

Miocene climatic oscillation recorded in the Lakes Entrance oil shaft, southern Australia: reappraisal of the planktonic foraminiferal record

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ABSTRACT: The stratigraphic section at Lakes Entrance accumulated on a narrow platform in a neritic environment, close to the interaction of the East Australian Current and the West Wind Drift. The biostratigraphic succession of planktonic foraminiferal events first presented by D.G. Jenkins in 1960 has been slightly revised and correlated with the integrated Miocene geochronology. To extend biostratigraphy to ecostratigraphy, we have revised the systematics and nomenclature of the planktonic taxa and profiled the faunal succession in sixteen assemblages falling into three groups. 1, From the later middle Miocene to late Miocene occurred assemblages XI to XVI, typified by the collapse of *woodi/bulloides* ratio and resurgence of spinose species, as well as a comeback by the cancellate and globorotaliid forms. 2, Assemblages IX to X range from the latest early Miocene to early middle Miocene (upper N7 to N10 equivalents), with greatest amplitudes in fluctuation in species diversity and other metrics. 3, The early Miocene contained assemblages I to VIII, in which a rising *woodi/bulloides* ratio was accompanied by abundant microperforates but decline in spinose and cancellate species and in the planktonic/benthic ratio.

At the second order or 10^7 years' scale, the Exxon sealevel curve rises sporadically through the early Miocene and falls sporadically to its lowest level in the late Miocene, broadly congruent with the pelagic oxygen isotopes, which indicate an early Miocene rise and a major decline into the late middle Miocene. At the third order and 10^6 years' scale, there may be promise of synchrony between the Mi glacial cycles and the marginal sequences. It is noteworthy that, at Lakes Entrance, there are about ten putatively global sequence boundaries and ten Mi glaciations spanning the time in which fifteen neritic faunal assemblages were recognized. Spikes in the *woodi/bulloides* ratio fit between the Mi glaciations and fall in the vicinity of maximum flooding surfaces. However, they fit lows, not highs, in planktonic diversity and planktonic/benthic ratios, suggesting intensified estuarine-type runoff as the control in this neritic setting. The perturbation in all measures increased in the 1.5 m.y. spanning assemblages IX and X straddling the early/middle Miocene boundary. At this time of peak warming and transgression, of stratification of pelagic water and planktonic communities, and bunching of third-order sequences, the biosphere was at its most sensitive and volatile and most responsive to perturbations (which led the big drops in climate and sealevel).

INTRODUCTION

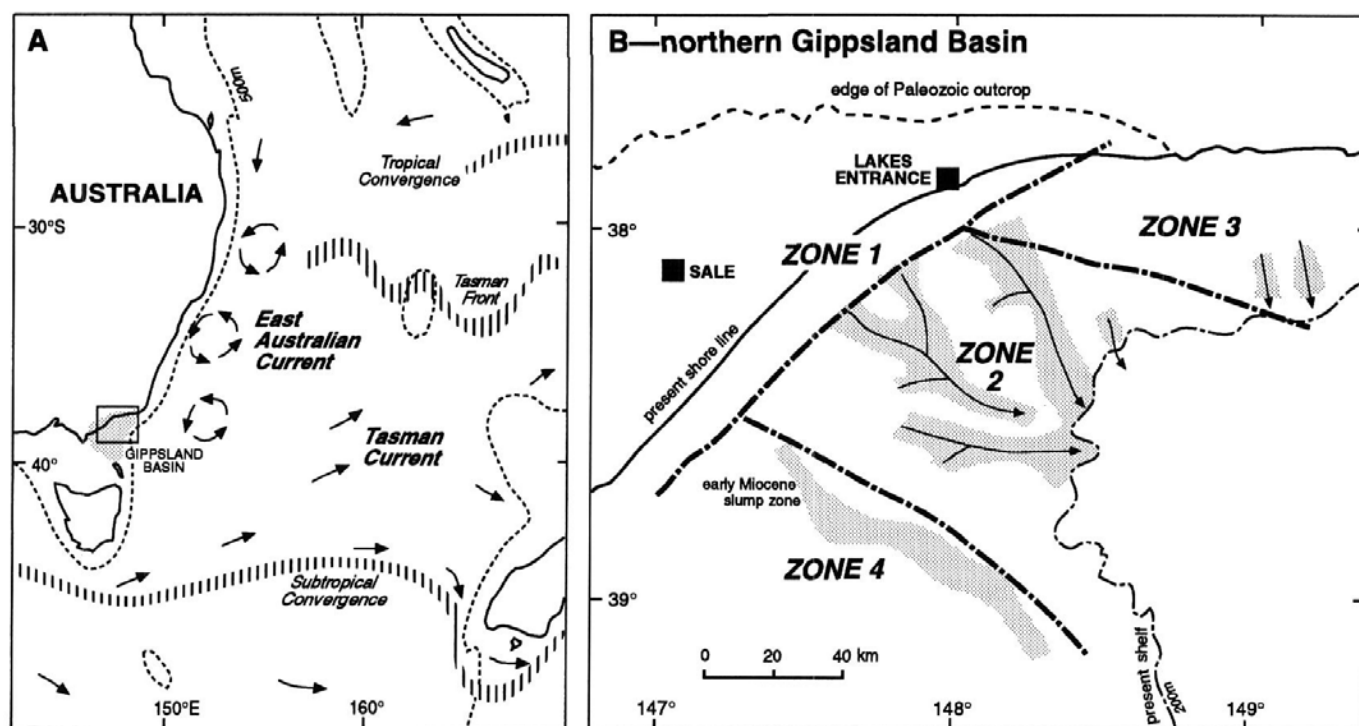
In a paper published in *Micropaleontology*, D.G. Jenkins (1960) described 11 planktonic foraminiferal biozones from the Lakes Entrance oil shaft in east Gippsland, Victoria (Crespin, 1947). His pioneer work laid a foundation for mid-Tertiary foraminiferal biostratigraphy in the extratropical southern hemisphere, for several of the zones established at Lake Entrance were confirmed with some modification in New Zealand (Jenkins 1966, 1971), confirmed (again with some modification) in South Australia (Ludbrook and Lindsay 1969), and still are in use today (Jenkins 1985, 1993; Hornibrook et al. 1989). In southern Australia, biostratigraphic correlations to this zonal scheme are discussed also in Wade (1964), McGowran et al. (1971), Abele et al. (1976), Heath and McGowran (1984), and Carter (1990).

Why do we return to this neritic section 35 years later, when the focus of microplanktonic biostratigraphy has shifted long since into the deep ocean? Our major motive is the central position of the neritic record in the geohistory and the biohistory of southern Australia and the key position of the Lakes Entrance section in that record. Within the four allostratigraphic "supersequences" comprising the Cenozoic stratigraphic record in Australia (McGowran 1979a), the late Oligocene to late Miocene is represented by "sequence three", a complete second-order cycle of transgression-regression in terms of sequence stratigraphy. A warming and subsequent cooling in global climate can be detected as an overall trend at 10^7 years' scale, and the same seems

to be true of global sealevel. At the next order down, we expect similar trends at 10^6 years' scale, as shown by the match between warming episodes and the extratropical migrations of neritic larger foraminifera (McGowran 1979a, 1986). The planktonic foraminiferal record in the Lakes Entrance section is expected to reveal changes at these scales.

The Gippsland Basin including the Lakes Entrance section faces the region of interaction between the Eastern Australian Current and the West Wind Drift (text-fig. 1). Planktonic foraminiferal communities would have advanced into and retreated from the neritic zone as the watermasses sloshed back and forth across the continental margin during times of climatic changes, and the local neritic record should reveal these changes. At the same time, however, immigrating faunas may have been filtered as they moved into less-than-optimal environments away from the open ocean (compare, e.g. Kennett 1985). Such matters characterize the ecostratigraphic dimension of biostratigraphy and they require detailed quantitative profiling of the entire faunal succession.

This paper summarizes our findings and extends the discussion beyond a preliminary report on planktonic foraminifera (McGowran and Li 1993). A consideration of several interesting implications is deferred to a companion paper on the benthic assemblages at the same Lakes Entrance section (Li and McGowran 1997).



TEXT-FIGURE 1

Locality map off eastern Australia showing present circulation (A) and the tectonic "zones" of the Gippsland Basin with Miocene channelling (B) (after Hocking et al. 1976 and Hegarty et al. 1986).

THE SECTION AND DATA BASE

The Lakes Entrance Oil Shaft was sunk in 1941-1945 about 1.6km northeast of Lakes Entrance. Crespin (1947) determined the upper part of the section as: Recent to Pleistocene (post-Kalimnan stage), 0-10ft, lower Pliocene (Kalimnan), 10-150ft, upper Miocene (Mitchellian), 150-208ft, middle Miocene (Bairnsdalian), 208-524ft. Thus the Miocene/Pliocene boundary was identified at about 150ft. Unfortunately, the top 200ft of the section was sampled at only two points. Jenkins' (1960) study spanned the sampled section from 212ft to 1204ft, upper Miocene to upper Oligocene, a total thickness of 992ft (ca.302m), and so does ours.

The section was deposited near the edge of the Lakes Entrance Platform in a shelf environment, and might have been influenced by Miocene channelling (text-fig. 1). The platform is a narrow tectonic unit between the highlands of Palaeozoic rocks that were uplifted in the Neogene and the Central Deep of the Gippsland Basin (Abele et al. 1976; Hegarty et al. 1986). The lower part of the sampled section consists of micaceous and glauconitic marls and silts assigned to the Metung Marl Member of the Lakes Entrance Formation. The overlying marls and limestones are part of a calcareous succession subject to somewhat complex lithostratigraphic nomenclature (Abele et al. 1976), but they can be assigned collectively to the Gippsland Limestone. In a broader context the strata record the major cycle of transgression-regression from late Oligocene to early Pliocene in the Gippsland Basin, and are classified as the Seaspray Group (Abele et al. 1976; Thompson 1986).

All 228 samples were washed, dried and examined and 128 of them, or more than every second sample, were selected for a

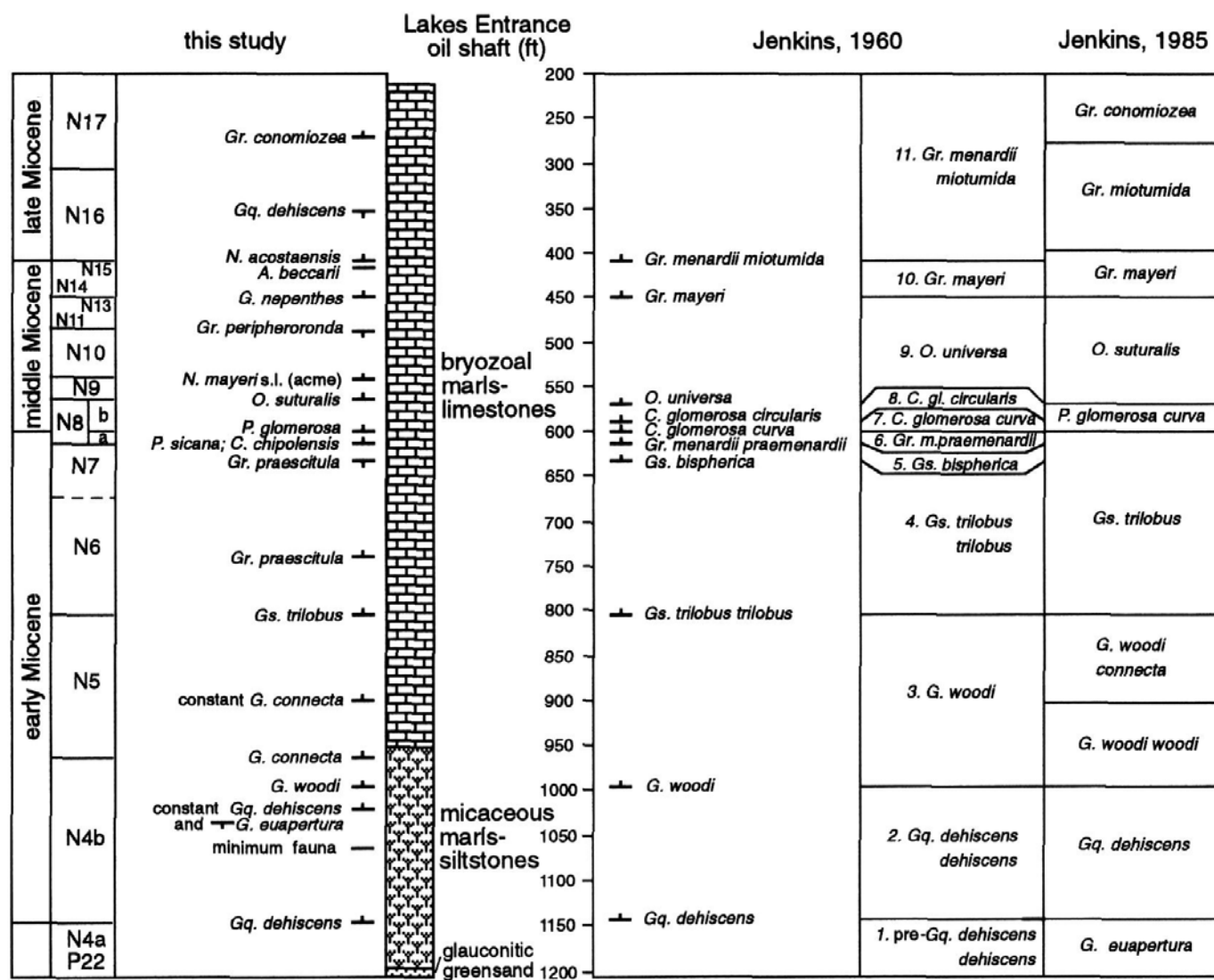
quantitative analysis of planktonic and benthic foraminifera. On average, over 500 specimens 63mm were picked and identified from each sample. As reported by Jenkins (1960), planktonic foraminifera are rich and diverse although the benthics usually dominate the assemblages. Planktonic profiles were based on about 15,000 individuals belonging to 65 species. A principal component factor analysis assembled several factors, but only the factor 1 for species groups seems relevant and is discussed here.

All planktonic foraminiferal species are listed in the Appendix and most of them are illustrated in Plates 1-3, including some topotypes of the species described by Jenkins (1960). Data files recording the detailed distribution of individual species can be obtained from the Micropaleontology Press or the authors.

BIOSTRATIGRAPHY AND JUSTIFICATION OF FAUNAL PROFILES

We confirm most of Jenkins' (1960) first and last appearance datums (text-fig. 2) which are correlated to Berggren's updated (in Berggren et al. 1995), integrated Miocene geochronology including the planktonic foraminiferal M- or N-zones (text-fig. 3). This does not mean that we recognized the N-zones; instead, we emphasize first appearance (FA) and last appearance (LA) datums, as advocated by Heath and McGowran (1984) and Lindsay (1985). Our correlations lack precision for two reasons: 1) there are few direct ties from this midlatitude site to the standard N-zones, and 2) we lack a geomagnetic record.

The first appearance of *Globoquadrina dehiscens* is used to mark the boundary between subzones N4a and N4b, and thus our Oligocene/Miocene boundary (see also Heath and



TEXT-FIGURE 2

Planktonic foraminiferal datums at Lakes Entrance (plus the euryhaline benthic *Ammonia beccarii*), correlation to the N-zones, and Jenkins' zonations (1960, Lakes Entrance section; 1985, southern mid-latitudes generally).

McGowran 1984). The boundary is so defined because we lack forms like *Globorotalia kugleri* whose FA datum is used by Berggren et al. (1995) for dating the boundary. As shown later (in text-fig. 8A), however, *Globoquadrina dehiscens* occurs only sporadically after its first appearance (at 1148ft) until becoming constant from 1024ft.

The central deep of the Gippsland Basin is the locus of some spectacular fossil canyons of Eocene and Miocene age (James and Evans 1971, Brown 1986) which were fed from the Lakes Entrance Platform. This raises the question of interruptions in the Lakes Entrance section near the edge of the platform. Jenkins (1960) implied that the biostratigraphic succession was continuous but Mallett (1978) shows a break from the *Orbulina* zone to the *Globorotalia conomiozea* zone. Since we find all of Mallett's datums from the interim, such as the FA of *Globorotalia mayeri* Cushman and Ellis, LA of *Globorotalia peripheroronda* Blow and Banner, FA of *Globigerina nepenthes*

Todd, and FA of *Globorotalia acostaensis* Blow, our conclusion as to the completeness of the succession agrees better with Jenkins' implied continuity. However, briefer hiatuses certainly remain undetected, except for a horizon with *Ammonia* near the middle/late Miocene boundary where there is very good evidence for an extensive hardground in the Gippsland Basin (Alan Partridge, pers. comm., 1994). The age/depth diagram for datum levels (text-fig. 4) shows lessening rates of accumulation up-section, which accords with the second-order trend of sealevel, but it does not contain sufficient points to pin down third-order breaks, as has been attempted recently by Zhang et al. (1993).

As well as a biostratigraphic succession of datums or events (text-fig. 4) and species ranges (text-fig. 5), planktonic foraminiferal evolution also leaves a faunal succession. Biostratigraphic zonations provide approximate ages based on calculating the FA and LA datums of marker species to geomagnetic events (e.g. Berggren et al. 1995), but they do not describe or

Ma	(sub)tropical				southern Australia		
	Berggren et al., 1995				Heath & McGowran, 1984	this study	
0	Pleistocene	late	PT1	b	N22	± <i>G. truncatulinoides</i>	± <i>G. truncatulinoides</i>
1				a			
2			PL6				
3			PL5				
4			PL4				
5	Pliocene	early	PL3		N20	± <i>G. margaritae</i>	
6			PL2				
7			PL1	b			
8				a			
9							
10	Miocene	late	M14		N18	± <i>G. tumida</i>	± <i>G. punctulata</i>
11							
12							
13							
14							
15		middle	M13		N17	± <i>G. lenguaensis</i>	± <i>G. plesiotumida</i>
16							
17							
18							
19							
20		early	M12		N16	± <i>Gs. extremus</i> ± <i>Gr. plesiotumida</i>	± <i>G. conomiozea</i>
21							
22							
23							
24							
25	Oligocene	late	M10		N15	± <i>N. acostaensis</i>	± <i>N. acostaensis</i>
26			M11				
27			M9				
28			M8				
29							
30		middle	M7		N14	± <i>N. mayeri</i> ± <i>G. nepenthes</i> ± <i>G. fohsi robusta</i> ± <i>G. fohsi lobata</i> ± <i>G. fohsi fohsi</i>	± <i>G. nepenthes</i>
31							
32							
33							
34							
35		early	M6		N13	± <i>G. peripheroacuta</i> ± <i>O. suturalis</i>	± <i>Gr. peripheroronda</i>
36							
37							
38							
39							
40		middle	M5		N12	± <i>N. acostaensis</i>	± <i>N. acostaensis</i>
41							
42							
43							
44							
45		early	M4		N11	± <i>G. nepenthes</i>	± <i>G. nepenthes</i>
46							
47							
48							
49							
50		middle	M3		N10	± <i>G. peripheroacuta</i> ± <i>O. suturalis</i>	± <i>G. peripheroacuta</i> ± <i>O. suturalis</i>
51							
52							
53							
54							
55		early	M2		N9	± <i>P. glomerosa</i> ± <i>P. sicana</i> ± <i>G. birnageae</i> ± <i>C. dissimilis</i>	± <i>P. glomerosa</i> ± <i>P. sicana</i> ± <i>C. chipolensis</i> ± <i>Gr. praescitula</i>
56							
57							
58							
59							
60		middle	M1		N8	± <i>G. mayeri</i> ± <i>O. suturalis</i>	± <i>N. mayeri</i> (acme) ± <i>O. suturalis</i>
61							
62							
63							
64							
65		early	M1		N7	± <i>G. sicanus</i>	± <i>G. sicanus</i>
66							
67							
68							
69							
70		middle	M1		N6	± <i>G. trilobus</i>	± <i>Gr. praescitula</i> ± <i>Gs. trilobus</i>
71							
72							
73							
74							
75		early	M1		N5	± <i>G. zealandica</i>	± constant <i>G. connecta</i> ± <i>G. connecta</i>
76							
77							
78							
79							
80		middle	M1		N4	± <i>G. kugleri</i> ± <i>G. woodi</i>	± <i>G. woodi</i> ± <i>G. euapertura</i> ± constant <i>Gq. dehiscens</i> ± <i>Gq. dehiscens</i>
81							
82							
83							
84							
85		early	M1		N3	± <i>G. dehiscens</i> ± <i>G. kugleri</i>	± <i>G. dehiscens</i> ± <i>G. kugleri</i>
86							
87							
88							
89							
90		middle	M1		N2	± <i>G. dehiscens</i> ± <i>G. kugleri</i>	± <i>G. dehiscens</i> ± <i>G. kugleri</i>
91							
92							
93							
94							
95		early	M1		N1	± <i>G. dehiscens</i> ± <i>G. kugleri</i>	± <i>G. dehiscens</i> ± <i>G. kugleri</i>
96							
97							
98							
99							

TEXT-FIGURE 3

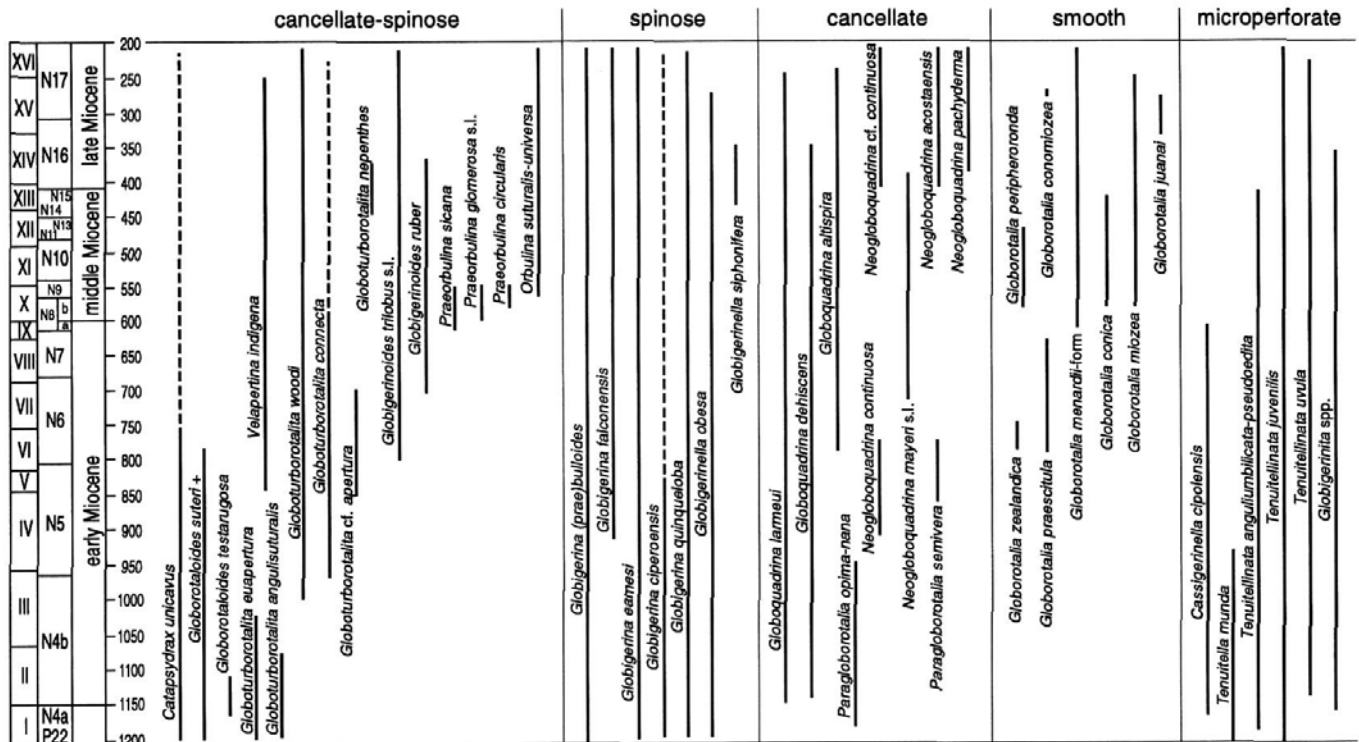
Correlation of planktonic foraminiferal datums in southern Australia with calibrated M- and N-zonations (Berggren et al. 1995). This study: Lakes Entrance section; Heath and McGowran 1984: composite for region.

characterize the fossil succession except in the most superficial or misleading way. We attempt that characterization here in order to extract neritic signals of an ocean undergoing major transformation during the Miocene (McGowran and Li 1994). The relative abundances of individual species or of species-groups and the proportional differences (or ratio) between two major groups with contrasting ecologies give us several of those signals. Relative abundances characterize successional assemblages and the most obvious ratio — cancellate-spinose versus spinose-noncancellate — help to separate them by identifying boundaries. The ratio between the two major groups was rarefied also by the ratio of [*Globobulimina woodi* (Jenkins)

plus *G. connecta* (Jenkins)] to [*Globigerina bulloides* d'Orbigny plus *G. falconensis* Blow], abbreviated to *woodi* ratio, below.

In addition to the relative abundances and the *woodi* ratio, we present several other measures (text-fig. 6):

1. The planktonic/benthic ratio (P/B), which varies commonly from very low in nearshore biofacies to very high in oceanic biofacies (unless obscured by dissolution).
2. The simple diversity that counts the number of species in each sample. Diversity tends to be low nearshore and at higher latitudes.



TEXT-FIGURE 4

Range chart of selected planktonic species, in five groups according to their wall texture characteristics. Dash line is the range of those small and atypical forms. Note that the early disappearance of *Globigerinella siphonifera* and *Globigerinoides ruber* (both warm indicators) coincides with the major change of climate and circulation in the late Miocene.

3. First and last appearances. This provides the frequency of species overturn and their net increase.

4. The plot of incoming and outgoing species sample by sample. In addition to a record of "ultimate" first and last appearances in this section, we plot multiple and repeated comings and goings to emphasize the importance of species' comings and goings, presumably in response to fluctuations in watermass. Classical range charts consist of solid lines drawn from the lowest to the highest recorded occurrences (hoping thereby to identify speciations and extinctions) whilst non-occurrences within the total range are reversible, hence are regarded as of less significance and tend to be ignored. But such records can be ecostatigraphically meaningful.

5. Principal component factor analysis of species groups. As well as the cancellate-spinose and spinose-noncancellate groups, three others were identified as the cancellate (e.g. *Globobulorotalia*), smooth-walled (*Globobulorotalia*) and microperforate (*tenuitellid*) groups. Representing almost 50% of total entities, Factor 1 reveals a relationship between the cancellate-spinose and the spinose plus microperforate groups (text-fig. 7).

THE FAUNAL SUCCESSION

Three generalizations arise from the inspection of these measures. The first and most apparent is that the abundances of species or species groups vary widely (text-figs. 7, 8). The fauna was initially dominated by spinose and microperforate groups and later by the cancellate-spinose forms during the late Oligo-

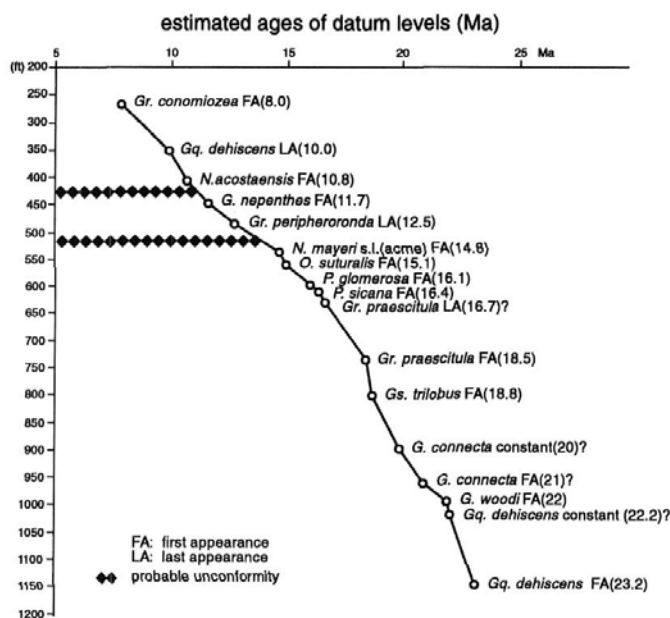
cene-early Miocene. The cancellate-spinose group subsequently diversified as the species of the *Globigerinoides*-*Praeorbulina*-*Orbulina* bioseries emerged. The smooth globobulorotaliids of the mid-early Miocene appeared at the same time, but those with a typical keel did not occur until the latest early Miocene. Towards the upper part of the section, in the later middle to late Miocene, there was a rebound to the spinose *Globigerina* even though others (except the microperforates) remained common.

The second generalization comes with the separation of the succession into sixteen assemblages (I-XVI), with boundaries mainly at the *woodi* spikes (Table 1 and text-fig. 8A). In total they span about 18 million years from the latest Oligocene to late Miocene, so that the assemblages are successional at the 106 years' scale.

The third generalization from this quantified profiling is that the succession of assemblages falls into three major groups. From bottom to top they are:

1. Assemblages I to VIII. Initially strong fluctuations in all species groups, then a rise in the cancellate-spinose and microperforate groups but a decline in spinose and cancellate species and in the P/B ratio, while diversity and incomings and outgoings were all relatively stable. Zones N4 to upper N7 equivalents; early Miocene.

2. Assemblages IX and X. Strongest fluctuations in all metrics, particularly the *woodi* and P/B ratios as well as the comings and



TEXT-FIGURE 5

Time-depth diagram for 17 datums at Lakes Entrance. Age estimates mainly follow Berggren et al. (1985, 1995), with some adjustments on the datum positions to zones and assemblages (Table 1). Note that the FA of *Gr. conomiozea* is now placed at about 6.9 Ma in Berggren et al. (1995).

goings of species. Introduction of *Praeorbulina-Orbulina* and keeled *Globorotalia* marks the sharpest increase in diversity, with diversity reaching its highest levels. The spinose *Globigerina bulloides* group drops to the lowest level. Zones upper N7 to N10 equivalents; latest early to early middle Miocene.

3. Assemblages XI to XVI. Collapse of the *woodi* ratio and decline in other metrics. A revival in the spinose group marked by abundant *Globigerina falconensis* (rather than *G. bulloides*) was coincident with *Neogloboquadrina* replacing *Globoquadrina-Paragloborotalia* in the cancellate group. Zones N11 to N17 equivalents; later middle to late Miocene.

DISCUSSION

Events at two geological scales: the 10^7 and 10^6 years' scales

"Sequence three" of the Cenozoic record in Australia represents an Oligo-Miocene "supercycle" of marine transgression-regression, with the zenith or maximum transgression coincident with migrations into the region by tropical-type neritic, benthic, larger foraminifera and the evolution of the planktonic *Orbulina* bioseries (McGowran 1979a, b; in Frakes et al. 1987; McGowran and Li 1994). Three correlations are relevant to our discussion. 1, The local "sequence three" approximates well the span of the second-order supercycles TB1 and TB2, from the pronounced low in sealevel at the early/middle Oligocene boundary to the next pronounced low in the late Miocene (Haq et al. 1987). 2, In text-figure 9 we present a global context for this local analysis of faunal succession. The Exxon curve is correlated to the geochronological scale independently of the correlation of two oceanic oxygen-isotopic curves from Wright et al. (1992). 3, The third correlation is of our local and regional data with the geochronological scale.

The putative curve of global sea level rises and falls in remarkable parallel with the oxygen-isotopic curves at the broader, second-order, 10^7 years' scale. The zeniths of both trajectories are in the approximately one-million-year interval (ca. 16-15Ma) straddling the early/middle Miocene boundary. At Lakes Entrance we see this second-order pattern quite clearly in the three groups of assemblages: first we have the assemblages I to VIII on the rising trends, then assemblages IX and X perching at the zenith, and finally assemblages XI to XVI on the falling trends.

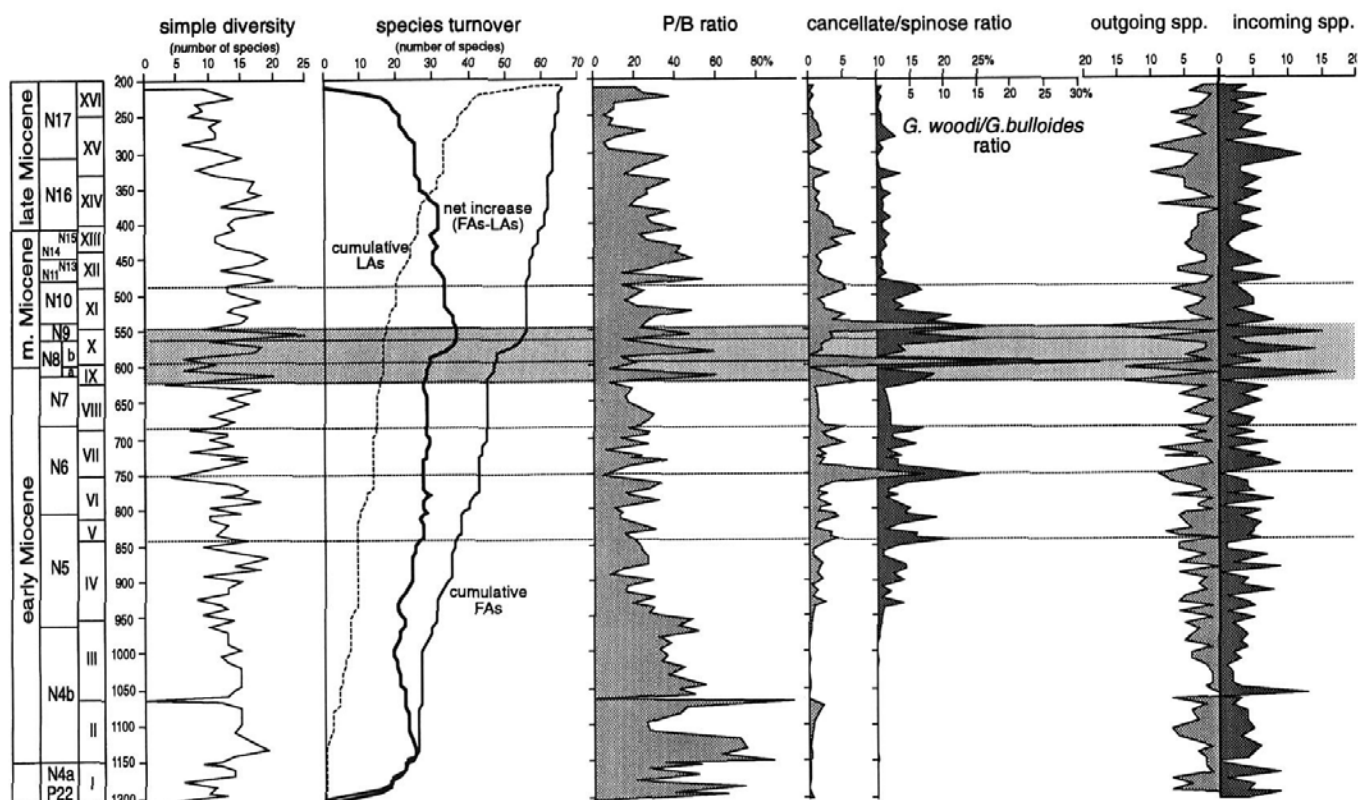
The oxygen-isotopic analysis by Wright et al. (1992) also extracted distinct fluctuations at the scale of 10^6 years—the so-called *Mi* glaciations. On the correlation chart some of the *Mi* glaciations match the Exxon third-order sequence boundaries and some do not. It is also noteworthy — being counterintuitive — that the $\delta^{18}O$ pulses continue up the second-order curve and down the other side rather than being huddled in the "cooler" parts of the second-order trajectory. Mismatch with the third-order sequences can be attributed to a lack of the necessary fine tuning. There are about 10 third-order sequences and 10 *Mi* glaciations — or about 20 sealevel and 20 climatic units if we consider each sequence to contain two parts — transgressive and highstand — and the same for the isotopes — a rise and a fall. Thus, the planktonic succession of sixteen assemblages is close enough in number to suggest some common control at the third-order scale of 10^6 years, even though this is but a suggestion awaiting a more precise correlation and analysis.

The Miocene climatic optimum

Planktonic foraminiferal diversity fluctuates and reaches its maximum at assemblages XI and X and so does the abundance of the cancellate-spinose group (text-figs. 6, 7). Diversity increase comes largely from speciations in the cancellate-spinose *Praeorbulina-Orbulina* plus the globorotaliid radiation (text-fig. 8A). In contrast, spinose and microporiferate species were at their lowest levels in both diversity and abundance. As the majority of cancellate-spinose species and smooth globorotaliids are typical warm-water specialists, they flourish at times of maximum warm when oligotrophic conditions prevail and circulation becomes sluggish and the upper water column is better stratified (Lipps and Mitchell 1976; Hart 1980; Hallock et al. 1992). This is at the same level that the larger benthic specialists including *Lepidocyclina*, *Cycloclpeus*, and *Flosculinella* are found in southern Australia — in the Batesfordian and Balcombian regional stages (McGowran 1979a,b, 1986; McGowran and Li 1994).

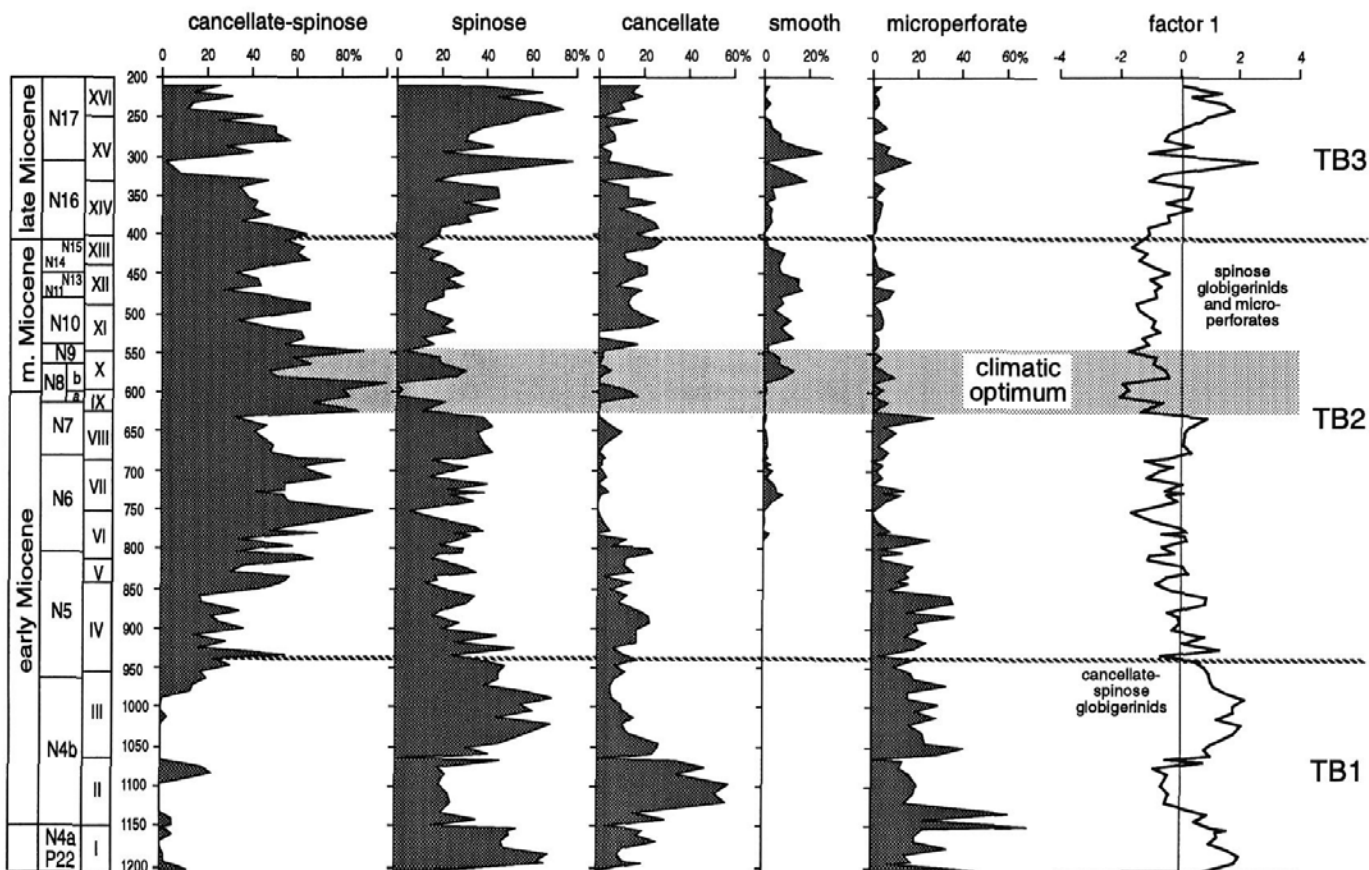
The biggest swings in these metrics match closely the biggest swings in both isotopic signals and the reconstructed sealevel (compare text-fig. 6 with text-fig. 9). They are packed into an interval of about 1.5 m.y. straddling the early/middle Miocene boundary which is the *Miocene climatic optimum* (McGowran and Li 1994). Since these patterns are from different and independent sources, the following suggestions are offered:

The biosphere is more responsive to third-order environmental perturbation during relatively "greenhouse" conditions than it is during relatively "icehouse" states. The warmer the environment, the more metastable or fragile the biosphere. The response of the local planktonic biota is quantitative not qualitative, reversible not irreversible. The greatest fluctuations in all planktonic metrics at intervals IX and X clearly indicate this. It is not the onset of the new global climatic and oceanic regime of the later middle Miocene — the major chilling and major regression



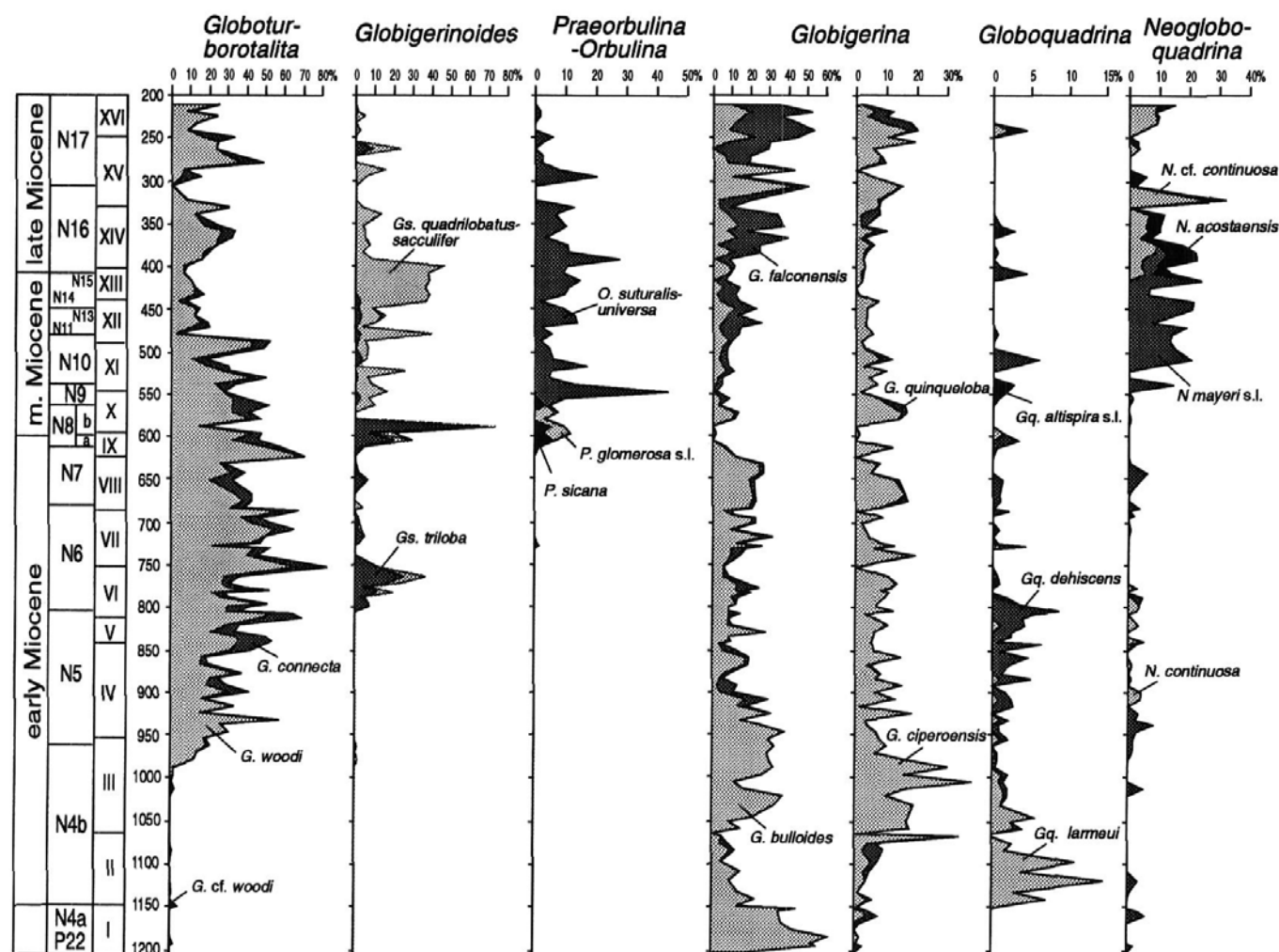
TEXT-FIGURE 6

Measures used to profile the planktonic foraminiferal succession at Lakes Entrance. The stippled interval spanning assemblages IX and X (Table 1) corresponds to the Miocene climatic optimum at the zeniths of the putatively global curves (see text-figure 9). The sixteen assemblages are separated mainly at peaks of the cancellate/spinose ratio and its major subset the *woodi/bulloides* ratio (dotted lines).



TEXT-FIGURE 7

Abundance profiles of the five major groups of planktonic foraminifera and factor 1.



TEXT-FIGURE 8A
Abundance profiles of selected planktonic species.

— that triggers these swings, for the volatile faunal fluctuations lead them, not lag them.

Why do the plankton reduce at warm pulses in neritic settings?

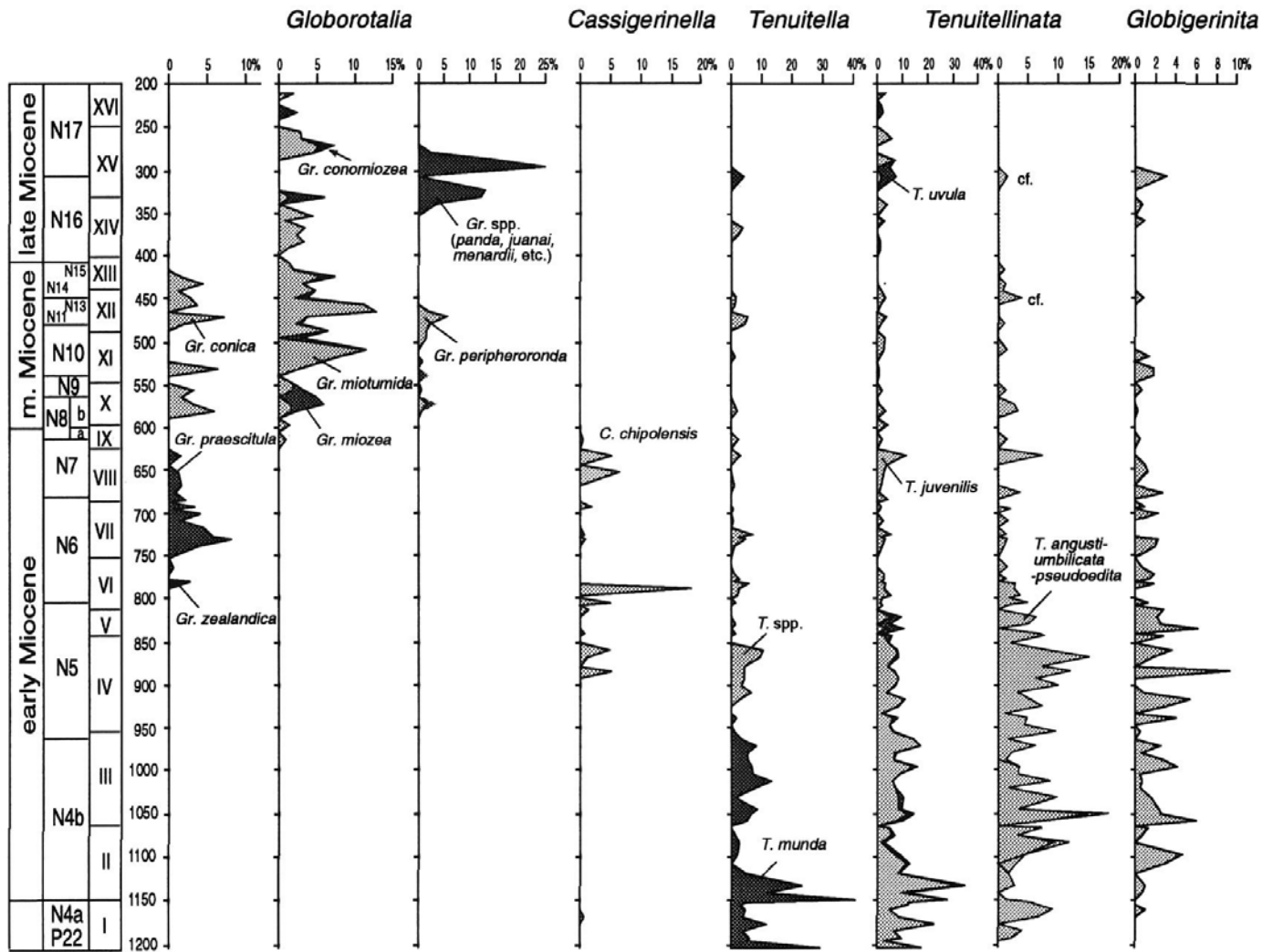
Chaproniere (1992) discussed the evolution and development of the cancellate-spinose group and concluded that forms like *Globoturborotalita woodi* gave rise to *Globigerinoides* at the advent of a warmer climate. It is likely that *G. woodi* had acquired a similar habitat preference to warm conditions (as *Globigerinoides* spp. did later) in the early period of the Miocene climatic warming and transgression, and flourished during warming pulses. The ratio between *G. woodi* and the cooler-water inhabitant *Globigerina bulloides* would therefore reflect climatic perturbations. The spikes of the *woodi* ratio represent warming pulses, the lows the reverse (text-fig. 6).

Our assemblage boundaries are mainly placed at spikes of the *woodi* ratio, hence at warmings. It is surprising then to see that these spikes fall between, not at, the high points in planktonic diversity and in the P/B ratio (text-fig. 6) (Note that this cannot be merely a poor correlation because it is a within-section relationship). Veevers (1984) found a parallel between rises in

sealevel and uplift in southeastern Australia as there formed a series of highlands around the Lakes Entrance region. The region in the Miocene was largely on the continental shelf, as indicated by benthic foraminifera (Li and McGowran, 1995). Palynological evidence indicates that southeastern Australia was extensively forested and mostly with rainforest prior to the middle Miocene (Martin, 1991). All this implies that the warmer times are wetter times, with a possible runoff that affected the biotic distribution. This runoff might have substantially enhanced stratification over the continental shelf and a slight lowering of surficial salinity could have reduced the planktonic abundance as well as the species number, although the overall highs in these metrics are still impressive at the period of Miocene climatic optimum (text-figs. 6, 7).

Upwelling signals

Intervals with a faunal association which cannot be simply interpreted as due to either warming or cooling are found in assemblages I, III, VIII and XV, at approximately ~24.5, 22, 17 and 8.5 m.y. respectively (compare the factor 1 in text-fig. 7 and text-fig. 9). They are characterized by abundant spinose and microporiferate planktonic herbivores and by high infaunal benthos typical of oxygen-deficient environments such as *Uvigerina*



TEXT-FIGURE 8B
Abundance profiles of selected planktonic species (continued).

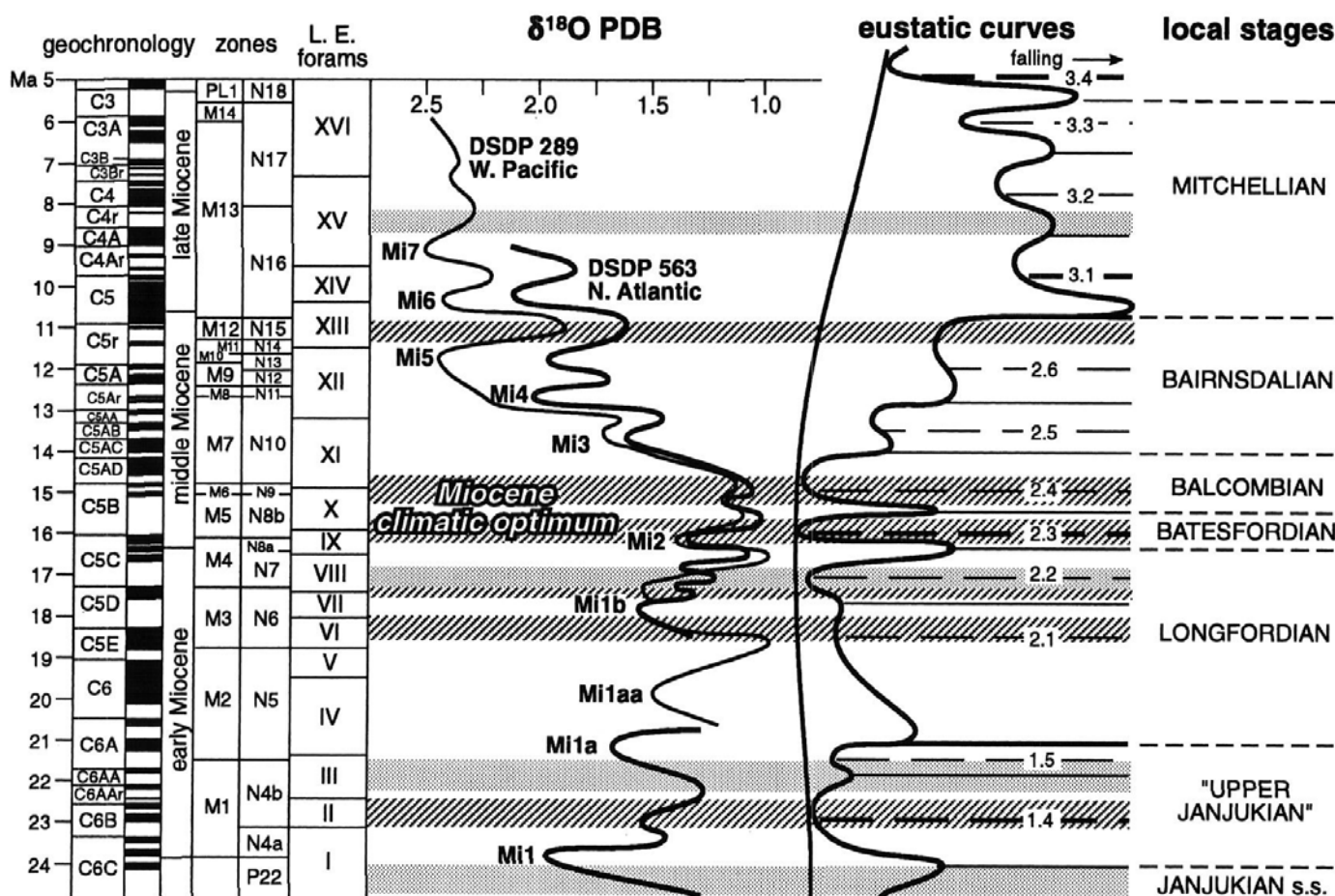
proboscidea Schwager and *Bolivina* spp. Because the benthic signals parallel the planktonic they together record four periods of upwelling-related, high productivity on that narrow shelf (see discussion in Li and McGowran 1994).

Local stages and sequences

The regional stages of the later Paleogene and Neogene in southern Australia were erected on various combinations of lithofacies and molluscan assemblages. By and large, local stages have not prospered as essential chronostratigraphic tools in this region. In the most comprehensive modern surveys of the classical Tertiary marine mollusc fossils, the local stages are used but they do not loom very large (Ludbrook 1973; Darragh 1985). As foraminifera came to dominate in correlation and age determination, the local stages were not used (e.g. Glaessner and Wade 1958; Wade 1964; Ludbrook 1971), or merely appended to the biostratigraphy (e.g. Carter 1964; Ludbrook and Lindsay 1969).

Singleton (1968) became sufficiently sanguine about progress in clarifying foraminiferal and macrofaunal biostratigraphy to

abandon the local stages altogether, but McGowran et al. (1971), attempting the first comprehensive correlation of the local stages to a modern "global" geochronology, believed that we still needed a local chronostratigraphic focus for the diverse biostratigraphic evidence obtained from continental to open marine environments. There will always be problems in applying an oceanic-planktonic biostratigraphy to neritic facies, for there will be problems in recognizing precise bio-events as chrono-events where diachronism or erratic preservation and recovery of index fossils are more likely. Instead, as suggested by Loutit et al. (1988), we should consider reorganizing stages as depositional sequences, for all strata above a sequence boundary are younger than all strata below it. A possible scheme is discussed in McGowran and Li (1994) and foreshadowed in Table 2 and text-figure 9. The concept of the local or regional stage would change for the better, and they would return to routine and widespread use as natural divisions of the stratigraphic record, should a comprehensive sequence-stratigraphic analysis cogently identify the boundaries. Meanwhile, we emphasize that the regional stage boundaries shown in text-figure 9 are suggestions, not conclusions.



TEXT-FIGURE 9

Integrated scenario for the Miocene. The two DSDP oceanic $\delta^{18}\text{O}$ curves were drawn from Wright et al. (1992) by filtering a cloud of points. The long- and short-term eustatic curves are from Haq et al. (1987); solid lines, sequence boundaries, broken lines, maximum flooding surfaces with third-order sequence notation. Note that those curves and the planktonic foraminiferal assemblages I-XVI from Lakes Entrance in Gippsland ("L.E. forams"; Table 1) are correlated independently with the time scale, not with each other. Fine tuning will improve the match between *Mi* glaciations and sequence boundaries (solid lines), and in due course will justify placing regional stage boundaries at sequence boundaries (discussion in McGowran and Li 1994). The four warm intervals recognized on the occurrence of larger foraminifera are striped with the twin peaked Miocene climatic optimum comprising the Batesfordian and Balcombian components (McGowran and Li 1994). The four stippled horizons are upwelling events based on benthic and planktonic evidence (Li and McGowran 1994).

CONCLUSIONS

1. The Lakes Entrance oil shaft provides a good planktonic foraminiferal biostratigraphy and neritic record of Miocene climatic oscillations in the southern hemisphere.
2. The quantified changes in the planktonic assemblages through the section parallel the trends in sealevel and isotope-climatic curves at both the 10^7 (second-order) and 10^6 (third-order) years' scales. The faunal succession is divided into sixteen assemblages which are ecostratigraphic units. In contrast to biozones defined on bounding events, assemblages provide a better resolution in transgressive than in regressive phase.
3. The strongest swings in simple diversity, P/B ratio, *woodi* ratio and the repeated comings and goings of species occur at the Miocene climatic optimum, which is also the zenith of transgression, straddling the early/middle Miocene boundary.
4. Local stages could in due course be defined in relation to third-order sequences to resurrect their usefulness in stratigraphical correlation.

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TABLE 1

The sixteen planktonic foraminiferal assemblages recognized at the Lakes Entrances oil shaft.

assemblage	depth base (ft)	age estimate (m.y.)	correlation	attributes
XVI	248'	late Miocene ~6-7.3	upper N17	rise of <i>N. continuosa</i> ; rise of <i>G. falconensis</i> ; decline of <i>Globorotalia</i>
<i>Globigerina falconensis</i> spike				
XV	324'	late Miocene 7.3-9.5	mid N17 to high N16	<i>Globorotalia</i> spp. increase and replace <i>Gr. miotumida</i> group; rise of microperforates
<i>woodi-connecta/bulloides-falconensis</i> spike				
XIV	400'	late Miocene 9.5-10.4	within N16	decline in <i>N. mayeri</i> and <i>Globigerinoides</i> ; rise of <i>N. acostaensis</i> and <i>G. falconensis</i>
<i>Gs. quadrilobatus-sacculifer</i> spike				
XIII	432'	m. Miocene 10.4-11.5	lowest N16 to N14	acme of <i>Gs. quadrilobatus-sacculifer</i>
<i>Gs. quadrilobatus-sacculifer</i> spike				
XII	488'	m. Miocene 11.5-14	N14 to N11	rise of <i>Orbulina</i> , decline in <i>G. woodi</i> ; <i>N. mayeri</i> remains high
<i>woodi-connecta/bulloides-falconensis</i> spike				
XI	548'	m. Miocene 14-14.9	N10 to high N9	last larger benthics (<i>Operculina</i>); rise of <i>N. mayeri</i> ; rise <i>Gr. miotumida</i>
conclusion of strongest fluctuations in diversity and incomings/outgoings				
<i>woodi-connecta/bulloides-falconensis</i> spike				
X	596'	m. Miocene 14.9-16	high N9 to low N8b	acme of <i>Orbulina</i> (near top); rise <i>Gr. miozea-Gr. conica</i> ; <i>Globigerinoides</i> spike (near base)
<i>woodi-connecta/bulloides-falconensis</i> strongest spike				
IX	624'	e. Miocene 16-16.5	lowest N8b to high N7	rise of <i>Globigerinoides</i> and <i>Praeorbulina</i> ; virtual absence of <i>Globorotalia</i> ; microperforates rare
onset of strongest fluctuations in diversity, P/B ratio and incomings/outgoings				
VIII	676'	e. Miocene 16.5-17.4	high N7 to base N7	decline of <i>Gr. praescitula</i> ; last <i>C. chipolensis</i> (top); high <i>G. bulloides</i>
<i>woodi-connecta/bulloides-falconensis</i> spike; larger benthics spike				
VII	752'	e. Miocene 17.4-18	upper N6	rise of <i>Gr. praescitula</i> ; decline of microperforates
<i>woodi-connecta/bulloides-falconensis</i> spike				
VI	808'	e. Miocene 18-18.8	mid N6 to high N5	acme of <i>Cassigerinella chipolensis</i> ; constant <i>Globigerinoides</i>
<i>woodi-connecta/bulloides-falconensis</i> spike				
V	844'	e. Miocene 18.8-19.5	upper N5	maximum <i>G. dehiscens</i> ; decline of <i>Tenuitella</i>
<i>woodi-connecta/bulloides-falconensis</i> spike				
IV	956'	e. Miocene 19.5-21.4	within N5	rise of <i>G. woodi-connecta</i> plexus; <i>Gq. dehiscens</i> replaces <i>Gq. larmeyi</i> ; acme of microperforates
onset of rise in cancellate-spinose species but fall in P/B ratio				
III	1064'	e. Miocene 21.4-22.5	low N5 to upper N4B	peaks in <i>G. bulloides</i> ; <i>G. ciperoensis</i> ; <i>Tenuitellinata</i> peak
cancellate/spinose minor spike				
II	1148'	e. Miocene 22.5-23.2	lower N4B	<i>Globoquadrina larmeyi</i> ; low in <i>Globigerina</i> ; microperforates common
<i>Tenuitella munda</i> spike; onset of the first decline in spinose species				
I	1204'	late Oligoc. 23.2-24	N4A to P22	high <i>Globigerina bulloides</i> ; high microperforates

TABLE 2

Local Miocene stages, with their major molluscan and foraminiferal components, are redefinable as representing third-order sequences.

local stages	mollusca	Darragh 1985	foraminifera	this study	correlated third-order sequence
6. Mitchellian	<i>Polinices subvarians</i> , <i>Austrotriton garrardi</i> , <i>Alocospira orycta</i> , <i>Bedevea approximans</i>	XIV	<i>Globorotalia conomiozea</i> , <i>Gr. panda</i> , <i>Neogloboquadrina</i> spp., <i>Globigerina falconensis</i> , <i>Elphidium chapmani</i> , <i>Valvulineria kalimnensis</i>	XVI XV XIV XIII- (part)	3.3, 3.2, 3.1
5. Bainsdalian	<i>Umbilia tatei</i> , <i>Athleta antiscalaris</i> , <i>Neotrigonia acuticostata</i> , <i>Serratifusus stellatus</i> , <i>Bathytoma decomposita</i>	XIII XII	<i>Neogloboquadrina mayeri</i> , <i>Globigerinoides sacculifer</i> , <i>Orbulina universa</i> , <i>Globorotalia conica</i> , <i>Dorothyia minima</i> , <i>Cibicides mediocris</i>	XIII- (part) XII XI-(part)	2.6, 2.5
4. Balcombian	<i>Zoila patypyga</i> , <i>Sigaretotrema subinfundibulum</i> , <i>Austrotriton woodsi</i> , <i>Amoria costellifera</i>	XI	<i>Orbulina universa</i> , <i>Neogloboquadrina mayeri</i> , <i>Globorotalia miozea</i> , <i>Gr. miotumida</i> , <i>Cycloclypeus</i> , <i>Lepidocyclina</i>	XI X-(part)	2.4
3. Batesfordian	<i>Gigantocypraea gigas</i> , <i>Palliocypraea gastrophax</i> , <i>Biplex maccoyi</i> , <i>Umbilia eximia</i>	X	<i>Praeorbulina glomerata</i> , <i>Globoturborotalita woodi</i> , <i>Globigerinoides trilobus</i> , <i>Lepidocyclina</i> , <i>Operculina</i>	X-(part) IX	2.3
2. Longfordian	<i>Serratifusus scabrosus</i> , <i>Subpterynotus wallacei</i> , <i>Notadusta victoriana</i> , <i>Baryspira tatei</i> , <i>Zemira australis</i>	IX VIII	<i>Globorotalia praescitula</i> , <i>Globigerinoides trilobus</i> , <i>Globoturborotalita woodi</i> , <i>Amphistegina</i> , <i>Heterolepa brevoralis</i>	VIII VII VI V IV	2.2, 2.1
1. Janjukian	<i>Austrocypraea contusa</i> , <i>Antephalium sufflatus</i> , <i>Rhynchocypraea leptorhyncha</i> , <i>Conus pullulescens</i>	VII	<i>Globigerina bulloides</i> , <i>G. cipoensis</i> , <i>Tenuitella</i> spp., <i>Almaena gippslandica</i> , <i>Uvigerina proboscidea</i> , <i>Anomalinoidea fasciatus</i>	III II I	1.5, 1.4

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APPENDIX 1

Species reference list

1, cancellate, non-spinose species

Catapsydrax unicavus Bolli, Loeblich and Tappan 1957, U.S. Natl. Mus. Bull., no. 215, p. 37, pl. 7, figs. 9a-c. (Pl. 1, fig. 19)

Catapsydrax parvulus Bolli, Loeblich and Tappan 1957, U.S. Natl. Mus. Bull., no. 215, p. 36, pl. 7, figs. 10a-c. (Pl. 1, fig. 18)

Globorotaloides testarugosus (Jenkins) = *Globorotalia testarugosa* Jenkins 1960, *Micropaleontology*, v. 6, p. 368, pl. 5, figs. 8a-c. (Pl. 1, figs. 20-22; topotypes)

Globorotaloides suteri Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 117, pl. 27, figs. 9a-13b. (Pl. 1, fig. 23)

Globorotaloides variabilis Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 117, pl. 27, figs. 15a-20c. (Pl. 1, figs. 24, 25)

Globoquadrina venezuelana (Hedberg) = *Globigerina venezuelata* Hedberg 1937, *Journ. Paleont.*, v. 11, p. 681, pl. 92, fig. 726.

Globoquadrina dehiscens (Chapman, Parr and Collins) = *Globorotalia dehiscens* Chapman, Parr and Collins 1934,

PLATE 1 (scale bar = 100mm)

1,2 *Globoturborotalita labiacrassata* (Jenkins): 1, Sample 1192, 2, Sample 1140, apertural views.

3 *Globoturborotalita euapertura* (Jenkins): Sample 1196, apertural view.

4 *Globoturborotalita opima* (Bolli): Sample 1168, apertural view.

5 *Globoturborotalita* sp.A: Sample 1140, apertural view.

6 *Globoturborotalita angulisuturalis* (Bolli): Sample 1184, juvenile specimen, apertural view.

7 *Globoturborotalita woodi* (Jenkins): Sample 972, apertural view.

8 *Globoturborotalita connecta* (Jenkins): Sample 844, apertural view.

9 *Globigerinoides trilobus* (Reuss): Sample 788, primarily apertural view.

10 *Globigerinoides quadrilobatus* (d'Orbigny): Sample 776, primarily apertural view.

11 *Globigerinoides sacculifer* (Brady) s.l.: Sample 964, secondarily apertural view.

12 *Praeorbulina sicana* (De Stefani): Sample 612, primarily apertural view.

13 *Praeorbulina glomerata* (Blow) s.l.: Sample 596, side view.

14 *Orbulina suturalis* Brönnimann: Sample 516, side view.

15 *Orbulina univera* d'Orbigny: Sample 480, side view.

16 *Globoturborotalita* cf. *apertura* (Cushman): Sample 840, apertural view.

17 *Globoturborotalita nepenthes* (Todd): Sample 444, apertural view.

18 *Catapsydrax parvulus* Bolli, Loeblich and Tappan: Sample 828, apertural view.

19 *Catapsydrax unicavus* Bolli, Loeblich and Tappan: Sample 1192, apertural view.

20-22 *Globorotaloides testarugosus* (Jenkins): Sample 1192, three specimens, 5, 6, apertural views, 7, peripheral view.

23 *Globorotaloides suteri* Bolli: Sample 1036, apertural view.

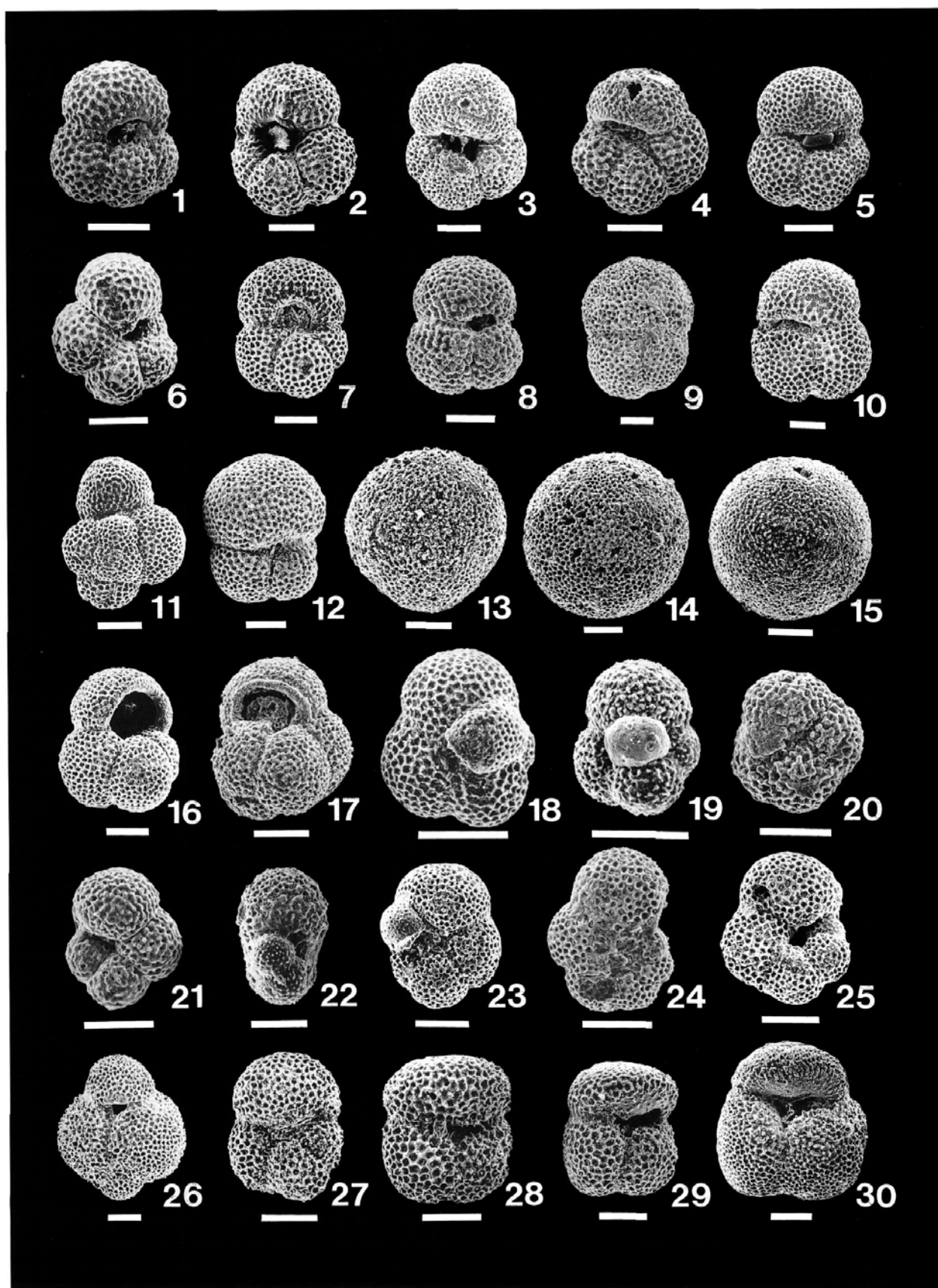
24,25 *Globorotaloides variabilis* Bolli: 24, Sample 804, spiral view, 25, Sample 1120, apertural view.

26 *Velapertina indigena* (Luczkowska): Sample 844 apertural view.

27 *Globoturborotalita larmeyi* (Akers - sensu Jenkins, 1960): Sample 972, twisted apertural view.

28,29 *Globoquadrina dehiscens* (Chapman, Parr and Collins): 28, Sample 1148, apertural views of the earliest specimen found, 29, Sample 714, apertural view.

30 *Globoquadrina altispira* (Cushman and Jarvis): Sample 788, apertural view.



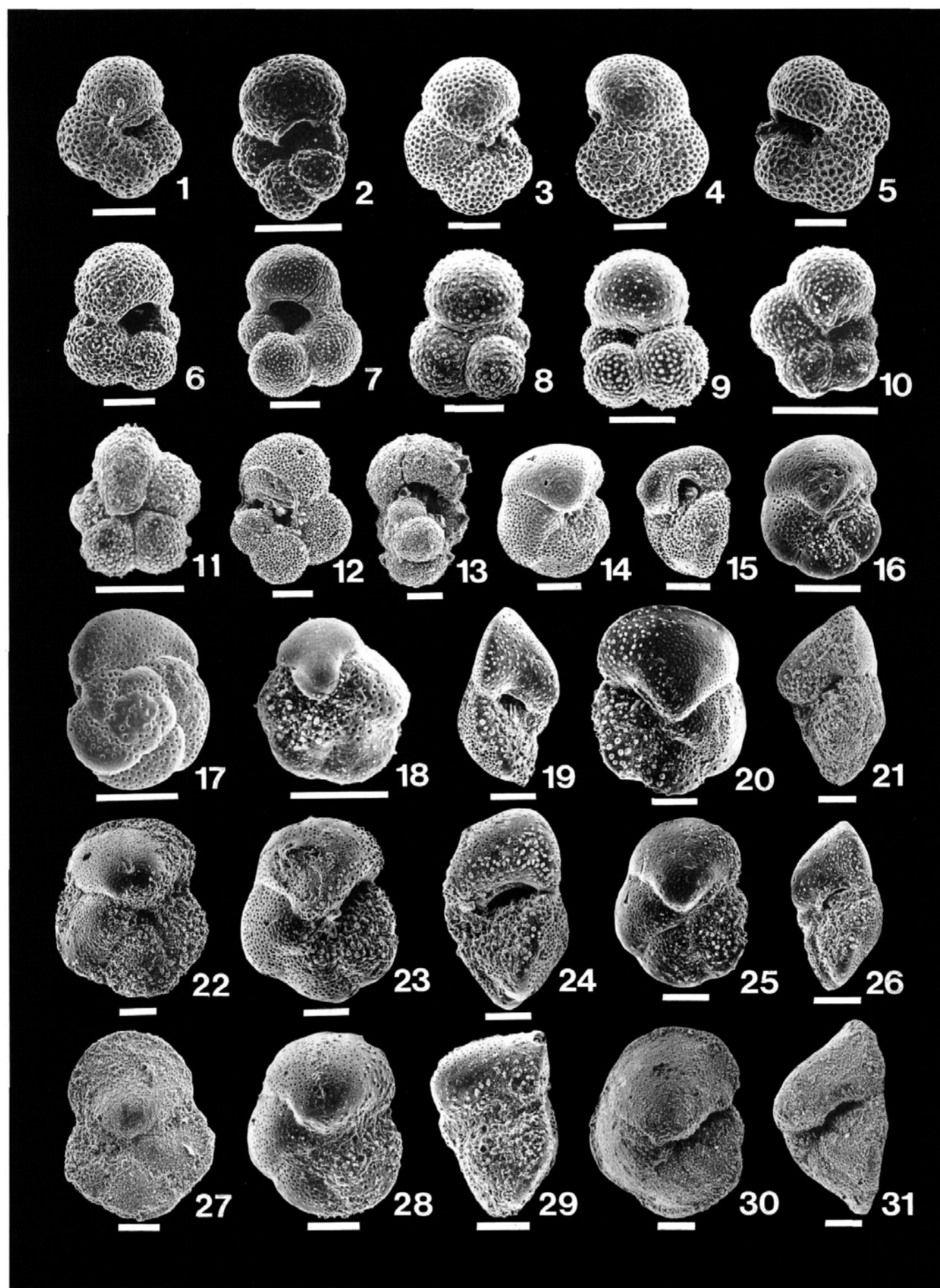
- Linn. Soc. London, Jour. Zool., v. 38, p. 569, pl. 11, figs. 36a-c. (Pl. 1, figs. 28, 29)
- Globoquadrina altispira* (Cushman and Jarvis) = *Globigerina altispira* Cushman and Jarvis 1936, Contr. Cushman Lab. Foram. Res., v. 12, p. 5, pl. 1, figs. 13a-c. (Pl. 1, fig. 30)
- Globoquadrina larmeyi* Akers 1955, J. Paleont., v. 29, p. 661, pl. 65, figs. 4a-c. (sensu Jenkins 1960) (Pl. 1, fig. 27)
- Paragloborotalia nana* (Bolli) = *Globorotalia nana* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 118, pl. 28, figs. 3a-c. (Pl. 2, fig. 1) Note that, though Cifelli (1982) discussed the presence of spines on *P. opima*, other members of that genus often show a non-spined to very weakly spined wall.
- Paragloborotalia incognita* (Walters) = *Globorotalia zealandica incognita* Walters 1965, N.Z. Jour. Geol. Geophys., v. 8, p. 120, figs. 6a-j. (Pl. 3, figs. 1, 2)
- Paragloborotalia semivera* (Hornibrook) = *Globigerina semivera* Hornibrook 1961, N.Z. Geol. Surv. Paleont. Bull., v. 34, p. 149, pl. 23, figs. 455-457. (Pl. 2, fig. 5)
- Paragloborotalia siakensis* (Cushman and Ellisor) = *Globorotalia siakensis* Cushman and Ellisor 1939, Natuurk. Tijdschr. Nederl.-Indie, v. 99, p. 262, pl. 4, figs. 20-22. This species is included in *P. mayeri* (see Pl. 2, figs. 2-4).
- Neogloboquadrina mayeri* (Cushman and Ellisor) = *Globorotalia mayeri* Cushman and Ellisor 1939, Contr. Cushman Lab. Foram. Res., v. 15, p. 11, pl. 2, figs. 4a-c. (Pl. 2, figs. 2-4)
- Neogloboquadrina continuosa* (Blow) = *Globorotalia opima* Bolli subsp. *continuosa* Blow 1959, Bull. Amer. Paleont., v. 39, p. 218, pl. 19, figs. 125a-c. (Pl. 3, figs. 3-5)
- Neogloboquadrina acostaensis* (Blow) = *Globorotalia acostaensis* Blow 1959, Bull. Amer. Paleont., v. 39, p. 208, pl. 17, figs. 106a-c. (Pl. 3, fig. 6)
- Neogloboquadrina pachyderma* (Ehrenberg) = *Aristospira pachyderma* Ehrenberg 1861 (fide Banner and Blow 1960, Contr. Cushman Found. Foram. Res., v. 11, p. 4, pl. 3, figs. 4a-c). (Pl. 3, fig. 7)

2, cancellate-spinose species

- Globoturborotalita labiacrassata* (Jenkins) = *Globigerina labiacrassata* Jenkins 1966, N.Z. Jour. Geol. Geophys., v. 8, p. 1102, fig. 8, nos. 64-71. (Pl. 1, figs. 1, 2)
- Globoturborotalita euapertura* (Jenkins) = *Globigerina euapertura* Jenkins 1960, Micropaleontology, v. 6, p. 351, pl. 1, figs. 8a-c. (Pl. 1, fig. 3; topotype)
- Globoturborotalita angulisuturalis* (Bolli) = *Globigerina angulisuturalis* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 109, pl. 22, figs. 11a-c. (Pl. 1, fig. 6)
- Globoturborotalita woodi* (Jenkins) = *Globigerina woodi* Jenkins 1960, Micropaleontology, v. 6, p. 352, pl. 2, figs. 2a-c. (Pl. 1, fig. 7; topotype)
- Globoturborotalita connecta* (Jenkins) = *Globigerina woodi connecta* Jenkins 1964, Micropaleontology, v. 10, p. 72, text-figs. 1a-c. (Pl. 1, fig. 8; topotype)

PLATE 2 (Scale bar = 100µm)

- 1 *Paragloborotalia nana* (Bolli): Sample 1184, apertural view.
- 24 *Neogloboquadrina mayeri* (Cushman and Ellisor) s.l.: 2, Sample 1152, twisted apertural view, 3, 4, Sample 940, umbilical and spiral views of a single specimen.
- 5 *Paragloborotalia semivera* (Hornibrook): Sample 860, apertural view.
- 6 *Globigerina praebulloides* Blow: Sample 1196, apertural view.
- 7 *Globigerina bulloides* d'Orbigny: Sample 820, apertural view.
- 8 *Globigerina eamesi* Blow: Sample 1192, apertural view.
- 9 *Globigerina falconensis* Blow: Sample 688, apertural view.
- 10 *Globigerina ciperoensis* Bolli: Sample 828, apertural views of an atypical specimen.
- 11 *Globigerina quinqueloba* Natland: Sample 720, apertural view.
- 12 *Globigerinella obesa* (Bolli): Sample 684, apertural view.
- 13 *Globigerinella siphonifera* (d'Orbigny): Sample 444, peripheral view.
- 14, 15 *Globorotalia (Globoconella) zealandica* Hornibrook: Sample 784, umbilical and peripheral views.
- 16, 17 *Globorotalia (Globoconella) praescitula* Blow: Sample 732, umbilical and spiral views.
- 18 *Globorotalia (Globoconella) miozea* Finlay: Sample 564, umbilical view.
- 19, 20 *Globorotalia (Globoconella) panda* Jenkins: Sample 580, peripheral and umbilical views.
- 21, 22 *Globorotalia (Globoconella) miotumida* Jenkins: Sample 516, peripheral and umbilical views.
- 23, 24 *Globorotalia (Globoconella) conica* Jenkins: Sample 556, umbilical and peripheral views.
- 25, 26 *Globorotalia praemenardii* Cushman and Stainforth: Sample 580, umbilical and peripheral views.
- 27 *Globorotalia menardii* (d'Orbigny): Sample 276, umbilical view.
- 28, 29 *Globorotalia (Globoconella) conica* Jenkins: Sample 428, umbilical and peripheral views.
- 30, 31 *Globorotalia (Globoconella) conomiozea* Kennett: Sample 272, umbilical and peripheral views.



- Globoturborotalita* cf. *apertura* (Cushman) = cf. *Globigerina apertura* Cushman 1918, U.S. Geol. Surv. Bull., v. 676, p. 57, pl. 12, figs. 8a-c. (Pl. 1, fig. 16)
- Globoturborotalita nepenthes* (Todd) = *Globigerina nepenthes* Todd 1957, U.S. Geol. Surv. Prof. Paper, no. 280-H, p. 301, figs. 7a-c. (Pl. 1, fig. 17)
- Globigerinoides trilobus* (Reuss) = *Globigerina triloba* Reuss 1850 K. Akad. Wiss. Wien, Bd. 1, p. 376, pl. 447, figs. 11a-c. (Pl. 1, fig. 9)
- Globigerinoides quadrilobatus* (d'Orbigny) = *Globigerina quadrilobatus* d'Orbigny 1886 (fide Kennett and Srinivasan 1983, p. 66, pl. 14, figs. 1-3). (Pl. 1, fig. 10)
- Globigerinoides ruber* (d'Orbigny) = *Globigerina rubra* d'Orbigny 1839 (fide Kennett and Srinivasan 1983, p. 78, pl. 17, figs. 1-3).
- Globigerinoides sacculifer* (Brady) = *Globigerina sacculifer* Brady 1877, Geol. Mag., n.s., decade 2, v. 4, p. 535; 1884, Rep. voy. Challenger, Zool., vol. p. 604, pl. 80, figs. 11-17, pl. 81, fig. 2, pl. 82, fig. 4. (Pl. 1, fig. 11)
- Praeorbulina sicana* (De Stefani) = *Globigerinoides sicanus* De Stefani 1950, Plinia, Italy, v. 3, p. 9, fig. 6. (Pl. 1, fig. 12)
- Praeorbulina glomerata* (Blow) s.l. = *Globigerinoides glomerata* (subsp. *curva* - *glomerata* - *circularis*) Blow 1956, Micropaleontology, v. 2, pp. 64, 65, text-fig. 1, nos. 9-19, text-fig. 2, nos. 1-4. (Pl. 1, fig. 13)
- Orbulina suturalis* Brönnimann 1951, Contr. Cushman Lab. Foram. Res., v. 2, p. 135, text-figs. IV, nos. 15, 16, 20). (Pl. 1, fig. 14)
- Orbulina universa* d'Orbigny 1839 (fide Kennett and Srinivasan 1983, p. 86, pl. 20, figs. 4-6). (Pl. 1, fig. 15)
- Sphaeroidinellopsis disjuncta* (Finlay) = *Sphaeroidinella disjuncta* Finlay 1940, Trans. Proc. Roy. Soc. N.Z., v. 69, p. 467, pl. 67, figs. 224-228.
- Velapertina indigena* (Luczkowska) (fide Liska, 1984, Rev. Esp. Micropaleont., v. 16, p. 305, pl. 4, fig. 1). (Pl. 1, fig. 26)

3, spinose species

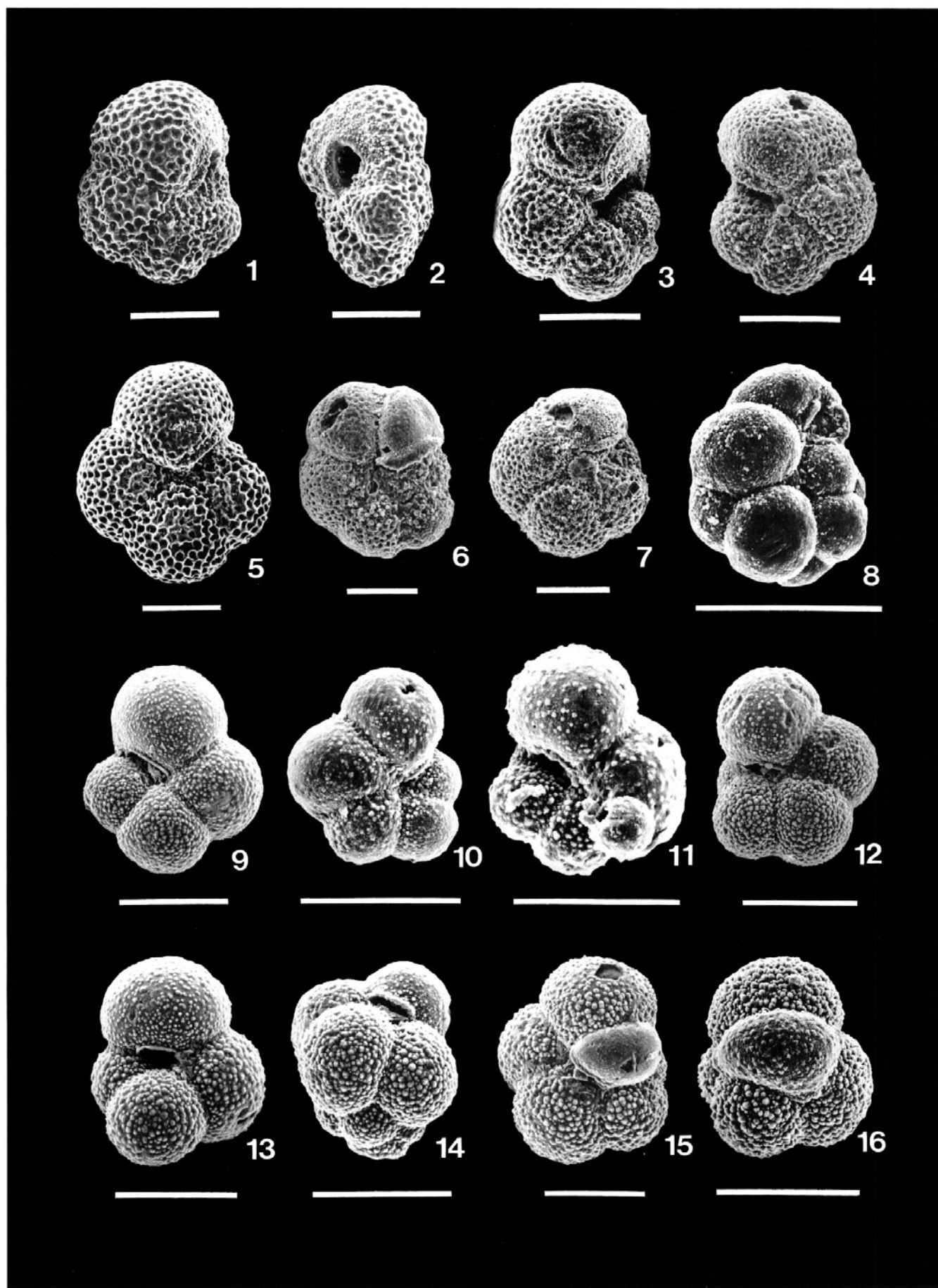
- Globigerina praebulloides* Blow 1959, Bull. Amer. Paleont., v. 39, p. 180, pl. 8, figs. 47a-c, pl. 9, fig. 48. (Pl. 2, fig. 6)
- This species is included in *G. bulloides* for counting.
- Globigerina bulloides* d'Orbigny 1826 (fide Banner and Blow 1960, Contr. Cushman Found. Foram. Res., v. 11, p. 3, pl. 1, figs. 1-4). (Pl. 2, fig. 7)
- Globigerina eamesi* Blow 1959, Bull. Amer. Paleont., v. 39, p. 176, pl. 9, figs. 39a-c. (Pl. 2, fig. 8)
- Globigerina falconensis* Blow 1959, Bull. Amer. Paleont., v. 39, p. 177, pl. 9, figs. 40a-c, 41. (Pl. 2, fig. 9)
- Globigerina ciperoensis* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 109, pl. 22, figs. 10a-c. (Pl. 2, fig. 10) For this, we also included forms usually smaller than typical *G. ciperoensis* with a peripheral-umbilical aperture.
- Globigerina quinqueloba* Natland 1938, Univ. Inst. Oceanogr. Bull. Tech., California, ser. 4, p. 149, pl. 6, figs. 7a-c. (Pl. 2, fig. 11)
- Globigerinella obesa* (Bolli) = *Globorotalia obesa* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 119, pl. 29, figs. 2a-3. (Pl. 2, fig. 12)
- Globigerinella siphonifera* (d'Orbigny) = *Globigerina siphonifera* d'Orbigny 1839 (fide Banner and Blow 1960, Contr. Cushman Found. Foram. Res., v. 11, p. 22, pl. 1, figs. 2a-c). (Pl. 2, fig. 13)

4, smooth-walled species

- Globorotalia* (*Globoconella*) *zealandica* Hornibrook = *Globorotalia zealandica* Hornibrook 1958, N.Z. Jour. Geol. Geophys., v. 1, p. 667, figs. 18, 19, 30. (Pl. 2, figs. 14, 15)
- Globorotalia* (*Globoconella*) *praescitula* Blow = *Globorotalia praescitula* Blow 1959, Bull. Amer. Paleont., v. 39, p. 221, pl. 19, figs. 128a-c. (Pl. 2, figs. 16, 17)
- Globorotalia* (*Globoconella*) *panda* Jenkins = *Globorotalia menardii* (d'Orbigny) *panda* Jenkins 1960, Micropaleontology, v. 6, p. 364, pl. 4, figs. 10a-c. (Pl. 2, figs. 19, 20)
- Globorotalia* (*Globoconella*) *miotumida* Jenkins = *Globorotalia menardii* (d'Orbigny) *miotumida* Jenkins 1960, Mi-

PLATE 3 (Scale bar = 100µm)

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| 1,2 <i>Paragloborotalia incognita</i> (Walters): Sample 808, umbilical and peripheral views. | 11 <i>Tenuitella clemenciae</i> (Bermúdez): Sample 932, umbilical view. |
| 3-5 <i>Neogloboquadrina continuosa</i> (Blow): 3, 4, Sample 324, umbilical views, 5, Sample 992, umbilical view. | 12 <i>Tenuitellinata angustiumbilitata</i> (Bolli): Sample 1184, umbilical view. |
| 6 <i>Neogloboquadrina acostaensis</i> (Blow): Sample 424, umbilical view. | 13 <i>Tenuitellinata juvenilis</i> (Bolli): Sample 1192, umbilical view. |
| 7 <i>Neogloboquadrina pachyderma</i> (Ehrenberg): Sample 392, umbilical view. Atypical specimen. | 14 <i>Tenuitellinata uvula</i> (Ehrenberg): Sample 868, side view. |
| 8 <i>Cassigerinella chipolensis</i> (Cushman and Ponton): Sample 788, side view. | 15 <i>Globigerinita praestainforthi</i> Blow: Sample 1036, umbilical view. |
| 9 <i>Tenuitella munda</i> (Jenkins): Sample 1192, umbilical view. | 16 <i>Globigerinita glutinata</i> (Egger) s.l.: Sample 732, umbilical view. |
| 10 <i>Tenuitella minutissima</i> (Bolli): Sample 732, umbilical view. | |



- cropaleontology, v. 6, p. 362, pl. 4, figs. 9a-c. (Pl. 2, figs. 21, 22; topotype)
- Globorotalia (Globoconella) conica* Jenkins = *Globorotalia conica* Jenkins 1960, Micropaleontology, v. 6, p. 358, pl. 4, figs. 3a-c. (Pl. 2, figs. 23, 24, 28, 29; topotypes)
- Globorotalia (Globoconella) conomiozea* Kennett = *Globorotalia conomiozea* Kennett 1966, Micropaleontology, v. 12, p. 235, text-figs. 10a-c. (Pl. 2, figs. 30, 31)
- Globorotalia (Globoconella) miozea* Finlay = *Globorotalia miozea* Finlay 1939, Trans. Royal Soc. N. Z., v. 69, p. 326, pl. 29, figs. 159-161. (Pl. 2, fig. 18)
- Globorotalia (Hirsutella) juanai* Bermúdez and Bolli = *Globorotalia juanai* Bermúdez and Bolli 1969, Bol. Geología, Venezuela, v. 10, p. 171, pl. 14, figs. 1-6.
- Globorotalia (Fohsella) peripheroronda* Blow and Banner = *Globorotalia (Turborotalia) peripheroronda* Blow and Banner 1966, Micropaleontology, v. 12, p. 294, pl. 1, figs. 1a-c.
- Globorotalia praemenardii* Cushman and Stainforth 1945, Contr. Cushman Lab. Foram. Res., Special Publ., v. 14, p. 70, pl. 13, figs. 14a-c. (Pl. 2, figs. 25, 26)
- Globorotalia menardii* (Parker, Jones and Brady) = *Rotalia menardii* Parker, Jones and Brady 1865 (fide Banner and Blow 1960, Contr. Cushman Found. Foram. Res., v. 11, p. 31, pl. 6, figs. 2a-c). (Pl. 2, fig. 27)
- 5, microporolate species**
- Cassigerinella chipolensis* (Cushman and Ponton) = *Cassidulina chipolensis* Cushman and Ponton 1932, Florida Geol. Surv. Bull., v. 9, p. 98, pl. 15, figs. 2a-c. (Pl. 3, fig. 8) Perforations on *C. chipolensis* differ from that on tenuitellids in having a coarser size, 1-1.5 mm, and a low pore density.
- Tenuitella munda* (Jenkins) = *Globorotalia munda* Jenkins 1966, N.Z. Jour. Geol. Geophys., v. 8, p. 1121, fig. 14, nos. 126-133, pl. 13, figs. 152-156. (Pl. 3, fig. 9)
- Tenuitella minutissima* (Bolli) = *Globorotalia minutissima* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 119, pl. 29, figs. 1a-c. (Pl. 3, fig. 10)
- Tenuitella clemenciae* (Bermúdez) = *Turborotalia clemenciae* Bermúdez 1961 Boletín de Geología, Venezuela, Special Publ., v. 3, p. 1321, pl. 17, figs. 10a, b (fide Li 1987, Jour. Foram. Res., v. 17, p. 309, pl. 2, fig. 9). (Pl. 3, fig. 11)
- Tenuitella jamesi* Li, Radford and Banner 1992, Proc. ODP, Sci. Results, v. 120, p. 581, pl. 4, figs. 8-11.
- Tenuitellinata angustiumbilocata* (Bolli) = *Globigerina ciperoensis angustiumbilocata* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 109, pl. 22, figs. 11a-c. (Pl. 3, fig. 12)
- Tenuitellinata pseudoedita* (Subbotina) = *Globigerina pseudoedita* Subbotina 1960 (fide Li 1987, Jour. Foraminiferal Res., v. 17, p. 312, pl. 3, figs. 1-5, pl. 4, figs. 11-13, pl. 5, figs. 1, 4, 7, 11).
- Tenuitellinata juvenilis* (Bolli) = *Globigerina juvenilis* Bolli 1957, U.S. Natl. Mus. Bull., no. 215, p. 110, pl. 24, figs. 5a-c. (Pl. 3, fig. 13)
- Tenuitellinata uvula* (Ehrenberg) = *Polodexia uvula* Ehrenberg 1861 (fide Kennett and Srinivasan 1983, p. 224, pl. 56, figs. 6-8, as *Globigerinita uvula*). (Pl. 3, fig. 14)
- Globigerinita praestainforthi* Blow 1969, Proc. 1st Internat. Conf. Plankt. Microfossils Geneva, v. 1, p. 383, pl. 25, figs. 3-5. (Pl. 3, fig. 15)
- Globigerinita glutinata* (Egger) s.l. = *Globigerina glutinata* Egger 1893 (fide Kennett and Srinivasan, 1983, p. 224, pl. 56, figs. 1, 3-5). (Pl. 3, fig. 16)
- Globigerinita boweni* Brönnimann and Resig 1971, Init. Repts. DSDP, v. 7, p. 1271, pl. 26, figs. 1-4.
- Globigerinita naparimaensis* Brönnimann 1951, Contr. Cushman Found. Foram. Res., v. 2, p. 16, text-figs. 1, 2.