cubagua-1 and Bodjonegoro-1 the last occurrence of *G. margaritae* is stratigraphically above a distinct left-to-right coiling event of *Pulleniatina* spp. This relationship is also apparent within latest Zone N.19 times during the mid Pliocene in my Indo-Pacific sites. There is no unequivocal evidence in these Venezuelan and Javan wells for the precise upward limit of the range of *G. margaritae*. However, the extinction of this species is considered to occur within the order of one to two hundred thousand years above this *Pulleniatina* spp. coiling event in all deep-sea sequences that have additional foraminiferal and palaeomagnetic control. Accordingly, the extinction of *G. margaritae* is considered synchronous, geologically speaking, on an international scale.

A major discrepancy occurs between this assessment of this part of the Cubagua-1 section and that of Blow (1969). The facts are as follows: the *Pulleniatina* spp. coiling event occurs near the 950 foot level in the well and the extinction of *G. margaritae* at approximately 700 feet (Figure 38). According to my interpretation this interval correlates with Zone N.19b at Site 214, which is about 2 Ma younger than the evolutionary appearance of

Globorotalia tumida s.s. at the Zone N.17/N.18 boundary. Blow (1969, Figure 31), however, records the "development of *Globorotalia (G.) tumida tumida*" near the 400 foot level, where he places his Zone N.17/N.18 boundary. This level is stratigraphically higher, and therefore younger, than the extinction of *G. margaritae* and the *Pulleniatina* spp. coiling event. Clearly the range of *G. tumida* is foreshortened at this well, a factor not appreciated by Blow that has resulted in his unwarranted criticism of the top of Bolli and Bermúdez' *Globorotalia margaritae* Zone. Unfortunately the term 'development' as used by Blow cannot necessarily be equated to evolutionary development, and therefore everywhere synchronous, as exemplified above. As an aside, it is noteworthy that the type-level of the Zone N.17 index species *Globorotalia tumida plesiotumida* in Cubagua-2, when projected into Cubagua-1 by Lamb and Beard (1972), lies above the *Pulleniatina* spp. coiling event and below the extinction horizon of *G. margaritae*. Thus *G. tumida plesiotumida* ranges as high as Zone N.19b in Venezuela.

The following discussion on the synchroneity of the first occurrence of *G. margaritae* in the type sections of the *Globorotalia margaritae* Zone of Bolli and Bermúdez (1965), illustrates two important points. Firstly, that this event is not synchronous between these zone type sections and secondly, and perhaps more importantly, it shows how general assemblage characteristics may provide a more reliable estimate of synchroneity than the cryptic appearance of a nominate index species.

I consider the base of *G. margaritae* at about the 1400 foot level in Cubagua-1 (Figure 38) to correlate approximately with the Zone N.18/N.19a boundary of Sites 214 and 289. On the other hand, the first occurrence of *G. margaritae* in Bodjonegoro-1 (Figure 38), at about 354 metres, is considered to correlate with the later part of Zone N.19a, approximately 2 Ma younger than at Cubagua-1. These conclusions are based on the following features: In terms of planktonic ranges the basal occurrence of *G. margaritae* at about 1400 feet, at Cubagua-1, occurs below the *Pulleniatina* spp. coiling event, below the extinction of *Globigerina nepenthes* and within the range of *Globigerinoides conglobatus*. This relationship is present at Sites 214 and 289 indicating that the first appearance of *G. margaritae* occurs within the interval of latest Zone N.17 to early Zone N.19. Therefore, correlation of this event with the Zone N.18/N.19 boundary, as is the case in Sites 214 and 289 (Figure 35), is not unreasonable. Support for this correlation can be found in the close similarity in the coiling history of *Globorotalia menardii* (=*G. cultrata* group of this study) in Cubagua-1 (Figure 38; Bolli, 1964, Figure 1), and in Site 214 (Figures 28 and 38). At Site 214 the coiling of the *G. cultrata* group fluctuates from dominantly left to dominantly right during latest Zone N.17 (Late Miocene) and Zone N.18 (Early Pliocene) becoming dominantly right coiled just below the Zone N.18/N.19a boundary and persisting with this dominance throughout the Pliocene. At Cubagua-1 this group is dominantly right coiled from near the 500 foot level to about 1350 feet where it changes, downsection, to dominantly left-coiled. This changeover point is just above the basal occurrence of *G. margaritae.* The close proximity of these events reinforces the idea that the 1350 foot level in Cubagua-1 correlates with the Zone N.18/N.19a boundary and not to within Zone N.17 as determined by Blow (1969).

At Bodjonegoro-1, the basal occurrence of *G. margaritae* is associated with *Sphaeroidinella dehiscens* and is therefore of Zone N.19 age. The base range is also coeval with the only right-coiled peak of *Globorotalia tumida* (Figure 38). This coiling peak is present in all my sites that cover the middle Pliocene where it occurs immediately below the *Pulleniatina* spp. coiling peak. Where these events are reported from deep-sea sections for which there is also palaeomagnetic control, the *G. tumida* coiling event is coeval with the top of the Gilbert "a" Palaeomagnetic Event, which, in turn is of latest Zone N.19 age (Hays *et al.* 1969). The basal occurrence of *G. margaritae* in Bodjonegoro-1 is therefore correlated to just below the Zone N.19a/N.19b boundary and is foreshortened by about 2 Ma in comparison to Cubagua-1 and Sites 214 and 289.

Globorotalia dutertrei Zone. This zone is defined as the "interval with zonal markers, from its first occurrence to first occurrence of *Globorotalia* *margaritae*" (Bolli, 1966a).

In the Cubagua-1 section, Blow (1969), refers this zonal interval to within his Late Miocene Zones N.16 and N.17, based on the evolution of *Globorotalia plesiotumida* from *Globorotalia merotumida* at the 1800 foot level. However, several assemblage features shown by Lamb and Beard (1972), together with additional coiling data by Bolli (1964), suggest an alternative interpretation (Figure 38). The occurrence of *Sphaeroidinellopsis sphaeroides* (=*S. subdehiscens paenedehiscens* of this thesis) to the base of this and the earlier *Globorotalia acostaensis* Zone implies an age for the base of the section of no older than Zone N.17. Also, the coiling history of *Globorotalia menardii* as outlined on Figure 38 and expanded by Bolli (1966b, Figure 1), indicates that below the base of the *G. margaritae* Zone *G. menardii* shows rapid fluctuations in coiling preference. This variable coiling episode occurs during an interval of dominantly left-coiled *Neogloboquadrina humerosa*. All three pieces of evidence suggest that the interval at this well encompassed by both the *G. dutertrei* and *G. acostaensis* Zones are directly comparable with latest Zone N.17 - early N.18. The left-to-right coiling change of *N. humerosa* in Zone N.19a at Cubagua-1 is not present in the tropical Indo-Pacific implying a degree of watermass isolation.

In Bodjonegoro-1 well the *Globorotalia dutertrei* Zone is suggested by Bolli (1966b), to be bounded by hiatuses. A minimum age of this zone of within the lower part of Zone N.19 is indicated by the presence of *Sphaeroidinella dehiscens s.s.* in the company of left-coiled *Pulleniatina* spp. A maximum age is more difficult to pin-point although the first down-section occurrence of left-coiled *Globorotalia menardii* within the middle part of the zone, below the base of *S. dehiscens s.s.* and association with right-coiled *Neogloboquadrina* spp. suggests a correlation to within Zone N.18 of Site 214 (Figure 38). The age of the lowest part of the zone is more equivocal and is suggested here to be correlated, at the most, with the latest part of Zone N.17 to within Zone N.18 on the basis of the occurrence of left-coiled *G. menardii* and right-coiled *Neogloboquadrina* spp.

Globorotalia acostaensis Zone. This zone of Bolli and Bermúdez (1965), is defined as the "interval with zonal marker, from its first occurrence to first occurrence of *Globorotalia dutertrei*" (Bolli, 1966a).

This zone at Cubagua-1 is assigned here to the upper part of Zone N.17 on the basis of variably coiled *Globorotalia menardii* and left-coiled *Neogloboquadrina* spp. within the limits of the stratigraphic framework of Site 214 and 289 and the limits imposed by the absence of a detailed Caribbean reference section. This interpretation for this zone, and the overlying *G. dutertrei* Zone, is accordingly regarded as being tentative.

The following interpretation of this zone at Bodjonegoro-1 is considered to lie on stronger grounds for reasons of proximity to my Ninetyeast Ridge reference sections.

The topmost occurrence of *Globoquadrina dehiscens* at the base of the zone is coeval with the base of left-coiled *Neogloboquadrina acostaensis* and is within an interval of left-coiled *Globorotalia menardii*. This level corresponds to the Zone N.15/N.16 boundary of Blow (1969), and fits the pattern established for these Indo-Pacific deep-water sites (Figure 38). Above this level the ranges of taxa, including *Globigerina nepenthes, Globorotalia lenguaensis, Globigerinoides obliquus extremus* and *Sphaeroidinellopsis seminulina*, are contracted compared to their ranges observed at Site 214. Near the top of the *G. acostaensis* Zone is the (only) left-to-right coiling change of *N. acostaensis*, suggesting a correlation within the top of Zone N.16. The randomly coiled interval of *N. acostaensis* below this coiling change may correlate with the intra-Zone N.16 dextral coiling excursions in Sites 214, 216A, 217 and 289 (Figures 21 and 38). The next younger, well dated level is correlated to within Zone N.18 (see above). Above the *Neogloboquadrina* left-to-right coiling trend it is noted that *Globorotalia menardii* remains left-coiled (Figure 38) contrary to what would be expected if the section was uninterrupted. In the face of good evidence for coiling synchronism (at least within the eastern Indian Ocean) it is suggested that most of Zone N.17 is absent in this Java section and that the duration of this hiatus is in the order of 3.5 Ma approximately.

Thus the conclusion of Blow (1969) that some of Bolli and Bermúdez' (1965) zones represent different intervals of time in different places is therefore supported, but for different reasons. This analysis illustrates, in all fairness to Bolli, Bermúdez and Blow, the possible improvements to biostratigraphic resolution that have emerged over the past decade. Perhaps, more importantly, it shows that age determination as generally based on the presence or absence of index species should be tempered with an analysis of both coeval non-phyletic and quantitative aspects of the planktonic foraminiferal assemblages.

THE LATE CAINOZOIC ZONATION OF STAINFORTH *et al.* (1975)

Stainforth *et al.* (1975) reviewed the current status of Cainozoic planktonic foraminiferal zonation and presented a zonal scheme, applicable not only for tropical to subtropical areas, but also for temperate areas. It was stated by them (p.94), that "the sequence of planktonic datums is essentially the same for both the western and eastern hemispheres; thus, these provide a basis for reliable worldwide biostratigraphic correlation irrespective of the zonation scheme applied". Analysis of the sequence of events outlined by Stainforth *et al.*, in terms of the sequence of events determined at Site 214, in particular, indicates several discrepancies.

They recognise the first appearance of *Sphaeroidinella dehiscens* as being above the base of *Globorotalia crassaformis* and above the extinction horizon of *Globorotalia margaritae* and *Globigerina nepenthes*. This initial appearance is obviously out of sequence with respect to these and other events as determined in many Indo-Pacific deep-water sections, for example at Site 214 and as cited by Hays *et al.* (1969), Parker (1967) and Blow (1969). The problem of the *Sphaeroidinella dehiscens* Datum has been discussed earlier on page 32 and also at length by Berggren and Van Couvering (1974). In essence, Stainforth *et al.*'s base *S. dehiscens* is considered here to represent the (cryptic) basal occurrence of abundant *S. dehiscens* and not its evolutionary appearance. In addition, abundant *S. dehiscens* overlap the last occurrence of *Globorotalia margaritae* in the Indo-Pacific whereas their base *S. dehiscens* lies above the extinction of *G. margaritae.* This allochronous base of *S. dehiscens* could represent about 0.5 Ma. The extinction of *G. margaritae* is considered synchronous within the Indo-Pacific as it occurs stratigraphically above the distinctive *Pulleniatina* spp. left-to-right coiling event. In other respects Stainforth *et al.* (1975) show the same relative order of events covering the latest Miocene to mid-Pliocene times as noted in the Indo-Pacific, although they have not used all of them as datums. That is, they show the following events in order of decreasing age: base *Pulleniatina primalis,* base *Globorotalia tumida s.s.*, base *Globorotalia margaritae, Pulleniatina* spp. left-to-right coiling and the extinction of *G. margaritae.*

Late Pliocene-Pleistocene biostratigraphic events are somewhat different so that correlation is hampered. Thus they use *Globorotalia miocenica,* known to occur only within the Atlantic-Caribbean.

THE LATE NEOGENE ZONATION OF BERGGREN (1973, 1977).

The 1973 zonation of Berggren was primarily intended for the Atlantic Ocean although the Early Pliocene zones (P11-4) are applicable to the Indo-Pacific, while the usefulness of the Late Pliocene zones (P15-6) is restricted to the Atlantic Ocean. Berggren (1977b) recently extended his zonation of Atlantic deep-sea cores to cover the Late Miocene. Correlation of these zones with the zones and subzones recognised in the Indo-Pacific is presented on Figure 37.

The sequence of Late Miocene events are as follows: concurrent range of *Globorotalia miozea* and *Globorotalia conoidea*, evolutionary appearance of *Globorotalia mediterranea* and *Globorotalia conomiozea,* evolutionary base of *Globorotalia margaritae* and the extinction of *Globoquadrina dehiscens.*

The basal occurrence of *G. conomiozea* is located within the middle of Palaeomagnetic Epoch 6 (Ryan *et al.* 1974), thereby correlating with the Zone N.17a/N.17b boundary at Sites 214 and 289 (Figures 21 and 37). The earliest, well documented, occurrence of *Globorotalia margaritae* is within Palaeomag-

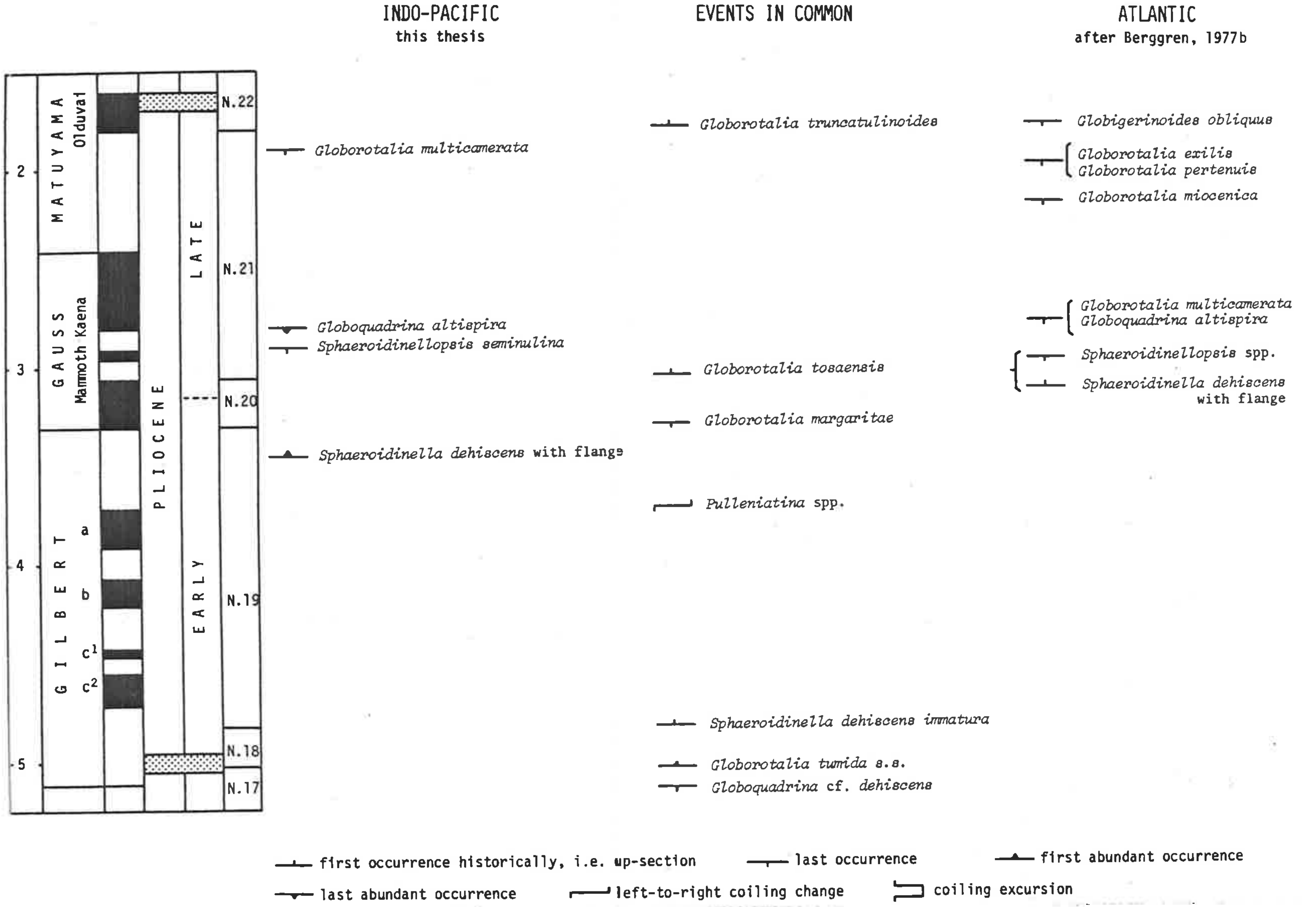

FIGURE 39. Correlation of Pliocene planktonic foraminiferal biostratigraphic events in the Indo-Pacific and Atlantic Oceans.

netic Epoch 5 (Saito *et al.* 1975), just above the *Pulleniatina* Datum. The extinction of *Globoquadrina* cf. *dehiscens* occurs immediately below the base of *Globorotalia tumida s.s.* at Site 214 and 289, thus the *Globorotalia margaritae-Globoquadrina dehiscens* Zone of Berggren (1977b) correlates to within Zone N.17c.

Berggren's Early Pliocene datums (Figure 39), in order of appearance, are base *Globorotalia tumida s.s.*, base *Sphaeroidinella dehiscens*, extinction of *Globigerina nepenthes* and extinction of *Globorotalia margaritae.* This is in the same relative stratigraphic order as is noted for the Indo-Pacific. Above the extinction of *G. margaritae* he notes the coeval extinction of *Sphaeroidinellopsis* spp. and appearance of *Sphaeroidinella dehiscens* (with flange) which is below his next younger datum, the extinctions of *Globoquadrina altispira* and *Globorotalia multicamerata.* In the Indo-Pacific the first occurrence of *S. dehiscens* (with flange) occurs earlier in association with *G. margaritae*, while the extinction of *G. multicamerata* occurs later just below the base of *Globorotalia truncatulinoides.* The variability of the extinction of *G. altispira* within the Indian Ocean has already been discussed (pp.68). Within the latest part of the Pliocene Berggren uses the extinctions of *Globorotalia miocenica, Globorotalia exilis* and *Globorotalia pertenuis* to assist in biostratigraphic subdivision. None of these species are confidently recorded from the Indo-Pacific. Finally, he notes the extinction of *Globigerinoides obliquus* at the base of *Globorotalia truncatulinoides.* At Site 214 *G. obliquus* ranges (in small numbers) well above the evolutionary appearance of *G. truncatulinoides.*

Within the later half of the Pliocene the sequence of foraminiferal events within the Indo-Pacific is no longer closely paralleled by events in the Atlantic-Caribbean. Such faunal differences include the effective absence of the marker species *Globorotalia miocenica* and *Globorotalia pertenuis* in the Indo-Pacific, the non-synchroneity of coiling trends of *Pulleniatina* spp. between these two provinces and the different levels of extinction of *Globorotalia multicamerata* and *Globoquadrina altispira* (Figure 39).

The lack of close correlation in the later Pliocene matches 'solid' evidence for climatic deterioration based on oxygen isotope studies and the stratigraphic and geographic distribution of ice-rafted debris. The severance of equatorial watermass communication between the Indo-Pacific and the Atlantic-Caribbean due to the emergence of the Isthmus of Panama is suggested by Saito (1976) to result in the non-synchroneity of *Pulleniatina* spp. coiling trends in the later Pliocene-Pleistocene. The detailed differences in ranges of these equatorially restricted planktonic foraminifera and their consequent zonal application suggests the separate development of these foraminifera within separate watermasses and is therefore compatible with the Panamanian Isthmus barrier hypothesis of Saito (1976). This emergence is also matched by the mixing of North and South American Pliocene mammals, notwithstanding the lack of mammal biostratigraphic resolution.

THE PLIOCENE-PLEISTOCENE ZONATION OF HUGHES (1978).

The sequence of zones outlined by Hughes (1978) for the Pliocene-Pleistocene of the Solomon Islands is based on phyletic and non-phyletic (quantitative) events enabling a close comparison with Sites 214 and 289, as shown on Figure 37.

The boundary between his Zones P1 and P2 is correlated to my Zone N.19a/N.19b boundary on the basis of *Pulleniatina* spp. coiling directions and is consistent with other Zone P1 and P2 assemblage components. Zone P3, characterised by the initial appearance of *Sphaeroidinella dehiscens s.s.* and *Pulleniatina obliquiloculata* (dominantly right-coiled) is correlated to within Zone N.19b which contains the abundance base of *S. dehiscens s.s.* in Sites 214 and 289. *Globigerinoides ruber* and *Globorotalia crassaformis* first appear in the overlying Zone P4 (Hughes, 1978), the former event correlating with the *G. ruber* abundance base within Zone N.19b in Site 289. As shown on Figure 31, the *G. ruber* abundance base lies immediately above the *S. dehiscens s.l.* abundance base at Site 289. This 'base' of *S. dehiscens* is also coeval with the 'base' of *G. ruber* in Irian Jaya (Visser and Hermes, 1962), and in the North New Guinea Basin (Grund, 1976), and are both correlated to within Zone N.19b.

Zone P5, marked by the initial appearance *Globigerinoides quadrilobatus fistulosus*, correlates with the Zone N.19b/N.20 boundary while the extinction of *Globoquadrina altispira* at the top of Zone P5, is correlated to the Zone N.21a/N.21b boundary. The occurrence of *Globorotalia tosaensis*, a Zone P6/P7 boundary marker, above the extinction of *G. altispira* is considered to be the result of a foreshortened range in view of its rarity in Zone N.21a at Site 214 and 289. Thus Zones P6 and P7 correlate with Zone N.21b and not Zone N.20. The extinction of *Globorotalia multicamerata* at the end of Zone P7 matches its last occurrence just below the evolutionary appearance of *Globorotalia truncatulinoides* in Sites 214 and 289, although Irvine (1978) records these two species as overlapping in the Tasman Sea DSDP Site 208. This discrepancy has yet to be resolved. The top of Zone P8 is marked by the last occurrence of *Globorotalia tosaensis tenuitheca* and *Globigerinoides quadrilobatus fistulosus*. Since Hughes (1978) records *G. tosaensis tosaensis* to range well above this horizon (to within (?) Zone N.22b), the former event is correlated to the last abundant occurrence of *G. quadrilobatus fistulosus* in Sites 214 and 289. If the Site 208 data of Zone N.22a *G. multicamerata* is omitted, then Zone P8 would correlate with the lowest part of Zone N.22a at Sites 214 and 289. However, Zones P8 and P9 are, conservatively, not separated here and, combined,they correlate with the interval of Zone N.22a to Recent.

CHAPTER 4

LATE CAINOZOIC PLANKTONIC MICROFOSSIL TIME-SCALE.

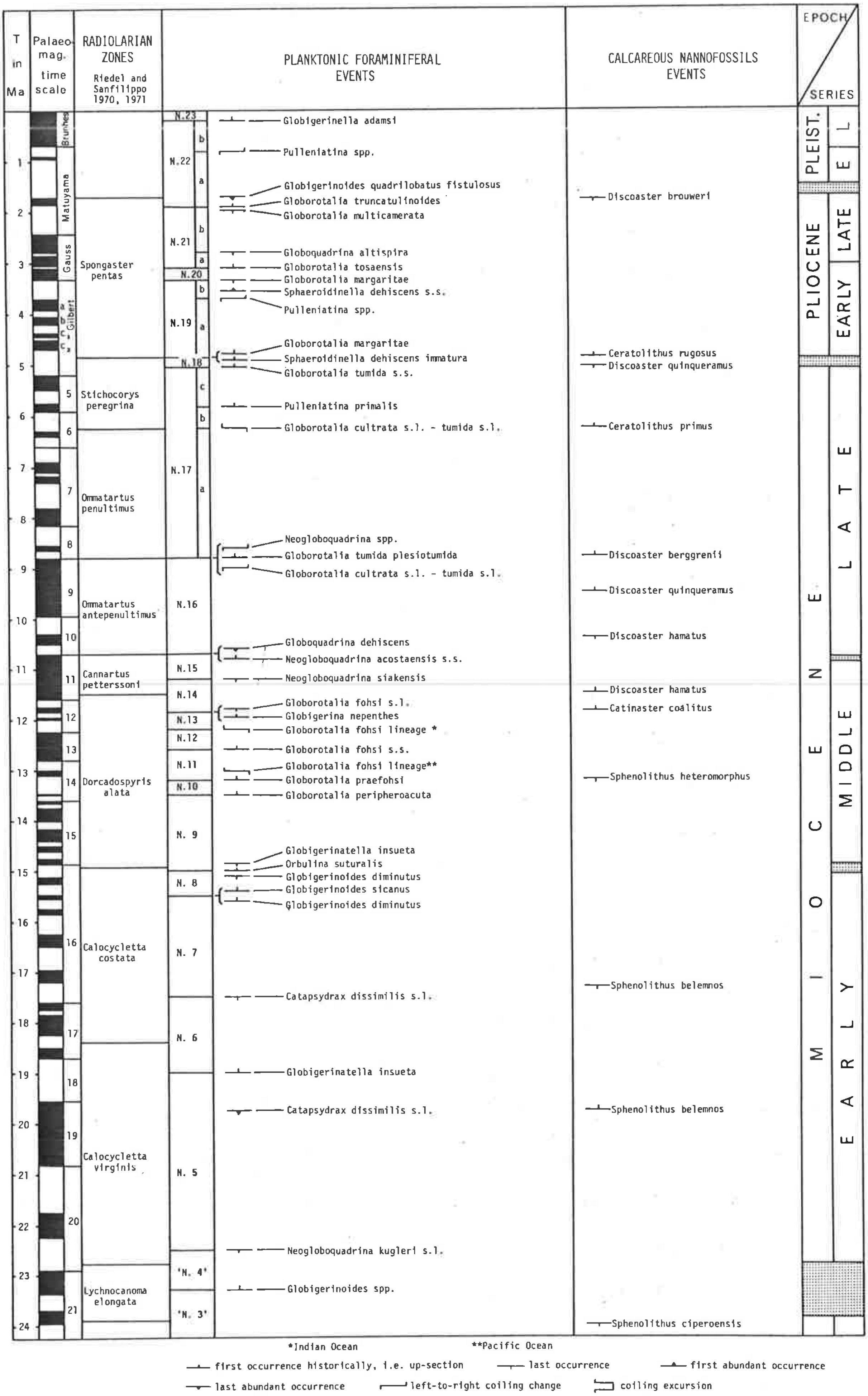

FIGURE 40. Late Cainozoic planktonic microfossil time-scale.

The framework of time in which to assess Neogene historical geology is provided by the integration of biostratigraphic data from the marine and continental record and its calibration to the radiometric and palaeomagnetic-reversal time-scales.

The extension of the palaeomagnetic time-scale and its (initial) calibration to the radiolarian biostratigraphy as far back as the Late Oligocene is a relatively new adjunct to the study of the Neogene. Prior to 1974, the palaeomagnetic time-scale extended only as far back as Epoch 4 to 5 (latest Miocene to the present). The investigation and integration of palaeomagnetic stratigraphy and planktonic microfossil biostratigraphy by Hays *et al.* (1969) remains a significant milestone for the interval covering the Pliocene and Pleistocene. The work of Opdyke *et al.* (1974) and Theyer and Hammond (1974a) extended the integrated palaeomagnetic and biostratigraphic time-scale to cover part of the Early Miocene to Late Miocene while Theyer and Hammond (1974b) further extended this to cover as far back as the Late Oligocene.

The integrated time-scale is based upon the radiometrically controlled palaeomagnetic time-scale of Van Couvering and Berggren (1977), and its calibration to biostratigraphic events that have been investigated by numerous workers on deep-sea cores. The historical development of this Neogene time-framework is discussed at length in Berggren and Van Couvering (1974), and need not be repeated here.

A comparison of the radiolarian and calcareous nannofossil biostratigraphic investigations from Leg 22 sites and Site 289, together with my analysis of their Neogene planktonic foraminifera, disclosed a number of differences from the currently accepted planktonic microfossil correlation of Van Couvering and Berggren (1977). These occur mainly within the interval from the later part of the Middle Miocene to the Early Pliocene. A correlation and calibration of Late Cainozoic planktonic microfossil biostratigraphies is presented on Figure 40, incorporating the revisions suggested in this thesis. The method of construction of this time-scale is outlined below.

The radiolarian zonation of Riedel and Sanfilippo (1970, 1971) is calibrated to the palaeomagnetic reversal sequence following Theyer and Hammond (1974a,b) which in turn is correlated to the radiometric time-scale of Van Couvering and Berggren (1977). For the sections under examination the planktonic foraminifera and calcareous nannofossil biostratigraphies are calibrated, via the radiolarian biostratigraphy to the palaeomagnetic reversal sequence and from there to the latest radiometric time-scale.

Of the eastern Indian Ocean sites examined the correlation of planktonic and radiolarian events is internally consistent in terms of sampling resolution and zonal schemes. The Leg 22 calcareous nannofossils were studied by both Gartner (1974) and Bukry (1974a) with varying degrees of sample spacing and often with slightly different zone-defining events. The situation is different at Site 289 where the calcareous nannofossils are well developed and studied in closely spaced samples by Shafik (1975) while the radiolaria are poorly developed by comparison (Holdsworth, 1975). The sequence of nannofossil events used by these workers is slightly different from that of the widely used scheme of Martini and Woresly (1970). Accordingly the sequence of calcareous nannofossil events, in Figure 40, are shown in terms of their basal and top occurrences of selected species rather than in terms of cumbersome zonal nomenclature.

The updating of the Neogene planktonic microfossil time-scale is based on the following reasons:

1) The basal, non-evolutionary, occurrence of *Globigerinoides* spp. lies within the *Lychnocanoma elongata* Zone (at Site 289) just above the extinction of *Sphenolithus ciperoensis* and is correlated to the Oligocene/Miocene boundary stratotype in the Aquitaine Basin.

2) The total range of *Sphenolithus belemnos* is used by Gartner (1974), Bukry (1974a, 1975) and Shafik (1975), for subdivision of the Early Miocene. The basal occurrence of this species occurs within the later part of Zone N.5 at Site 289 where it matches the abundance top of *Catapsydrax dissimilis s.l.* The significance of the overlap in ranges of *S. belemnos* and *Neoglobo-*

quadrina kugleri s.l. in Site 214 (Gartner *et al.* 1974) has yet to be resolved. The extinction of *S. belemnos* lies within Zone N.7 of Site 289. Absence of much of the middle part of the Early Miocene at Sites 214 and 216/216A precludes confirmation of the timing of this extinction.

3) The *Calocycletta virginis/Calocycletta costata* radiolarian zonal boundary approximates the Zone N.7/N.8 boundary, at Site 289, while Van Couvering and Berggren (1977) correlate this radiolarian datum to within Zone N.6 as is the case in Site 64.1 (Brönnimann *et al.* 1971). Such a wide discrepancy suggests a closer examination of these events in additional sites since both Sites 289 and 64.1 were drilled in relatively close proximity on the Ontong Java Plateau.

4) The *Calocycletta costata/Dorcadospyris alata* radiolarian zonal boundary lies within Zone N.9 at Site 289 and several Leg 7 sites (Brönnimann *et al.* 1971). This relationship is shown on Figure 5 of Berggren and Van Couvering (1974), but later moved, without explanation, to within Zone N.7 (Van Couvering and Berggren, 1977 Text-Figure 1). The Leg 7 and Site 289 evidence appears to have the weight of evidence in this case.

5) The *Dorcadospyris alata/Cannartus petterssoni* radiolarian zonal boundary lies above the *Globigerina nepenthes* Datum at Site 214 and the Atlantic DSDP Site 11 (Berggren and Van Couvering, 1974), agreeing with Van Couvering and Berggren (1977).

6) The range of *Globorotalia fohsi s.l.* overlaps the *Globigerina nepenthes* Datum. The extinction of *G. fohsi s.l.* is therefore of biostratigraphic significance in situations when *G. nepenthes* is absent to very rare. Sites 216 and 289 are cases in point where the extinction of *G. fohsi s.l.* is used to approximate the Zone N.13/N.14 boundary. Support for this age assessment is provided by correlation of this extinction with the radiolarian biostratigraphy. At Site 214, where *G. fohsi s.l.* overlaps *G. nepenthes*, the extinction of the former species occurs within the *Dorcadospyris alata* Zone. At Sites 216 and 289 the extinction of *G. fohsi s.l.* occurs within this radiolarian zone, being just below the *D. alata/Cannartus petterssoni* zonal

boundary, while the base of *G. nepenthes* is within the *C. petterssoni* Zone.

Drawing on the conclusions from the study of the Late Miocene the following data are important for the discussion of a recalibration of the Late Neogene interval:

(1) The *Cannartus petterssoni/Ommatartus antepenultimus* radiolarian zonal boundary is shown by Van Couvering and Berggren (1977) to lie within Zone N.15 whereas at Sites 214 and 216A this event corresponds to the Zone N.15/N.16 boundary. This boundary is also marked by the rapid abundance decrease or local disappearance of *Globoquadrina dehiscens*. The extinction of *Discoaster hamatus* (= NN9/NN10 boundary of Martini and Worsley, 1970), occurs at the same time in these sites but is recorded as ranging to within the middle part of Epoch 10 by Ryan *et al.* (1974), and Berggren and Van Couvering (1974). An age of 11.0 to 11.2 Ma is estimated for this level which is also taken to approximate the Middle/Late Miocene boundary.

(2) The *Ommatartus antepenultimus/Ommatartus penultimus* radiolarian zonal boundary correlates with the Zone N.16/N.17 boundary at Site 214. This radiolarian boundary is coeval with rapid and distinct changes in coiling preferences in *Neogloboquadrina* spp. and *Globorotalia cultrata s.l.*-*tumida s.l.*, as well as corresponding to an interval of morphological change within the *Globoquadrina venezuelana* plexus (Figure 21). The basal occurrence of *Discoaster berggrenii* is coeval with these assemblage changes at Site 214 (Shafik, 1978, personal communication). At Site 216A, the *O. antepenultimus/O. penultimus* boundary is coeval with the base of *D. berggrenii* (Shafik, 1978, personal communication) and the same quantitative and qualitative changes in the planktonic foraminiferal assemblages as noted above for Site 214. At Site 289, the Zone N.16/N.17 species *Globorotalia tumida plesiotumida* is poorly developed as are the Late Miocene radiolaria. However, the same, distinct, coiling trends, as outlined above, are approximately coeval with the basal occurrence of *D. berggrenii* as determined by Shafik (1975). Accordingly Figure 40 outlines these multiple criteria that provides biostratigraphic resolution in an interval which has previously been

difficult to biostratigraphically resolve with certainty.

(3) The *Ommatartus penultimus/Stichocorys peregrina* radiolarian zonal boundary is documented by Saito *et al.* (1975) and Ryan *et al.* (1974) as correlating with the middle of Palaeomagnetic Epoch 6, dated at about 6.2 Ma, and being stratigraphically below the evolutionary appearance of *Pulleniatina primalis*. The relative position of these events is the same in Site 214, where the basal occurrence of *Ceratolithus tricorniculatus* and *Ceratolithus primus* lie at about the same level as the *O. penultimus/S.peregrina* boundary and a distinctive coiling change in *Globorotalia cultrata s.l.-tumida s.l.* (Figure 40). At Site 289 the base of *C. primus* is coeval with this coiling change and stratigraphically below the evolutionary appearance of *Pulleniatina primalis*. Vincent (1975 Figure 3) notes a close relationship between the basal occurrence of *C. primus* and the base of *Stichocorys peregrina* in the central Pacific DSDP Site 310.

(4) The extinction of *Discoaster quinqueramus* has been suggested to occur at approximately 5.5 Ma, at the base of the Messinian evaporitic phase (Berggren and Haq, 1976). This relationship is shown in the correlation chart of Van Couvering and Berggren (1977), corresponding to the later part of Zone N.17, lying within the *S. peregrina* Zone and within the lower part of Palaeomagnetic Epoch 5. This is clearly not the case at Sites 214 and 289 where the extinction of *D. quinqueramus* is coeval with the base of *Globorotalia tumida s.s.*, that is, the base of Zone N.18. The latter event is within the lower part of the Gilbert Palaeomagnetic Epoch, dated at approximately 5.0 Ma (Saito *et al.* 1975). In other words the extinction of *D. quinqueramus* in the Andalusian of Berggren and Haq (1976) is not synchronous with its extinction in these Indo-Pacific deep-sea sites. A more positive age for the Andalusian stratotype section can be based on the presence of *Ceratolithus tricorniculatus* which they record about 110 metres below the Tortonian/Messinian boundary (sample C4 of Berggren and Haq, 1976), as denoted by the first indication of a marked assemblage change due to a eustatic fall in sea-level. A similar faunal impoverishment is noted in the Rio

Mazzapiedi Castellania section (Italy) approximately 35 metres above the basal occurrence of *C. tricorniculatus* (Ryan *et al.* 1974), which in turn is some 55 metres below the evaporitic phase of Messinian sedimentation. Since the base of *C. tricorniculatus* lies near the Epoch 6/7 boundary (Ryan *et al.* 1974), it is concluded that a major part of Berggren and Haq's (1976) Andalusian section (from sample C4 to C12) is correlable to (part) Zone N.17b,c.

(5) The *Stichocorys peregrina/Spongaster pentas* radiolarian zonal boundary correlates with the Zone N.18/N.19 boundary at Site 214 and 289 as does the basal occurrence of *Ceratolithus rugosus*. Both events were previously recorded as lying well within Zone N.19 by Van Couvering and Berggren (1977).

(6) There are several discrepancies in the correlation of the various planktonic microfossil zonations for the Pliocene interval. However, since considerably greater attention has been paid to the planktonic foraminifera in comparison to the resolution and consistency of the calcareous nannofossil biostratigraphy the urge to revise the Pliocene-Pleistocene time-scale is tempered by the need for stability.

CHAPTER 5

CLASSIFICATION OF NEOGENE AND SELECTED PALEOGENE PLANKTONIC FORAMINIFERA

INTRODUCTION

The rapid rise in the use of planktonic foraminifera for solving biostratigraphic problems, during the 1950's, provided much of the basic data on test morphology and stratigraphy that was to be assessed and incorporated into the comprehensive classification scheme of Bolli, Loeblich and Tappan (1957). This scheme and the subsequent, commonly used, classifications of Banner and Blow (1959), Loeblich and Tappan (1964) and Blow (1969) are based on their assessment of the taxonomic weight to be given to the various morphological characters. The different classifications represent different weights given to essentially the same 'fundamental' characters, evolutionary relationships between taxa becoming apparent after the process of classifying.

A classification reflecting the phylogenetic development of the foraminifera has been a long time in coming even though the principles were outlined by Glaessner as far back as 1945 (McGowran, 1971). Recent advocates of an evolutionary classification of planktonic foraminifera include Parker (1962), Berggren (1968a), McGowran (1968, 1971), Steineck (1971) and Steineck and Fleisher (1978). Although these workers and Cifelli (1969) have outlined the broad evolutionary features of this group in emphasizing the basic pattern of radiation, relay, extinction, parallelism and convergence, much remains to be documented and to be reflected in the classification.

The classification established by Bolli *et al.* (1957), endorsed and enlarged by Blow (1969) and Brönnimann and Resig (1971), reflects the widely held view that the foraminifera are merely biostratigraphic tools and therefore study of the specific level is most important. This biostratigraphic contribution is undoubted yet the foraminifera constitute a superb biohistorical record which should be exploited as such. Thus there is a conflict between the specialists, for progress in systematics, and non-specialists or 'applied' specialists, for conservative systematics (McGowran, 1971). The dominance of biostratigraphy over palaeobiology, of the foraminifera, is

FIGURE 41. Interpreted phylogeny of Neogene and selected Paleogene planktonic foraminifera.

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clearly shown in a recent compilation of evolution and the fossil record (Hallam, 1977), which contains no chapter on foraminifera, yet this group is well represented in another compilation on biostratigraphy (Kauffman and Hazel, 1977). This study of systematics is therefore needed to incorporate the available phylogenetic information, which has accumulated over the past decade, into the classification of the foraminifera. Accordingly this study reverses the pervasive biostratigraphic influence and attempts to bring foraminiferology back into the realm of palaeobiology.

The foundations of the proposed classification are the principles of evolutionary taxonomy as discussed by Simpson (1961, 1975). The evolution of the planktonic foraminifera results in the diversity of successional morphotypes that are to be classified. The evolutionary classification incorporates the factual evidence of phylogenetic relationships that is, currently, best assessed in terms of comparative morphology within the framework of time. It is these evolving populations manifest as successive fossil assemblages that are classified, not the characters of the populations. Morphological characters are assessed in conjunction with interpreted phylogeny and their importance for classification only then emerges. The diagnostic value of such characteristics are not assumed prior to the act of classifying.

The methodology is first to establish phylogenetic relationships on the basis of observations of resemblances and differences within the time-framework and then to reflect these phylogenetic inferences in a classification scheme using the same morphological observations. The importance of characters in sorting out Neogene planktonics emerges as the result of an assessment of historical evidence and not in response to the lure of functional significance and possible stability.

PHYLETIC RECONSTRUCTION

A synthesis of phyletic relationships among planktonic foraminifera is presented in Figure 41. This data comes mainly from the work of Bolli (1957), Blow (1956, 1959, 1969), Blow and Banner (1962), Berggren (1968a, 1971, 1977b), Berggren and Amdurer (1973), Jenkins (1971), McGowran (1968) and Fleisher (1974), as well as the comprehensive documentation of the present study. In this figure the vertical ranges of successional morphotypes are shown by solid lines while broken lines indicate more equivocal relationships and possible evolutionary alternatives.

In spite of the many controversies at the species-level the broad groupings of phyletically related species are sufficiently well-known to form a base on which to assess supraspecific relationships. Thus classification of higher taxa can be attempted without having to revise all the species-group nomenclature which has arisen through excessive splitting for 'practical' purposes. Problems of species (= morphotype) transitions and nomenclature, together with the writer's concept of most of the genera included in this classification, are outlined in the following systematic checklist chapter. The phyletic relationships of some of the lesser known genera are discussed in this section. Since the origins of many components of the Neogene radiation lie within Paleogene faunas so the analysis of phyletic relationships, and consequent taxonomic evaluation, results in the classification of Neogene as well as selected Paleogene lineages.

The following discussion is concerned with the establishment of the phyletic relationships, and associated controversies, as outlined on Figure 41. Examination of this figure reveals several groups of phyletically related species which are referred to here as Groups 1, 2, 3, and 4.

GROUP ONE

This group includes the evolution and subsequent diversification from *Globorotalia peripheroronda* in the Early Miocene and includes the type species of the Genera *Globorotalia* and *Truncorotalia.* The general consensus is that the finely perforate *G. peripheroronda* evolved from the *kugleri*-group which has a surface wall texture intermediate between distinctly cancellate and distinctly finely perforate (*sensu* Fleisher, 1974). The *kugleri*-group is generally placed in the *Globorotalia* although here it is considered to be morphologically closer to *Neogloboquadrina siakensis,* its presumed ancestor (Berggren, 1968a). Material examined during this research has not shed any new light on the details on the origin of *G. peripheroronda* or the other Zone N.5 globorotaliid, *G. praescitula.*

That two closely related species such as *kugleri* and *peripheroronda* may be placed in different genera and higher taxa is common in the classification of foraminifera because of their excellent biohistorical record coupled with their history of repeated convergence in relatively few characters.

Several Neogene species that have previously been assigned to the *Globorotalia,* by virtue of their trochospirally coiled test with an interiomarginal, umbilical to extraumbilical aperture, are suggested by Fleisher (1974) to be phyletically distinct from Group 1. These *Globorotalia* homeomorphs are discussed under Group 3. Thus Group 1 is uncontroversial in its internal phylogeny.

This rapidly diversifying group shows repeated trends towards angular chambers and keel development in many separate Neogene lineages. Keels have also evolved in the Paleogene globorotaliid Genus *Morozovella* (McGowran, 1968) (Plate 25, Figures 1-4) and in the Late Eocene within the *Turborotalia cerroazulensis* group (Toumarkine and Bolli, 1970) (Plate 25, Figures 5-8).

It is evident that the sole characteristics of a trochospirally coiled test bearing an interiomarginal, umbilical to extraumbilical aperture, with or without a keel, are inadequate to represent this phyletically distinct Group 1. On the other hand, all species included in this group have a finely perforate surface wall texture (*sensu* Fleisher, 1974; Steineck and Fleisher, 1978).

GROUP TWO

This group includes the type species of the following genera: *Pulleniatina, Neogloboquadrina, Globoquadrina, Catapsydrax,* and *Globorotaloides.*

Although the phylogeny of the Neogene members of this group is reasonably well documented, later Eocene-Oligocene relationships are obscure, with current opinions indicating that the group is polyphyletic. In spite of the lack of detailed relationships it seems that the ancestors of this group (and Group 3), are to be found within the *Subbotina* and "pitted *Globorotalia*" of McGowran (1968), and to this extent are more closely related to one another than to members of either Groups 1 and 4.

Figure 41 suggests that the Group 2 taxa comprise two subgroups of lineages based on the later Eocene-Oligocene species *opima* and *galavisi*.

The first subgroup shows *opima* as ancestral to a most successful line of descent which includes the ancestor of the finely perforate *Globorotalia*. Living representatives are *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata*; both are non-spinose when living Bé (1977). The report of spinose *P. obliquiloculata* by Parker (1962) is not supported by personal observations nor by the latest survey of Recent planktonic foraminifera by Bé (1977).

Most members of this subgroup are trochospirally coiled with globular shaped chambers throughout ontogeny and have a cancellate surface wall texture. The evolution of *Pulleniatina primalis* from *Neogloboquadrina acostaensis*, detailed by Banner and Blow (1967), and illustrated in the present study (Figure 19), involves the development of an almost imperforate 'skin' of calcite over a cancellate-walled juvenile stage, together with a change in coiling mode from trochospiral to streptospiral.

The second major subgroup is clustered around *galavisi* and includes some of the more equivocal phylogenetic relationships. All members are trochospirally coiled and generally show an ontogenetic change from globular shaped juvenile chambers to flattened, compressed chambers in the adult stage. The divergence from *galavisi* is represented by *Globoquadrina dehiscens*, *G. sellii/binaiensis*, *G. venezuelana* and *G. altispira*. All members of this group have a cancellate surface wall texture and its extant representative, *Globoquadrina conglomerata*, is non-spinose when living (Parker, 1962). A further subdivision of this subgroup into two groups of lineages can be recognised and distinguished on the basis of ontogenetic changes in the position of the interiomarginal aperture. The complex including *Globoquadrina dehiscens*, *G. sellii/binaiensis*, *G. venezuelana* and *G. conglomerata* have an umbilical to extra-umbilical aperture ('globorotaliid') in their juvenile stage which changes to umbilical ('globigerinid') in position by the adult stage. The *Globoquadrina altispira* complex maintains an essentially umbilically positioned aperture throughout ontogeny and is tentatively maintained within *Globoquadrina*.

Other Neogene planktonic foraminifera in Group 2 include the genera *Catapsydrax* and *Globorotaloides*. These forms appear to be related to the other cancellate taxa, but details of their exact relationship are unknown at this time. The development of *Catapsydrax* from the cancellate-walled *Subbotina* group (see for example, *S. angiporoides*, Plate 25, Figures 9-11), as suggested by Lipps (1966) and McGowran (1968), is intuitively supported. The presence or absence of a bulla is no longer considered of generic importance within Late Cainozoic planktonics thus the distinction between *Catapsydrax* and *Subbotina* become more equivocal. In other respects the most readily apparent difference is the typically encrusted wall of Neogene *Catapsydrax* spp. in contrast with the relatively non-encrusted Paleogene subbotinids. Thus *Catapsydrax* may merely be an encrusted and bullate subbotinid. Detailed morphological investigation of these taxa is, however, beyond the scope of this thesis.

That Eocene to Early Miocene species of *Globorotaloides* represent a phyletically coherent taxon is open to question since it is not inconceivable that they may represent various ontogenetic stages of species belonging to the Genus *Globoquadrina* or are very close to the *opima* lineage. However, the later Neogene *bermudezi-hexagona-oveyi* lineage is clearly divergent from *Neogloboquadrina* and *Globoquadrina* and is therefore less controversial. Recent *G. hexagona* are non-spinose when living (Parker, 1962).

In spite of these problems both *Catapsydrax* and *Globorotaloides* are more closely related to Group 2 taxa than to any other group of Late Cainozoic planktonic foraminifera, and this relationship is reflected in their suprageneric classification.

The affinities of many Late Paleogene cancellate-walled taxa such as *ampliapertura, pseudoampliapertura, euapertura, prasaepis, pseudovenezuelana* and *brevis* are considered to lie near the globoquadrinid-subbotinid plexus yet detailed relationships are yet to be fully documented. Although the internal phylogeny of this group remains equivocal, externally (within the Neogene) the group comprises a taxon together with the neogloboquadrinids that is phyletically distinct from Groups 1, 3 and 4.

GROUP THREE

The third group is manifest by the origin and subsequent divergence of the following genera: *Beella, Globigerinella, Globigerina, Sphaeroidinellopsis, Sphaeroidinella, Globigerinoides, Praeorbulina* and *Orbulina*. Problems concerning the internal phylogeny of the group are relatively uncontroversial.

The origin of the Genus *Sphaeroidinellopsis* is discussed by Jenkins (1971) and Berggren and Amdurer (1973). The earliest *Sphaeroidinellopsis, S. seminulina,* probably evolved from *Globigerina woodi* through the acquisition of minor changes in chamber arrangement and, more obviously, the development of an outer 'skin' or cortex that covers a cancellate-walled juvenile stage leaving a smooth, almost imperforate, wall texture. This development of a 'composite' wall parallels the evolutionary development of *Pulleniatina*. Recent *Sphaeroidinella dehiscens* bear spines when living (Parker, 1962; Hofker, 1972).

The argument for the polyphyletic nature of the Genus *Globigerina* is outlined by Fleisher (1974) who considers there to be two phyletically distinct taxa included within the presently accepted concept of *Globigerina*. He informally designates these as *Globigerina* and "*Globigerina*". *Globigerina* has a spinose surface wall texture (*sensu* Fleisher) while "*Globigerina*" is characterised by a cancellate surface wall texture and a thickened apertural rim. While I do not dispute the validity of the lineages outlined by Fleisher, I consider that the differences between these surface wall textures are not sufficient to warrant recognition of separate genera. It will be shown that his spinose and cancellate textures form a continuous spectrum during ontogeny.

The concept of spinose and cancellate wall textures of Fleisher (1974 p.1011) are quoted below:

> "1) Spinose wall [*Globigerina*], characterized in living specimens by long acicular spines, which are usually represented in fossils by short spine bases. High-magnification photographs ... reveal that the wall is fundamentally flat, with spines rising above, and moderately large pores penetrating an otherwise regular and unmodified surface. No distinct pore pits are present.
>
> 2) Cancellate wall [*"Globigerina"*], characterized by distinct pores located at the center of well-developed depressions (pore pits) separated by relatively narrow ridges. The visual impression created by this wall type is of a regular reticulate network of intersecting ridges. Spines may be present ... or absent ... which suggests that further subdivision may be possible. Spines, when present, are localized at ridge intersections."

The distinction between these textural types is disputed for the following reasons. Firstly, the Genus *Globigerinoides* is regarded by Fleisher as having a typically cancellate surface wall texture. Stereoscan examination of a Late Pleistocene *Globigerinoides ruber* (Plate 19, Figure 4) shows a spinose last chamber with a cancellate texture becoming progressively more pronounced on the earlier chambers. The degree of ontogenetic change in surface wall texture is also variable amongst other species of *Globigerinoides*. Secondly, the evolution of spinose *Globigerinella siphonifera* from a spinose globigerinid in the Middle Miocene is generally accepted, in terms of comparative morphological and stratigraphic studies. However, Bé (1969 Plate 2) illustrates a specimen of *G. siphonifera* (= *aequilateralis* of Bé) in which pores are located in distinct pore-pits, contrary to Fleisher's definition of spinose wall textures and known phylogeny. I would agree with him that *G. siphonifera* appears typically 'spinose', that is, not obviously cancellate, using light microscopy. Thirdly, the evolution of *Orbulina* from *Globigerinoides* is well established by Blow (1956). As mentioned above, *Globigerinoides* typically has a well developed cancellate wall texture. However, Bé, Harrison and Lott (1973) illustrate Recent *Orbulina universa* from the Indian Ocean with a typically smooth surface wall texture, punctuated by long slender spines reminiscent of Fleisher's spinose wall textural category. Thus *Orbulina* is convergent with *Globigerina* of the *bulloides* group.

It is concluded that the spinose category of surface wall texture of Fleisher (1974) is a character that cuts across well established lineages, and represents, in the examples cited above, only a stage in the ontogenetic development of surface wall texture. His spinose textural category emerges through analysis as having less diagnostic value than he assumes.

The concept of the Genus *Globigerina* accepted here includes morphotypes with both distinctly cancellate and spinose surface wall textures in addition to the other structural features of globigerinids.

The affinity of the spine-bearing *Beella* genotype, *Globigerina digitata*, is generally agreed to lie near to *Globigerina*, differing mainly by having smaller diameter, irregularly distributed pores.

Living representatives of Group 3 are characterised by the presence of spines and a cancellate to 'spinose' (*sensu* Fleisher, 1974) surface wall texture. The phylogeny of Group 3 is, internally, uncontroversial with the phena being distinguishable from the other groups at least as far back as the Late Eocene occurrences of *Globigerina praebulloides*. Fleisher (1974) speculates that the oldest globigerinid species is *G. officinalis* whose ancestry would seem to lie near to members of the Paleogene Genus *Subbotina*, although this is not yet established.

GROUP FOUR

The fourth major group of Late Paleogene-Neogene planktonic foraminifera includes many species previously assigned to the Genera *Globigerina* and *Globorotalia* by most workers, and are almost always not included in phyletic reconstructions. Included in this group are the type species of the following genera; *Candeina*, *Globigerinatella*, *Globigerinita* and *Tenuitella*. The Genus *Turborotalita* is tentatively included in the group.

Fleisher (1974) was first to formally recognise the gross convergence toward the Neogene Genus *Globorotalia* within Oligocene-Recent assemblages of planktonic foraminifera in addition to the Paleogene homeomorphic globorotaliid genera *Morozovella* and *Turborotalia*. He erected the Genus

Tenuitella for this group of closely related species, including such species as *Globorotalia gemma, Globorotalia munda, Globorotalia anfracta, Globorotalia minutissima* and *Globigerinita stainforthi praestainforthi.* The main diagnostic character common to all tenuitellids is a microperforate surface wall texture (*sensu* Fleisher 1974).

Similarly, Fleisher re-examined the concepts of *Catapsydrax* and *Globigerinita,* recognising that they represent phyletically distinct groups of lineages and that this distinction should be reflected in their classification. The presence of a bulla within members of each taxon is considered to result from convergence and not phylogeny. These genera can be distinguished on the basis of their surface wall texture; *Catapsydrax* is cancellate while *Globigerinita* is microperforate.

Figure 41 shows the reconstructed phylogeny of *Tenuitella* and *Globigerinita.* Jenkins (1965) documents the morphological transition from *Tenuitella munda* (= his *Globorotalia munda*) to *Globigerinita glutinata* (= his *Globigerina juvenilis*) in the Late Oligocene of New Zealand. *Globigerinatella insueta* evolved from *G. glutinata* in the Early Miocene (Brönnimann, 1950; Hofker, 1954; Blow, 1959, 1969) while *Candeina nitida* evolved from *G. glutinata* in the Late Miocene (Blow, 1969; Saito and Thompson, 1976). These lineages were established on the basis of comparative morphology in terms of chamber arrangement and the nature of the aperture(s) and are supported here by their mutual microperforate surface wall texture.

This group highlights additional evidence of convergence within Late Cainozoic planktonic foraminifera that must be considered prior to the erection of a classification. *Globigerinatella insueta* and *Candeina nitida,* for example, are morphologically convergent with the globular-chambered, multi-apertured Genus *Orbulina* yet are by no means closely related. Similarly, non-bullate specimens of *Globigerinita glutinata* are often identified as various 'species' of the cancellate-walled *Globigerina bulloides-praebulloides* complex.

Historically, the earliest occurrence of a microperforate (*sensu* *stricto*) species (*Tenuitella insolita*) is from the early Late Eogene Zone P.15 at Brown's Creek, Victoria (McGowran, 1978). *Globorotalia inconspicua aculeata* Jenkins is placed within the *Tenuitella* by Fleisher (1974) and ranges from the Middle Eocene Zone P.12 (McGowran, 1978). Specimens of *T. aculeata* from the Late Eocene of Brown's Creek are shown on Plate 27, Figures 1-3. In terms of surface wall texture, *T. aculeata* is very similar to the spine-bearing *Globoconusa daubjergensis* as illustrated by Olsson (1970). Both species have a surface wall texture (minus the spines) similar to the genera *Pseudohastigerina, Hantkenina* and *Cassigerinella*. Thus there are a number of possible lines of descent for *Tenuitella*. The suggestion of Fleisher (1974) that *Tenuitella* may have developed from the Danian *Globoconusa* is not supported by morphologic and stratigraphic intermediaries. That *Tenuitella insolita* evolved from the *Pseudohastigerina* - *Cassigerinella* complex is considered more realistic in terms of comparative morphology. *T. aculeata* is considered to be related to this complex, representing a phyletic dead-end. Its spinosity notwithstanding, it is not sufficiently divergent from the main lineage(s) to warrant separate generic recognition. In spite of its problematic origin, *Tenuitella* and its descendants are phyletically and morphologically distinct to the same degree as are the finely perforate and cancellate-walled Late Cainozoic planktonic foraminifera.

Origin of the Genus *Turborotalita*. This genus was originally defined on the nature of the bullate extension of the final chamber. The basis of the genus has recently been altered by Fleisher (1974) who considers the nature of the surface wall texture to be a more satisfactory character for recognition. In terms of test morphology and phylogeny all *Turborotalita* species are very small in size, trochospirally coiled with an interiomarginal, umbilical to extra-umbilical aperture, occasionally with a bullate final chamber, parts of the bulla variously covering the umbilicus and segments of the ventral intercameral sutures. The external chamber walls are marked by large pores and spine bases, generally concentrated along the equatorial periphery. Fleisher's (1974) observation that species have a microperforate wall is seemingly supported by Hofker (1976) whose thin-section illustrations of Recent *Turborotalita* spp. walls show very fine perforations as well as the larger and more peripherally restricted pores. I have not as yet been able to confirm the presence of a microperforate surface wall texture in any *Turborotalita* spp. encountered in this research. Illustrations of the microperforate *Tenuitella anfracta* by Brönnimann and Resig (1971, Plate 43) show a number of specimens that appear to represent a gradation from solely microperforate to microperforate with large pores concentrated along the equatorial periphery. Similarly Reiss, Halicz and Perelis (1974) illustrate *T. anfracta* with morphology and a pore pattern similar to the Paleogene Genus *Planorotalites*.

The oldest occurrence of a morphotype belonging to *Turborotalita* is recorded from Site 214 where *T. primitiva* occurs in sample 214-26-3 Top, assigned to the Oligocene Zone N.1/P.20. This represents a considerable downward extension of its range from within the Early Miocene Zone N.4 as determined by Brönnimann and Resig (1971).

In terms of phylogeny, Fleisher (1974) suggests that *T. primitiva* may have evolved from his late Middle to Late Eocene *Planorotalites laccadivensis* (= his *Globanomalina laccadivensis*) which in turn, he suggests, may have evolved from *Planorotalites pseudoscitula*. He also considers that *primitiva* is more closely allied to *Planorotalites* than to *Turborotalita*. In this case the development of a microperforate wall texture and 'spines' occurs much later, presumably in the Late Miocene with the evolution of *T. humilis*.

Other possible pathway seems equally plausible notwithstanding the possibility that *Tenuitella* and *Turborotalita* may represent polymorphic end-members. An alternative to *P. laccadivensis* as the ancestor to the *Turborotalita* could be found with the Late Eocene *Tenuitella aculeata*. The Oligocene specimen of *T. primitiva* has an even distribution of pores (perforations becoming more peripherally restricted from the Early Neogene onwards) that is reminiscent of the size and distribution of pores in

T. aculeata. Both *T. primitiva* and *T. aculeata* are trochospirally coiled the latter bearing small spine bases. The best evidence for spine bases in *Turborotalita* is in Recent specimens of *T. cristata* (Poore, 1979 Plate 2, Figures 10-12), the presence of spine bases being more difficult to establish in the fossil record. In spite of the lack of detailed morphological transitions, it is clear that *Turborotalita* is more closely related to the Late Eocene plexus of tenuitellids and pseudohastigerinids than to the other Cainozoic taxa.

The residue of taxa of the Neogene radiation not included in Groups 1 to 4 is comprised of the enrolled biserial *Cassigerinella* and the biserial *Streptochilus* whose origins are generally not discussed in the literature.

Origin of the Genus *Cassigerinella*. This genus is most often classified together with planispirally coiled genera as *Hantkenina, Hastigerina, Clavigerinella, Planorotalites* and *Pseudohastigerina* in view of its planispiral juvenile stage. Subsequent ontogenetic development of enrolled biserial coiling distinguishes this genus from other genera.

This morphological transition is not generally regarded as evidence of phylogeny in that some workers question whether *Cassigerinella* even belongs to the planktonic foraminiferal Subfamily Globigerinacea. Three species of *Cassigerinella* are recognised, *chipolensis, martinezpicoi* and *eocaenica*. *C. chipolensis* is known from all major planktonic foraminiferal provinces and in both neritic and deep-water facies; *C. martinezpicoi* is known from deep-sea sediments in the Indian and Pacific Oceans and is associated with shallower water benthonic foraminifera in Trinidad; *C. eocaenica* is known from the Caribbean, associated with a diverse assemblage of planktonic foraminifera (Cordey, 1968), and from South Australia (Lindsay, 1969). The widespread distribution and presence in differing facies suggests that *Cassigerinella* assumed a planktonic existence.

The presence of a toothplate within *C. chipolensis* is assessed by Hofker (1963) and Steineck and Darrell (1971) as evidence of a non-Globigerinacean origin of the genus. Such a priorism does not seem compatible with the principle that characters may be strongly convergent and may vary in value for classification from one group to the next.

In other respects *Cassigerinella* is very similar to *Pseudohastigerina* (Lipps 1966, = his *Globanomalina*). Gross test form, controlled by growth, is the only major difference. Both genotypes have a very similar surface wall texture (see Plate 22, Figure 8 and Plate 26, Figure 12), which may also indicate close genetic relationship, although the well preserved wall texture of some Trinidad specimens of *C. martinezpicoi* (Plate 22, Figure 17) may represent yet another convergent trend towards a finely perforate surface wall texture.

It is considered that the Genus *Cassigerinella* is more closely related to pseudohastigerinid-like taxa than it is to other genera, and is accordingly grouped with these taxa in the Family Hantkeninidae.

<u>Origin of the Genus</u> *Streptochilus*. The pattern of planktonic foraminiferal evolution since the Lower Cretaceous is one of repeated radiation followed by extinction, with similar gross test forms evolving independently, in most cases, in each of the four major radiations (McGowran, 1968; Cifelli, 1969). Convergence and parallelism of gross test form would seem to be the rule.

With this pattern of planktonic foraminiferal evolution in mind one must entertain the notion that the Neogene biserial form *Streptochilus* has converged with its Paleogene homeomorph *Chiloguembelina* rather than descended from it. No obvious ancestor of *Streptochilus* is known. The stratigraphic interval apparently lacking biserial planktonic foraminifera extends from the extinction of *Chiloguembelina* within the Late Oligocene Zone N.2/P.21 to the basal occurrence of *Streptochilus* in the Early Miocene Zone N.4 (Brönnimann and Resig, 1971).

The presence of a mutually similar surface wall texture might be regarded as a measure of homology. This, plus the similarity in gross test form (Plate 24, Figures 14-16) would tip the balance towards phyletic relationship. Such speculation notwithstanding, *Streptochilus* is assigned as a conservative decision to the Family Heterohelicidae together with *Chiloguembelina* (whose relationship to Cretaceous members is also unclear).

ANALYSIS OF PHYLOGENY

On the basis of the reconstructed phylogenies outlined on Figure 41 the following observations are made. Four major groups of phyletically related species are recognised. Each species within each group has a similar surface wall texture and the different groups have different wall textures, notwithstanding transitional morphotypes signalling speciation in the areas of initial divergence. The morphological range within each group ranges from comparatively narrow in Group 1 to broad in Group 3. The mode of coiling, test and chamber shape, nature and position of aperture(s) together with apertural modifications (bullae) and keel development are characteristics that cut across well established lineages.

The most important interpretation of these observations is that the single characteristic of the conservative nature of the surface wall texture is of greater diagnostic value for the recognition of these four established groups than most of the other commonly used test characteristics. One major collection of phyletically related taxa are spine-bearing within the Neogene, although not uniquely so as the problematic *Turborotalita* is apparently spine-bearing.

PROPOSED CLASSIFICATION

The Neogene radiation of Figure 41 is the basis for the classification shown on Table 1. Assessment of the historical evidence of the major part of the radiation indicates that four higher taxa are to be recognised and ranked equally. The phyletic divergence represented by these higher taxa is most clearly shown by the distinctive surface wall texture, together with the presence or absence of spines, of each higher taxon.

The rank of these higher taxa is selected so as to be comparable with the rank assigned to the major groups of living planktonic foraminifera which have been extensively studied by Bé (1977). Accordingly four Neogene groups of the rank of Family are recognised. Each family is recognisable on the basis of surface wall texture. Homology is suggested by common wall texture which assists attempts to separate the effects of convergence from phylogeny. The appropriate Family names are governed by the Law of Priority in accordance with the International Code of Zoological Nomenclature.

DISCUSSION

The names available to assess the Group 1 segment of the radiation include *Globorotalia* and *Truncorotalia*. In addition Bandy (1972) introduced the subgeneric names *Fohsella, Menardella* and *Hirsutella* to classify several Neogene lineages showing parallel evolutionary development towards angular chambers with keels. Steineck and Fleisher (1978) maintain the genera *Globorotalia* and *Truncorotalia* to reflect two major lineages in this group as exemplified by the respective typespecies *G. tumida* and *T. truncatulinoides*. This is in contrast to the broader concept of *Globorotalia* and suppression of *Truncorotalia* adopted in this classification. That different classifications can be consistent with the same, agreed, phylogeny is admitted; my criticism refers strictly to their classification and not to their reconstructed phylogeny. The lineage plays a major role in the classification of Bandy (1972) and Steineck and Fleisher (1978) who stress the 'vertical' component at the expense of the rate and extent of evolutionary divergence.

I consider that the separation of this phyletically distinct group into two genera (Steineck and Fleisher, 1978) or four subgenera (Bandy, 1972) is too extreme in view of the strong parallelisms between these two main lineages even though *Truncorotalia* and *Globorotalia* (*sensu* Steineck and Fleisher, 1978) diverged as far back as Early Miocene Zone N.6. Contrary to Steineck and Fleisher (1978) I consider the factual evidence of phylogeny and evolutionary divergence to be more suitably expressed by conservatively maintaining the complex as a single Neogene genus of *Globorotalia*. I do not accept the subgenera of Bandy (1972).

The Genus *Turborotalia* is maintained for the chronologically and phyletically distinct, yet morphologically convergent Middle to Late Eocene *cerroazulensis* group. The phyletically distinct Cretaceous rotaliporids and globotruncanids, Paleogene *Planorotalites* and *Turborotalia*, and Neogene *Globorotalia*, together constitute a remarkable example of allochronous evolutionary parallelism in terms of the repeated emergence of an angular test, often with a keeled periphery (McGowran, 1968) and a finely perforate surface wall texture. This is even more remarkable if the finely perforate and 'spinose' Paleogene *Morozovella* is included. The functional significance of this highly convergent surface wall texture amongst all the planktonic foraminiferal lineages that lead to morphotypes with angular and keeled tests is unknown at present.

Within the cancellate-walled Late Cainozoic planktonics two groups are recognisable. One group includes the genera *Pulleniatina, Neogloboquadrina, Globoquadrina, Globorotaloides* and *Catapsydrax,* the other group includes the genera *Beella, Globigerinella, Globigerina, Sphaeroidinella, Sphaeroidinellopsis, Globigerinoides, Praeorbulina* and *Orbulina.* Recent living specimens of the first group are non-spinose while the second group bear spines (Bé, 1977). The presence or absence of spines, when living, is used as a Family rank character in the classification of Recent planktonic foraminifera by Parker (1962). Saito and Thompson (1976) have gone one step further by using the shape of the spines as a Family rank characteristic. It is possible that the shape of spines may reflect phyletic affinity yet this factual evidence of affinity is extremely poor in the fossil record due to the poor preservation of fragile spines. Also living specimens of *Hastigerina pelagica* and *Globigerinoides sacculifer* lose their spines during gametogenesis (Bé and Anderson, 1976) representing a previously unknown factor controlling the preservation of spines. In terms of the mechanics of classification, the degree of morphologic and phyletic divergence between their spinose forms is not matched by the degree of divergence between other Neogene taxa of Family rank, and is therefore considered as unnecessarily extreme splitting. The presence or absence of spines is a characteristic common to the extant representatives of a large group of phyletically related morphotypes. Although spines as such have a poor preservation potential the spine-bearing taxa of Group 3 are sufficiently distinct in terms of gross morphology as early as the Late Eocene *Globigerina praebulloides* to allow separate Family status. Accordingly the Family Orbulinidae is maintained to incorporate the spinose Group 3 taxa and the Family Catapsydracidae is used to represent the non-spinose Group 2 taxa.

This classification stresses the four major components of the Neogene radiation although it is apparent that there are Neogene representatives of two additional families. Both the Hantkeninidae, as represented by *Cassigerinella*, and the Heterohelicidae, as exemplified by *Streptochilus*, are considered as phyletically distinct from one another as they are from the other Neogene families.

This reconstructed phylogeny provides the basis of the classification of the Neogene planktonic foraminiferal species encountered during examination of my eastern Indian and Pacific Ocean deep sea sites. The classification is applied in the following systematic checklist chapter.

TABLE 1

PROPOSED CLASSIFICATION OF NEOGENE PLANKTONIC FORAMINIFERA

Family Globorotaliidae	Cushman, 1927
Genus *Globorotalia*	Cushman, 1927
Family Catapsydracidae	Bolli, Loeblich & Tappan, 1957
Genus *Pulleniatina*	Cushman, 1927
Genus *Neogloboquadrina*	Bandy, Frerichs and Vincent, 1967
Genus *Globoquadrina*	Finlay, 1947
Genus *Globorotaloides*	Bolli, 1957
Genus *Catapsydrax*	Bolli, Loeblich and Tappan, 1957
Family Orbulinidae	Schultze, 1854
Genus *Beella*	Banner and Blow, 1960
Genus *Globigerinella*	Cushman, 1927
Genus *Globigerina*	d'Orbigny, 1826
Genus *Sphaeroidinella*	Cushman, 1927
Genus *Sphaeroidinellopsis*	Banner and Blow, 1959
Genus *Globigerinoides*	Cushman, 1927
Genus *Praeorbulina*	Olsson, 1964
Genus *Orbulina*	d'Orbigny, 1839
Family Candeinidae	Cushman, 1927
Genus *Candeina*	d'Orbigny, 1839
Genus *Globigerinatella*	Cushman and Stainforth, 1945
Genus *Tenuitella*	Fleisher, 1974
Genus *Turborotalita*	Banner and Blow, 1962
Family Hantkeninidae	Cushman, 1927
Genus *Cassigerinella*	Pokorný, 1955
Family Heterohelicidae	Cushman, 1927
Genus *Streptochilus*	Brönnimann and Resig, 1971

CHAPTER 6

SYSTEMATICS

Families and genera are treated in the same order as in Figure 41, starting from the left-hand side. Species within each genus are discussed in alphabetic order for ease of reference. Both Neogene and selected Paleogene planktonics are discussed, the Neogene taxa are discussed first followed by the Paleogene forms. For ease of reference, all Neogene and Paleogene species discussed are listed alphabetically by species name at the end of this chapter.

Systematic treatment is kept to a minimum in view of the extensive documentation of this information in many studies, including Ellis and Messina (1940) *et seq*. and the various palaeontological reports in the Initial Reports of the Deep Sea Drilling Project. Notes on synonyms and morphological details are included for the purposes of outlining the writer's concept of some of the less well-defined taxa.

NEOGENE PLANKTONIC FORAMINIFERA

Superfamily Globigerinacea Carpenter, Parker & Jones, 1862

Family Globorotaliidae Cushman, 1927

Remarks: This family includes those species with a finely perforate surface wall texture that is 'characterised by pores without recognisable pore pits, distributed in apparently random fashion over a smooth, spineless surface' (Fleisher, 1974, p.1011).

Genus *Globorotalia* Cushman, 1927

type species *Pulvinulina menardii* var. *tumida* Brady, 1877

Remarks: This genus represents the Miocene to Recent radiation of finely perforate taxa.

Globorotalia archeomenardii Bolli, 1957

Plate 1, Figures 1-3.

Globorotalia archeomenardii Bolli, 1957, p.119, pl.28, fig.11.

Remarks: This species is distinguished from its descendant *Globorotalia praemenardii* by its relatively strongly convex spiral side and less lobate equatorial periphery.

Stratigraphic Range: Site 214; base Zone N.8 to within Zone N.9.
Site 289; within Zone N.8 to within Zone N.9.

Globorotalia crassaformis s.l. (Galloway & Wissler, 1927)
Plate 1, Figures 4-7.

Globigerina crassaformis Galloway and Wissler, 1927, p.41, pl.7, fig.12a-c.

Globorotalia (Turborotalia) crassaformis oceanica Cushman and Bermúdez, 1949, p.43, pl.8, fig.13-15 (*vide* Ellis & Messina).

Globorotalia (Turborotalia) crassaformis ronda Blow, 1969, p.388, pl.4, fig.4-6; pl.37, fig.6-9.

Globorotalia (Globorotalia) crassula viola Blow, 1969, p.397, pl.5, fig.4-9.

Remarks: Lidz (1972) has shown *G. crassaformis oceanica* and *G. crassaformis ronda* to represent ecophenotypic variants of *G. crassaformis s.s.* Accordingly the *G. crassaformis s.l.* plexus is considered to represent one taxon albeit variable particularly in terms of test size, chamber height, peripheral thickening (keel development) and degree of calcite encrustation. Blow (1969) recorded *G. crassaformis s.l.* as ranging from early Zone N.17 although its occurrence in the tropical Indo-Pacific is restricted from within Zone N.19 to Zone N.23. As a result its Early Pliocene evolution from *Globorotalia puncticulata*, as documented by Berggren (1977b), could not be examined.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19b to within Zone N.22b.

Globorotalia cultrata cultrata (d'Orbigny, 1839)
Plate 1, Figures 8-10.

Rotalina (Rotalina) cultrata d'Orbigny, 1839, pl.5, fig.7-9 (*vide* Ellis & Messina).

Globorotalia (Globorotalia) cultrata cultrata (d'Orbigny), Blow, 1969, p.358, pl.6, fig.4-8.

Remarks: The writer's concept of the variation within this group of *Globorotalia* morphotypes is expressed in terms of three subspecies:

Globorotalia cultrata cultrata is biconvex with a low spire height and smoothly curved dorsal intercameral sutures; *Globorotalia cultrata menardii* is unequally biconvex with smoothly curved dorsal intercameral sutures; *Globorotalia cultrata limbata* is also unequally biconvex but has dog-leg shaped dorsal intercameral sutures. All three forms are intergradational and the possibility that some of these differences are the result of comparing different ontogenetic stages of different specimens, as suggested by Fleisher (1974), cannot be overlooked.

Stratigraphic Range: Site 214; within Zone 'N.13' to Zone N.23.
Site 289; within Zone N.12-N.13 to within Zone N.22b.

Globorotalia cultrata limbata (d'Orbigny, 1826)
Plate 1, Figures 11-13.

Rotalia limbata d'Orbigny, *in* Fornasini, 1902, fig.55.

Globorotalia (Globorotalia) cultrata limbata (d'Orbigny), Blow, 1969, p.359, pl.7, fig.4-6; pl.42, fig.2,3.

Remarks: A continuous intergradation exists between *Globorotalia cultrata limbata* and *Globorotalia multicamerata*, the distinction being taken somewhat artificially that specimens with eight or more chambers in the last whorl are referred to *G. multicamerata* while those with fewer chambers are maintained within the *G. cultrata limbata* complex.

Stratigraphic Range: Site 214; within Zone N.14 to within Zone N.21b.

Globorotalia cultrata menardii (Parker, Jones & Brady, 1865)
Plate 1, Figures 14-16.

Rotalia menardii Parker, Jones and Brady, 1865, p.20, pl.3, fig.81 (*vide* Ellis & Messina).

Globorotalia (Globorotalia) cultrata menardii (Parker, Jones and Brady), Blow, 1969, p.359, pl.6, fig.9-11.

Remarks: See comments under *G. cultrata cultrata.*

Stratigraphic Range: Site 214; within Zone 'N.13' to Zone N.23.

Globorotalia eastropacia Boltovskoy, 1974

Plate 2, Figures 1-4.

Globorotalia hirsuta eastropacia Boltovskoy, 1974, p.128, pl.1, fig.1-11.

Globorotalia theyeri Fleisher, 1974, p.1028, pl.12, fig.9; pl.13, fig.1-5.

Remarks: Specimens are confined to Site 217, Bay of Bengal, and are morphologically similar to *Globorotalia theyeri* described from the Arabian Sea by Fleisher (1974). Their rarity precluded an investigation of its variability and therefore its precise relationship to the similar *Globorotalia hirsuta*, from which it differs in possessing a much flatter dorsal side (of neo-type of *G. hirsuta*, Blow, 1969, pl.8, fig.1-3). The description and illustrations of the Pacific *Globorotalia hirsuta eastropacia* Boltovskoy are close to *G. theyeri* which differs mainly in being dominantly right-coiled. Boltovskoy (1974) described his subspecies as being non-keeled yet his Figure 11 shows a raised imperforate ridge along the equatorial periphery of the last chamber indicating a keel. This corresponds to the often discontinuous keel noted by Fleisher (1974) on his *G. theyeri*. These two taxa are probably synonymous in which case *G. theyeri* Fleisher is to be suppressed as the junior synonym. This taxon, which shows distinct coiling preference provinciality between the Indian and Pacific Oceans, is considered sufficiently morphologically distinct to warrant specific status.

Globorotalia eastropacia was only present in sample 217-2-4 80-82cm which is considered to belong to Zone N.19b; however, the presence of *Beella digitata s.s.* and *G. eastropacia* together with the suggestion of mixed preservation states implies a degree of Quaternary contamination.

Globorotalia fohsi s.l. Cushman & Ellisor, 1939

Plate 2, Figures 5-11.

Globorotalia fohsi Cushman and Ellisor, 1939, p.12, pl.2, fig.6.

Globorotalia lobata Bermúdez, 1949, p.286, pl.22, fig.15-17.

Globorotalia fohsi robusta Bolli, 1950, p.89, pl.15, fig.2.

Remarks: The concept of Blow and Banner (1966) for expressing the *Globorotalia peripheroronda - peripheroacuta - praefohsi - fohsi* evolutionary transition is used in this thesis, such that *G. fohsi s.l.* is distinguished from earlier members of the lineage by having a fully-keeled equatorial periphery. *G. fohsi robusta* and *G. fohsi lobata* were not separated. A specimen of *G. fohsi s.l.* (Plate 2, Figures 8-11) from the type *Globorotalia fohsi lobata* Zone (Trinidad) of Bolli (1957) is included to illustrate its finely perforate surface wall texture. This evolutionary lineage was not observed at Site 214, but is apparently represented at Site 289, preservational problems notwithstanding.

Stratigraphic Range: Site 214; within Zone 'N.12' to basal Zone N.14.
Site 289; base Zone N.12 to (?)basal Zone N.14.

Globorotalia lenguaensis Bolli, 1957
Plate 2, Figures 12-14.

Globorotalia lenguaensis Bolli, 1957, p.120, pl.29, fig.5a-c.

Remarks: This species is characterised by its small size, strongly curved dorsal intercameral sutures and its almost circular outline which occasionally becomes somewhat radially elongate towards *paralenguaensis*. No keeled specimens (*paralenguaensis*) were found although rare specimens from within Zone N.17 showed an acute semi-perforate margin. *G. lenguaensis*, which ranges from Zone N.12 (Blow, 1969), is similar to the non-keeled *Globorotalia peripheroronda; G. lenguaensis* having a more circular equatorial periphery and a lower conical axial profile. Accordingly it seems that the ancestor to *G. lenguaensis* is to be found in the *G. peripheroronda-fohsi* lineage rather than from *Globorotalia merotumida* as suggested by Blow (1969).

The extinction of *G. lenguaensis* overlaps the basal occurrence of *Pulleniatina primalis* and is therefore a useful guide to latest Zone N.17.

Stratigraphic Range: Site 214; within Zone N.14 to within Zone N.17c.
Site 289; (?)Zone N.14, within Zone N.16 to within Zone N.17c.

Globorotalia margaritae Bolli & Bermúdez, 1965

Plate 3, Figures 1-3.

Globorotalia margaritae Bolli and Bermúdez, 1965, p.139, pl.1, fig.16-18.

Remarks: This distinctive keeled species ranges within Zone N.19 at Sites 214 and 289 where it is almost 100% left-coiled.

Stratigraphic Range: Site 214; base Zone N.19a to top Zone N.19b.
Site 289; base Zone N.19a to top Zone N.19b.

Globorotalia merotumida Blow & Banner, 1965

Plate 3, Figures 4-6.

Globorotalia (Globorotalia) merotumida Blow and Banner, *in* Banner and Blow, 1965, p.1352, fig.1.

Remarks: The development of *Globorotalia merotumida* within Site 214 has been adequately dealt with by Berggren and Poore (1974). Rare and isolated occurrences of this species in Site 289 are within Zones N.16 and N.17.

Stratigraphic Range: Site 214; within Zone N.15 to within Zone N.17a.
Site 289; (?)within Zone N.16 to within Zone N.17c.

Globorotalia miozea conoidea Walters, 1965

Plate 3, Figures 7-9.

Globorotalia miozea conoidea Walters, 1965, p.124, fig.8 I-M.

Remarks: Forms referable to *Globorotalia miozea conoidea* have a restricted range at Site 214. A taxonomic review of the *Globorotalia miozea-conoidea-conomiozea-mediterranea* group has been presented by Berggren and Amdurer (1973) and Berggren (1977a,b). The rarity of specimens referable to these lineages precluded a detailed investigation of these forms.

Stratigraphic Range: Site 214; within Zone N.17c.
Site 289; within Zone N.17c.

Globorotalia miozea miozea Finlay, 1939

Plate 3, Figures 10-12.

Globorotalia miozea Finlay, 1939, p.326, pl.29, fig.159-161.

Remarks: This species is relatively abundant in the Middle Miocene at

Site 214 where specimens are typically calcite-encrusted.

Stratigraphic Range: Site 214; within Zone 'N.12' to top Zone N.14.

Globorotalia multicamerata Cushman & Jarvis, 1930

Plate 3, Figures 13-16.

Globorotalia menardii var. *multicamerata* Cushman and Jarvis, 1930, p.367, pl.34, fig.8a-c.

Remarks: See comments under *G. cultrata limbata.*

Stratigraphic Range: Site 214; within Zone N.17c to latest Zone N.21b.
Site 289; within Zone N.17a to latest Zone N.21b.

Globorotalia peripheroacuta Blow & Banner, 1966

Plate 4, Figures 1-4.

Globorotalia (Turborotalia) peripheroacuta Blow and Banner, 1966, p.294, pl.1, fig.2; pl.2, fig.4,5,13.

Stratigraphic Range: Site 214; within Zone 'N.12'.
Site 289; base Zone N.10 to within Zone N.11.

Globorotalia peripheroronda Blow & Banner, 1966

Plate 4, Figures 5-7.

Globorotalia (Turborotalia) peripheroronda Blow and Banner, 1966, p.294, pl.1, fig.1a-c; pl.2, fig.1-3.

Stratigraphic Range: Site 214; (?)Zone N.6, Zone N.8 to Zone 'N.12'.
Site 289; basal Zone N.8 to Zone N.10, (?)Zone N.11.

Globorotalia praefohsi Blow & Banner, 1966

Plate 4, Figures 8-10.

Globorotalia (Globorotalia) praefohsi Blow and Banner, 1966, p.295, pl.1, fig.3-4; pl.2, fig.6-7, 10-11.

Stratigraphic Range: Site 214; within Zone 'N.12' to within Zone 'N.13'.
Site 289; base Zone N.11 to within Zone N.11.

Globorotalia praemenardii Cushman & Stainforth, 1945

Plate 4, Figures 11-13.

Globorotalia praemenardii Cushman and Stainforth, 1945, p.70, pl.13, fig.14.

Remarks: This species occurs rarely in Sites 214 and 289.

Stratigraphic Range: Site 214; (?)Zone 'N.12', within Zone 'N.13'.
Site 289; within Zone N.9 to within Zone N.10.

Globorotalia scitula praescitula Blow, 1959

Plate 4, Figures 14-16.

Globorotalia scitula praescitula Blow, 1959, p.221, pl.19, fig.128.

Stratigraphic Range: Site 214; within Zone N.5 to basal Zone 'N.12'.
Site 289; within Zone N.7, (?)Zone N.9.

Globorotalia scitula scitula (Brady, 1882)

Plate 5, Figures 1-3.

Pulvinulina scitula Brady, 1882, p.716 (*vide* Ellis & Messina).

Globorotalia scitula scitula (Brady), Blow, 1959, p.219, pl.19, fig.126a-c.

Stratigraphic Range: Site 214; within Zone 'N.13' to Zone N.23.
Site 289; within Zone N.10 to within Zone N.22b.

Globorotalia tosaensis Takayanagi & Saito, 1962

Plate 5, Figures 4-6.

Globorotalia tosaensis Takayanagi and Saito, 1962, p.81, pl.28, fig.11-12.

Stratigraphic Range: Site 214; base Zone N.21a to top Zone N.22a.
Site 289; base Zone N.21a to within Zone N.22b.

Globorotalia truncatulinoides (d'Orbigny, 1839)

Plate 5, Figures 7-9.

?*Rotalina truncatulinoides* d'Orbigny, 1839, p.132, pl.2, fig.25-27 (*vide* Ellis & Messina).

Globorotalia (Globorotalia) truncatulinoides (d'Orbigny), Blow, 1969, p.403, pl.5, fig.10-12; pl.49, fig.6.

Remarks: The writer's concept of this species is restricted to plano-convex forms with at least five chambers in the final whorl, an almost circular equatorial periphery and the presence of a keel (*sensu* Scott, 1973) whether it covers only part or is present on all chambers in the final whorl. *G. truncatulinoides* is dominantly right-coiled throughout its range.

Stratigraphic Range: Site 214; base Zone N.22a to N.23.
Site 289; base Zone N.22a to within Zone N.22b.

Globorotalia tumida plesiotumida Blow & Banner, 1965
Plate 5, Figures 10-12.

Globorotalia (Globorotalia) tumida plesiotumida Blow and Banner, *in* Banner and Blow, 1965, p.1353, fig.2.

Remarks: The evolutionary development of *Globorotalia tumida plesiotumida* from *Globorotalia merotumida* at Site 214 has been adequately discussed by Berggren and Poore (1974) together with the criteria on which to distinguish these taxa from *Globorotalia tumida s.s.*

Stratigraphic Range: Site 214; base Zone N.17a to within Zone N.18.
Site 289; within Zone N.17a to basal Zone N.19a.

Globorotalia tumida tumida (Brady, 1877)
Plate 5, Figures 13-16.

Pulvinulina menardii var. *tumida* Brady, 1877, p.535 (*vide* Ellis & Messina).
Globorotalia (Globorotalia) tumida tumida (Brady), Blow, 1969, p.371, pl.9, fig.10-12.

Stratigraphic Range: Site 214; base Zone N.18 to Zone N.23.
Site 289; base Zone N.18 to within Zone N.22b.

Family Catapsydracidae Bolli, Loeblich & Tappan, 1957

Remarks: The morphotypes included in this family have a cancellate surface wall texture (*sensu* Fleisher, 1974). Recent representatives are non spine bearing when living. The Genus *Pulleniatina* is included because its pre-adult chambers are cancellate-walled becoming covered later in ontogeny by an almost imperforate 'skin' of calcite giving a smooth walled appearance.

Genus *Pulleniatina* Cushman, 1927

type species *Pullenia obliquiloculata* Parker & Jones, 1865

Pulleniatina obliquiloculata finalis Banner & Blow, 1967

Plate 6, Figures 1-3.

Pulleniatina obliquiloculata finalis Banner and Blow, 1967, p.140, pl.2, fig.4-10; pl.3, fig.5a-b; pl.4, fig.10.

Stratigraphic Range: Site 214; within Zone N.22a to Zone N.23.
Site 289; within Zone N.22a to within Zone N.22b.

Pulleniatina obliquiloculata obliquiloculata (Parker & Jones, 1865)

Plate 6, Figures 4-8.

Pullenia obliquiloculata Parker and Jones, 1865, p.365, pl.19, fig.4a-b (*vide* Ellis & Messina).

Pulleniatina obliquiloculata obliquiloculata (Parker and Jones), Banner and Blow, 1967, p.137, pl.3, fig.4a-c; pl.4, fig.9.

Remarks: The ontogenetic development of the *Pulleniatina obliquiloculata s.l.* surface wall texture, from a cancellate-walled juvenile stage (Plate 6, Figures 4,6) through to the adult stage having an almost imperforate 'skin' of calcite rendering a smooth outer wall (Plate 6, Figure 5), reflects the phylogenetic development of *Pulleniatina primalis* from the cancellate-walled *Neogloboquadrina acostaensis*. Extant representatives of both ancestral and descendant genera are considered to be non-spine bearing (Bé, 1977) in spite of the interpretation of Burt and Scott (1974) that conical pustules on specimens of Recent *P. obliquiloculata* suggest spine bases.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19a to within Zone N.22b.

Pulleniatina obliquiloculata praecursor Banner & Blow, 1967

Plate 6, Figures 9,10.

Pulleniatina obliquiloculata praecursor Banner and Blow, 1967, p.139, pl.3, fig.3a-c.

Stratigraphic Range: Site 214; within Zone N.17c to within Zone N.22a.
Site 289; within Zone N.17c to within Zone N.22a.

Pulleniatina praespectabilis Brönnimann & Resig, 1971
Plate 6, Figures 11-13.

Pulleniatina spectabilis praespectabilis Brönnimann and Resig, 1971, p.1286, pl.19, fig.4,7.

Remarks: The gradation from *Pulleniatina primalis* to *Pulleniatina praespectabilis* occurs within Zone N.18 to 'lower' Zone N.19 at Site 289 and is shown by the development from the almost parallel sided with rounded periphery of *primalis* to the relatively triangular axial profile of *praespectabilis.*

Stratigraphic Range: Site 289; within Zone N.18 to within Zone N.19a.

Pulleniatina primalis Banner & Blow, 1967
Plate 7, Figures 1-3.

Pulleniatina primalis Banner and Blow, 1967, p.142, pl.1, fig.3-8; pl.3, fig.2a-c.

Stratigraphic Range: Site 214; base Zone N.17c to within Zone N.21b.
Site 289; base Zone N.17c to within Zone N.19a.

Pulleniatina cf. *spectabilis* Parker, 1965
Plate 7, Figures 4-6.

Pulleniatina spectabilis Parker, 1965, p.151, fig.1-4.

Remarks: The development of a discontinuous peripheral thickening occurs in only very few specimens indicating their proximity to *P. spectabilis.*

Stratigraphic Range: Site 289; within Zone N.19a.

Genus *Neogloboquadrina* Bandy, Frerichs & Vincent, 1967 emended herein
type species *Globigerina dutertrei* d'Orbigny, 1839

Remarks: The concept of the Genus *Neogloboquadrina* is expanded from that of Bandy, Frerichs and Vincent (1967) to distinguish those species which evolved from the Paleogene species *N. opima.* Species maintained within this genus include *N. siakensis, N. kugleri, N. acostaensis* and *N. dutertrei* which are characterised by a trochospiral coiled test, globular to angular chambers, are generally paralleled-sided in axial view with a circular equatorial profile, an interiomarginal umbilical to extra-umbilical aperture which varies in shape from a low-arched slit to distinctly comma-shaped, apertural teeth and tegilla are occasionally present. *Neogloboquadrina* species have a cancellate surface wall texture which distinguishes them from the finely perforate *Globorotalia* and the microperforate *Tenuitella.*

The evolution of *N. opima* and therefore the Paleogene evolutionary development of this genus is beyond the scope of this thesis.

Neogloboquadrina acostaensis acostaensis (Blow, 1959)

Plate 7, Figures 7-10.

Globorotalia acostaensis Blow, 1959, p.208, pl.17, fig.106a-c, 107.

Globorotalia (Turborotalia) acostaensis acostaensis Blow, Blow, 1969, p.344, pl.9, fig.13-15; pl.33, fig.1,2.

Neogloboquadrina acostaensis acostaensis (Blow), Fleisher, 1975, p.754.

Stratigraphic Range: Site 214; base Zone N.16 to within Zone N.21b.
Site 289; base Zone N.16 to within Zone N.21a.

Neogloboquadrina acostaensis humerosa (Takayanagi & Saito, 1962)

Plate 7, Figures 11-13.

Globorotalia humerosa Takayanagi and Saito, 1962, p.78, pl.28, fig.1a-2b.

Globorotalia (Turborotalia) acostaensis humerosa Takayanagi and Saito, Blow, 1969, p.345, pl.33, fig.4,5,7-9; pl.34, fig.1-2.

Neogloboquadrina humerosa (Takayanagi and Saito), Fleisher, 1975, p.754.

Stratigraphic Range: Site 214; mid Zone N.16 to within Zone N.22a.
Site 289; mid Zone N.16 to within Zone N.21b.

Neogloboquadrina acostaensis pseudopima (Blow, 1969)

Plate 7, Figures 14-16.

Globorotalia (Turborotalia) acostaensis pseudopima Blow, 1969, p.387, pl.35, fig.1-7.

Neogloboquadrina pseudopima (Blow), Fleisher, 1975, p.754.

Remarks: At Site 214 there are many medium-sized, trochospiral, non-keeled, cancellate-walled specimens with about 4½ chambers in the final whorl, often with a small open umbilicus and an umbilical to extra-umbilical aperture. Three central morphotypes within this plexus are recognised; *N. acostaensis pseudopima, N. nigriniae* and *N. vincentae.*

N. nigriniae is distinguished from *N. acostaensis pseudopima* by its large, open and obliquely directed aperture which does not protrude above the plane of the dorsal surface (Fleisher, 1974). The writer concurs with Fleisher (1974) that *pseudopima* and *vincentae* appear to be closely related. These two species were distinguished by the presence of the apertural-umbilical flange, more open umbilicus and more convex dorsal surface of *N. vincentae* (Fleisher, 1974).

Both *N. nigriniae* and *N. vincentae* were confined to the Indian Ocean DSDP material.

Stratigraphic Range: Site 214; top Zone N.19b to within Zone N.22a.

Neogloboquadrina birnageae (Blow, 1959)

Plate 8, Figures 1-3.

Globorotalia birnageae Blow, 1959, p.210, pl.17, fig.108.

Remarks: At Site 214, *N. birnageae* ranges from just below the extinction horizon of *N. kugleri* to just below the first occurrence of *Praeorbulina* spp. This range represents a lowering of its first occurrence from within Zone N.7 (Blow, 1969) to within Zone N.4. The close morphological and wall textural similarity suggests that the origin of *birnageae* is to be found within the *kugleri* group *(N. kugleri, N. mendacis, N. pseudokugleri).* Blow (1969) recognised that *birnageae* especially resembled the *mendacis* morphotype. This resemblance is also evident at Site 214 and in view of the range extention of *birnageae* this taxon is considered to have evolved from *N. mendacis.*

The morphological differences between *birnageae* and *mendacis* are listed by Blow (1969, p.346) in that *birnageae* is "characterised by its closed umbilicus, tight coiling and well developed apertural lip". In addition, *birnageae* typically has a flat to slightly convex spiral side compared to the almost biconvex *mendacis*. Although *birnageae* is tightly coiled some specimens show a tendency toward relaxation of the spire and consequent development of a small umbilical depression. The presence of later Zone N.5 to early Zone N.6 forms of *birnageae* morphologically similar to *kugleri* is noted and awaits further investigation.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.8.

Neogloboquadrina continuosa (Blow, 1959)

Plate 8, Figures 4,5.

Globorotalia continuosa Blow, 1959, p.218, pl.19, fig.125a-c.

Neogloboquadrina continuosa (Blow), Fleisher, 1975, p.754.

Remarks: This four-chamber per whorl neogloboquadrinid occurs rarely and sporadically at Site 214.

Stratigraphic Range: Site 214; within Zone 'N.12' to within Zone N.17a.
Site 289; basal Zone N.9 to within Zone N.16.

Neogloboquadrina dutertrei (d'Orbigny, 1839)

Plate 8, Figures 6-8.

Globigerina dutertrei d'Orbigny, 1839, p.84, pl.4, fig.19-21 (*vide* Ellis & Messina).

Neogloboquadrina dutertrei (d'Orbigny), Bandy, Frerichs and Vincent, 1967, p.152, pl.14, fig.2-12.

Remarks: This species is separated from *Neogloboquadrina acostaensis humerosa* by the greater rate of increase in chamber size and by the wedge-shaped chambers of *N. dutertrei* in comparison with the more globular chambers of *N. acostaensis humerosa*.

Stratigraphic Range: Site 214; base Zone N.21b to Zone N.23.
Site 289; (?)Zone N.19b, within Zone N.21b to within Zone N.22b.

Neogloboquadrina kugleri kugleri (Bolli, 1957)

Plate 8, Figures 9-11; Plate 9, Figures 1-4.

Globorotalia kugleri Bolli, 1957, p.118, pl.28, fig.5-6.

Remarks: The criteria suggested by Blow (1969) for recognising the various morphotypic end-members of the *kugleri-mendacis-pseudokugleri* group are used in this study. In terms of surface wall texture the *kugleri* group is transitional between the cancellate-walled *N. opima-siakensis* taxa and the Early Miocene finely perforate *Globorotalia*. The balance of evidence suggests placement of the *kugleri* group within the Genus *Neogloboquadrina*, as indicated by both comparative test geometry and surface wall textural considerations.

Stratigraphic Range: Site 214; within Zone P.22 to top Zone 'N.4'.
Site 289; pre-Zone 'N.4' to top Zone 'N.4'.

Neogloboquadrina kugleri mendacis (Blow, 1969)

Plate 8, Figures 12-14.

Globorotalia (Turborotalia) mendacis Blow, 1969, p.390, pl.38, fig.5-9.

Remarks: The presence of the complete spectrum of morphotypes from *kugleri* to *mendacis* in the youngest sample assigned to Zone 'N.4' at Site 214 means the extinction horizon of *mendacis* is increased from within the early part of Zone N.4 (Blow, 1969) to latest Zone N.4.

Stratigraphic Range: Site 214; within Zone P.21 to latest Zone 'N.4'.

Neogloboquadrina kugleri pseudokugleri (Blow, 1969)

Plate 8, Figures 15-17.

Globorotalia (Turborotalia) pseudokugleri Blow, 1969, p.391, pl.10, fig.4-6; pl.39, fig.5,6.

Remarks: See comments under *N. kugleri kugleri*.

Stratigraphic Range: Site 214; within Zone P.22 to latest Zone 'N.4'.

Neogloboquadrina nigriniae (Fleisher, 1974)

Plate 9, Figures 5,6.

Turborotalia (Turborotalia) nigriniae Fleisher, 1974, p.1036, pl.20, fig.1-5.

Remarks: See comments under *N. acostaensis pseudopima.*

Stratigraphic Range: Site 214; within Zone N.19a to top Zone N.19b.

Neogloboquadrina opima s.l. (Bolli, 1957)

Plate 9, Figures 7-13.

Globorotalia opima opima Bolli, 1957, p.117, pl.28, fig.1,2.

Globorotalia opima nana Bolli, 1957, p.118, pl.28, fig.3.

Remarks: Early Miocene reports of *Neogloboquadrina opima* are not uncommon; Berggren and Amdurer (1973) recorded *N. opima nana* as ranging to within Zone N.4 at DSDP Site 18, whereupon it gave rise to the comma-shaped apertural forms *N. semivera* and *N. pseudocontinuosa*, while Shafik and Chaproniere (1978) noted the *N. opima-N.siakensis* plexus within Zone N.4 sediments of the Ashmore Reef No. 1 Well, Bonaparte Gulf Basin, offshore Western Australia. At Site 214 the *N. opima* group disappeared in the Late Oligocene and reappeared later within Zone N.5. These Early Miocene forms contain a broad spectrum of 4 to 5½ chambers per whorl, cancellate-walled specimens, randomly coiled and generally dominated numerically by a central morphotype. There is a trend for an overall increase in number of chambers per last whorl of the central morph throughout Zone N.5 to within Zone N.6. This gradational plexus is provisionally included in *N. opima s.l.*, being distinctly different in apertural form from *N. semivera* and *N. pseudocontinuosa* (compare Plate 9, Figures 7,11 with Plate 9, Figure 14 and Plate 10, Figures 1 and 3).

Stratigraphic Range: Site 214; within Zone N.5 to within Zone N.8.
Site 289; within Zone 'N.4' to within Zone N.8.

Neogloboquadrina pseudocontinuosa (Jenkins, 1960)

Plate 9, Figures 14-16; Plate 10, Figures 1,2.

Globorotalia opima Bolli subsp. *continuosa* Jenkins, 1960, p.366, pl.5, fig.4a-c.

Globorotalia (Turborotalia) nana pseudocontinuosa Jenkins, Jenkins, 1971, p.124, pl.12, fig.336-41.

Remarks: Specimens illustrated are taken from a sample of the Gambier Limestone, South Australia, collected by Abele (1961) and included here for comparison with the tropical cancellate-walled Early Miocene 'turborotaliids' of Site 214.

Neogloboquadrina semivera (Hornibrook, 1961)

Plate 10, Figures 3-6.

Globigerina semivera Hornibrook, 1961, p.149, pl.23, fig.455-7.

Globorotalia (Turborotalia) nana semivera (Hornibrook), Jenkins, 1971, p.125, pl.12, fig.342-4.

Remarks: Specimens from the basal part of Gellibrand Clay, Point Ronald Victoria, and from the B.M.R. Lakes Entrance Well are included for comparison with the Early Neogene *Neogloboquadrina* spp. at Site 214.

Neogloboquadrina siakensis (LeRoy, 1939)

Plate 10, Figures 7-9.

Globorotalia siakensis LeRoy, 1939, p.262, pl.4, fig.20-22.

Neogloboquadrina siakensis (LeRoy), Fleisher, 1974, p.754.

Remarks: The variability of *N. siakensis* at Site 214 includes those Early Miocene specimens in which the last formed (adult) chamber contains a very low arched apertural slit reminiscent of *'Globorotalia' bella* Jenkins; removal of this ultimate chamber reveals the typical comma-shaped aperture of *N. siakensis*.

Stratigraphic Range: Site 214; within Zone P.22 to top Zone N.14.
Site 289; pre-Zone 'N.4' to top Zone N.14.

Neogloboquadrina vincentae (Fleisher, 1974)

Plate 10, Figures 10-12.

Turborotalia (Turborotalia) vincentae Fleisher, 1974, p.1036, pl.21, fig.1-5.

Remarks: See comments under *N. acostaensis pseudopima*.

Stratigraphic Range: Site 214; within Zone N.17c to within Zone N.19b.

Neogloboquadrina zealandica (Hornibrook, 1958)

Plate 10, Figures 13-15.

Globorotalia zealandica Hornibrook, 1958, p.667, fig.18,19,30.

Globorotalia (Turborotalia) zealandica zealandica Hornibrook, Jenkins, 1971, p.133, pl.14, fig.395-7.

Remarks: All specimens of *N. zealandica* were selected from a sample of the Gambier Limestone (South Australia) collected by Abele (1961) which also contained *Globigerinoides quadrilobatus trilobus.* The evolutionary development of this species from *N. pseudocontinuosa,* as suggested by Berggren and Amdurer (1973) is supported on the basis of a similar cancellate surface wall texture as well as other morphological details. However, their suggestion that *zealandica* gave rise to the (finely perforate) *Globorotalia miozea* group requires closer study in view of the suggested monophyletic nature of the Genus *Globorotalia.*

Genus *Globoquadrina* Finlay, 1947

type species *Globorotalia dehiscens* Chapman, Parr & Collins, 1934

Remarks: The writer's concept of this genus includes the taxa representing four lineages that range during at least part of the Neogene. They are based on *G. sellii/G. binaiensis; G. dehiscens praedehiscens/G. dehiscens s.s.,* *G. venezuelana/G. conglomerata* and *G. altispira.* These taxa are characterised by a cancellate surface wall texture, trochospiral coiled test, with (rarely) subglobular, (generally) compressed to angular shaped chambers without a peripheral keel. They are distinguished from *Neogloboquadrina* species by the generally globular to subglobular chambers and almost parallel-sided axial profile of the latter taxon.

Globoquadrina altispira s.l. (Cushman & Jarvis, 1936)

Plate 11, Figures 1-3.

Globigerina altispira Cushman and Jarvis, 1936, p.5, pl.1, fig.13,14.

Globoquadrina altispira altispira (Cushman and Jarvis), Bolli, 1957, p.111, pl.24, fig.7,8.

Globoquadrina altispira globosa Bolli, 1957, p.111, pl.24, fig.9,10.

Stratigraphic Range: Site 214; within Zone 'N.4' to top Zone N.21a.
Site 289; (?)Zone 'N.4', Zone N.5 to top Zone N.21a.

Globoquadrina binaiensis (Koch, 1926)

Plate 11, Figures 4-6.

Globigerina ? aspera Koch, 1926, (not Ehrenberg), p.746, fig.22,23 (*vide* Ellis & Messina).

Globigerina binaiensis Koch, 1935, p.558, *nom.nov.*

Globoquadrina binaiensis (Koch), Fleisher, 1974, p.1024.

Remarks: *Globoquadrina binaiensis* differs from its ancestor *Globoquadrina sellii* by its high, flat apertural face and acute shape of the last formed chamber as seen in spiral and side orientations.

Stratigraphic Range: Site 214; pre-Zone 'N.4' to latest Zone N.5.
Site 289; within Zone 'N.4' to base Zone N.6.

Globoquadrina conglomerata (Schwager, 1866)

Plate 11, Figures 7-11.

Globigerina conglomerata Schwager, 1866, p.255, pl.7, fig.113 (*vide* Ellis & Messina).

Globoquadrina conglomerata (Schwager), Parker, 1962, p.240, pl.6, fig.11-18.

Remarks: Parker (1962) showed the considerable morphologic change that occurred throughout ontogeny in *G. conglomerata*. Representative specimens illustrating this change from a 'turborotaliid' juvenile to a 'globigerinid' adult stage are shown (Plate 11) for comparison with the very similar ontogenetic development of its ancestor, *Globoquadrina venezuelana*.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; base Zone N.19b to within Zone N.22b.

Globoquadrina dehiscens dehiscens (Chapman, Parr & Collins, 1934)

Plate 11, Figures 12-16; Plate 12, Figures 1-4.

Globorotalia dehiscens Chapman, Parr and Collins, 1934, p.569, pl.11, fig.36.

Globoquadrina dehiscens dehiscens (Chapman, Parr and Collins), Blow, 1969, p.341, pl.29, fig.1.

Remarks: *Globoquadrina dehiscens* has a disjunct range at Sites 214 and 289, ranging from Early to early Late Miocene, disappearing near the Zone N.15/N.16 boundary, and reappearing in latest Zone N.17 before disappearing at the Zone N.17/N.18 boundary.

Stratigraphic Range: Site 214; base Zone N.5 to within Zone N.16, within Zone N.17c.

Site 289; base Zone N.8 to within Zone N.16, within Zone N.17c.

Globoquadrina dehiscens praedehiscens Blow & Banner, 1962

Plate 12, Figures 5-7.

Globoquadrina dehiscens praedehiscens Blow and Banner, 1962, p.116, pl.15, fig.Q-S.

Stratigraphic Range: Site 214; base Zone 'N.4' to latest Zone N.5.

Site 289; with Zone 'N.4' to base Zone N.6.

Globoquadrina sellii Borsetti, 1959

Plate 12, Figures 8,9.

Globoquadrina sellii Borsetti, 1959, p.209, pl.1, fig.3 (*vide* Ellis & Messina).

Remarks: See comments under *Globoquadrina binaiensis*.

Stratigraphic Range: Site 214; to within Zone 'N.4'.

Site 289; within Zone 'N.4'.

Globoquadrina venezuelana s.l. (Hedberg, 1937)

Plate 12, Figures 11-18.

Globigerina venezuelana Hedberg, 1937, p.681, pl.92, fig.7a-b.

Globoquadrina venezuelana (Hedberg), Parker, 1967, p.171, pl.26, fig.4-10.

Remarks: Early Zone N.17 assemblages of *G. venezuelana* show a marked tendency to develop a flattened apertural face with laterally compressed chambers reminiscent of *Globoquadrina dehiscens praedehiscens*. Both earlier and later occurrences of *G. venezuelana* have the typical rounded apertural face and subglobular chambers. Progressive dissection techniques confirm Parker (1967) on the variability of *G. venezuelana* and *G. dehiscens* which show a consistant morphologic and stratigraphic pattern as discussed on pp.26.

In detail *G. venezuelana s.s.* (Plate 12, Figure 13) pre-adults have subglobular, moderately apressed chambers which increase relatively slowly in size resulting in a subcircular lobulate equatorial profile. The ontogenetic change from a 'turborotaliid' juvenile to a 'globigerinid' adult is accompanied by a reduction in the number of chambers per whorl. Distinctly less ontogenetic change was noted in *G. dehiscens* (Plate 12, Figure 4) whose pre-adults have a quadrate equatorial profile, relatively closely apressed chambers which increase rapidly in size and possess a distinctly flattened aperture throughout ontogeny. The *'praedehiscens'* (Plate 12, Figures 14-18) morphotype with laterally compressed chambers and a flattened apertural face shows the *venezuelana s.s.* ontogenetic trend on dissection, in that juveniles are 'turborotaliid' with subglobular chambers which later become laterally compressed, with a consequent flattened apertural face, in the 'globigerinid' adult stage. In addition *G. dehiscens* is dominantly left-coiled in the Middle to early Late Miocene while *G. venezuelana s.l.*, is randomly coiled throughout the Middle and Late Miocene.

Stratigraphic Range: Site 214; pre-Zone 'N.4' to within Zone N.19a.
Site 289; pre-Zone 'N.4' to within Zone N.19a.

Genus *Globorotaloides* Bolli, 1957

type species *Globorotaloides variabilis* Bolli, 1957

Globorotaloides bermudezi (Bolli, 1957)

Plate 13, Figures 1-3.

Hastigerinella bermudezi Bolli, 1957, p.112, pl.25, fig.1a-c.

Remarks: There is general agreement that *G. bermudezi* is closely related to *G. hexagona* in both surface wall texture and other morphological details (Fleisher, 1974; Srinivasan and Kennett, 1975; Saito, Thompson and Breger, 1976). They differ mainly by the presence of elongate chambers in the adult stage of *G. bermudezi*. The taxonomic weight attributed to such chamber elongation has resulted in this species being removed to the Genus *Clavatorella* by Fleisher (1974) and to *Protentella (Clavatorella)* by Srinivasan and Kennett (1975). In view of the subtle morphological difference between *hexagona* and *bermudezi*, particularly in pre-adult stage specimens, the latter species is retained within the Genus *Globorotaloides*. The stalagmite calcite pustules shown on a juvenile specimen of *bermudezi* by Srinivasan and Kennett (1975) are considered by them to indicate its spinose nature. This evidence is regarded as equivocal and is at odds with its suggested phyletic relationship to the non-spinose *G. hexagona* (Parker, 1962).

Stratigraphic Range: Site 216A; within Zone N.9 to within Zone 'N.12'.

Globorotaloides hexagona (Natland, 1938)

Plate 13, Figures 4-6.

Globigerina hexagona Natland, 1938, p.149, pl.7, fig.1 (*vide* Ellis & Messina).

Globorotaloides hexagona hexagona (Natland), Blow, 1969, p.373.

Stratigraphic Range: Site 214; within Zone N.14 to Zone N.23.
Site 289; (?)Zone N.15, within Zone N.17a to within Zone N.22b.

Globorotaloides oveyi (Buckley, 1974)

Plate 13, Figures 7-10.

Globorotalia (Clavatorella) oveyi Buckley, 1974, p.169, pl.1, fig.1-10.

Remarks: *Globorotaloides oveyi*, described by Buckley (1974) from a Bay of Bengal plankton tow sample, was found only within the northernmost DSDP site on the Ninetyeast Ridge. *G. oveyi* is considered to have evolved from *G. hexagona* from which it differs in its larger size, more axially compressed chambers and umbilically projecting apertural flaps.

Stratigraphic Range: Site 217A; within Zone N.22a.

Genus *Catapsydrax* Bolli, Loeblich & Tappan, 1957

type species *Globigerina dissimilis* Cushman & Bermúdez, 1937

Remarks: Bolli, Loeblich and Tappan (1957) originally defined the genus on the nature of the umbilical bulla which is insufficient to adequately distinguish it from the convergent Genus *Globigerinita*. The concept of the Genus *Catapsydrax* adopted here is outlined by Fleisher (1974) who stressed the cancellate nature of the surface wall texture as characteristic of this group of closely related species.

Catapsydrax dissimilis ciperoensis (Blow & Banner, 1962)

Plate 13, Figure 11.

Catapsydrax dissimilis (Cushman and Bermúdez), Bolli, Loeblich and Tappan, 1957, pl.7, fig.8.

Globigerinita dissimilis ciperoensis Blow and Banner, *in* Eames *et al.*, 1962, p.107, pl.14, fig.A-C.

Stratigraphic Range: Site 214; pre-Zone 'N.4' to latest Zone N.5.
Site 289; pre-Zone 'N.4' to within Zone N.6.

Catapsydrax dissimilis dissimilis (Cushman & Bermúdez, 1937)

Plate 13, Figure 12.

Globigerina dissimilis Cushman and Bermúdez, 1937, p.25, pl.3, fig.4-6.

Catapsydrax dissimilis (Cushman and Bermúdez), Bolli, Loeblich and Tappan, 1957, p.36, pl.7, fig.6,7 only.

Globigerinita dissimilis dissimilis (Cushman and Bermúdez), Blow and Banner, *in* Eames *et al.*, 1962, p.106, pl.14, fig.A-D.

Stratigraphic Range: Site 214; pre-Zone 'N.4' to within Zone N.5.
Site 289; pre-Zone 'N.4' to within Zone N.6.

Catapsydrax parvulus Bolli, Loeblich & Tappan, 1957
Plate 13, Figures 13-16.

Catapsydrax parvulus Bolli, Loeblich and Tappan, 1957, p.36, pl.7, fig.10a-c.

Remarks: This species has a cancellate surface wall texture, the 'finely perforate, smooth surface' of *C. parvulus* as recorded by Bolli, Loeblich and Tappan (1957) being an artifact due to the typical small specimen size. On the basis of the wall texture this generally bullate species is referable to the Genus *Catapsydrax* (*sensu* Fleisher, 1974). Blow (1969) recorded the range of this species from within Zone N.13 to Zone N.22, (?)N.23. The earliest occurrence is suggested to be within Zone N.2 (Brönnimann and Resig, 1971) in Site 64.1, Ontong Java Plateau.

Stratigraphic Range: Site 214; basal Zone N.5 to within Zone N.22a.
Site 289; within Zone N.6 to within Zone N.16.

Catapsydrax stainforthi Bolli, Loeblich & Tappan, 1957
Plate 13, Figure 14; Plate 14, Figures 1,2.

Catapsydrax stainforthi Bolli, Loeblich and Tappan, 1957, p.37, pl.7, fig.11.

Remarks: Extremely rare specimens were found confined to one sample of Zone N.5 age at Site 214 and one sample of Zone 'N.4' age at Site 289.

Catapsydrax unicavus s.l. Bolli, Loeblich & Tappan, 1957
Plate 14, Figure 3.

Catapsydrax unicavus Bolli, Loeblich and Tappan, 1957, p.37, pl.7, fig.9a-c.

Stratigraphic Range: Site 214; basal Zone 'N.4' to latest Zone N.5.
Site 289; within Zone 'N.4' to within Zone N.5.

Family Orbulinidae Schultze, 1854

Remarks: This family includes forms which have long thin spines when living and a surface wall texture ranging from cancellate to relatively smooth.

Genus *Beella* Banner & Blow, 1960

type species *Globigerina digitata* Brady, 1879 *partim*.

Beella digitata (Brady, 1879)

Plate 14, Figures 4-6.

Globigerina digitata Brady, 1879, (part), p.286 (*vide* Ellis & Messina).

Globigerina digitata Brady, 1884, p.599, pl.80, fig.6-10; not pl.82, fig.6-7 (*vide* Ellis & Messina).

Globorotalia (Beella) digitata (Brady), Banner and Blow, 1960, p.26, text-fig.11.

Beella digitata (Brady), Saito, Thompson and Breger, 1976, p.280, pl.1, fig.1; pl.6, fig.1.

Remarks: Saito *et al.*, (1976) recognised the distinctive perforate nature of the *digitata* test as well as other morphological details reflecting significant divergence from other spinose globigerinids to warrant separate generic status. *B. digitata* is distinguished by its thin wall with irregularly distributed pores of distinctly smaller diameter than those of *Globigerina bulloides*. See also comments for *Beella nicobarensis*.

Stratigraphic Range: Site 217; within Zone N.19a to within Zone N.19b.
Site 217A; within Zone N.19a.

Beella nicobarensis (Srinivasan & Kennett, 1974)

Plate 14, Figures 7-12.

Clavatorella nicobarensis Srinivasan and Kennett, 1974, p.78, pl.1, fig.1-13.

Remarks: *B. nicobarensis* occurs rarely at Site 217, Bay of Bengal. It is thin-walled with irregularly distributed pores and lacks a distinctive cancellate surface wall texture. In this respect it is considered more closely related to *Beella digitata* (Plate 14, Figures 4-6) than to *Globorotaloides bermudezi* (Plate 13, Figures 1-3) as suggested by Srinivasan and Kennett (1975).

Stratigraphic Range: Site 217; within Zone N.19a.

Genus *Globigerinella* Cushman, 1927

type species *Globigerina aequilateralis* Brady, 1884

Globigerinella adamsi (Banner & Blow, 1959)

Plate 14, Figures 13-15.

Hastigerina (Bolliella) adamsi Banner and Blow, 1959, p.13, fig.4a-d.

Globigerinella adamsi (Banner and Blow), Parker, 1962, p.226, pl.2, fig.19-21.

Remarks: This species occurs rarely in Sites 214 and 216 where is indicates the presence of Zone N.23 (by definition).

Globigerinella siphonifera (d'Orbigny, 1839)

Plate 15, Figures 1,2.

Globigerina siphonifera d'Orbigny, 1839, p.83, pl.4, fig.15-18 (*vide* Ellis & Messina).

Globigerina aequilateralis Brady, 1884, p.605, pl.80, fig.18-21 (*vide* Ellis & Messina).

Globigerinella siphonifera (d'Orbigny), Parker, 1962, p.228, pl.2, fig.22-28.

Stratigraphic Range: Site 214; within Zone N.14 to Zone N.23.
Site 289; within Zone N.16 to within Zone N.22b.

Genus *Globigerina* d'Orbigny, 1826

type species *Globigerina bulloides* d'Orbigny, 1826

Remarks: The commonly accepted concept of the Genus *Globigerina* was used here. Fleisher (1974) suggested that this genus was composed of two evolutionary distinct but highly convergent groups of species which should be classified as two separate genera to be identified primarily on the basis of surface wall textural differences. While not disputing this reconstructed phylogeny I consider the differences in surface wall textures insufficient to warrant such formalised splitting for the reasons outlined in greater detail on pp.99.

Globigerina bulloides d'Orbigny, 1826

Plate 15, Figures 3-6.

Globigerina bulloides d'Orbigny, 1826, Model No. 76 (*vide* Ellis & Messina).

Globigerina bulloides d'Orbigny, Banner and Blow, 1960, p.3, pl.1, fig.1a-c, (lectotype erected).

Remarks: This species is generally a rare component of the tropical Neogene assemblages investigated.

Stratigraphic Range: Site 214; within Zone N.16 to Zone N.23.
Site 289; within Zone N.15 to within Zone N.22b.

Globigerina calida calida Parker, 1962

Plate 15, Figures 7,8.

Globigerina calida Parker, 1962, p.221, pl.1, fig.9-11 only.

Globigerina calida calida Parker, Blow, 1969, p.317, pl.13, fig.9,10.

Stratigraphic Range: Site 214; within Zone N.23.

Globigerina druryi Akers, 1955

Plate 15, Figures 9,10.

Globigerina druryi Akers, 1955, p.654, pl.65, fig.1.

Remarks: The succession of *Globigerina* morphotypes at Site 214 supports the suggestion of Blow (1969) that *G. druryi* is ancestral to *G. nepenthes*.

Stratigraphic Range: Site 214; within Zone N.5 to within Zone N.14.
Site 289; within Zone N.8 to within Zone N.12-N.13.

Globigerina falconensis Blow, 1959

Plate 15, Figure 11.

Globigerina falconensis Blow, 1959, p.177, pl.9, fig.40a-c, 41.

Stratigraphic Range: Site 214; within Zone N.8 to basal Zone N.14.
Site 289; within Zone N.7 to within Zone N.12-N.13.

Globigerina incisa (Brönnimann & Resig, 1971)

Plate 15, Figures 12-14.

Globorotalia (Turborotalia) incisa Brönnimann and Resig, 1971, p.1278, pl.45, fig.5,7; pl.46, fig.1-8.

Remarks: Specimens referable to *Globorotalia (Turborotalia) incisa* Brönnimann and Resig have a spinose surface wall texture. Cavities within the rounded pustules (Plate 15, Figure 14) are regarded as the sites of former spines. A similar wall texture is present on *G. bulloides* (Plate 15, Figure 5). On these grounds *incisa* is removed from the Genus *Globorotalia* and is considered to be more closely related to the *Globigerina obesa-bulloides* group in terms of comparative morphology including surface wall texture. The suggestion that *G. incisa* is related to *Globorotalia pseudopachyderma* Cita, Premoli Silva and Rossi (Brönnimann and Resig, 1971) could not be adequately investigated due to the absence of suitable illustrations of the latter species. The Zone N.21 to N.23 occurrences at Site 214 represent the upward extension of its range from that suggested by Brönnimann and Resig (1971).

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19a to within Zone N.22b.

Globigerina nepenthes Todd, 1957

Plate 16, Figures 1,2.

Globigerina nepenthes Todd, 1957, p.301, pl.78, fig.1.

Remarks: *G. nepenthes* stratigraphically overlaps the last occurrence of *Globorotalia fohsi s.l.* in the South Atlantic (Berggren and Amdurer, 1973) and at Site 214 where it occurs consistently throughout its range although is present only as a minor component of the assemblages.

Stratigraphic Range: Site 214; base Zone N.14 to within Zone N.19a.
Site 289; within Zone N.14 to within Zone N.19a.

Globigerina obesa (Bolli, 1957)

Plate 16, Figures 3-5.

Globorotalia obesa Bolli, 1957, p.119, pl.29, fig.2,3.

Globigerina obesa (Bolli), Parker, 1962, p.228,235.

Remarks: The writer concurs with Banner and Blow (1960) and Parker (1962) that this spinose species is more closely related to the spinose *Globigerinella* spp. and *Globigerina* spp. than to the non-spinose *Globorotalia.*

Stratigraphic Range: Site 214; within Zone 'N.4' to Zone N.23.
Site 289; within Zone 'N.4' to within Zone N.22b.

Globigerina praebulloides s.l. Blow, 1959

Plate 16, Figures 6-8.

Globigerina praebulloides Blow, 1959, p.180, pl.8, fig.47; pl.9, fig.48.

Globigerina praebulloides praebulloides Blow, Banner and Blow, *in* Eames *et al.,* 1962, p.92, pl.9, fig.O,P,Q.

Globigerina praebulloides occlusa Blow and Banner, *in* Eames *et al.,* 1962, p.93, pl.9, fig.U,V,W.

Globigerina praebulloides leroyi Blow and Banner, *in* Eames *et al.,* 1962, p.93, pl.9, fig.R,S,T.

Remarks: The surface wall texture of *G. praebulloides s.l.* varies from weakly cancellate on the ultimate chamber to strong cancellate on the penultimate and preceding chambers and is therefore intermediate between the non-cancellate *G. bulloides* and the totally cancellate *Subbotina.* The presence of spines is noted on the well preserved Early Miocene *G. praebulloides* from the Gellibrand Clay, near Pt. Ronald, Victoria (Plate 16, Figures 6,7). Only rare, poorly preserved specimens were noted in Site 214.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.16.
Site 289; within Zone 'N.4' to within Zone N.10.

Globigerina pseudodruryi Brönnimann & Resig, 1971
Plate 16, Figure 9.

Globigerina pseudodruryi Brönnimann and Resig, 1971, p.1270, pl.7, fig.1,2.

Remarks: This rimless-apertured *'G. druryi'* taxon was rare and typically heavily encrusted at Site 214.

Stratigraphic Range: Site 214; within Zone N.6 to within Zone N.14.

Globigerina rubescens decoraperta Takayanagi & Saito, 1962
Plate 16, Figure 10.

Globigerina druryi Akers *decoraperta* Takayanagi and Saito, 1962, p.85, pl.28, fig.10a-c.

'Globigerina' rubescens decoraperta Takayanagi and Saito, Fleisher, 1974, p.1019, pl.6, fig.8; pl.7, fig.4.

Remarks: The writer agrees with the suggestion of Blow (1969) that this taxon is only subspecifically related to *Globigerina rubescens* Hofker. The variability of the spire height and aperture size of *G. decoraperta* has been noted by Parker (1967). For these Indo-Pacific sites two taxa were distinguished; *G. rubescens s.s.* and *G. rubescens decoraperta* the latter subspecies being distinguished by its slightly larger aperture with a well-defined rim, higher spire and larger test size.

Stratigraphic Range: Site 214; within Zone N.14 to within Zone N.21b.
Site 289; within Zone N.15 to within Zone N.21b.

Globigerina rubescens rubescens Hofker, 1956
Plate 16, Figures 11,12.

Globigerina rubescens Hofker, 1956, p.234, pl.35, fig.18-21.

Remarks: See comments under *G. rubescens decoraperta*.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19a to within Zone N.22b.

Globigerina tenella (Parker, 1958)

Plate 16, Figure 13.

Globigerinoides tenellus Parker, 1958, p.280, pl.6, fig.7-11.

'Globigerina' tenella (Parker), Fleisher, 1974, p.1020, pl.6, fig.5,6; pl.7, fig.3.

Remarks: This species is morphologically very similar to *Globigerina rubescens s.s.* from which it differs by the presence of a small dorsal supplementary aperture restricted to the ultimate chamber.

Stratigraphic Range: Site 214; within Zone N.22a to Zone N.23.
Site 289; within Zone N.22a to within Zone N.22b.

Globigerina woodi Jenkins, 1960

Plate 16, Figure 14.

Globigerina woodi Jenkins, 1960, p.352, pl.2, fig.2a-c.

Remarks: Always a rare component of Neogene assemblages at Site 214.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.19b.
Site 289; within Zone 'N.4'.

Genus *Sphaeroidinella* Cushman, 1927

type species *Sphaeroidina bulloides* var. *dehiscens* Parker & Jones, 1865

Sphaeroidinella dehiscens dehiscens (Parker & Jones, 1865)

Plate 17, Figures 1,2.

Sphaeroidina bulloides var. *dehiscens* Parker and Jones, 1865, p.369, pl.19, fig.5a,b (*vide* Ellis & Messina).

Sphaeroidinella dehiscens dehiscens (Parker and Jones), Blow, 1969, p.336, pl.29, fig.9.

Remarks: The phylogenetic development of this species from *Sphaeroidinellopsis subdehiscens paenedehiscens* at Site 214 is well illustrated by Berggren and Poore (1974).

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; base Zone N.19a to within Zone N.22b.

Sphaeroidinella dehiscens excavata Banner & Blow, 1965

Plate 17, Figure 3.

Sphaeroidinella dehiscens excavata Banner and Blow, 1965, p.1164.

Remarks: This taxon is distinguished from *S. dehiscens s.s.* by its deeply excavated sutures which expose the inner whorl (Banner and Blow, 1965).

Stratigraphic Range: Site 214; within Zone N.22a to Zone N.23.

Sphaeroidinella dehiscens immatura (Cushman, 1919)

Plate 17, Figures 4-7.

Sphaeroidina dehiscens var. *immatura* Cushman, 1919, p.40, pl.14, fig.2.

Sphaeroidinella dehiscens forma *immatura* (Cushman), Blow, 1969, p.336, pl.29, fig.6-8.

Stratigraphic Range: Site 214; base Zone N.19a to within Zone N.19b.
Site 289; base Zone N.19a to top Zone N.21a.

Genus *Sphaeroidinellopsis* Banner & Blow, 1959

type species *Sphaeroidinella dehiscens subdehiscens* Blow, 1959

Sphaeroidinellopsis seminulina kochi (Caudri, 1934)

Plate 17, Figures 8,9.

Globigerina sp. Koch, 1923, p.355, fig.8 (*vide* Ellis & Messina).

Globigerina kochi Caudri, 1934, p.144.

Sphaeroidinellopsis seminulina kochi (Caudri), Blow, 1969, p.337, pl.30, fig.8.

Stratigraphic Range: Site 214; within Zone 'N.12' to within Zone N.21a.
Site 289; within Zone N.16 to within Zone N.19a.

Sphaeroidinellopsis seminulina seminulina (Schwager, 1866)

Plate 17, Figures 10-12.

Globigerina seminulina Schwager, 1866, p.256, pl.7, fig.112 (*vide* Ellis & Messina).

Sphaeroidinellopsis seminulina seminulina (Schwager), Blow, 1969, p.337, pl.30, fig.7.

Stratigraphic Range: Site 214; within Zone N.5 to within Zone N.21a.
Site 289; within Zone N.8 to within Zone N.21a.

Sphaeroidinellopsis subdehiscens paenedehiscens Blow, 1969

Plate 17, Figures 13,14.

Sphaeroidinellopsis subdehiscens paenedehiscens Blow, 1969, p.386, pl.30, fig.4,5,9.

Sphaeroidinellopsis sphaeroides Lamb, 1969, p.571, pl.1, fig.1-5; pl.2, fig.1-3.

Stratigraphic Range: Site 214; within Zone N.17a to within Zone N.20.

Sphaeroidinellopsis subdehiscens subdehiscens (Blow, 1959)

Plate 17, Figures 15,16.

Sphaeroidinella dehiscens subdehiscens Blow, 1959, p.195, pl.12, fig.71.

Sphaeroidinellopsis subdehiscens subdehiscens (Blow), Blow, 1969, p.338, pl.30, fig.1-3,6; pl.31; pl.32.

Stratigraphic Range: Site 214; (?)Zone N.9 to within Zone N.20.
Site 289; base Zone N.10 to within Zone N.21b.

Genus *Globigerinoides* Cushman, 1927

type species *Globigerina rubra* d'Orbigny, 1839

Globigerinoides conglobatus (Brady, 1879)

Plate 18, Figures 1,2.

Globigerina conglobata Brady, 1879, p.286 (*vide* Ellis & Messina).

Globigerinoides conglobata (Brady), Parker, 1962, p.229, pl.3, fig.1-5.

Stratigraphic Range: Site 214; within Zone N.17a to Zone N.23.
Site 289; within Zone N.16 to within Zone N.22b.

Globigerinoides diminutus Bolli, 1957

Plate 18, Figures 3-5.

Globigerinoides diminuta Bolli, 1957, p.114, pl.25, fig.11a-c.

Stratigraphic Range: Site 214; within Zone N.8.
Site 289; base Zone N.8 to top Zone N.8.

Globigerinoides obliquus extremus Bolli & Bermúdez, 1965

Plate 18, Figures 6,7.

Globigerinoides obliquus extremus Bolli and Bermúdez, 1965, p.139, pl.1, fig.10-12.

Remarks: This species is distinguished from *Globigerinoides obliquus s.s.* by its compressed and distinctly flattened chambers.

Stratigraphic Range: Site 214; within Zone N.14 to within Zone N.22b.
Site 289; within Zone N.16 to within Zone N.21b.

Globigerinoides obliquus obliquus Bolli, 1957

Plate 18, Figures 8,9.

Globigerinoides obliqua Bolli, 1957, p.113, pl.25, fig.9,10.

Globigerinoides obliquus obliquus Bolli, Fleisher, 1974, p.1023.

Stratigraphic Range: Site 214; base Zone N.6 to within Zone N.22a.
Site 289; within Zone N.7 to within Zone N.21b,
(?)Zone N.22b.

Globigerinoides quadrilobatus aff. *altiapertura* Bolli, 1957

Plate 18, Figure 10.

Globigerinoides triloba altiapertura Bolli, 1957, p.113, pl.25, fig.7,8.

Globigerinoides quadrilobatus altiapertura Bolli, Blow, 1969, p.325.

Remarks: Site 214 specimens are very similar to those illustrated by Fleisher (1974) which have a slightly smaller dorsal supplementary aperture than the holotype. See also comments under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.8.

Globigerinoides quadrilobatus fistulosus (Schubert, 1910)

Plate 18, Figure 11.

Globigerina fistulosa Schubert, 1910, p.323, fig.2 (*vide* Ellis & Messina).

Globigerinoides quadrilobatus fistulosus (Schubert), Blow, 1969, p.325.

Remarks: This species ranges high into Zone N.22 at the Arabian Sea Site 219 (Fleisher, 1974) as well as Sites 214 and 289 representing a significant upward extension to its range as recorded by Hays *et al.*, (1969). See also remarks under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; top Zone N.19b to within Zone N.22b.
Site 289; within Zone N.19b to within Zone N.22a,
(?)Zone N.22b.

Globigerinoides quadrilobatus immaturus LeRoy, 1939
Plate 18, Figure 12.

Globigerinoides sacculiferus (Brady) var. *immaturus* LeRoy, 1939, p.263, pl.3, fig.19-21.

Globigerinoides quadrilobatus immaturus LeRoy, Blow, 1969, p.325.

Remarks: See remarks under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; within Zone 'N.4' to Zone N.23.

Globigerinoides quadrilobatus primordius Blow & Banner, 1962
Plate 18, Figures 13,14.

Globigerinoides quadrilobatus primordius Blow and Banner, *in* Eames *et al.*, 1962, p.115, pl.9, fig.Dd-Ff.

Remarks: See remarks under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; basal Zone 'N.4'.

Globigerinoides quadrilobatus quadrilobatus (d'Orbigny, 1846)
Plate 19, Figure 1.

Globigerina quadrilobata d'Orbigny, 1846, p.164, pl.9, fig.7-10 (*vide* Ellis & Messina).

Globigerinoides quadrilobatus quadrilobatus (d'Orbigny), Blow, 1969, p.325.

Remarks: Seven subspecies of the *G. quadrilobatus* complex have been recognised at Site 214, the differences based on the rate of chamber expansion, chamber shape and apertural characteristics. *Trilobus* and *immaturus* differ from *quadrilobatus s.s.* by their very rapidly enlarging chambers while *triloba* differs from *immaturus* in having a final chamber which is larger than all the previous chambers combined. *Sacculifer* and *fistulosus* differ from the others in having final chambers that are sac-like and digitate respectively. *Primordius* is distinguished by its single dorsal supplementary aperture while *altiapertura* is distinguished by its large primary and accessory apertures.

Only the stratigraphically important *G. quadrilobatus fistulosus* was separated from this plexus at Site 289.

Stratigraphic Range: Site 214; within Zone 'N.4' to Zone N.23.
Site 289; base Zone 'N.4' to within Zone N.22b.

Globigerinoides quadrilobatus sacculifer (Brady, 1877)

Plate 19, Figure 2.

Globigerina sacculifera Brady, 1877, p.535 (*vide* Ellis & Messina).

Globigerinoides quadrilobatus sacculifer (Brady), Blow, 1969, p.326.

Remarks: See remarks under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; basal Zone N.5 to Zone N.23.

Globigerinoides quadrilobatus trilobus (Reuss, 1850)

Plate 19, Figure 3.

Globigerina triloba Reuss, 1850, p.375, pl.47, fig.11a-d (*vide* Ellis & Messina).

Globigerinoides quadrilobatus trilobus (Reuss), Blow, 1969, p.326.

Remarks: See remarks under *G. quadrilobatus quadrilobatus*.

Stratigraphic Range: Site 214; within Zone 'N.4' to Zone N.23.

Globigerinoides ruber (d'Orbigny, 1839)

Plate 19, Figures 4,5.

Globigerina rubra d'Orbigny, 1839, p.82, pl.4, fig.12-14 (*vide* Ellis & Messina).

Globigerinoides ruber (d'Orbigny), Parker, 1962, p.230, pl.3, fig.11-14; pl.4, fig.1-10.

Remarks: The 3 to 3½ chambers in the penultimate whorl distinguishes this species from its Early Neogene homeomorph, *Globigerinoides subquadratus*, which has 4 chambers in the penultimate whorl (Cordey, 1967). Although this species ranges from within Zone N.16 (Blow, 1969) it occurs in abundance only in latest Zone N.19 to Zone N.23 in these Indo-Pacific DSDP Sites.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19a to within Zone N.22b.

Globigerinoides sicanus de Stefani, 1952
Plate 19, Figures 6,7.

Globigerinoides sicana de Stefani, 1952, p.9 (type figure designated as Cushman and Stainforth, 1945, pl.13, fig.6).

Globigerinoides sicanus de Stefani, Blow, 1969, p.326, pl.3, fig.10-11.

Stratigraphic Range: Site 214; (?)within Zone N.6, base Zone N.8 to early Zone N.9.
Site 289; base Zone N.8 to top Zone N.8.

Globigerinoides subquadratus Brönnimann, 1954
Plate 19, Figures 8,9.

Globigerinoides subquadratus Brönnimann, *in* Todd *et al.*, 1954, p.680, pl.1, fig.5,8.

Remarks: See comments under *Globigerinoides ruber*.

Stratigraphic Range: Site 214; latest Zone 'N.4' to within Zone N.14, (?)Zone N.16.
Site 289; within Zone 'N.4' to basal Zone N.14, (?)Zone N.16.

Genus *Praeorbulina* Olsson, 1964
type species *Globigerinoides glomerosa glomerosa* Blow, 1956

Praeorbulina glomerosa circularis (Blow, 1956)
Plate 19, Figure 10.

Globigerinoides glomerosa circularis Blow, 1956, p.65, fig.2, no.3,4.

Remarks: This taxon occurs rarely in Site 214.

Stratigraphic Range: Site 214; within Zone N.8.

Praeorbulina glomerosa glomerosa (Blow, 1956)

Plate 19, Figure 11.

Globigerinoides glomerosa glomerosa Blow, 1956, p.65, fig.1, no.15-19; fig.2, no.1,2.

Remarks: Very rare specimens at Site 289 are referable to this taxon.

Stratigraphic Range: Site 214; within Zone N.8 to basal Zone N.9.
Site 289; within Zone N.8.

Genus *Orbulina* d'Orbigny, 1839

type species *Orbulina universa* d'Orbigny, 1839

Orbulina suturalis Brönnimann, 1951

Plate 19, Figure 12.

Orbulina suturalis Brönnimann, 1951, p.135, fig.2-4.

Stratigraphic Range: Site 214; base Zone N.9 to Zone N.23.
Site 289; within Zone N.10 to within Zone N.22b.

Orbulina universa d'Orbigny, 1839

Plate 19, Figures 13,14.

Orbulina universa d'Orbigny, 1839, p.2, pl.1, fig.1 (*vide* Ellis & Messina).

Stratigraphic Range: Site 214; base Zone N.9 to Zone N.23.
Site 289; within Zone N.10 to within Zone N.22b.

Family Candeinidae Cushman, 1927

Remarks: This family includes those species with a microperforate surface wall texture 'characterised by extremely small perforations irregularly distributed on an otherwise smooth surface' (Fleisher, 1974). Pustules and other secondary incrustations may cover the original smooth wall giving a roughened appearance.

Genus *Candeina* d'Orbigny, 1839

type species *Candeina nitida* d'Orbigny, 1839

Candeina nitida d'Orbigny, 1839

Plate 20, Figures 1-3.

Candeina nitida d'Orbigny, 1839, p.108, pl.2, fig.27,28 (*vide* Ellis & Messina).

Remarks: Blow (1969) has discussed in detail the evolution of this species from *Candeina nitida praenitida* and the criteria by which these subspecies may be identified.

Stratigraphic Range: Site 214; within Zone N.16 to Zone N.23.
Site 289; within Zone N.16 to within Zone N.22b.

Genus *Globigerinatella* Cushman & Stainforth, 1945

type species *Globigerinatella insueta* Cushman & Stainforth, 1945

Globigerinatella insueta Cushman & Stainforth, 1945

Plate 20, Figures 4-7.

Globigerinatella insueta Cushman and Stainforth, 1945, p.69, pl.13, fig.7-9.

Remarks: The test morphology and ontogenetic development of *G. insueta* is discussed in detail by Hofker (1954) and Brönnimann (1950) supporting the suggestion by Blow (1969) that this species evolved from *Globigerinita glutinata ambitacrena*. The presence of a microperforate wall texture on *G. insueta* (Plate 20, Figure 6) and *G. glutinata s.l.* (Plate 20, Figure 12) is consistent with this suggestion.

Stratigraphic Range: Site 214; base Zone N.6 to within Zone N.9.
Site 289; base Zone N.6 to within Zone N.9.

Genus *Globigerinita* Brönnimann, 1951

type species *Globigerinita naparimaensis* Brönnimann, 1951

Remarks: The concept of this genus adopted by the writer is that employed by Fleisher (1974) to include microperforate 'globigerinids' with or without a bulla which are phyletically distinct from the cancellate-walled and (generally) bullate Genus *Catapsydrax*.

Globigerinita glutinata ambitacrena (Loeblich & Tappan, 1957)

Plate 20, Figures 8-10.

Tinophodella ambitacrena Loeblich and Tappan, 1957, p.114, fig.2,3.

Globigerinita glutinata ambitacrena (Loeblich and Tappan), Fleisher, 1974, p.1022, pl.9, fig.5.

Remarks: Confusion over the significance in classification of the umbilical bulla has led to a proliferation of nomenclature for the Neogene *Globigerinita* complex. Observation of a large number of *G. glutinata s.l.* from Site 214 has led the writer to concur with Parker (1962) and Fleisher (1974) that there is a complete intergradation of bulla morphology, from multiple apertured, often highly digitate, umbilical bulla to bulla with few accessory apertures. Bullae have also been noted with varying degrees of inflation. In view of this intergradation the recognition of taxa at the species level on the basis of bulla(e) variations does not seem justified. Accordingly two subspecies of *G. glutinata s.l.* are recognised; non-bullate forms being referred to *G. glutinata glutinata* and bullate forms to *G. glutinata ambitacrena*. Specimens with dorsal supplementary apertures (= *Globigerinita glutinata parkerae* of Fleisher, 1974) have been observed at Site 214 and are regarded as yet another variation in the broad spectrum of bulla-variability and have not been separated from *G. glutinata ambitacrena*. Similarly the degree to which the external wall surface is covered by pustules of calcite is variable implying its low taxonomic weight for classification purposes. *Globigerinita incrusta* Akers is therefore regarded as a calcite encrusted variant of *G. glutinata ambitacrena* and is not formally separated from other members of the complex.

Stratigraphic Range: Site 214; basal Zone 'N.4' to Zone N.23.
Site 289; basal Zone 'N.4' to within Zone N.22b.

Globigerinita glutinata glutinata (Egger, 1893)

Plate 20, Figures 11,12.

Globigerina glutinata Egger, 1893, p.371, pl.13, fig.19-21 (*vide* Ellis & Messina).

Globigerina juvenilis Bolli, 1957, p.110, pl.24, fig.5,6.

Globigerinita glutinata glutinata (Egger), Fleisher, 1974, p.1022, pl.9, fig.1,2.

Remarks: See comments under *Globigerinita glutinata ambitacrena.*

Stratigraphic Range: Site 214; basal Zone 'N.4' to Zone N.23.
Site 289; basal Zone 'N.4' to within Zone N.22b.

Globigerinita uvula (Ehrenberg, 1861)
Plate 20, Figure 13.

Pylodexia uvula Ehrenberg, 1861, p.276; 1873, pl.2, fig.24,25 (*vide* Ellis & Messina).

Globigerina brady Wiesner, 1931, p.133 (*vide* Ellis & Messina).

Globigerinita uvula (Ehrenberg), Parker, 1962, p.252, pl.8, fig.14-26.

Remarks: This species is generally rare throughout its range at Site 214.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.18.
Site 289; basal Zone 'N.4' to within Zone N.22b.

Genus *Tenuitella* Fleisher, 1974
type species *Globorotalia gemma* Jenkins, 1966

Remarks: This nomenclature represents the phyletic unity of a group of Late Paleogene and Neogene species which is reflected by their distinctive microperforate surface wall texture. The possible origin of this genus from the Paleogene *Planorotalites-Pseudohastigerina* complex is discussed in Chapter 5, pp.102.

Tenuitella angustiumbilicata (Bolli, 1957)
Plate 21, Figures 1,2; Plate 27, Figures 4-6.

Globigerina ciperoensis angustiumbilicata Bolli, 1957, p.109, pl.22, fig.12a-13c.

Globigerina angustiumbilicata Bolli, Blow, 1959, p.172, pl.7, fig.33,34.

Tenuitella angustiumbilicata (Bolli), Fleisher, 1975, p.756.

Remarks: Specimens referable to this species were taken from a sample (Bo291A) of the type *Globigerina ciperoensis ciperoensis* Zone of Bolli (1957). This sample also serves as the type locality for *G. ciperoensis angustiumbilicata*. The smooth wall of *angustiumbilicata* referred to by Bolli (1957) is shown here to be typically microperforate as distinct from the cancellate-walled *G. ciperoensis* (Plate 25, Figure 14) and *G. angulisuturalis* (Plate 26, Figure 3). Blow (1959) remarked that *angustiumbilicata* showed morphological features different from *G. ciperoensis* and *G. angulisuturalis* including the tendency for the aperture to be in an umbilical to extraumbilical position in addition to the presence of a distinct apertural lip. All these features suggest that *angustiumbilicata* is related to the microperforate *Tenuitella-Globigerinita* complex rather than to the cancellate-walled *Globigerina*. Occurrences of the *angustiumbilicata* morphotype (surface wall texture excluded) are reported from as low as the Late Eocene by Lindsay (1969). These are denoted here as "*angustiumbilicata*" and are tentatively placed near the *Globigerina praebulloides-ciperoensis* lineage (Figure 41).

Stratigraphic Range: Site 214; basal Zone N.5 to Zone 'N.12' (?) Zone N.14.
Site 289; within Zone 'N.4'.

Tenuitella cifellii (Brönnimann & Resig, 1971)

Plate 21, Figures 3-5.

Globorotalia (Turborotalia) cifellii Brönnimann and Resig, 1971, p.1278, pl.42, fig.1-5,8,9, not 6,7.

Globorotalia (Turborotalia) nkbrowni Brönnimann and Resig, 1971, p.1279, pl.40, fig.1-8.

Remarks: This small sized microperforate 'turborotaliid' provides a morphologic and stratigraphic link from the Eocene-Oligocene *T. gemma* to the mid-Miocene *T. minutissima*. Morphotypes bearing a dorsal, sutural, supplementary aperture (*G.*(*T.*) *nkbrowni*) are included in the writer's concept of this taxon.

Stratigraphic Range: Site 214; within Zone N.5 to within Zone 'N.12'.
Site 289; within Zone 'N.4' to within Zone N.6.

Tenuitella clemenciae (Bermúdez, 1960)

Plate 21, Figures 6-8.

Turborotalia clemenciae Bermúdez, 1960, p.17, fig.10 (*vide* Ellis & Messina).

Tenuitella clemenciae (Bermúdez), Fleisher, 1974, p.1033, pl.17, fig.8.

Remarks: The possibility that this species is a prior synonym of *Tenuitella munda* has been suggested by Blow (1969). A close relationship is indicated in terms of test geometry as well as a common microperforate surface wall texture.

The range of this species is restricted from that noted by Blow (1969), being confined to the later part of the Early Miocene to the middle part of the Middle Miocene in Site 214 as well as the Arabian Sea Site 219 (Fleisher, 1974).

See also comments under *Tenuitella grata.*

Stratigraphic Range: Site 214; within Zone 'N.4' to top Zone 'N.12'.

Tenuitella grata (Todd, 1957)

Plate 21, Figures 9-12.

?Globigerina grata Todd, 1957, p.300, pl.74, fig.4.

Globorotalia n.sp. Krasheninnikov and Hoskins, 1973, pl.21, fig.10-12.

Globorotalia sp.4 Jenkins and Orr, 1972, p.1096, pl.18, fig.7-12.

Tenuitella sp.1 Fleisher, 1974, p.1034, pl.17, fig.5.

Globorotalia grata (Todd), Poore, 1977, fig.9,12,13.

Remarks: Morphological variation includes forms in which the aperture may extend slightly over the equatorial periphery onto the dorsal side. The low-arched apertural slit is often bordered by a distinct flap that may extend as far as to cover the umbilicus. Small *Candeina*-like supplementary (sutural) apertures surrounded by raised rims, are present on several large specimens where they are restricted to the equatorial periphery between the last two chambers.

Continuous morphological variation between *T. clemenciae* and *T. grata*, is most obvious in terms of number of chambers in the final whorl, the distinction being taken somewhat arbitrarily that *T. clemenciae* includes forms with less than 4½ chambers in the final whorl. *Hastigerina klampisensis* Kadar may prove to be a 5 to 6 chamber per whorl end member of this lineage.

Stratigraphic Range: Site 214; within Zone N.8 to within Zone 'N.12'.
Site 289; within Zone N.8.

Tenuitella iota anfracta (Parker, 1967)

Plate 21, Figures 13-16.

Globorotalia anfracta Parker, 1967, p.175, pl.28, fig.3-8.

Globorotalia (Turborotalia) parkerae Brönnimann and Resig, 1971, p.1280, pl.43, fig.7,10; pl.47, fig.4,6; pl.48, fig.2,3.

Tenuitella anfracta (Parker), Fleisher, 1974, p.1033, pl.17, fig.9,10.

Remarks: Examination of many Late Pleistocene microperforate 'turborotaliid' planktonics suggests that *Globorotalia anfracta* Parker represents the non-bullate form of *Globigerinita iota* Parker. In view of this gradation and the decreasing emphasis placed on the taxonomic weight of the bulla together with the increasing emphasis on surface wall texture, these two microperforate forms are considered here as two subspecies, the specific name *iota* having priority.

Brönnimann and Resig (1971) erected *G.(T.) parkerae* as a variant of *anfracta* with a radially elongate final chamber. Such variants were not systematically recognised in this study.

Stratigraphic Range: Site 214; within Zone N.21a to Zone N.23.
Site 289; within Zone N.21b to within Zone N.22b.

Tenuitella iota iota (Parker, 1962)

Plate 14, Figures 1-3.

Globigerinita iota Parker, 1962, p.250, pl.10, fig.26-30.

Remarks: This taxon represents the bullate forms of *Tenuitella iota anfracta.*

Stratigraphic Range: Site 214; within Zone N.22a to Zone N.23.
Site 289; within Zone N.22a to within Zone N.22b.

Tenuitella praestainforthi (Blow, 1969)

Plate 14, Figures 4,5.

Globigerinita stainforthi praestainforthi Blow, 1969, p.383, pl.25, fig.3-5.

Tenuitella praestainforthi (Blow), Fleisher, 1974, p.1033.

Remarks: The phylogeny of this taxon was not examined at Site 214 where it occurs only rarely over a short stratigraphic range. However, the possibility of this taxon representing a bullate variant of the non-bullate *T. angustiumbilicata* should not be overlooked.

Stratigraphic Range: Site 214; within Zone 'N.4'.

Genus *Turborotalita* Banner & Blow, 1962

type species *Truncatulina humilis* Brady, 1884

Turborotalita clarkei (Rögl & Bolli, 1973)

Plate 23, Figures 1,2.

Globigerina clarkei Rögl and Bolli, 1973, p.563, pl.4, fig.13-15.

Turborotalita "quinqueloba" (Natland), Fleisher, 1974, p.1037.

Remarks: Examination of the variability of *T. clarkei* and the morphologically similar *T. humilis* may show the former taxon to be a subspecies of the latter. The specific nomenclature is tentatively maintained until such investigation.

Stratigraphic Range: Site 214; within Zone N.18 to within Zone N.22b.
Site 289; (?)Zone N.17c, Zone N.18 to within Zone N.22b.

Turborotalita cristata (Heron-Allen & Earland, 1929)

Plate 23, Figures 3,4.

Globigerina cristata Heron-Allen and Earland, 1929, p.331, pl.4, fig.33-39 (*vide* Ellis & Messina).

Turborotalita cristata (Heron-Allen and Earland), Blow, 1969, p.373.

Remarks: Parker (1962) considered *T. cristata* as a warm-water lobulate variant of *T. humilis*. Occurrences of this taxon at Site 214 were relatively rare and sufficiently distinct to suggest specific status.

Stratigraphic Range: Site 214; within Zone N.19a to Zone N.23.
Site 289; within Zone N.19a to within Zone N.19b.

Turborotalita humilis (Brady, 1884)

Plate 23, Figures 5-7.

Truncatulina humilis Brady, 1884, pl.94, fig.7a-c (*vide* Ellis & Messina).

Turborotalita humilis (Brady), Blow, 1969, p.373.

Stratigraphic Range: Site 214; top Zone N.17c to Zone N.23.
Site 289; within Zone N.17a to within Zone N.22b.

Turborotalita primitiva Brönnimann & Resig, 1971

Plate 23, Figures 8-11.

Turborotalita primitiva Brönnimann and Resig, 1971, p.1287, pl.26, fig.5-9.

Remarks: The oldest occurrence so far of the Genus *Turborotalita* is represented by specimens of *T. primitiva* from sample 214-26-3 Top, dated as Zone P.20 by McGowran (1974).

Stratigraphic Range: Site 214; Zone P.20 to within Zone N.17c.
Site 289; within Zone 'N.4' to within Zone N.15.

Turborotalita pumilio (Parker, 1962)

Plate 23, Figures 12-15.

Globorotalia pumilio Parker, 1962, p.238, pl.6, fig.2,3.

Turborotalita pumilio (Parker), Fleisher, 1974, p.1037, pl.21, fig.7.

Remarks: The concept of *T. pumilio* is restricted to specimens with coarse perforations, that tend to concentrate around the equatorial periphery, and with an angular dorsal spiral suture and radial intercameral sutures. Several unidentified Recent specimens appear convergent with *T. pumilio* in terms of trochospiral coiling, having a parallel-sided axial profile with about 5 chambers in the last whorl, yet have a microperforate surface wall texture. Further study is required to determine the systematic relationship of these rare specimens.

Stratigraphic Range: Site 214; within Zone N.22a to Zone N.23.

Family Hantkeninidae Cushman, 1927

Genus *Cassigerinella* Pokorný, 1955

type species *Cassigerinella boudecensis* Pokorný, 1955

Cassigerinella chipolensis (Cushman & Ponton, 1932)

Plate 22, Figures 6-11.

Cassidulina chipolensis Cushman and Ponton, 1932, p.98, pl.15, fig.2.

Cassigerinella boudecensis Pokorný, 1955, p.136, fig.1-3.

Cassigerinella chipolensis (Cushman and Ponton), Blow and Banner, *in* Eames *et al.*, 1962, p.81, pl.15, fig.M-N.

Stratigraphic Range: Site 214; within Zone 'N.4' to within Zone N.14.
Site 289; base Zone 'N.4' to within Zone N.14.

Cassigerinella martinezpicoi (Bermúdez & Seiglie,1967) emended Saito, 1977

Plate 22, Figures 12-17.

Riveroinella martinezpicoi Bermúdez and Seiglie, 1967, p.177, pl.1, fig.1-6.

Globorotalia (Turborotalia) scitula n.subsp. Quilty, 1976, pl.14, fig.3,4.

Cassigerinella sp. Quilty, 1976, pl.19, fig.13,14.

Cassigerinella martinezpicoi (Bermúdez and Seiglie), emended Saito, *in* Saito and Biscaye, 1977, p.322, pl.1, fig. 1-8; pl.2, fig.1-2a,b, 4a,b.

Remarks: The occurrence of this species in Sites 214 and 289 extends its known palaeogeographic range from the Caribbean and Pacific into the eastern Indian Ocean. *C. martinezpicoi* is present within a sample of Bolli's (1957) *Globorotalia fohsi barisanensis* Zone type sample (Professor M.F. Glaessner collection, University of Adelaide). These well preserved Trinidad specimens have a more coarsely perforate surface wall texture than *Cassigerinella chipolensis* (Plate 22, Figure 8) and highlights the poor preservation of surface wall textures in deep-sea assemblages of *C. martinezpicoi*.

Stratigraphic Range: Site 214; within Zone N.8 to within Zone 'N.12'.
Site 216A; within Zone N.9 to within Zone 'N.12'.

Family Heterohelicidae Cushman, 1927

Genus *Streptochilus* Brönnimann & Resig, 1971

type species *Bolivina tokelauae* Boersma, 1969

Streptochilus globigerum (Schwager, 1866)

Plate 24, Figures 1-4.

Textilaria globigera Schwager, 1866, p.252, pl.7, fig.100 (*vide* Ellis & Messina).

Streptochilus globigerum (Schwager), Brönnimann and Resig, 1971, p.1288, pl.51, fig.2.

Remarks: The surface wall texture of this species consists of small, irregularly distributed pores, often surrounded by rough, irregular ridges giving a pseudo-cancellate textural appearance. Distinct pore-pits are absent. The degree of these rugosities vary greatly showing a gradation to the smooth-walled *S. tokelauae*, its presumed descendant. *S. globigerum* is the most abundant Neogene biserial planktonic in Site 214.

Stratigraphic Range: Site 214; within Zone N.14 to within Zone N.21b.
Site 289; (?)Zone N.14, within Zone N.15 to top Zone N.21b.

Streptochilus latum Brönnimann & Resig, 1971

Plate 24, Figures 5,6.

Streptochilus latum Brönnimann and Resig, 1971, p.1289, pl.51, fig.3.

Stratigraphic Range: Site 214; within Zone N.5 to within Zone N.8.
Site 289; (?)Zone N.9, within Zone N.17c.

Streptochilus pristinum Brönnimann & Resig, 1971

Plate 24, Figure 7.

Streptochilus pristinum Brönnimann and Resig, 1971, p.1289, pl.51, fig.4.

Remarks: Occurrences of this species at Sites 214 and 289 are extremely rare.

Stratigraphic Range: Site 214; within Zone 'N.12'.
Site 289; within Zone N.14 to within Zone N.17c.

Streptochilus tokelauae (Boersma, 1969)
Plate 24, Figures 8-12.

Bolivina tokelauae Boersma, *in* Kierstead *et al.*, 1969, p.329, pl.1, fig.1.

Streptochilus tokelauae (Boersma), Brönnimann and Resig, 1971, p.1288, pl.51, fig.1.

Remarks: The range of this species is extended downwards into the Middle Miocene at Site 214 from the Early Pliocene record of Brönnimann and Resig (1971). Miocene specimens exhibit morphological gradations between both *S. globigerum* and the more compact *S. pristinum*.

Stratigraphic Range: Site 214; (?)Zone N.16, within Zone N.19a to within Zone N.22b.
Site 289; (?)Zone N.17b, within Zone N.19b to within Zone N.22b.

incertae sedis

Bulava indica Boltovskoy, 1976
Plate 24, Figure 13.

"*Bulava indica*" Boltovskoy, 1976, p.301, pl.1, fig.1-23.

?*Nodosaria arundinea* Schwager, Boomgaart, 1949, p.78, pl.6, fig.9.

Remarks: *B. indica* is confined to the Middle-Late Miocene in the Indian Ocean and to one sample of Pliocene age in the Pacific Site 289. It is morphologically similar to the isolated elongate-chambers of the Late Oligocene-Early Miocene *Clavigerinella nazcaensis* Quilty and possibly to members of the Genus *Beella*.

Stratigraphic Range: Site 214; within Zone 'N.12' to within Zone N.17b.
Site 289; within Zone N.21b.

SELECTED PALEOGENE PLANKTONIC FORAMINIFERA

The Paleogene species referred to below are illustrated as morphological evidence for some phyletic perspective to the Neogene planktonic foraminiferal radiation. The higher classification of these species and genera was not closely examined in this thesis. For this reason the Paleogene planktonics outlined here are not placed into suprageneric categories. They are arranged, subjectively, into generalised phyletically related groupings in approximately the same order as discussed in the previous classification chapter.

Morozovella acutispira (Bolli & Cita, 1960)

Plate 25, Figures 1-4.

Globorotalia acutispira Bolli and Cita, 1960, p.375, pl.35, fig.3a-c.

Remarks: Specimens illustrated, identified by Dr. B. McGowran, are from the Boongerooda Greensand (Zone P.4), Carnarvon Basin, Western Australia.

Turborotalia cerroazulensis s.l. (Cole, 1928)

Plate 25, Figures 5-8.

Globigerina cerroazulensis Cole, 1928, p.217, pl.1, fig.11-13.

Remarks: Specimens of this Upper Eocene smooth-walled and finely perforate taxon are from core 17 of the WAPET Rough Range South No. 1 well, Carnarvon Basin, Western Australia.

Subbotina angiporoides (Hornibrook, 1965)

Plate 25, Figures 9-11.

Globigerina angiporoides Hornibrook, 1965, p.834, fig.1,2.

Remarks: This cancellate-walled and probably non-spinose subbotinid is illustrated by specimens from the Late Eocene Brown's Creek section, Victoria, discussed by McGowran (1978).

Globigerina angulisuturalis Bolli, 1957

Plate 26, Figures 1-3.

Globigerina ciperoensis angulisuturalis Bolli, 1957, p.109, pl.22, fig.11.

Remarks: The specimens of *G. angulisuturalis* and *G. ciperoensis* illustrated here are from the Trinidad sample Bo291A, the type sample of the *Globigerina ciperoensis ciperoensis* Zone of Bolli (1957). They are included for comparison with *Tenuitella angustiumbilicata*, a taxon previously placed by Bolli (1957) within the Genus *Globigerina* as a subspecies of both *angulisuturalis* and *ciperoensis*. See also comments under *T. angustiumbilicata*.

Globigerina ciperoensis Bolli, 1954

Plate 25, Figures 12-14.

Globigerina ciperoensis Bolli, 1954, p.1, fig.3-6.

Remarks: See comments under *G. angulisuturalis*.

Tenuitella aculeata (Jenkins, 1966)

Plate 27, Figures 1-3.

Globorotalia inconspicua aculeata Jenkins, 1966, p.1118, fig.13, nos.119-125.

Tenuitella aculeata (Jenkins), Fleisher, 1974, p.1033.

Remarks: *Tenuitella* spp. from the Late Eocene section at Brown's Creek, Aire District, Victoria, have been identified by Dr. Brian McGowran who provided specimens of *T. aculeata, T. gemma, T. insolita* and *T. munda*. Micrographs of these species are included for comparison with Neogene *Tenuitella* spp. As outlined in greater detail in Chapter 5 *T. aculeata* is considered to be more closely related to the Genus *Tenuitella* than to any other Paleogene genus, in spite of its 'spines' and slightly larger diameter pores.

Tenuitella gemma (Jenkins, 1966)

Plate 27, Figures 7-10.

Globorotalia gemma Jenkins, 1966, p.1115, fig.11, nos.97-103.

Tenuitella gemma (Jenkins), Fleisher, 1974, p.1033, pl.17, fig.4,6,7.

Remarks: See comments under *T. aculeata*.

Tenuitella insolita (Jenkins, 1966)

Plate 27, Figures 11-13.

Globorotalia insolita Jenkins, 1966, p.1120, fig.13, nos.113-118.

Tenuitella insolita (Jenkins), Fleisher, 1974, p.1033.

Remarks: See comments under *T. aculeata.*

Tenuitella munda (Jenkins, 1965)

Plate 27, Figures 14-16.

Globorotalia munda Jenkins, 1965, p.1121, fig.14, nos.126-133; fig.15, nos.152-166.

Tenuitella munda (Jenkins), Fleisher, 1974, p.1033.

Remarks: The suggestion by Blow (1969, p.378) that *Globorotalia (T.) permicra* Blow and Banner is probably ancestral to *G. (T.) clemenciae* ((?) senior synonym of *T. munda*) is not supported because his illustration of *permicra* shows it to have a cancellate surface wall texture in contrast to the microperforate wall texture of *T. munda-clemenciae.* See also comments under *T. aculeata.*

Cassigerinella eocaenica Cordey, 1968

Plate 26, Figures 13,14.

Cassigerinella eocaenica Cordey, 1968, p.368, fig.a-e.

Remarks: The illustrated specimen, provided and identified by Mr. J.M. Lindsay, shows the ontogenetic development from planispiral to alternating biserial chamber arrangement. This specimen is very small and wall perforations rare. The initial planispiral chamber arrangement is reminiscent of *Pseudohastigerina* its presumed ancestor.

Pseudohastigerina micra (Cole, 1927)

Plate 26, Figures 10-12.

Nonion micrus Cole, 1927, p.22, pl.5, fig.12.

Remarks: The surface wall texture of this pseudohastigerinid is similar to that of *Cassigerinella chipolensis* (Plate 22, Figure 8) and to

Hantkenina primitiva (Plate 26, Figure 9). Both genera are considered to have evolved from *Pseudohastigerina.*

Hantkenina primitiva Cushman & Jarvis, 1929

Plate 26, Figures 7-9.

Hantkenina alabamensis Cushman var. *primitiva* Cushman and Jarvis, 1929, p.16, pl.3, fig.2,3.

Remarks: Specimens illustrated are from the Late Eocene Brown's Creek section, Victoria.

Planorotalites chapmani (Parr, 1938)

Plate 26, Figures 4-6.

Globorotalia chapmani Parr, 1938, p.87, pl.3, fig.8,9a,b.

Remarks: This illustrated specimen, identified by Dr. B. McGowran, is from the Boongerooda Greensand (Zone P.4), Carnarvon Basin, Western Australia. Note the similarity in surface wall textures between this taxon, *Pseudohastigerina* and *Hantkenina.*

Chiloguembelina cubensis (Palmer, 1934)

Plate 24, Figures 14-16.

Gümbelina cubensis Palmer, 1934, p.74, fig.1-6.

Remarks: Specimens illustrated are from the Late Eocene Brown's Creek section, Victoria. The similarity in pore size and pore distribution between *Chiloguembelina* and *Streptochilus*, in additional to chamber arrangement, suggests either affinity or close convergence.

SPECIES INDEX

REFERENCES

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PLATE 1

Figures 1-3 *Globorotalia archeomenardii* Bolli

1. 214-21-3 12-14cm x150 721-1
2. 214-21-3 12-14cm x150 721-2
3. 214-21-3 12-14cm x100 721-3

Figures 4-7 *Globorotalia crassaformis s.l.* (Galloway & Wissler)

4. 214-3-3 5-6cm x150 721-4
5. 214-3-3 5-6cm x130 721-5
6. 214-3-3 5-6cm x170 721-6
7. 214-3-3 5-6cm x80 721-7

Figures 8-10 *Globorotalia cultrata cultrata* (d'Orbigny)

8. 214-1-1 10-18cm x50 721-8
9. 214-1-1 10-18cm x50 721-9
10. same specimen as 8 x50

Figures 11-13 *Globorotalia cultrata limbata* (d'Orbigny)

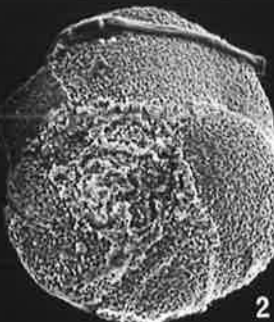
11. 214-11-2 5-7cm x50 721-10
12. 214-11-2 5-7cm x70 721-11
13. same specimen as 12, surface wall texture of penultimate chamber x1000

Figures 14-16 *Globorotalia cultrata menardii* (Parker, Jones & Brady)

14. 214-1-1 10-18cm x50 721-12
15. 214-10-1 5-7cm x75 721-13
16. same specimen as 15 x80

Plate 1


1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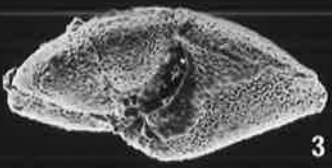
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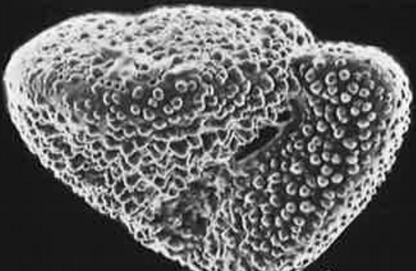
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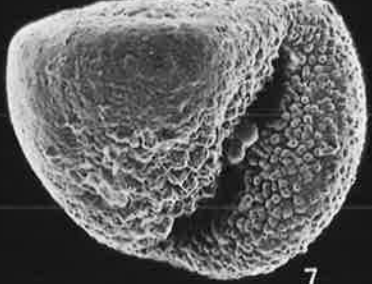
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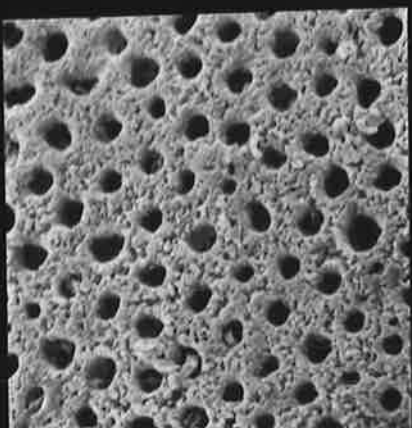
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PLATE 2

Figures 1-4 *Globorotalia eastropacia* Boltovskoy

1. 217-1-1 18-20cm x70 721-14
2. 217-1-1 18-20cm x80 721-15
3. 217-1-1 18-20cm x80 721-16
4. same specimens as 2, surface wall texture of ultimate chamber x1000

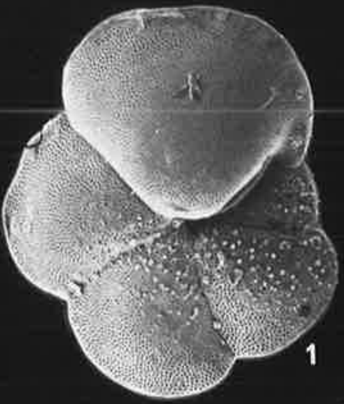
Figures 5-11 *Globorotalia fohsi s.l.* Cushman & Ellisor

5. 214-19-5 26-28cm x70 721-17
6. 214-19-5 26-28cm x90 721-18
7. 289-44-3 146-148cm x100 721-19
8. *Globorotalia fohsi lobata* Zone, Trinidad x70 721-20
9. *Globorotalia fohsi lobata* Zone, Trinidad x70 721-21
10. same specimen as 8 x70
11. same specimen as 9, surface wall texture of ultimate chamber x1000

Figures 12-14 *Globorotalia lenguaensis* Bolli

12. 214-12-cc x170 721-22
13. 214-12-cc x170 721-23
14. same specimen as 13 x180

Plate 2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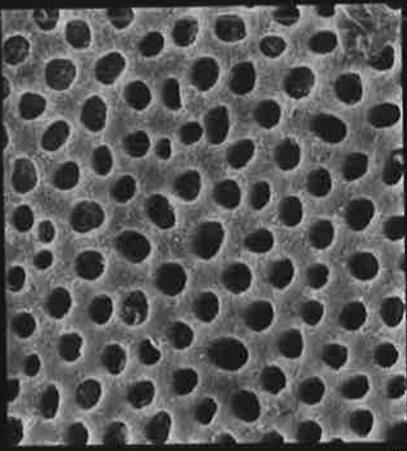
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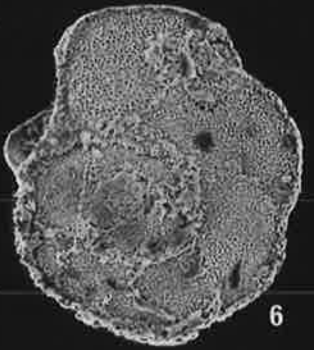
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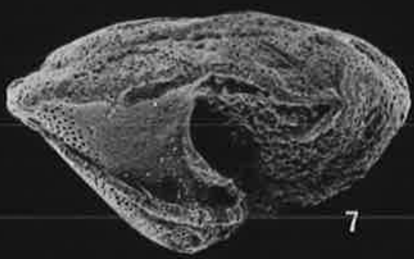
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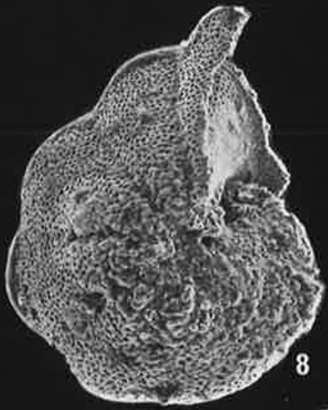
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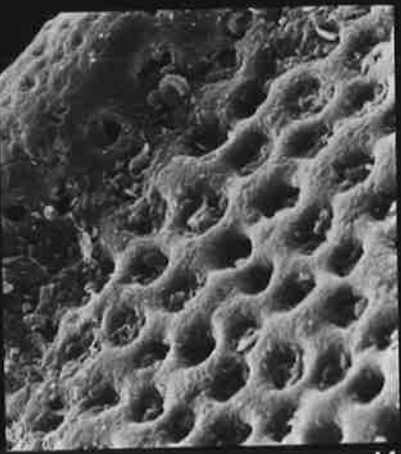
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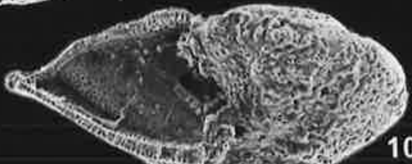
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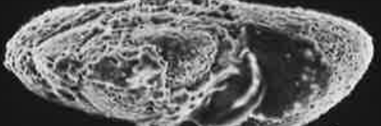
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PLATE 3

Figures 1-3 *Globorotalia margaritae* Bolli & Bermúdez

1. 289-11-1 142-144cm x110 721-24
2. 289-11-1 142-144cm x100 721-25
3. 289-11-1 142-144cm x130 721-26

Figures 4-6 *Globorotalia merotumida* Blow & Banner

4. 214-16-3 5-7cm x130 721-27
5. same specimen x110
6. same specimen x160

Figures 7-9 *Globorotalia miozea conoidea* Walters

7. 214-12-cc x100 721-28
8. 214-12-cc x120 721-29
9. same specimen as 8 x150

Figures 10-12 *Globorotalia miozea miozea* Finlay

10. 214-19-cc x100 721-30
11. 214-19-cc x120 721-31
12. same specimen as 10 x90

Figures 13-16 *Globorotalia multicamerata* Cushman & Jarvis

13. 214-4-5 5-7cm x60 721-32
14. 214-5-6 25-27cm x40 721-33
15. 214-5-6 25-27cm x50 721-34
16. same specimen as 14, surface wall texture of penultimate chamber x1000

Plate 3


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2


3


4


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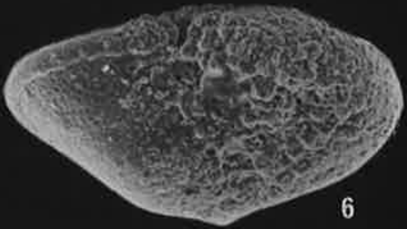
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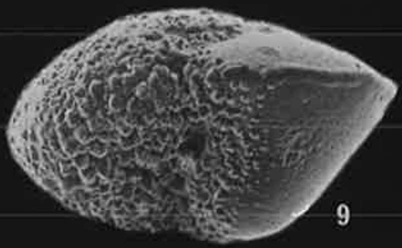
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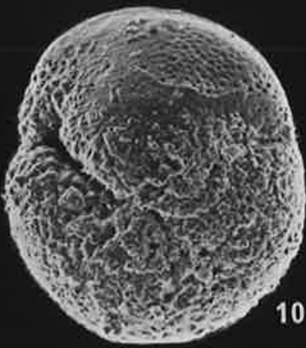
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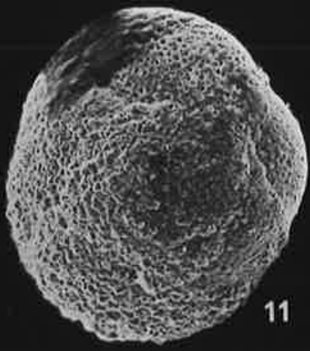
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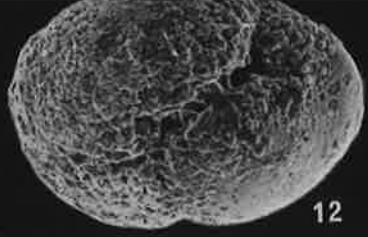
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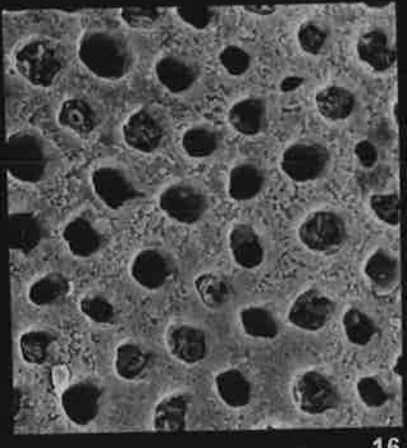
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PLATE 4

Figures 1-4 *Globorotalia peripheroacuta* Blow & Banner

1. 289-46-2 145-147cm x130 721-35
2. 289-46-2 145-147cm x120 721-36
3. same specimen as 2, surface wall texture of ultimate chamber x1000
4. 289-46-2 145-147cm x150 721-37

Figures 5-7 *Globorotalia peripheroronda* Blow & Banner

5. 214-21-2 30-32cm x110 721-38
6. 214-21-2 30-32cm x110 721-39
7. same specimen as 5 x110

Figures 8-10 *Globorotalia praefohsi* Blow & Banner

8. 289-45-3 117-119cm x110 721-40
9. 289-45-3 117-119cm x110 721-41
10. same specimen as 8 x110

Figures 11-13 *Globorotalia praemenardii* Cushman & Stainforth

11. 216A-5-1 2-4cm x120 721-42
12. 216A-5-1 2-4cm x120 721-43
13. 216A-5-1 2-4cm x120 721-44

Figures 14-16 *Globorotalia scitula praescitula* Blow

14. 214-21-5 5-7cm x200 721-45
15. 214-21-5 5-7cm x200 721-46
16. 214-21-5 5-7cm x220 721-47

Plate 4


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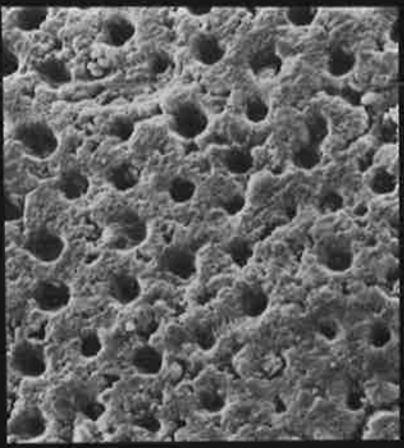
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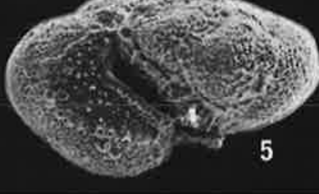
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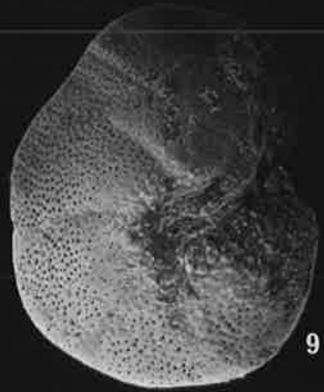
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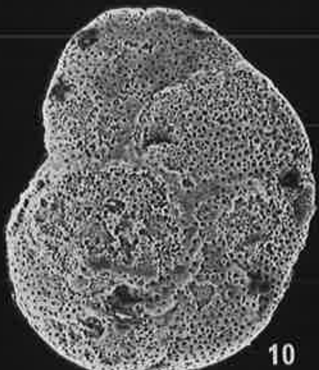
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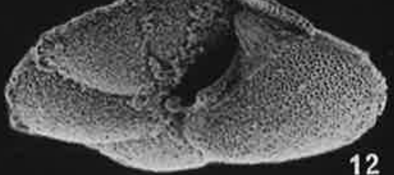
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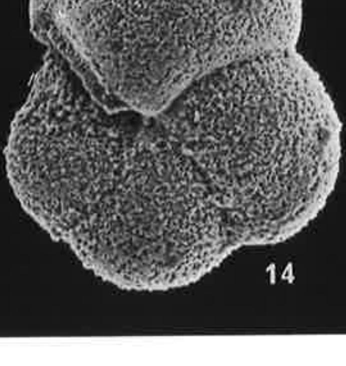
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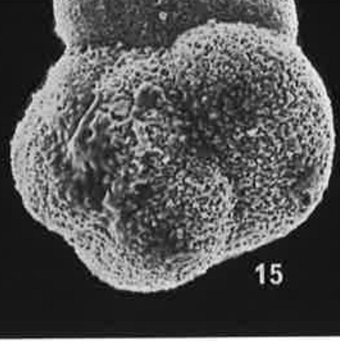
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PLATE 5

Figures 1-3 *Globorotalia scitula scitula* (Brady)

1. 214-3-3 5-6cm x110 721-48
2. 214-1-1 10-18cm x80 721-49
3. 214-1-1 10-18cm x120 721-50

Figures 4-6 *Globorotalia tosaensis* Takayanagi & Saito

4. 214-3-2 13-16cm x120 721-51
5. 214-3-2 13-16cm x100 721-52
6. same specimen as 5 x100

Figures 7-9 *Globorotalia truncatulinoides* (d'Orbigny)

7. 214-1-1 10-18cm x50 721-53
8. 214-1-1 10-18cm x80 721-54
9. same specimen as 8 x80

Figures 10-12 *Globorotalia tumida plesiotumida* Blow & Banner

10. 214-11-5 30-32cm x90 721-55
11. 214-11-2 5-7cm x100 721-56
12. same specimen as 10 x120

Figures 13-16 *Globorotalia tumida tumida* (Brady)

13. 214-1-1 10-18cm x60 721-57
14. 214-1-1 10-18cm x50 721-58
15. 214-3-3 5-6cm x1000 721-59
16. 214-1-1 10-18cm x50 721-60

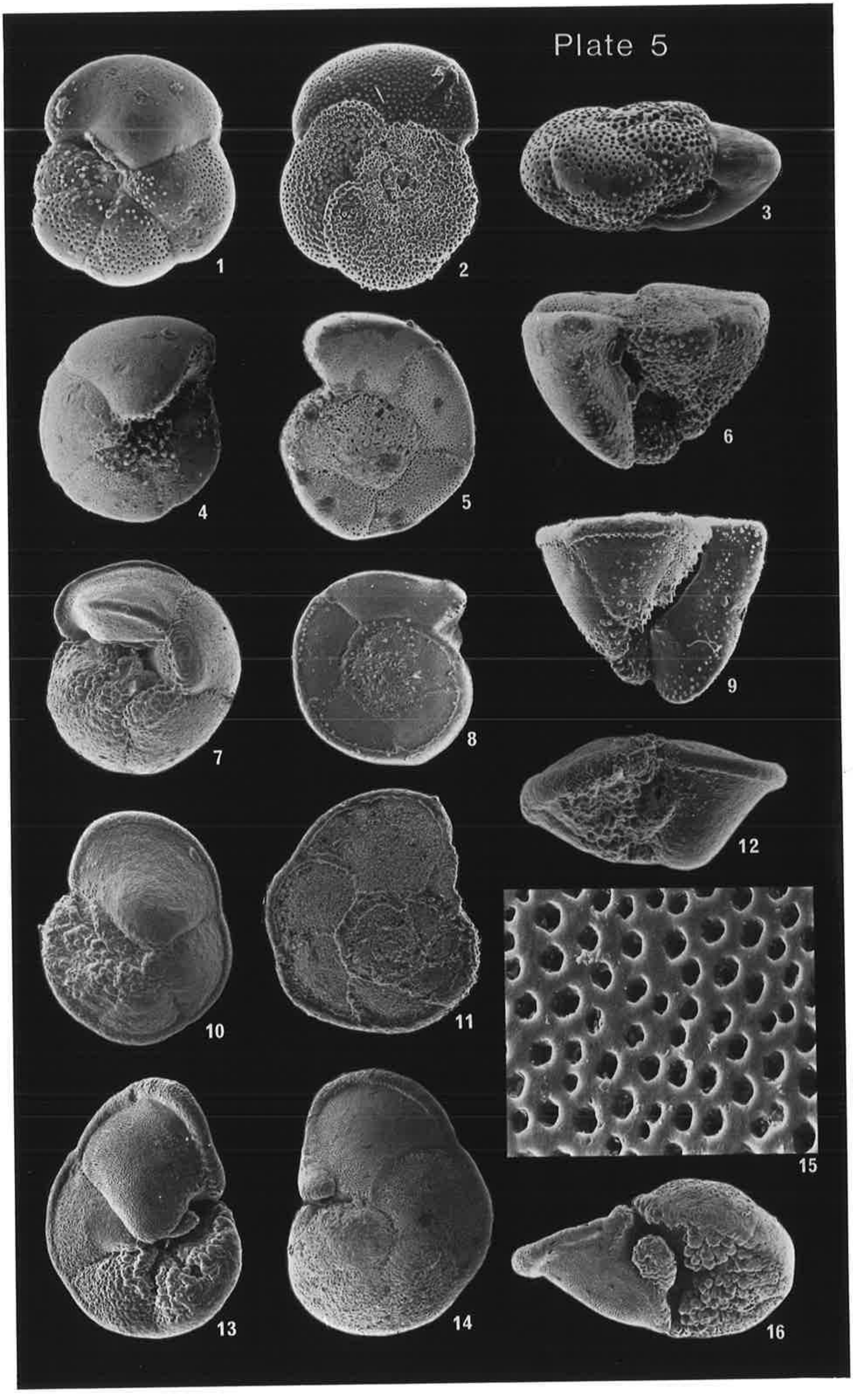
Plate 5

PLATE 6

Figures 1-3 *Pulleniatina obliquiloculata finalis* Banner & Blow

1. 214-1-1 10-18cm x60 721-61
2. same specimen as 1 x60
3. 214-1-1 10-18cm x70 721-62

Figures 4-8 *Pulleniatina obliquiloculata obliquiloculata* (Parker & Jones)

4. 214-1-1 10-18cm x70 721-63
5. same specimen as 4 x1000
6. same specimen as 4, surface wall texture of antepenultimate chamber in exposed whorl x1000
7. 214-3-3 5-6cm x80 721-64
8. 214-3-1 12-14cm x70 721-65

Figures 9,10 *Pulleniatina obliquiloculata praecursor* Banner & Blow

9. 214-3-3 5-6cm x70 721-66
10. 214-6-1 7-9cm x110 721-67

Figures 11-13 *Pulleniatina praespectabilis* Brönnimann & Resig

11. 289-13-1 146-148cm x100 721-68
12. 289-13-1 146-148cm x100 721-69
13. 289-13-1 146-148cm x100 721-70

Plate 6


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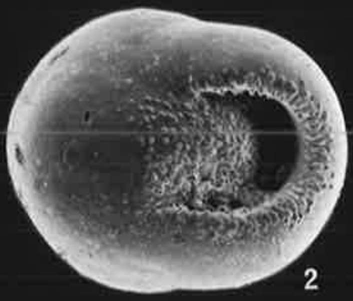
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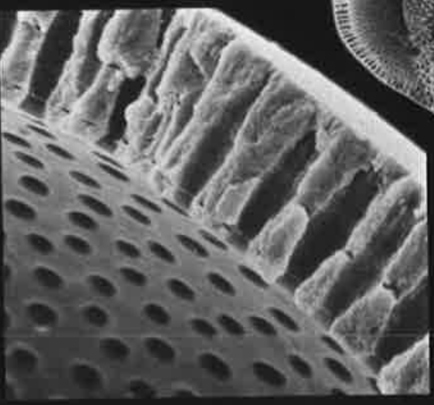
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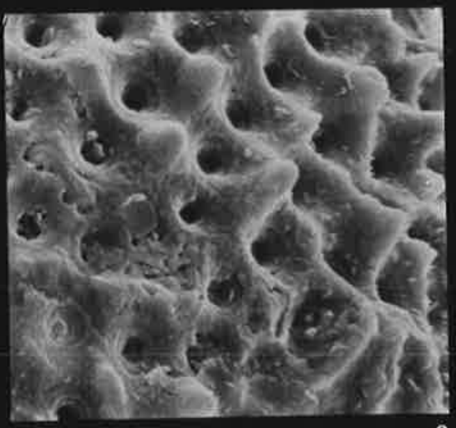
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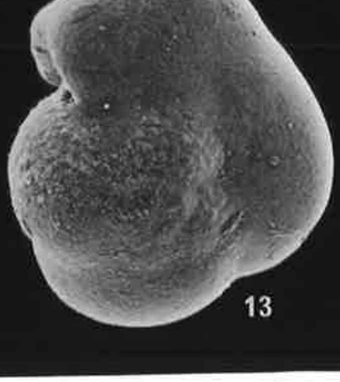
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PLATE 7

Figures 1-3 *Pulleniatina primalis* Banner & Blow

1. 214-11-2 5-7cm x100 721-71
2. 214-11-2 5-7cm x120 721-72
3. 214-11-2 5-7cm x100 721-73

Figures 4-6 *Pulleniatina* cf. *spectabilis* Parker

4. 289-13-1 146-148cm x100 721-74
5. same specimen as 4 x100
6. 289-13-1 146-148cm x90 721-75

Figures 7-10 *Neogloboquadrina acostaensis acostaensis* (Blow)

7. 214-10-1 5-7cm x140 721-76
8. 214-10-1 5-7cm x160 721-77
9. 214-10-1 5-7cm x150 721-78
10. same specimen as 7, surface wall texture of penultimate chamber x1000

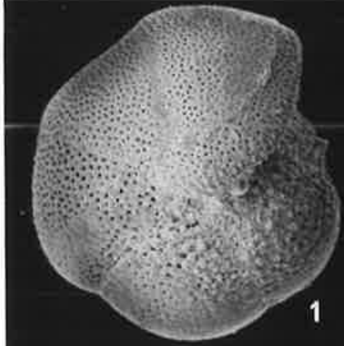
Figures 11-13 *Neogloboquadrina acostaensis humerosa* (Takayanagi & Saito)

11. 214-10-1 5-7cm x110 721-79
12. 214-11-1 5-7cm x100 721-80
13. 214-11-1 5-7cm x130 721-81

Figures 14-16 *Neogloboquadrina acostaensis pseudopima* (Blow)

14. 214-3-3 5-6cm x110 721-82
15. 214-3-3 5-6cm x130 721-83
16. 214-3-3 5-6cm x140 721-84

Plate 7



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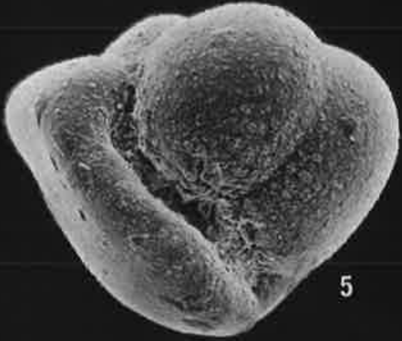

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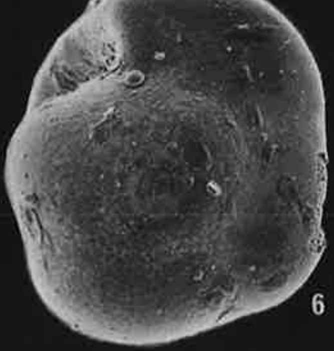

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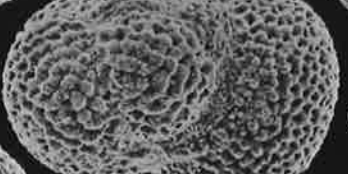

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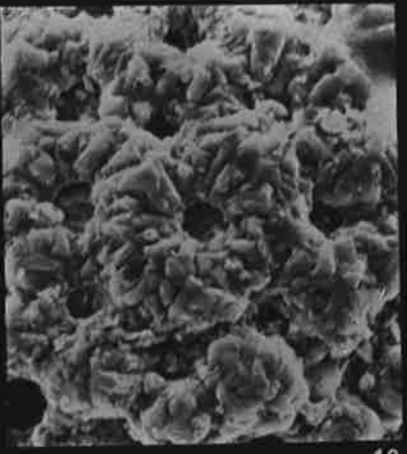

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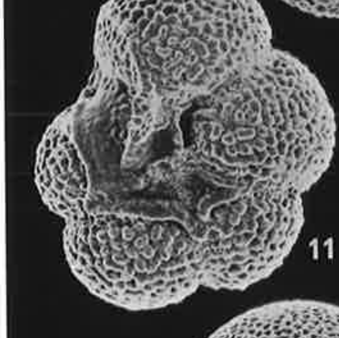

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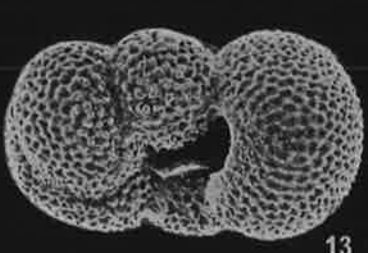

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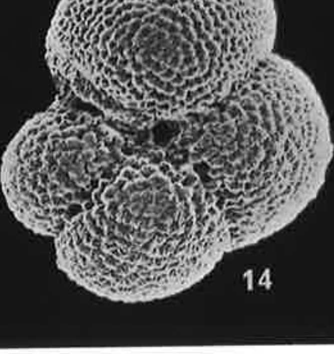

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PLATE 8

Figures 1-3 *Neogloboquadrina birnageae* (Blow)

1. 214-22-cc x180 721-85
2. 214-22-cc x180 721-86
3. 214-22-cc x180 721-87

Figures 4,5 *Neogloboquadrina continuosa* (Blow)

4. 214-20-cc x160 721-88
5. same specimen x160

Figures 6-8 *Neogloboquadrina dutertrei* (d'Orbigny)

6. 214-1-1 10-18cm x80 721-89
7. 214-1-1 10-18cm x60 721-90
8. 214-1-1 10-18cm x70 721-91

Figures 9-11 *Neogloboquadrina kugleri kugleri* (Bolli)

9. 214-23-6 5-7cm x140 721-92
10. 214-23-6 5-7cm x150 721-93
11. 214-23-6 5-7cm x200 721-94

Figures 12-14 *Neogloboquadrina kugleri mendacis* (Blow)

12. 214-23-cc x190 721-95
13. 214-23-cc x180 721-96
14. 214-23-cc x160 721-97

Figures 15-17 *Neogloboquadrina kugleri pseudokugleri* (Blow)

15. 214-24-1 Top x150 721-98
16. 214-24-1 Top x210 721-99
17. 214-24-1 Top x220 721-100

Plate 8


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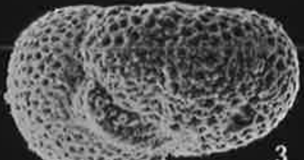
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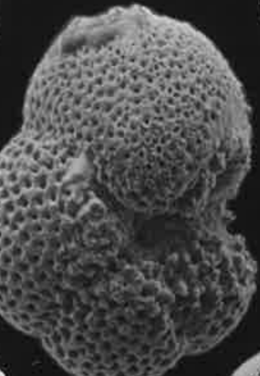
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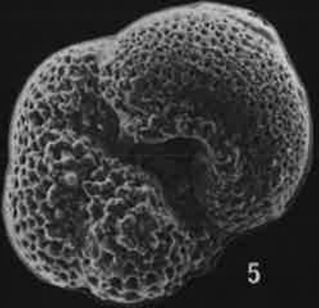
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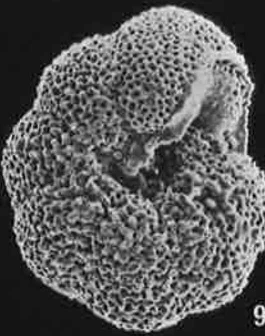
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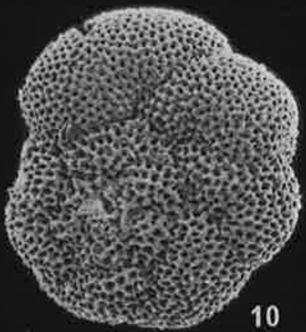
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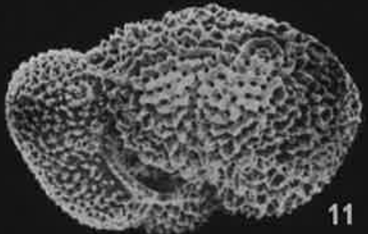
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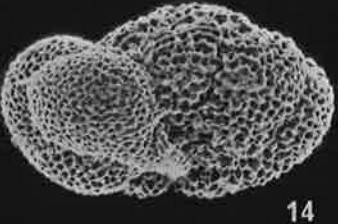
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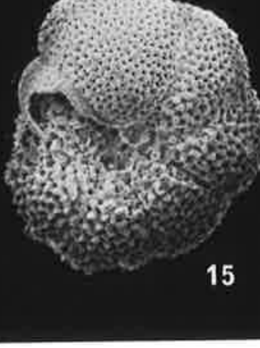
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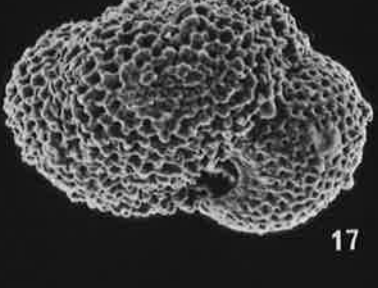
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PLATE 9

Figures 1-4 *Neogloboquadrina kugleri kugleri* (Bolli)

1. *Globorotalia kugleri* Zone, Trinidad x180 721-101
2. *Globorotalia kugleri* Zone, Trinidad x170 721-102
3. *Globorotalia kugleri* Zone, Trinidad x190 721-103
4. same specimen as 2, surface wall texture of penultimate chamber x1000

Figures 5,6 *Neogloboquadrina nigriniae* (Fleisher)

5. 214-7-4 5-7cm x110 721-104
6. 214-7-4 5-7cm x110 721-105

Figures 7-13 *Neogloboquadrina opima s.l.* (Bolli)

7. 214-25-2 Top x190 721-106
8. 214-25-2 Top x180 721-107
9. same specimen as 8, surface wall texture of ultimate chamber x1000
10. 214-25-2 Top x170 721-108
11. 214-22-cc x130 721-109
12. same specimen as 11 x130
13. 214-22-cc x140 721-110

Figures 14-16 *Neogloboquadrina pseudocontinuosa* (Jenkins)

14. Abele (1961) sample E.22 x180 721-111
15. same specimen x180
16. same specimen, surface wall texture of ultimate chamber x1000

Plate 9


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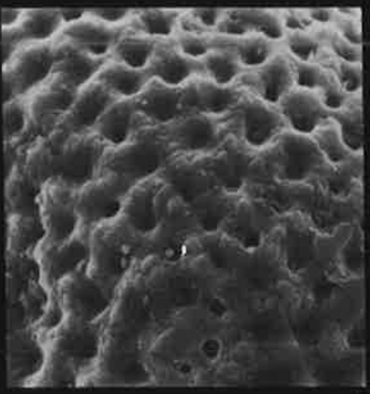
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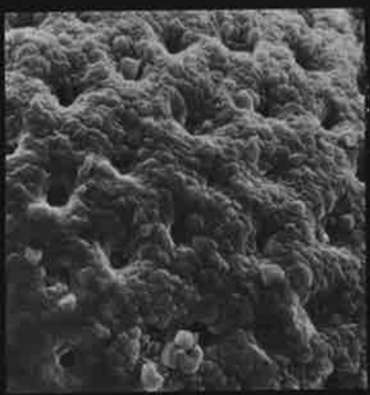
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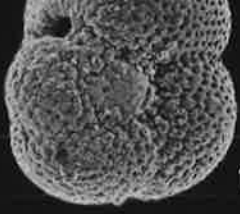
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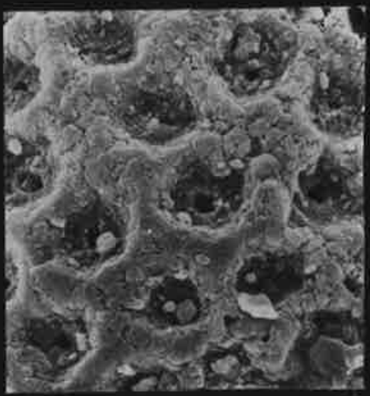
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PLATE 10

Figures 1,2 *Neogloboquadrina pseudocontinuosa* (Jenkins)

1. Abele (1961) sample E.22 x150 721-112
2. same specimen x150

Figures 3-6 *Neogloboquadrina semivera* (Hornibrook)

3. B.M.R. Lakes Entrance, 1132 feet x160 721-113
4. Gellibrand Clay, Victoria, sample 5 x190 721-114
5. Gellibrand Clay, Victoria, sample 5 x160 721-115
6. same specimen as 5, surface wall texture of ultimate chamber x1000

Figures 7-9 *Neogloboquadrina siakensis* (LeRoy)

7. 214-21-3 12-14cm x140 721-116
8. 214-21-3 12-14cm x120 721-117
9. 214-22-cc x110 721-118

Figures 10-12 *Neogloboquadrina vincentae* (Fleisher)

10. 214-7-4 5-7cm x120 721-119
11. 214-7-4 5-7cm x110 721-120
12. 214-7-4 5-7cm x120 721-121

Figures 13-15 *Neogloboquadrina zealandica* (Hornibrook)

13. Abele (1961) sample E.122, surface wall texture of ultimate chamber x1000 721-122
14. same specimen x120
15. same specimen x120

Plate 10


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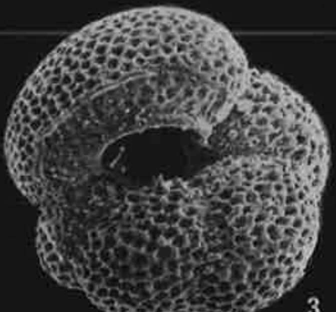
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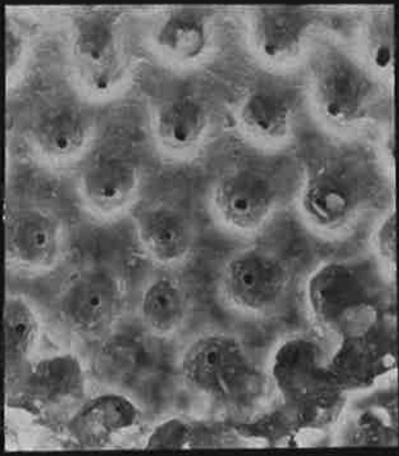
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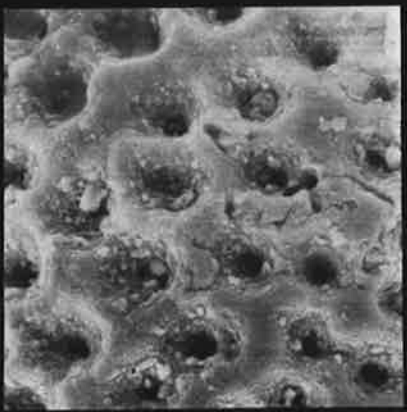
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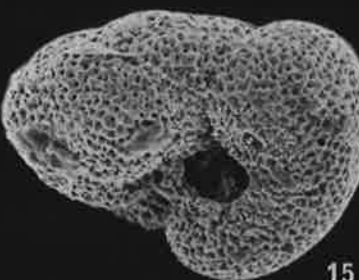
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PLATE 11

Figures 1-3 *Globoquadrina altispira s.l.* (Cushman & Jarvis)

1. 214-5-6 25-27cm x80 721-123
2. 214-8-2 7-9cm x90 721-124
3. same specimen as 1 x90

Figures 4-6 *Globoquadrina binaiensis* (Koch)

4. 214-22-6 5-7cm x130 721-125
5. 214-22-6 5-7cm x120 721-126
6. 214-23-2 5-7cm x110 721-127

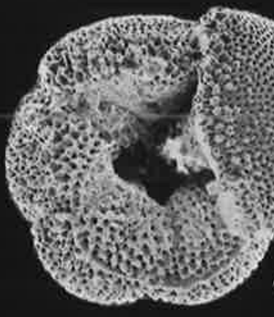
Figures 7-11 *Globoquadrina conglomerata* (Schwager)

7. 214-3-3 5-6cm x60 721-128
8. 214-3-3 5-6cm x60 721-129
9. 214-3-3 5-6cm x60 721-130
10. 214-3-3 5-6cm x100 721-131
11. 214-3-3 5-6cm x130 721-132

Figures 12-16 *Globoquadrina dehiscens dehiscens* (Chapman, Parr & Collins)

12. 214-11-3 5-7cm x70 721-133
13. same specimen x70
14. same specimen x70
15. same specimen with ultimate chamber removed x70
16. same specimen with penultimate chamber removed x70

Plate 11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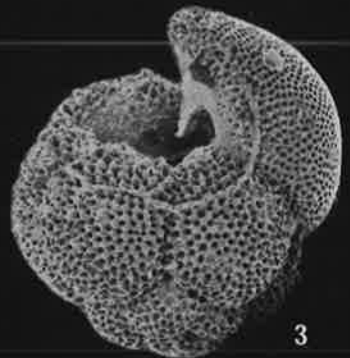
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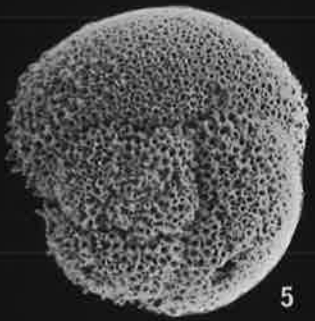
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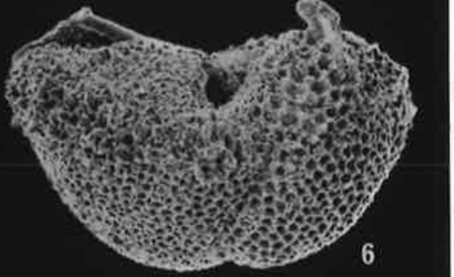
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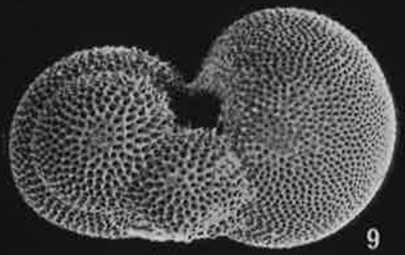
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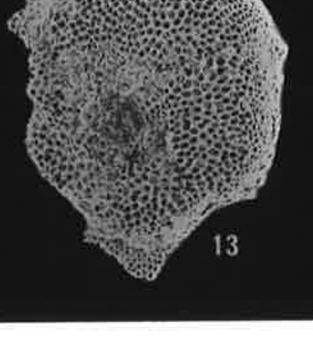
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PLATE 12

Figures 1-4 *Globoquadrina dehiscens dehiscens* (Chapman, Parr & Collins)

1. 214-21-cc x100 721-134
2. 214-19-cc x100 721-135
3. 214-19-cc x160 721-136
4. 214-19-cc x70 721-137

Figures 5-7 *Globoquadrina dehiscens praedehiscens* Blow & Banner

5. 214-22-5 5-7cm x70 721-138
6. 214-22-5 5-7cm x70 721-139
7. 214-22-5 5-7cm x70 721-140

Figures 8,9 *Globoquadrina sellii* Borsetti

8. 214-23-6 5-7cm x110 721-141
9. 214-23-6 5-7cm x100 721-142

Figures 10-13 *Globoquadrina venezuelana venezuelana* (Hedberg)

10. 214-18-2 8-10cm x90 721-143
11. 214-18-2 8-10cm x80 721-144
12. 214-15-2 5-7cm x70 721-145
13. 214-18-2 8-10cm, adult specimen with antepenultimate chamber removed x100 721-146

Figures 14-18 *Globoquadrina venezuelana praedehiscens*

14. 214-13-6 18-20cm x60 721-147
15. same specimen x70
16. same specimen with gerontic ultimate chamber removed x70
17. same specimen with penultimate chamber removed x60
18. same specimen with antepenultimate chamber removed x60

Plate 12

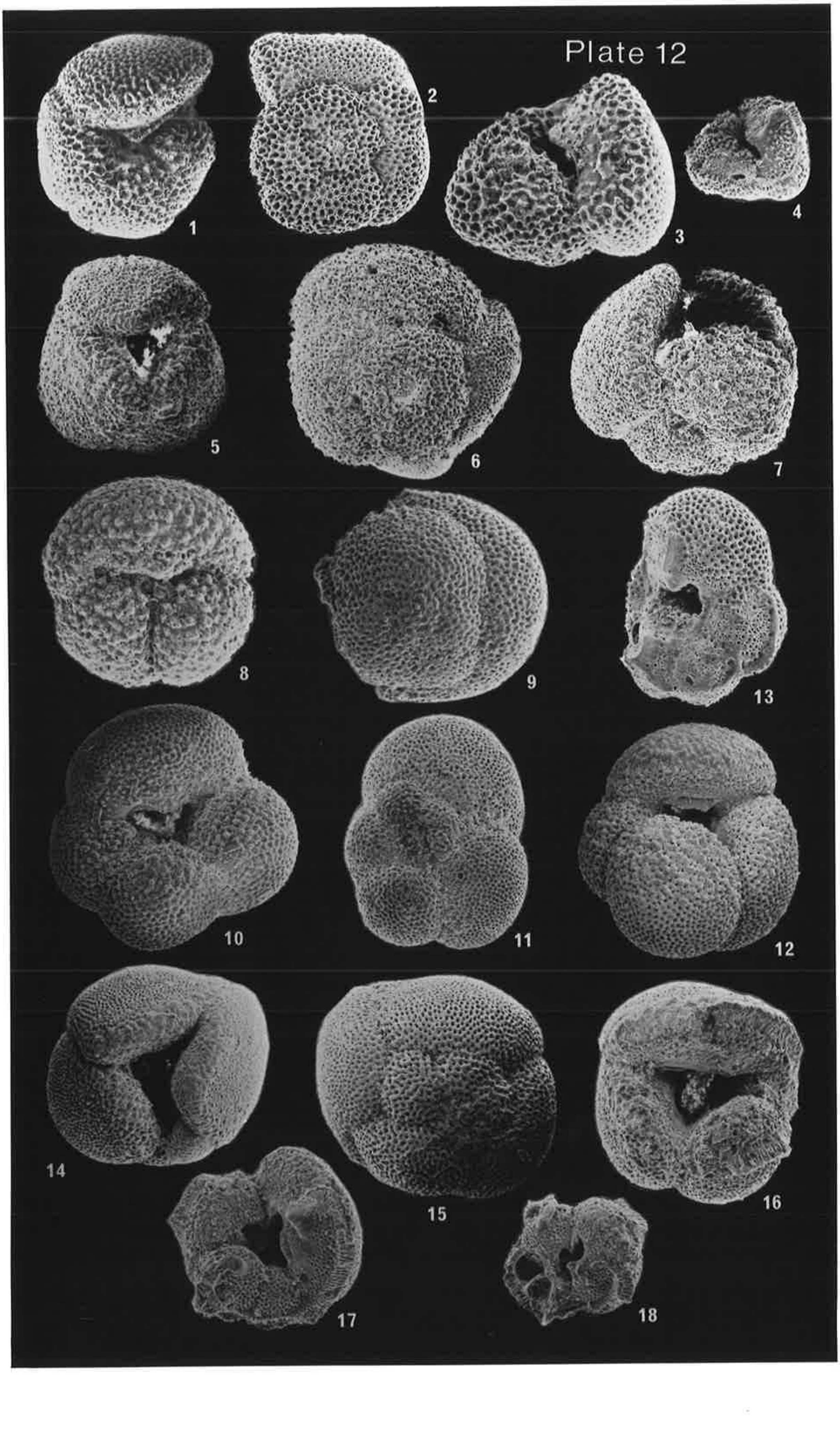

PLATE 13

Figures 1-3 *Globorotaloides bermudezi* (Bolli)
1. 216A-5-2 6-8cm x90 721-148
2. same specimen as 1 x90
3. 216A-5-2 6-8cm, surface wall texture of ultimate chamber x1000 721-149

Figures 4-6 *Globorotaloides hexagona* (Natland)
4. 214-3-5 21-23cm x150 721-150
5. 214-1-1 10-18cm x200 721-151
6. 214-3-5 21-23cm x200 721-152

Figures 7-10 *Globorotaloides oveyi* (Buckley)
7. 217-2-4 80-82cm x100 721-153
8. 217-2-4 80-82cm x100 721-154
9. same specimen as 8, surface wall texture of penultimate chamber x1000
10. 217-2-4 80-82cm x140 721-155

Figure 11 *Catapsydrax dissimilis ciperoensis* (Blow & Banner)
11. 214-22-cc x90 721-156

Figure 12 *Catapsydrax dissimilis dissimilis* (Cushman & Bermúdez)
12. 214-22-cc x90 721-157

Figures 13,15,16 *Catapsydrax parvulus* Bolli, Loeblich & Tappan
13. 214-20-6 Top x275 721-158
15. 214-17-6 5-7cm x120 721-159
16. 214-17-6 5-7cm x120 721-160

Figure 14 *Catapsydrax stainforthi* Bolli, Loeblich & Tappan
14. 214-22-5 5-7cm, surface wall texture of ultimate chamber x1000 721-161

Plate 13


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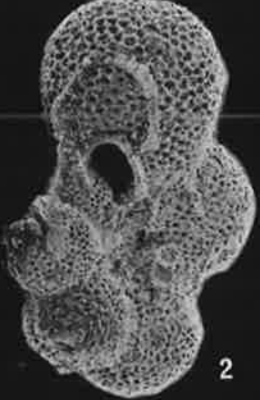
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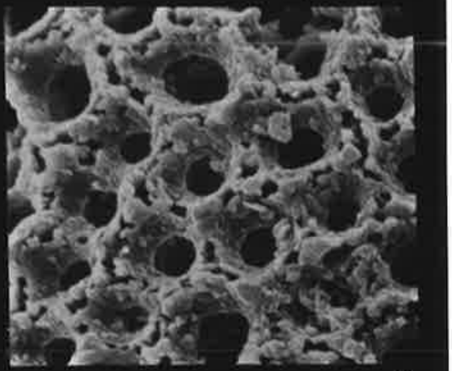
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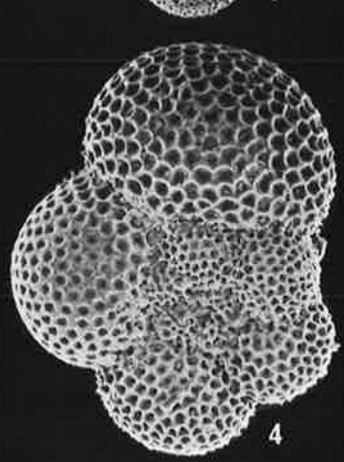
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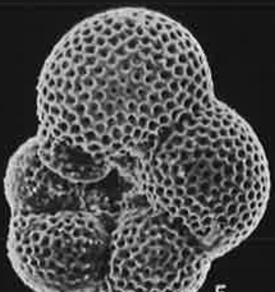
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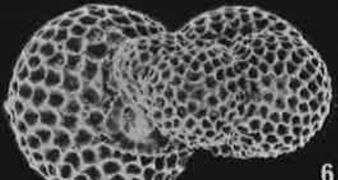
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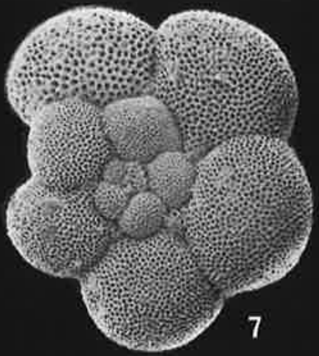
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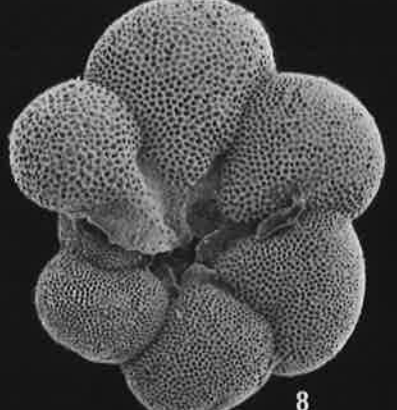
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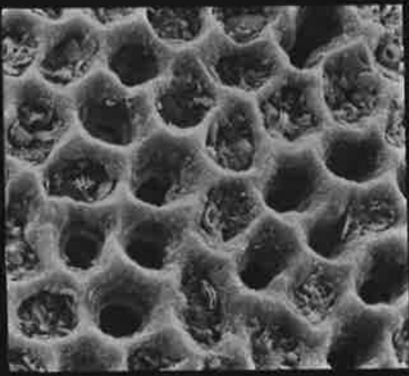
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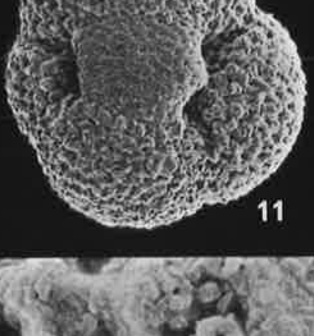
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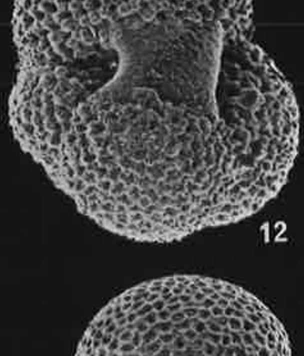
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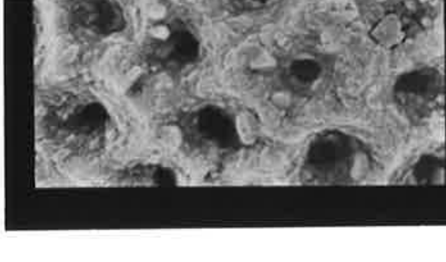
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PLATE 14

Figures 1,2	*Catapsydrax stainforthi* Bolli, Loeblich & Tappan
	1. same specimen as Plate 13 Figure 14 x160
	2. 214-22-5 5-7cm x160 721-162
Figure 3	*Catapsydrax unicavus s.l.* Bolli, Loeblich & Tappan
	3. 214-23-6 5-7cm x110 721-163
Figures 4-6	*Beella digitata* (Brady)
	4. 217-1-6 Top, surface wall texture of penultimate chamber x1000 721-164
	5. same specimen as 4 x120
	6. 217-2-1 135-137cm x130 721-165
Figures 7-12	*Beella nicobarensis* (Srinivasan & Kennett)
	7. 217-2-4 80-82cm x110 721-166
	8. same specimen as 7 x110
	9. 217-2-4 80-82cm, surface wall texture of ultimate chamber x1000 721-167
	10. same specimen as 9 x100
	11. same specimen as 9 x100
	12. 217-2-4 80-82cm x150 721-168
Figures 13-15	*Globigerinella adamsi* (Banner & Blow)
	13. 214-1-1 10-18cm x100 721-169
	14. same specimen x110
	15. same specimen, surface wall texture of ultimate chamber x1000

Plate 14


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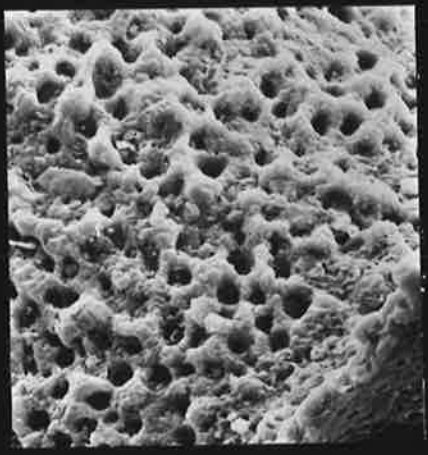
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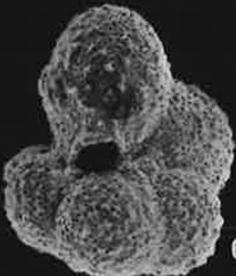
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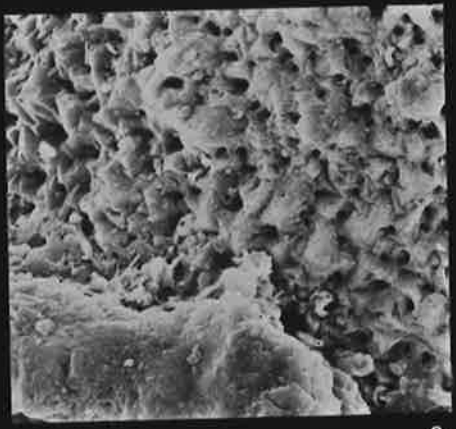
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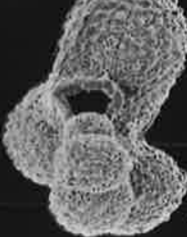
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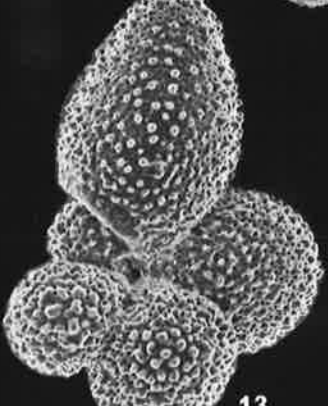
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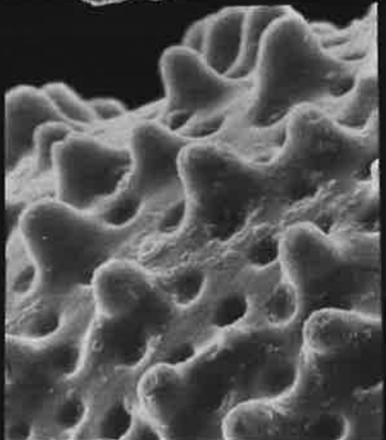
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PLATE 15

Figures 1,2 *Globigerinella siphonifera* (d'Orbigny)

1. 214-3-3 5-6cm x90 721-170
2. 214-3-3 5-6cm x110 721-171

Figures 3-6 *Globigerina bulloides* d'Orbigny

3. 214-3-3 5-6cm x160 721-172
4. 214-3-3 5-6cm x150 721-173
5. same specimen as 3, surface wall texture of ultimate chamber x900
6. 214-3-3 5-6cm x150 721-174

Figures 7,8 *Globigerina calida calida* Parker

7. 214-1-1 10-18cm x110 721-175
8. 214-1-1 10-18cm x80 721-176

Figures 9,10 *Globigerina druryi* Akers

9. 214-20-6 Top x275 721-177
10. 214-20-6 Top x300 721-178

Figure 11 *Globigerina falconensis* Blow

11. 214-21-5 5-7cm x170 721-179

Figures 12-14 *Globigerina incisa* (Brönnimann & Resig)

12. 214-3-3 5-6cm x150 721-180
13. 214-3-3 5-6cm x130 721-181
14. same specimen as 12, surface wall texture of ultimate chamber x1500

Plate 15


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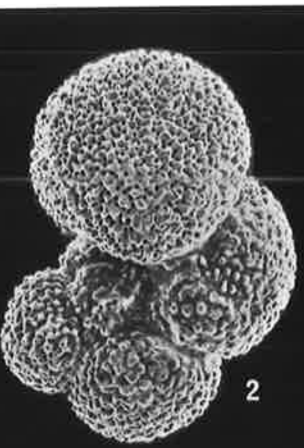
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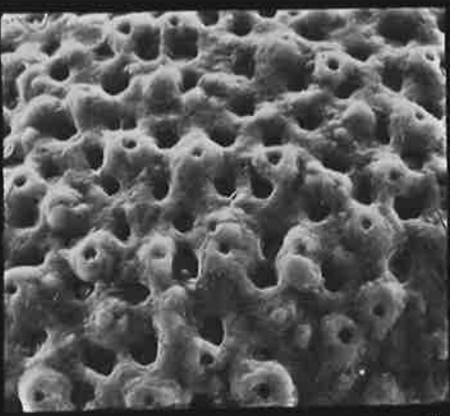
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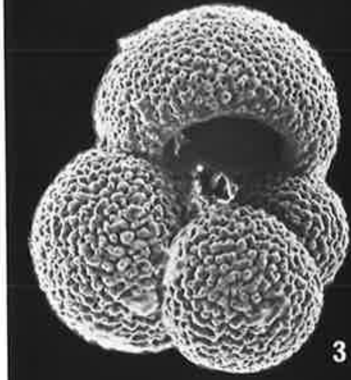
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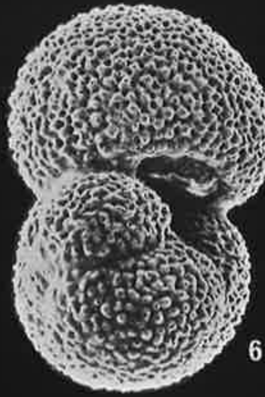
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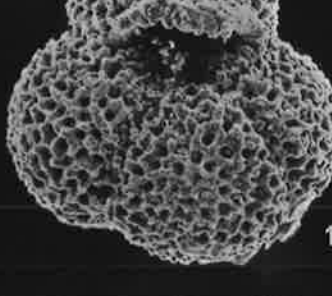
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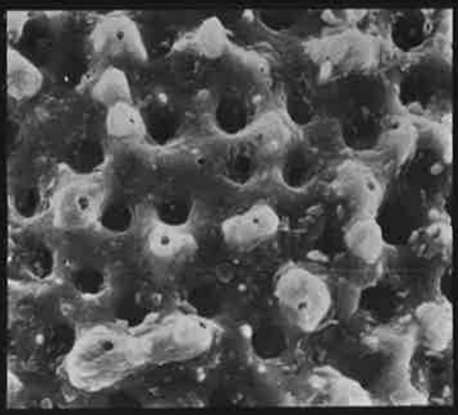
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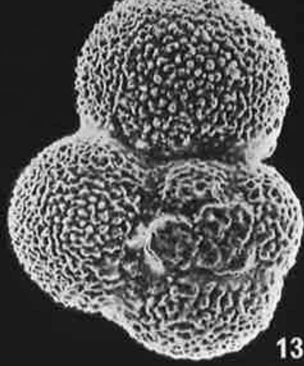
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PLATE 16

Figures 1,2 *Globigerina nepenthes* Todd
1. 214-8-2 7-9cm x200 721-182
2. 214-18-3 10-12cm x140 721-183

Figures 3-5 *Globigerina obesa* (Bolli)
3. 214-3-3 5-6cm x140 721-184
4. 214-3-3 5-6cm x140 721-185
5. 214-3-3 5-6cm x160 721-186

Figures 6-8 *Globigerina praebulloides* Blow
6. Gellibrand Clay, Victoria, sample 6 x130 721-187
7. same specimen as 6, surface wall texture showing broken spines x1000
8. 214-22-2 5-7cm x90 721-188

Figure 9 *Globigerina pseudodruryi* Brönnimann & Resig
9. 214-18-3 10-12cm x170 721-189

Figure 10 *Globigerina rubescens decoraperta* Takayanagi & Saito
10. 214-10-1 5-7cm x200 721-190

Figures 11,12 *Globigerina rubescens rubescens* Hofker
11. 214-1-1 10-18cm x300 721-191
12. 214-1-1 10-18cm x210 721-192

Figure 13 *Globigerina tenella* (Parker)
13. 214-1-6 Top x170 721-193

Figure 14 *Globigerina woodi* Jenkins
14. 214-10-1 5-7cm x180 721-194

Plate 16


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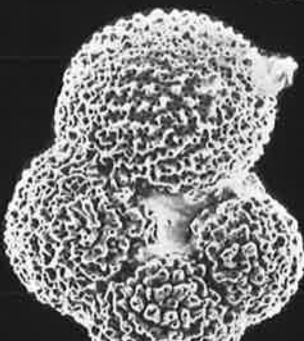
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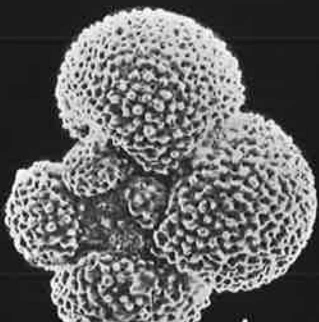
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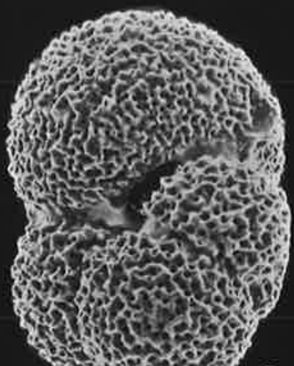
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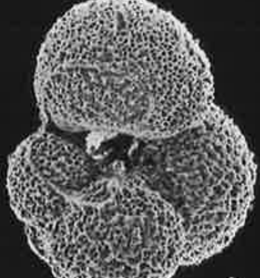
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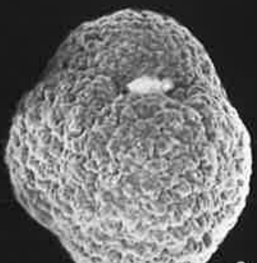
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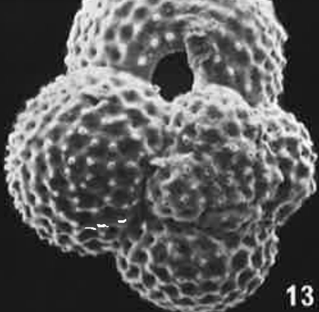
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PLATE 17

Figures 1,2 *Sphaeroidinella dehiscens dehiscens* (Parker & Jones)

1. 214-3-3 5-6cm x70 721-195
2. 214-4-1 Top x100 721-196

Figure 3 *Sphaeroidinella dehiscens excavata* Banner & Blow

3. 214-3-3 5-6cm x40 721-197

Figures 4-7 *Sphaeroidinella dehiscens immatura* (Cushman)

4. 214-8-2 7-9cm x60 721-198
5. same specimen as 4 x200
6. 214-10-1 5-7cm x60 721-199
7. same specimen as 6 x200

Figures 8,9 *Sphaeroidinellopsis seminulina kochi* (Caudri)

8. 214-18-cc x60 721-200
9. 214-10-2 5-7cm x60 721-201

Figures 10-12 *Sphaeroidinellopsis seminulina seminulina* (Schwager)

10. 214-14-5 15-17cm x100 721-202
11. 214-20-3 5-7cm x90 721-203
12. 214-5-6 25-27cm, specimen decorticated x70 721-204

Figures 13,14 *Sphaeroidinellopsis subdehiscens paenedehiscens* Blow

13. 214-12-5 18-20cm x120 721-205
14. 214-8-2 7-9cm x80 721-206

Figures 15,16 *Sphaeroidinellopsis subdehiscens subdehiscens* (Blow)

15. 214-8-2 7-9cm x70 721-207
16. 214-10-1 5-7cm x110 721-208

Plate 17


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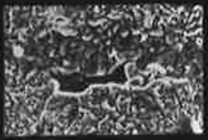
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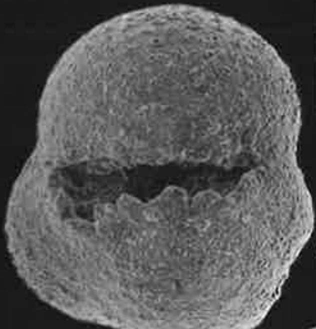
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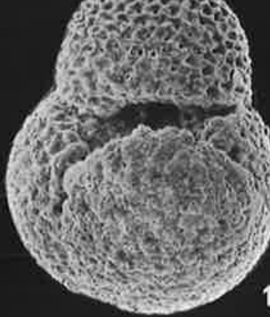
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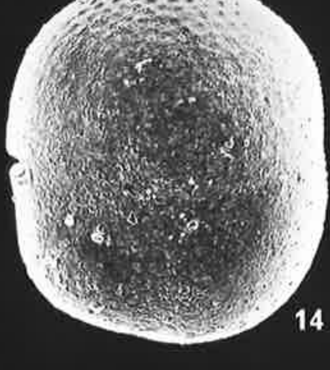
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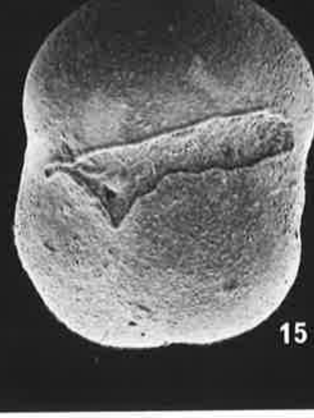
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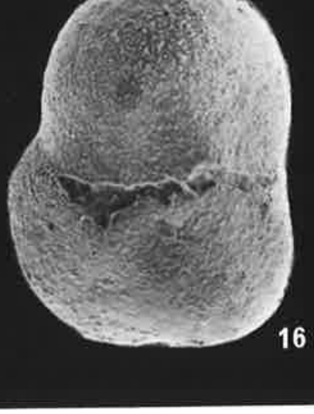
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PLATE 18

Figures 1,2 *Globigerinoides conglobatus* (Brady)

1. 214-3-3 5-6cm x70 721-209
2. 214-4-1 Top x100 721-210

Figures 3-5 *Globigerinoides diminutus* Bolli

3. 214-21-5 5-7cm x140 721-211
4. 214-21-5 5-7cm x150 721-212
5. 214-21-5 5-7cm x140 721-213

Figures 6,7 *Globigerinoides obliquus extremus* Bolli & Bermúdez

6. 214-4-3 6-8cm x150 721-214
7. 214-4-3 6-8cm x150 721-215

Figures 8,9 *Globigerinoides obliquus obliquus* Bolli

8. 214-3-3 5-6cm x110 721-216
9. 214-18-3 10-12cm x100 721-217

Figure 10 *Globigerinoides quadrilobatus* aff. *altiapertura* Bolli

10. 214-22-2 5-7cm x100 721-218

Figure 11 *Globigerinoides quadrilobatus fistulosus* (Schubert)

11. 214-4-5 5-7cm x60 721-219

Figure 12 *Globigerinoides quadrilobatus immaturus* LeRoy

12. 214-3-3 5-6cm x70 721-220

Figures 13,14 *Globigerinoides quadrilobatus primordius* Blow & Banner

13. 214-23-cc x120 721-221
14. Gellibrand Clay, Victoria, sample 3 x110 721-222

Plate 18

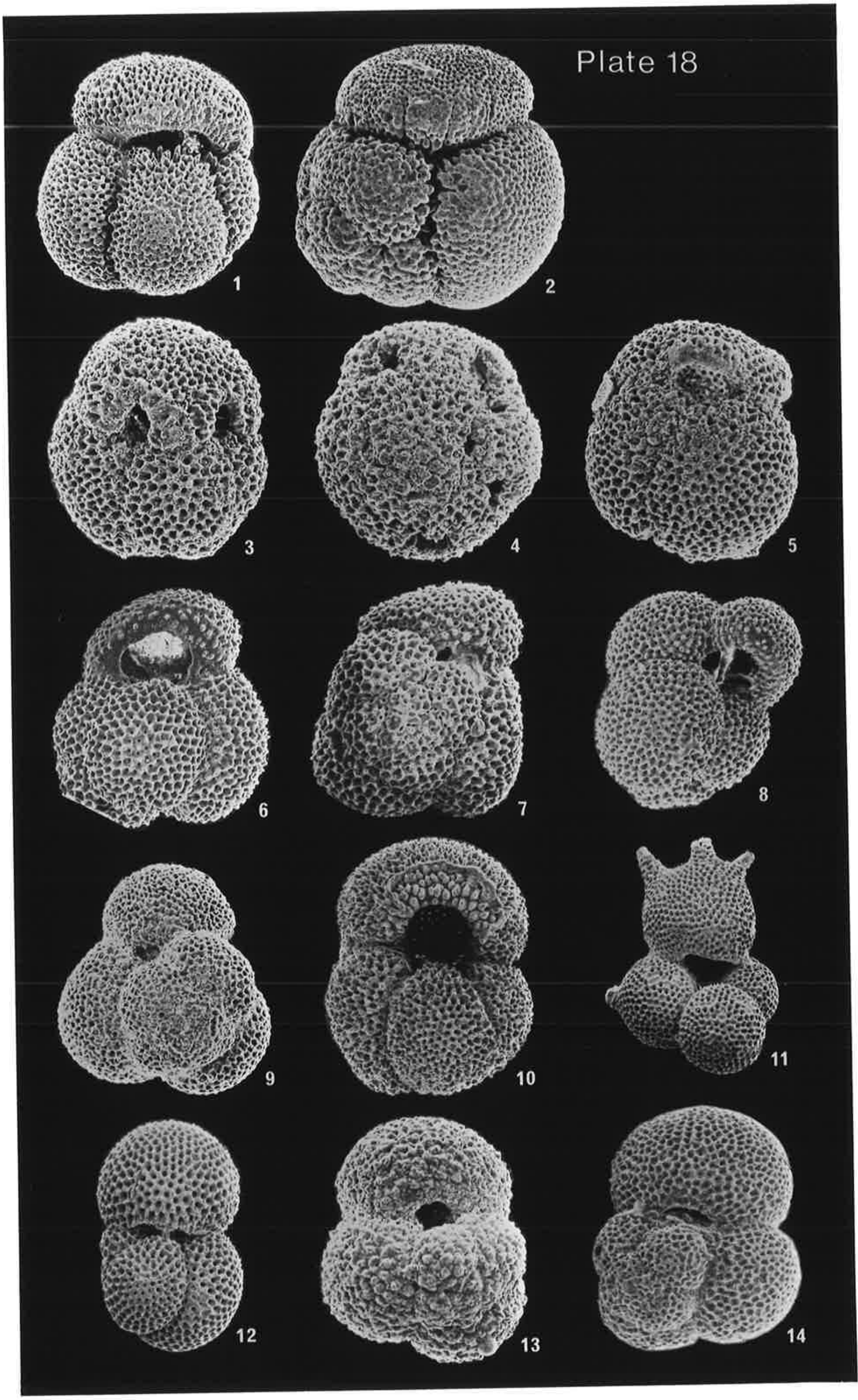
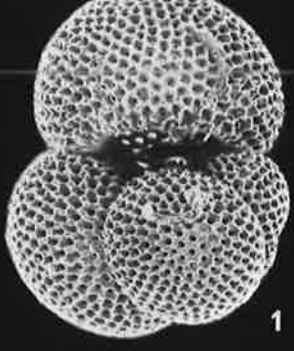


PLATE 19

Figure 1	*Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny) 1. 214-3-3 5-6cm x80 721-223
Figure 2	*Globigerinoides quadrilobatus sacculifer* (Brady) 2. 214-1-1 10-18cm x45 721-224
Figure 3	*Globigerinoides quadrilobatus trilobus* (Reuss) 3. 214-21-5 5-7cm x130 721-225
Figures 4,5	*Globigerinoides ruber* (d'Orbigny) 4. 214-4-1 Top x200 721-226 5. 214-3-3 5-6cm x80 721-227
Figures 6,7	*Globigerinoides sicanus* de Stefani 6. 214-21-5 5-7cm x100 721-228 7. 214-21-5 5-7cm x100 721-229
Figures 8,9	*Globigerinoides subquadratus* Brönnimann 8. 214-18-cc x100 721-230 9. 214-20-cc x110 721-231
Figure 10	*Praeorbulina glomerosa circularis* (Blow) 10. 214-21-1 Top x110 721-232
Figure 11	*Praeorbulina glomerosa glomerosa* (Blow) 11. 214-21-2 30-32cm x100 721-233
Figure 12	*Orbulina suturalis* Brönnimann 12. 214-19-cc x70 721-234
Figure 13,14	*Orbulina universa* d'Orbigny 13. 214-1-1 10-18cm x40 721-235 14. same specimen, surface wall texture x1000

Plate 19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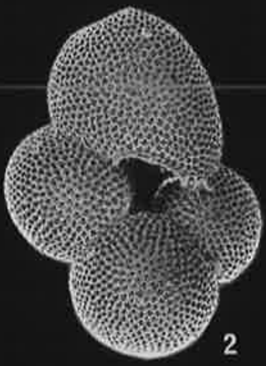
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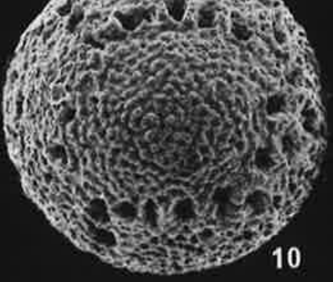
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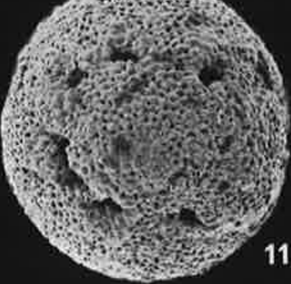
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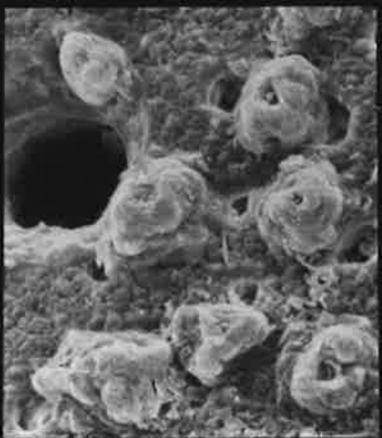
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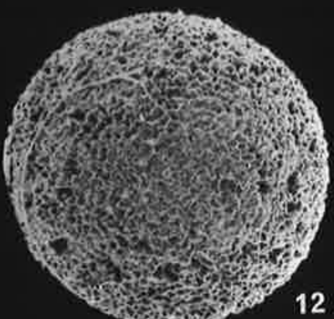
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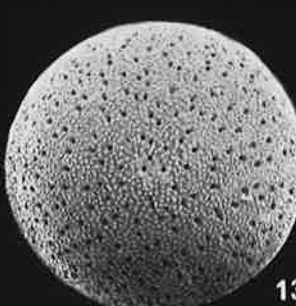
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PLATE 20

Figures 1-3 *Candeina nitida* d'Orbigny

1. 214-1-1 10-18cm x100 721-236
2. 214-4-3 6-8cm x110 721-237
3. same specimen as 1, surface wall texture of ultimate chamber x1000

Figures 4-7 *Globigerinatella insueta* Cushman & Stainforth

4. 214-21-2 30-32cm x100 721-238
5. *Globigerinatella insueta* Zone, Trinidad x100 721-239
6. same specimen as 5, surface wall texture x1000
7. 214-21-2 30-32cm x110 721-240

Figures 8-10 *Globigerinita glutinata ambitacrena* (Loeblich & Tappan)

8. 214-4-5 5-7cm x240 721-241
9. 214-8-2 7-9cm x225 721-242
10. 214-4-5 5-7cm x300 721-243

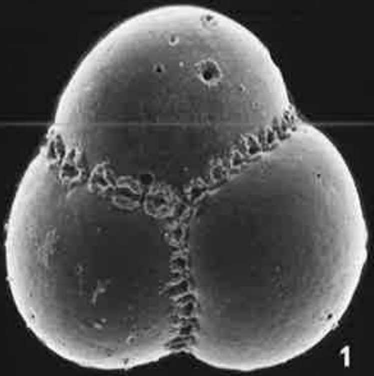
Figures 11,12 *Globigerinita glutinata glutinata* (Egger)

11. 214-3-3 5-6cm x160 721-244
12. same specimen, surface wall texture of ultimate chamber x1000

Figure 13 *Globigerinita uvula* (Ehrenberg)

13. 214-22-2 5-7cm x180 721-245

Plate 20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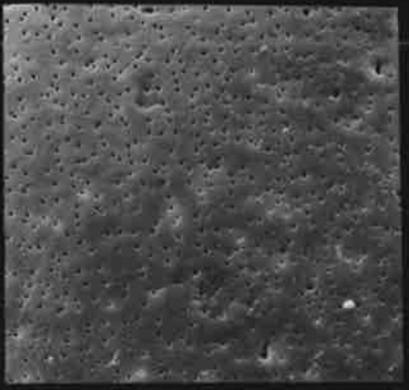
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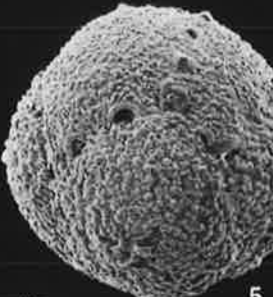
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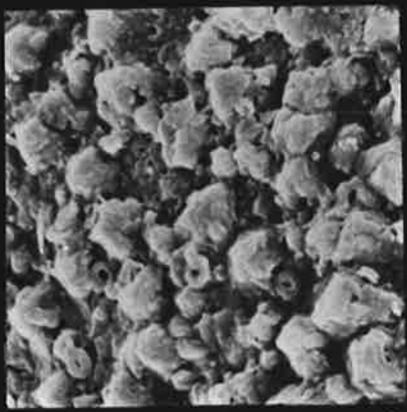
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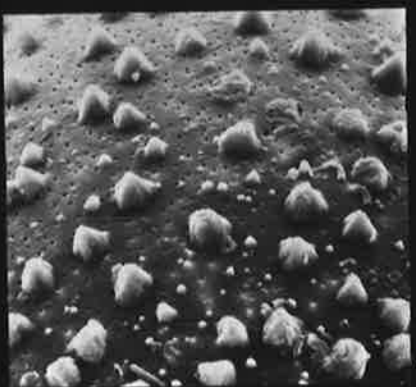
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PLATE 21

Figures 1,2 *Tenuitella angustiumbilicata* (Bolli)

1. 214-22-6 5-7cm x350 721-246
2. 214-22-6 5-7cm x300 721-247

Figures 3-5 *Tenuitella cifellii* (Brönnimann & Resig)

3. 214-22-3 90-92cm x300 721-248
4. 214-22-6 5-7cm x300 721-249
5. 214-22-3 90-92cm x300 721-250

Figures 6-8 *Tenuitella clemenciae* (Bermúdez)

6. 214-21-5 5-7cm x190 721-251
7. 214-21-5 5-7cm x300 721-252
8. 214-20-cc x170 721-253

Figures 9-12 *Tenuitella grata* (Todd)

9. 214-21-5 5-7cm x130 721-254
10. 214-21-5 5-7cm x180 721-255
11. 214-21-5 5-7cm x170 721-256
12. 214-21-2 30-32cm x140 721-257

Figures 13-16 *Tenuitella iota anfracta* (Parker)

13. 214-1-1 10-18cm x350 721-258
14. 214-1-1 10-18cm x350 721-259
15. same specimen as 14 x350
16. same specimen as 14, surface wall texture of ultimate chamber x1000

Plate 21


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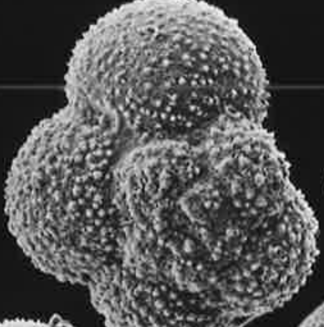
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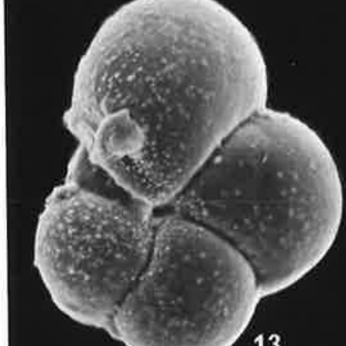
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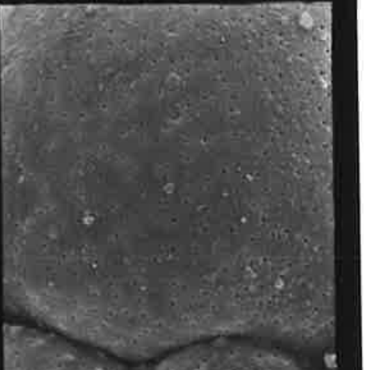
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PLATE 22

Figures 1-3 *Tenuitella iota iota* (Parker)

1. 214-1-1 10-18cm x210 721-260
2. 214-3-3 5-6cm x350 721-261
3. 214-1-1 10-18cm x350 721-262

Figures 4,5 *Tenuitella praestainforthi* (Blow)

4. 214-23-6 5-7cm x220 721-263
5. 214-23-6 5-7cm x220 721-264

Figures 6-11 *Cassigerinella chipolensis* (Cushman & Ponton)

6. Gellibrand Clay, Victoria, sample 10 x250 721-265
7. same specimen as 6 x250
8. same specimen as 6, surface wall texture of antepenultimate chamber x1000
9. 214-22-1 5-7cm x200 721-266
10. 214-22-1 5-7cm x270 721-267
11. 214-22-1 5-7cm x300 721-268

Figures 12-17 *Cassigerinella martinezpicoi* (Bermúdez & Seiglie)

12. 214-21-3 12-14cm x350 721-269
13. same specimen as 12 x350
14. 214-21-3 12-14cm x150 721-270
15. *Globorotalia fohsi barisanensis* Zone, Trinidad x250 721-271
16. same specimen as 15 x300
17. same specimen as 15, surface wall texture of penultimate chamber x1000

Plate 22


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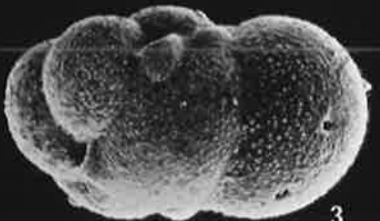
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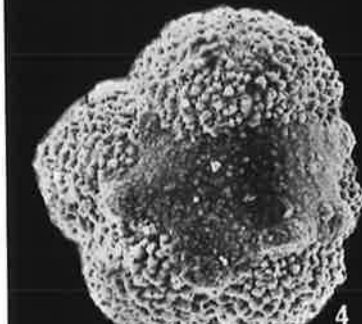
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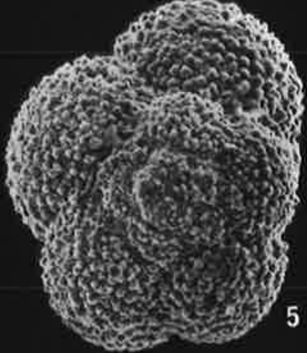
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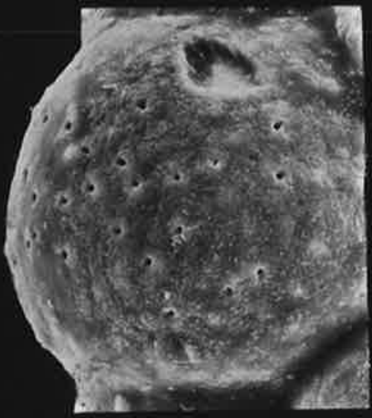
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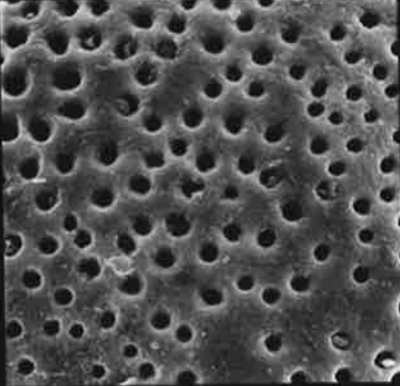
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PLATE 23

Figures 1,2 *Turborotalita clarkei* (Rögl & Bolli)

1. 214-1-1 10-18cm x500 721-272
2. 214-1-1 10-18cm, surface wall texture of ultimate chamber x1000 721-273

Figures 3,4 *Turborotalita cristata* (Heron-Allen & Earland)

3. 214-7-4 5-7cm x350 721-274
4. 214-4-5 5-7cm x390 721-275

Figures 5-7 *Turborotalita humilis* (Brady)

5. 214-1-1 10-18cm x300 721-276
6. 214-4-5 5-7cm x300 721-277
7. 214-1-1 10-18cm x300 721-278

Figures 8-11 *Turborotalita primitiva* Brönnimann & Resig

8. 214-16-3 5-7cm x500 721-279
9. 214-19-cc x500 721-280
10. 214-23-6 5-7cm x500 721-281
11. 214-26-3 Top x380 721-282

Figures 12-15 *Turborotalita pumilio* (Parker)

12. 214-1-1 10-18cm x240 721-283
13. same specimen as 12, surface wall texture of ultimate chamber x1000
14. 214-1-1 10-18cm x350 721-284
15. 214-1-1 10-18cm x250 721-285

Plate 23


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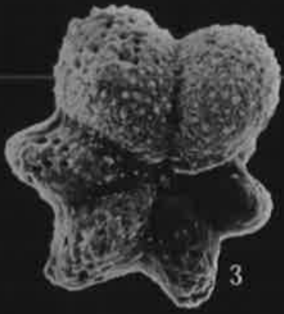
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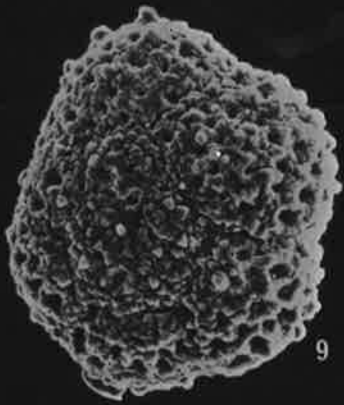
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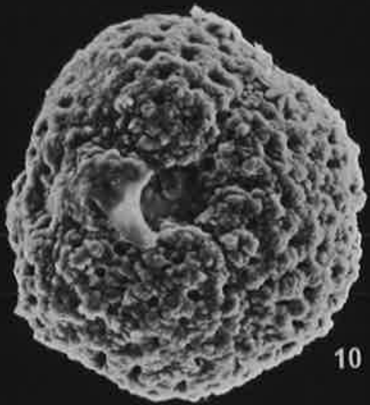
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PLATE 24

Figures 1-4	*Streptochilus globigerum* (Schwager)
	1. 214-16-2 5-7cm x300 721-286
	2. 214-10-1 5-7cm x280 721-287
	3. 214-8-5 Top x400 721-288
	4. same specimen as 3, surface wall texture of penultimate chamber x1000
Figures 5,6	*Streptochilus latum* Brönnimann & Resig
	5. 214-22-2 5-7cm x300 721-289
	6. 214-22-3 5-7cm x300 721-290
Figure 7	*Streptochilus pristinum* Brönnimann & Resig
	7. 214-20-cc x300 721-291
Figures 8-12	*Streptochilus tokelauae* (Boersma)
	8. 214-7-4 5-7cm x300 721-292
	9. 214-7-4 5-7cm x350 721-293
	10. 214-13-5 9-11cm x400 721-294
	11. 214-18-3 10-12cm x300 721-295
	12. 214-18-3 10-12cm x300 721-296
Figure 13	*Bulava indica* Boltovskoy
	13. 214-16-1 5-7cm x80 721-297
Figures 14-16	*Chiloguembelina cubensis* (Palmer)
	14. Brown's Creek, Victoria, sample V70/22 x300 721-298
	15. Brown's Creek, Victoria, sample V70/22 surface wall texture of penultimate chamber x1000 721-299
	16. same specimen as 15 x250

Plate 24


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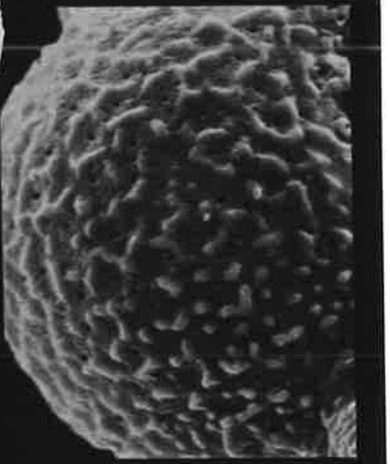
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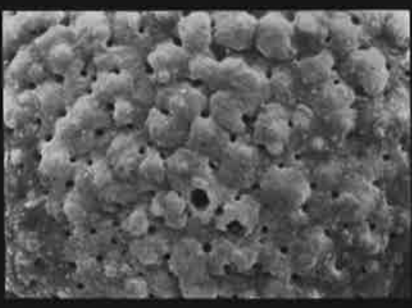
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PLATE 25

Figures 1-4 *Morozovella acutispira* (Bolli & Cita)

1. Boongerooda Greensand, Western Australia, sample WAB. B11 x90 721-300
2. Boongerooda Greensand, Western Australia, sample WAB. B11 x120 721-301
3. same sample as 1, surface wall texture of penultimate chamber x1000
4. Boongerooda Greensand, Western Australia, sample WAB. B11 x120 721-302

Figures 5-8 *Turborotalia cerroazulensis s.l.* (Cole)

5. W.A.P.E.T. Rough Range South No. 1, core 17 1170-1175 ft x150 721-303
6. W.A.P.E.T. Rough Range South No. 1, core 17 1170-1175 ft x110 721-304
7. same specimen as 5, surface wall texture of ultimate chamber x1000
8. same specimen as 6 x120

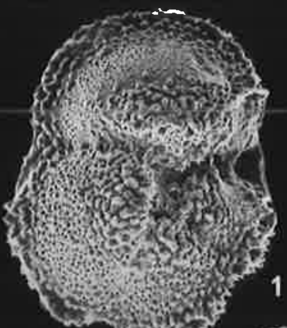
Figures 9-11 *Subbotina angiporoides* (Hornibrook)

9. Brown's Creek, Victoria, sample V70/20 x170 721-305
10. Brown's Creek, Victoria, sample V70/20 x210 721-306
11. same specimen as 9, surface wall texture of ultimate chamber x1000

Figures 12-14 *Globigerina ciperoensis* Bolli

12. *Globigerina ciperoensis ciperoensis* Zone, Trinidad x150 721-307
13. *Globigerina ciperoensis ciperoensis* Zone, Trinidad x170 721-308
14. same specimen as 12, surface wall texture of ultimate chamber x1000

Plate 25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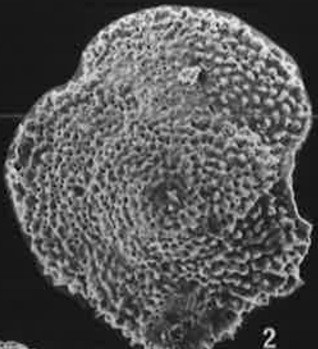
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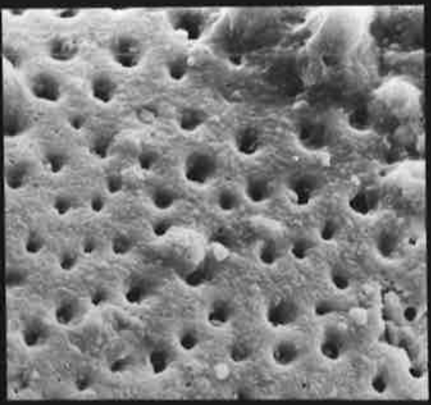
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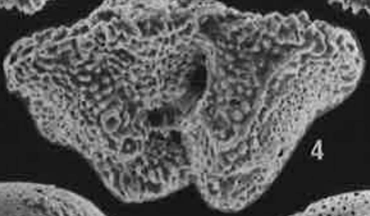
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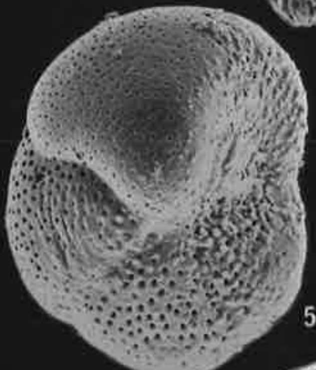
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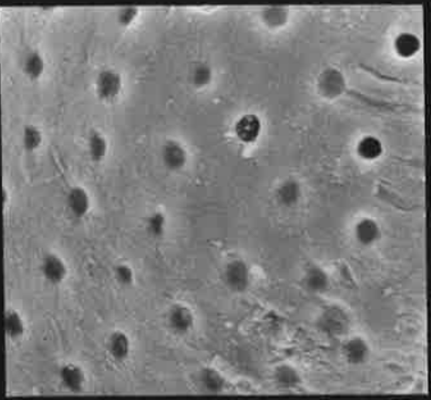
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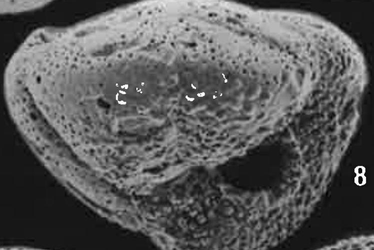
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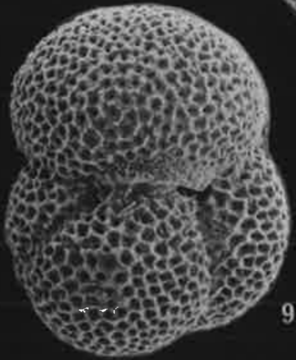
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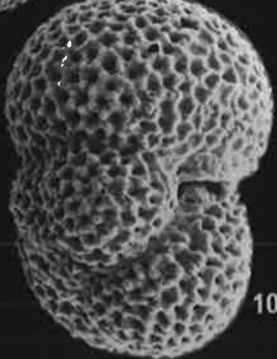
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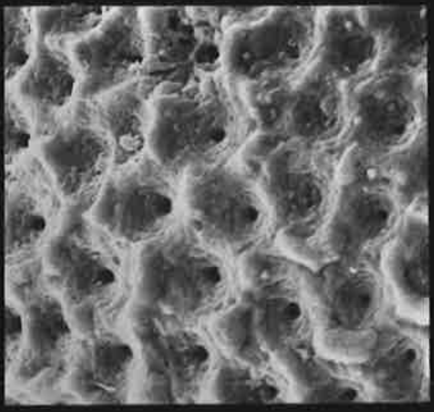
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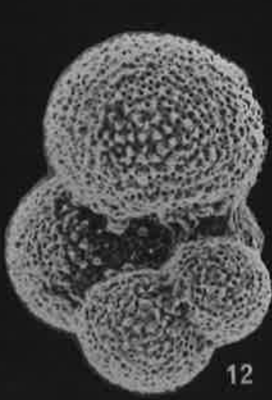
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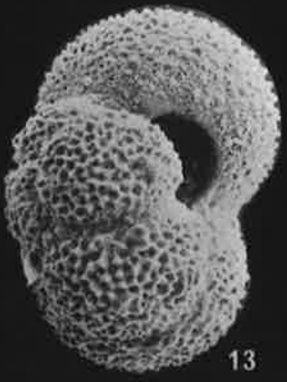
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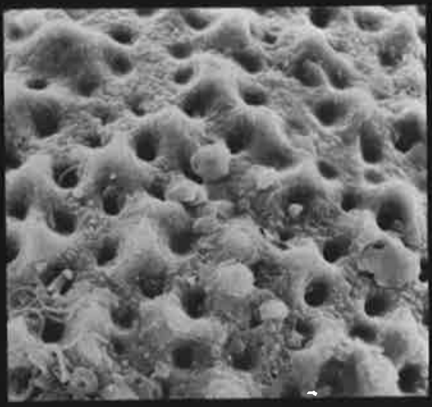
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PLATE 26

Figures 1-3 *Globigerina angulisuturalis* Bolli

1. *Globigerina ciperoensis ciperoensis* Zone, Trinidad x220 721-309
2. *Globigerina ciperoensis ciperoensis* Zone, Trinidad x230 721-310
3. same specimen as 1, surface wall texture of ultimate chamber x1000

Figures 4-6 *Planorotalites chapmani* (Parr)

4. Boongerooda Greensand, Western Australia, sample WAB. B11 x130 721-311
5. Boongerooda Greensand, Western Australia, sample WAB. B11 x170 721-312
6. same specimen as 4, surface wall texture of ultimate chamber x1000

Figures 7-9 *Hantkenina primitiva* Cushman & Jarvis

7. Brown's Creek, Victoria, sample V70/18 x180 721-313
8. same specimen x200
9. same specimen, surface wall texture of ultimate chamber x1000

Figures 10-12 *Pseudohastigerina micra* (Cole)

10. Brown's Creek, Victoria, sample V70/18 x250 721-314
11. Brown's Creek, Victoria, sample V70/18 x250 721-315
12. same specimen as 11, surface wall texture of penultimate chamber x1000

Figures 13,14 *Cassigerinella eocaenica* Cordey

13. South Australian Department of Minerals and Energy, Supreme Court PB No. 1, 90-95 ft x600 721-316
14. same specimen x600

Plate 26

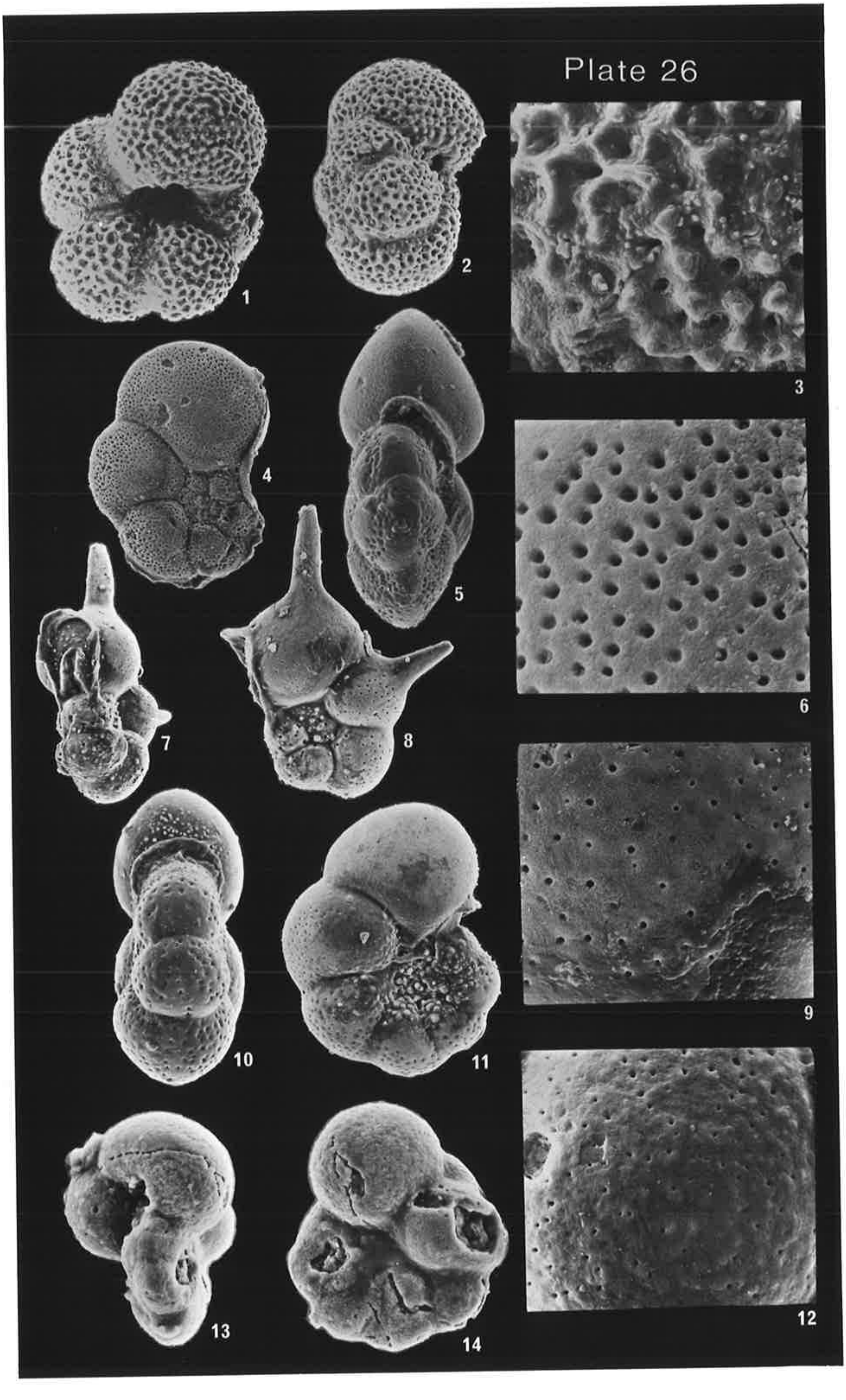


PLATE 27

Figures 1-3 *Tenuitella aculeata* (Jenkins)

1. Brown's Creek, Victoria, sample V70/15 x300 721-317
2. Brown's Creek, Victoria, sample V70/15 x300 721-318
3. same specimen as 1, surface wall texture of ultimate chamber x1000

Figures 4-6 *Tenuitella angustiumbilicata* (Bolli)

4. *Globigerina ciperoensis ciperoensis* Zone, Trinidad x250 721-319
5. same specimen x250
6. same specimen, surface wall texture of ultimate chamber x1000

Figures 7-10 *Tenuitella gemma* (Jenkins)

7. Brown's Creek, Victoria, sample V70/18 x300 721-320
8. Brown's Creek, Victoria, sample V70/11 x250 721-321
9. Brown's Creek, Victoria, sample V70/18 x300 721-322
10. same specimen as 8, surface wall texture of ultimate chamber x1000

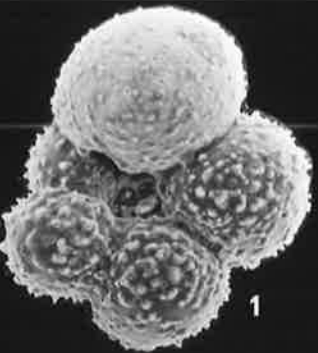
Figures 11-13 *Tenuitella insolita* (Jenkins)

11. Brown's Creek, Victoria, sample BC 1971/21 x350 721-323
12. Brown's Creek, Victoria, sample BC 1971/21 x350 721-324
13. Brown's Creek, Victoria, sample BC 1971/21 x300 721-325

Figures 14-16 *Tenuitella munda* (Jenkins)

14. Brown's Creek, Victoria, sample BC 1971/20 x250 721-326
15. Brown's Creek, Victoria, sample BC 1971/20 x250 721-327
16. Brown's Creek, Victoria, sample BC 1971/20 x250 721-328

Plate 27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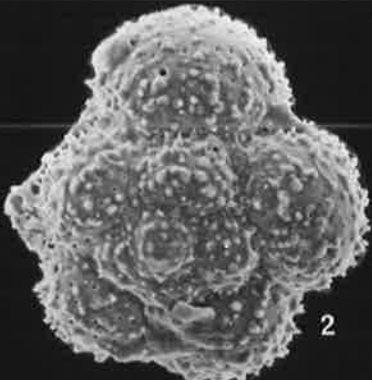
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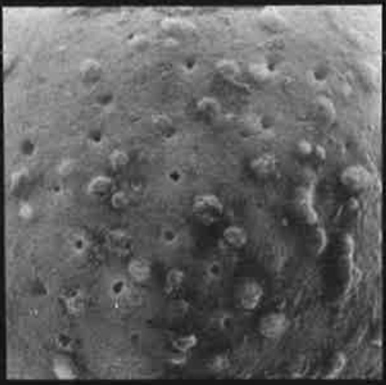
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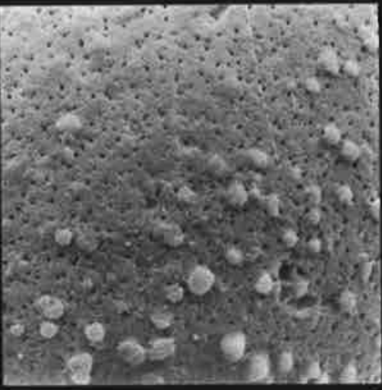
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