

MARINE NEOGENE SAMPLES FROM AROUND TASMANIA: AN EXTENSION TO THE MIOCENE/PLIOCENE MARINE RECORD IN TASMANIA

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(with two tables, three text-figures and two plates)

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New Miocene and Quaternary foraminiferid faunas have been recovered from previously unrecorded localities onshore near Penguin and Strahan, and at nine offshore localities off northwestern, northeastern and southeastern Tasmania. Most Miocene benthic forms found in these samples are well known from other Tasmanian Tertiary sections but a few previously unreported taxa are recorded in Tasmania for the first time. Two samples from off northeastern Tasmania are Miocene. The sample from southeastern Tasmania is Early Miocene with Quaternary overlying it. Pebbles from Ocean Beach, north of Strahan, contain earliest Middle Miocene faunas. Other samples from off northeastern and northwestern Tasmania contain Quaternary faunas which probably reflect both periods of lower sea level and cool water and also periods of higher sea level and warmer water.

These samples extend the range of Miocene calcareous sediments much farther south on both west and east coasts of Tasmania. They also reinforce the pattern of Tasmanian Neogene sedimentation cycles (earliest Early Miocene, latest Early–earliest Middle Miocene, mid-Late Pliocene) identified previously.

Key Words: Neogene, Miocene, Quaternary, marine fauna, Tasmania, foraminifera.

INTRODUCTION

The biostratigraphy of Tasmanian Tertiary marine sediments was summarised by Quilty (1972), and the foraminiferid faunas were documented by Quilty (1974, 1977a, 1980a, 1982). Since then, fieldwork on Flinders Island, and accidental sediment recoveries during trawling by Tasmanian Sea Fisheries (then the Tasmanian Fisheries Development Authority, TFDA) have yielded foraminiferid bearing samples (Quilty 1985a, b). Further biostratigraphic data have been obtained from drilling for hydrocarbons. The most recent biostratigraphic summary that includes references to the Neogene is the relevant section of Burrett & Martin (1989).

The aim of this paper is to record the foraminiferid faunas and interpret the environment of deposition of several new Tasmanian Neogene samples. A revised model of the Tasmanian marine environment during the Neogene will then be presented.

Unfortunately, conditions throughout the Miocene–Quaternary in the waters around Tasmania generally were cool enough, with exceptions noted by Quilty (1972), that low-latitude, planktonic foraminiferid-based zonations such as those of Blow (1969) and Stainforth *et al.* (1975) are not readily applicable, and it is necessary to use both southeastern Australian benthic zonations, such as proposed by Carter (1958, 1964), Ludbrook & Lindsay (1969), and also mid-latitude, planktonic foraminiferid-based schemes such as those of Jenkins (1971, 1985) and Kennett & Srinivasan (1983). These schemes do not provide the resolution of zones, as do the Blow/Stainforth schemes mentioned above, nor do they allow spot samples, such as available here, to be dated with the precision of samples from warmer water continuous sequences. Another feature is that some samples were deposited in waters shallow enough for the full diversity

of planktonic foraminiferids in existence in the region not to be represented in the sediments.

Samples and location

Locations of the samples are shown in figure 1. Detailed coordinates, depth and University of Tasmania acquisition numbers are shown on table 1.

The sample from between Penguin and Ulverstone (UTGD76649, near sea level, below the Lonah Road, between Tea Tree Point and Penguin Point; fig. 2) was discovered late in 1986 by the Tasmanian Geological Survey (now Mineral Resources, Tasmania), during fieldwork related to the large landslip known as Grooms Slip. The features of the slip were reported initially by Balsille (1936). A very thin, fossiliferous horizon is present and consists of sandy, silty clay with approximately 30% shell material in small lenses. It comes from the base of the cliff section next to an adit located above the centre of the slip and on a level at, or slightly above, a wave cut bench. Sediments above the marine horizon appear to be nonmarine clayey sand and sand.

Several offshore samples (UTGD66532–536) were recovered by CSIRO in 1986, as an unexpected and unwanted benefit of trawling activities during fishery research cruises in the region, conducted on *R/V Soela* (Cruises SO3/86 and SO4/86). In mid-July 1992, one was collected accidentally in approximately 1000 m water depth from an area known locally as the St Helens Hills during fishing operations of FRV *Southern Surveyor* (Cruise SS3/92). The St Helens Hills is the local term applied to an area of water depth 580–1000 m lying about 45 nautical miles east of St Helens, a known Orange Roughy (*Hoplostethus atlanticus* Collett) fishing area with a rugged bottom.

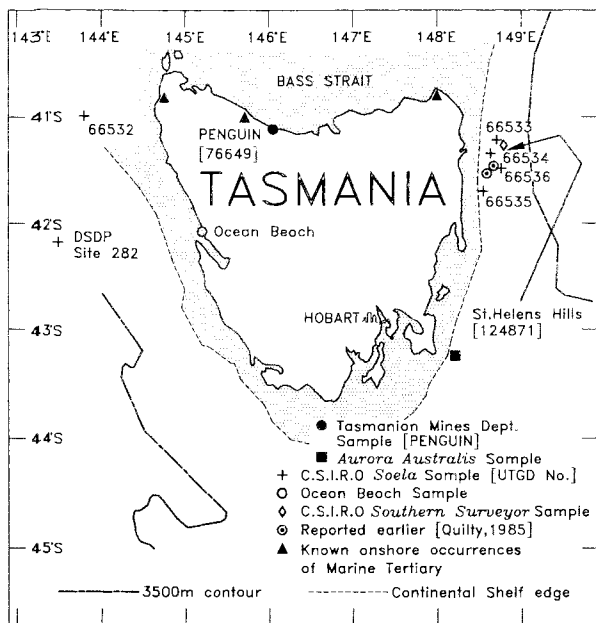


FIG. 1 — Locality map.

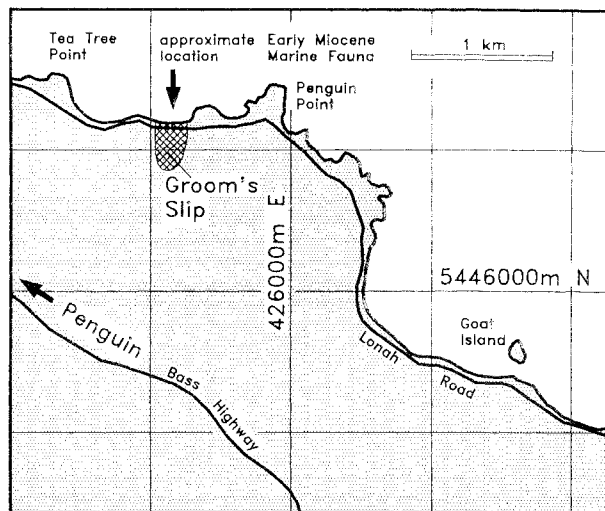


FIG. 2 — Details of location of Grooms Slip sample.

TABLE 1
Sample information

Location	UTGD sample	Latitude	Longitude	Depth (m)
<i>Soela samples</i>				
Western Tasmania				
S03/86 Station 31	66532	41°01'S	143°51'E	560
Eastern Tasmania				
S04/86 Station 3	66535	41°42'S	148°43'E	1160
S04/86 Station 5	66536	41°38'S	148°50'E	940
S04/86 Station 7	66533	41°15.7'S	148°46.9'E	1136
S04/86 Station 8	66534	41°26'S	148°44.8'E	870
St Helens Hills	124871	41°14'S	148°45.5'E	c.1000
Ocean Beach, Strahan	124886 124887 124888 124889 124890 124891	42°07.5'S	145°15.5E'	0
<i>Aurora Australis sample</i>				
Southeastern Tasmania	78185	43°15.53'S	148°14.25'E	810
North Coast, Penguin outcrop	76649	41°37.2'S	146°6.4'E	0

FAUNAS, AGE AND PALAEOECOLOGY

Penguin–Grooms Slip

Samples collected from off northeastern Tasmania by CSIRO are from within a few nautical miles of the samples reported by Quilty (1985b).

The core from offshore southeastern Tasmania was taken on 3 January 1993, during testing of gravity coring equipment supplied by the Australian Geological Survey Organisation (AGSO), from RSV *Aurora Australis* under charter to the Australian Antarctic Division. The core is approximately 200 mm long, and has a diameter of 85 mm. There is some poorly controlled bottom profiler information for this site.

The samples from Ocean Beach, 6 km north of Strahan, consist of six rounded beach pebbles, 40–60 mm in diameter, in which mollusc fossils are abundant and clearly visible. They were collected early in 1993. Their source is not known but is likely to be nearby, probably offshore in waters less than 30 m deep. They probably have been brought to the beach by wave activity. They are much softer and less smoothed and rounded than other abundant beach pebbles of tough, silica rich Palaeozoic and Precambrian rocks, which seem to be brought to their position by long-shore currents or reworked onto the beach from pebble horizons in nearby Quaternary sediments. The older material is probably redistributed from conglomerates in the Palaeogene and Quaternary sediments that fill the Macquarie Harbour Graben (Baillie & Corbett 1985). The Neogene calcareous pebbles are taken to be within a few kilometres of their source.

Processing

Material from most samples was soaked in water or Calgon solution to disaggregate. It was then washed over sieves, and the residue retained on sieves coarser than 125 microns was picked to yield the faunas recorded here. The sample from the *Aurora Australis* core was more indurated than the others, and some crushing was needed before routine processing. The samples from Ocean Beach, Strahan, and from the St Helens Hills were studied from thin sections, as they were too indurated for disaggregation.

Sample repository

Specimens of the rocks yielding the faunas are held in the collections of the Geology Department, University of Tasmania. Table 1 shows the relationship between the number of that specimen in the Geology Department collection and field numbers. Mounted foraminiferid specimens from each sample are held by the senior author. Figured specimens of foraminiferids are housed in the UTGD collections, and accession numbers for the figured specimens are given on the plate explanation. Geology Department (UTGD) numbers are used throughout this paper.

Lithology

UTGD76649 is soft, friable, apparently nonbedded, poorly sorted, iron-stained, shelly marl that disaggregates readily.

Age

The diverse foraminiferid fauna from the single sample is very similar to that reported by Quilty (1972) from the lowest part of the Fossil Bluff section, 37 km to the northwest. Both sections occur within a few metres of modern sea level. Approximately 99% of the fauna is of benthic species, which are dominated by "*Valvulineria*" *kalimnensis* (Parr), *Elphidium* spp. and several miliolid species, including *Crenulostomina banksi* Quilty. The species distribution is shown on table 2. *Sherbornina cuneimarginata* and *Globorosalina scabricula* (Chapman) are recorded for the first time in Tasmania. Planktonic species are uncommon, and only *Globigerina brazieri* Jenkins and *G. connecta* Jenkins have been identified from the sample. Other elements of the biota include wood fragments, bryozoans, cirripedes, gastropods, bivalves and rare fish otoliths.

Key benthic species for age determination in the Carter (1958) Faunal Unit scheme are *Calcarina mackayi* (Karrer), *Planorbulinella inaequilateralis* (Heron-Allen and Earland), *Sherbornina cuneimarginata*, *Notorotalia howchini* (Chapman, Parr and Collins) and *Operculina victoriensis* Chapman and Parr. *P. inaequilateralis*, although stated by Carter to appear in Faunal Unit 7, has been documented by Quilty (1982) from Faunal Unit 6 sediments at Fossil Bluff, Wynyard, where "*Valvulineria*" *kalimnensis* also is abundant and commonly the dominant species.

The fauna is typical of assemblages that can be correlated with Carter's (1958) Faunal Unit 6, which is earliest Miocene (approximately N5, *Globoquadrina debiscens praedebiscens*–*G. debiscens debiscens* Partial-range zone of Blow 1969; see figure 3, based on Abele, in Douglas & Ferguson 1976).

Palaeoenvironment

Dominance (the proportion of the benthic fauna made up by the dominant species – Walton 1964, Quilty 1972) is 17%, and Diversity (the number of species making up 95% of the benthic fauna) is 18. These figures are characteristic of faunas from the deeper end of the 0–10 fathom field identified by Quilty (1972). Other elements of the biota noted above, however, suggest shallower water deposition and are a little at variance with the Dominance/Diversity figures. Dominance is lower and Diversity higher than expected from interpretation based on other elements of the fauna. The evidence from planktonic percentage and macrofauna is consistent with deposition in a close inshore, protected environment within a few metres of sea level.

Table 2 cont.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<i>G. falconensis</i>	X	X												
<i>G. foliata</i>			X	X										
<i>G. internec woodi-brazieri</i>	X													
<i>G. venezuelana</i>								X						
<i>G. woodi</i>				X			X		X	X				
<i>G. cf. woodi</i>					X	X								
<i>G. sp.</i>			X		X		X					X		
<i>Globigerinita incrusta</i>					X									
<i>G. sp.</i>	X	X		X					X	X				
<i>Globigerinoides obliquus obliquus</i>	X													
<i>G. quadrilobatus</i>					X									
<i>G. quadrilobatus immaturus</i>	X					X								
<i>G. quadrilobatus quadrilobatus</i>	X													
<i>G. quadrilobatus sacculifer</i>	X													
<i>G. quadrilobatus trilobus</i>	X													
<i>G. sp.</i>							X	X						
<i>G. extremus</i>		X												
<i>Globoquadrina dehiscens dehiscens</i>					X	X					X			
<i>G. altispira</i>						X	X							
<i>G. sp.</i>							X					X		
<i>Globorotalia cf. conomiozea</i>			X							X	X			
<i>G. cf. conoidea</i>				X				X	X					
<i>G. cf. conoidea/miozea</i>													X	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
<i>G. crassaformis</i>					X									
<i>G. crassula</i>					X									
<i>G. inflata</i>			X	X	X	X								
<i>G. miozea</i>					X								X	
<i>G. cf. miozea</i>					X						X			
<i>G. nana</i>														X
<i>G. scitula scitula</i>			X	X					X		X	X	X	
<i>G. cf. scitula</i>								X						
<i>G. tosaensis</i>					X									
<i>G. truncatulinoides</i>			X	X	X									
<i>G. cf. tumida</i>					X			X						
<i>Hastigerina pelagica</i>					X									
<i>Orbulina bilobata</i>					X									
<i>O. universa</i>			X	X			X	X		X				
<i>Praeorbulina glomerata circularis</i>								X						
<i>P. glomerata glomerata</i>										X				
<i>P. glomerata undiff.</i>										X				
<i>? Pulleniatina cf. primalis</i>									X					
<i>Sphaeroidinella sp.</i>										X				
<i>Sphaeroidinellopsis cf. subdehiscens subdehiscens</i>									X					
Classification uncertain														
<i>Triangulina aequilateralis</i>														X

* Key to localities. (A–E) CSIRO samples, UTGD66532, UTGD66535, UTGD66536, UTGD66533 and UTGD66534 respectively; (F) St Helens Hills sample, UTGD124871; (G–L) Ocean Beach, Strahan, samples UTGD124886–91 respectively; (M) *Aurora Australia* sample, UTGD78185; (N) Penguin sample, UTGD76649.

SAMPLES TRAWLED BY CSIRO

UTGD66532 — offshore northwestern Tasmania

Lithology

Grey-green, nonbedded marl with minor bryozoan and mollusc content. When dried it is quite hard but dis-aggregates readily, producing very small residue coarser than 125 microns, with high proportion of clay and very well preserved foraminiferids, very dominantly planktonic.

Age

This is the sole CSIRO specimen from offshore northwestern Tasmania — from the West Tasmanian Shelf of Jones & Holdgate (1980). The sample is from approximately one nautical mile (1.85 km) south of the western end of shallow seismic profile Line 28 illustrated on figure 4 of Jones & Holdgate (1980). Although the correlation is imperfect, it suggests that the sample is part of the sequence of older rocks which appears to outcrop at this locality and to form the continental slope. In oil exploration well Clam-1, these were taken to be “hard brown limestone of Miocene age” (Port Campbell Limestone equivalent) (Jones & Holdgate 1980).

Biostratigraphic interpretation of this sample is ambiguous, and several samples were processed. Sediments of at least

two ages are present, but whether they were mixed by dredging or geological factors cannot be ascertained. The two ages are based on ranges of well-known planktonic species and of a benthic species which has not been recorded from Tasmania before.

The mixed planktonic fauna is characterised by a low diversity of planktonic species which are dominated by *Globigerina bulloides* d’Orbigny, small globigerines and *Globorotalia scitula* (Brady). Keeled globorotalids are rare. A single specimen of *Orbulina universa* d’Orbigny was recovered but is taken as possible contamination and, thus, not significant stratigraphically. The fauna lacks sphaeroidinellids, pulleniatinids, hastigerinids or even the more complex variants of *Globigerinoides trilobus* (Reuss). The benthic fauna comprises 40% of the assemblage and is diverse but composed mostly of species that are not age diagnostic.

The younger fauna contains rare *Globorotalia inflata* (d’Orbigny), *G. truncatulinoides* (d’Orbigny) and *G. tosaensis* Takayanagi & Saito (differentiated from *G. truncatulinoides* by being more heavily thickened, possessing a less open umbilicus and less well-developed keel). This fauna is consistent with deposition during the earliest Pleistocene N22 (*Globorotalia* [*G.*] *truncatulinoides truncatulinoides* Partial-range Zone of Blow 1969).

Several specimens of *Globorotalia miozea* Finlay also are present and indicate that at least part of the fauna is Early to Middle Miocene, N7–N15 (*Globigerinatella insueta*–*Globigerinoides quadrilobatus trilobus* Partial-range Zone to *Globorotalia continuosa* Consecutive-range Zone of Blow 1969).

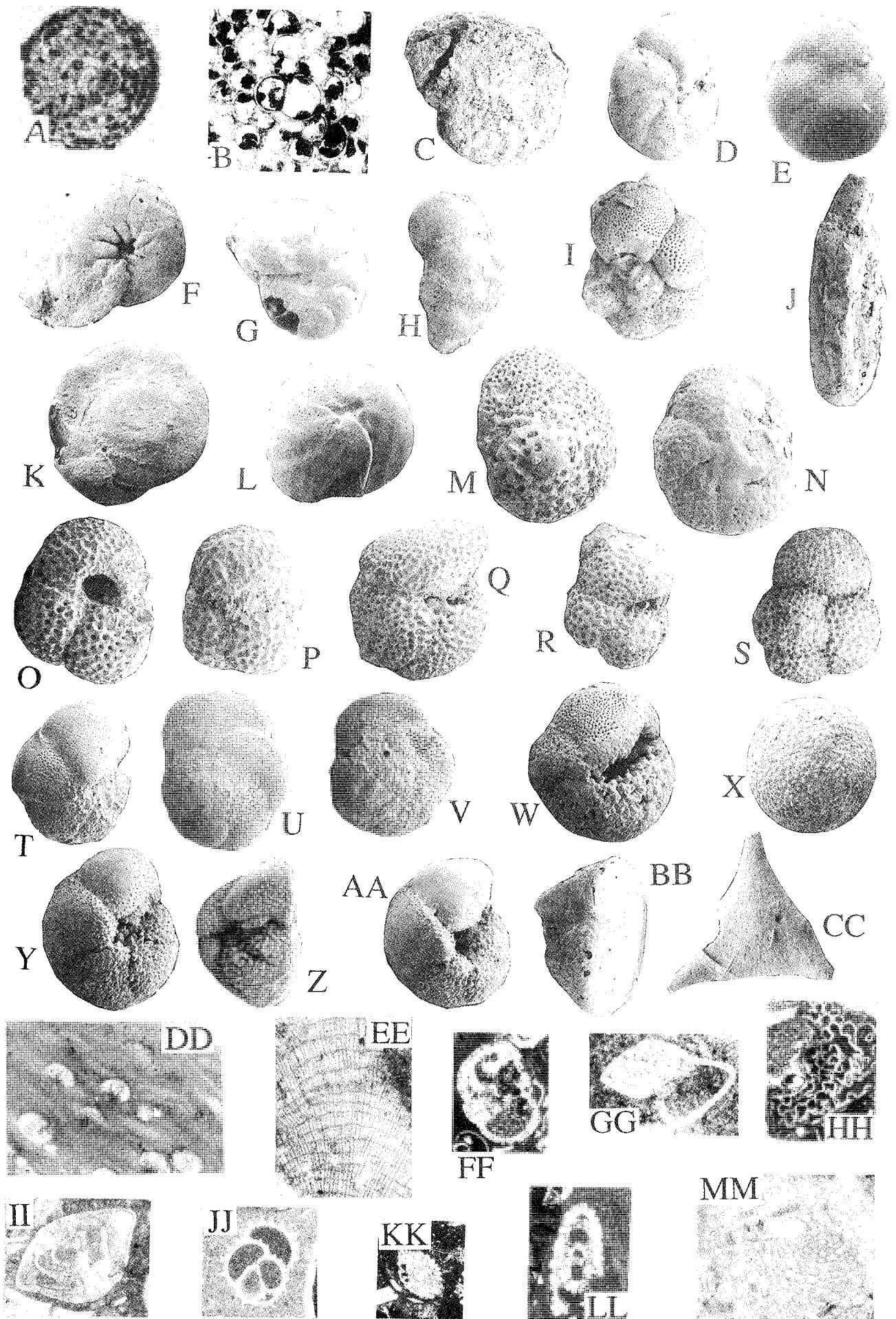


PLATE 1

Several well-preserved specimens of *Cibicidoides notocenicus* (Dorreen) were recovered and originally identified as *C. mexicanus* (Nuttall). It seems that the two forms may be identical. *C. mexicanus* has a range from latest Eocene to Early Miocene (P16–N5 of Blow 1969) (Van Morkhoven *et al.* 1986), and thus it represents a time period not represented by the planktonic faunas. It occurred in middle and lower bathyal depths (600–2000 m) and, thus, should co-occur with abundant contemporaneous planktonic forms.

The age of the older fauna is not well constrained but probably belongs to the earlier part of the N7–N15 interval given above, and is here taken as later part of the Early Miocene (N7–N8, if the New Zealand range of *C. notocenicus* is to be followed).

Palaeoenvironment

UTGD66532 contains material from several ages and several different marine environments of deposition which are difficult to isolate. The sample locality now lies in 560 m water depth, but all faunas are consistent with accumulation in a mid- to outer-continental shelf depth. The 58% planktonic content suggests some subsidence since deposition. Comparison with the distribution of individual species and species groups discussed by Bé & Hutson (1977) indicates that the fauna is most similar to the living subpolar

assemblage or the polar/subpolar fossil assemblage and that the waters at this location were colder in the past than they are now. The low diversity, virtual absence of keeled globorotalids and lack of many other groups common elsewhere also suggest that the water temperature was low during all intervals of deposition.

UTGD66533 — offshore eastern Tasmania

Lithology

Pale, well-sorted, massive bryozoal calcarenite described as “rocks from a coral patch”, yielding large residue coarser than 125 microns. Some iron staining present and some foraminiferid chamber lumina filled with secondary iron oxide (Fe/Mn?). This occurrence may be similar in character to that of phosphates with goethite recorded by Jones & Davies (1983) in samples 2121 and 2126 from northwestern Tasmania. All carbonate grains are significantly overgrown, varying from light frosting to severe overgrowth on echinoderm fragments.

Additional fauna is very diverse in benthos and dominated by bryozoans, but also alcyonarians, bivalve fragments, rare, small, ribbed brachiopods, isocrinoid ossicles and echinoid spines.

PLATE 1

- (A) *Sherbornina cuneimarginata* Wade, Penguin, UTGD124959, equatorial section, $\times 65^*$.
 (B) *Planorbulinella inaequilateralis* (Heron-Allen & Earland), Penguin, UTGD124960, equatorial section through embryonic chambers, $\times 125$.
 (C) *Operculina* sp. A of Carter (1964), from UTGD66534 off northeastern Tasmania, UTGD124961, $\times 36$.
 (D, E) “*Valvulineria*” *kalimnensis* (Parr), Penguin, UTGD124962, ventral and dorsal views, $\times 55$.
 (F) *Astrononion centroplax* Carter, southeastern Tasmania, UTGD124964, $\times 50$.
 (G) *Astrononion australe* Cushman & Edwards, Penguin, UTGD124965, $\times 90$.
 (H) *Karrerria maoria* (Finlay), from UTGD66534 off northeastern Tasmania, UTGD124966, dorsal view, $\times 55$.
 (I) *Carpenteria rotaliformis* Chapman & Crespin, southeastern Tasmania, UTGD124963, dorsal view, $\times 24$.
 (J) *Crenulostomina banksi* Quilty, from southeastern Tasmania, UTGD124967, lateral view, $\times 30$.
 (K, L) *Cibicidoides notocenicus* Dorreen, offshore northwestern Tasmania, dorsal and ventral views, UTGD124968, (K) dorsal $\times 35$, (L) ventral $\times 38$.
 (M, N) *Globorotalia scabricula* (Chapman), Penguin, dorsal and ventral views, UTGD124969, $\times 38$.
 (O) *Globigerina woodi* Jenkins, from off northeastern Tasmania, UTGD124970, ventral view, $\times 90$.
 (P) *Globigerina connecta* Jenkins, Penguin, UTGD124971, ventral view, $\times 130$.
 (Q) *Globoquadrina dehiscens* (Chapman, Parr & Collins), off northeastern Tasmania, UTGD124972, ventral view, $\times 105$.
 (R, S) *Globorotalia nana* Bolli, off southeastern Tasmania, UTGD124973, ventral and dorsal views, $\times 90$.
 (T, U) *Globorotalia scitula* (Brady), offshore northwestern Tasmania, UTGD124974, ventral and dorsal views, $\times 60$.
 (V, W) *Globorotalia miozea* Finlay, offshore northwestern Tasmania, UTGD124975, dorsal and ventral views, $\times 70$ and $\times 65$ respectively.
 (X) *Pracorbulina glomerata circularis* (Blow), offshore northeastern Tasmania, UTGD124976, $\times 105$.
 (Y, Z) *Globorotalia tosaensis* Takayanagi & Saito, offshore northwestern Tasmania, UTGD124977, ventral and oblique apertural views $\times 70$ and $\times 65$ respectively.
 (AA, BB) *Globorotalia truncatulinoides* (d’Orbigny), off southeastern Tasmania, UTGD124978, ventral and oblique dorsal views, $\times 55$ and $\times 80$ respectively.
 (CC) *Triangulina aequilateralis* Quilty, off southeastern Tasmania, UTGD124979, $\times 80$.
 (DD–MM) Early Middle Miocene, Ocean Beach Strahan, UTGD124886. (DD) *Mesophyllum/Lithophyllum* sp., $\times 25$; (EE) *Lithophyllum* sp., $\times 50$; (FF) *Carpenteria* cf. *rotaliformis* Chapman and Crespin, $\times 25$; (GG) *Globorotalia scitula* (Brady), $\times 95$; (HH) *Acervulina inhaerens* Schultze, $\times 27$; (II) *Cibicides* sp., $\times 60$; (JJ) spinose buliminid, $\times 100$; (KK) Small Elphidium sp. *indet.*, $\times 25$; (LL) Large Elphidium sp. *indet.*, $\times 25$; (MM) *Gypsina globulus* (Reuss), $\times 55$.

* Most magnifications rounded to the nearest 5 \times .

Age

The poorly preserved foraminiferid fauna is difficult to identify with certainty and, thus, the rock cannot be dated precisely. The benthic component (20–25% of the fauna) contains *Elphidium crespinae* Cushman, *Cibicides perforatus* (Karrer), *Gaudryina convexa* (Karrer) and *Pseudoclavulina* cf. *anglica* Cushman, all of which are known from Early Miocene sediments in southeastern Australia, and some range into the Middle Miocene in Tasmania and even younger in New Zealand. The early Miocene age assignment is consistent with the presence of common *Globigerina* species (including *G. connecta* Jenkins), which dominate over the benthic component. Other planktonic genera are absent. There is no evidence of reworking. A few Quaternary species, including *Globorotalia truncatulinoides*, are present and probably result from some mixing during dredging.

Although the age is not well constrained, the sediment is estimated to be Early Miocene and probably equivalent to the Fossil Bluff section. This is the interval within the Early Miocene that seems to have had water temperature conditions that yielded planktonic foraminiferid faunas with composition and diversity similar to those listed here (Quilty 1972).

Palaeoenvironment

The fauna in UTGD66533 is so poorly preserved that even the planktonic/benthic ratio cannot be estimated accurately. Based on the low diversity and domination of the planktonic content by hispid *Globigerina* spp., it was deposited in cool water conditions.

The sediment is lithologically similar to some described from the Marawah region (Quilty 1972), which also have similar faunal composition, benthic and planktonic foraminiferid fauna and preservation, even if not age. They probably accumulated in similar palaeoenvironment on the inner to middle continental shelf, at depths of about 100 m or less, and at sites lacking significant sediment input. The sediment is well sorted, suggesting some current action, but there is no obvious abrasion of the foraminiferid tests, although preservation is inadequate to state this definitively. The sediment was recovered from over 1100 m and clearly has moved to its present depth, suggesting some continental margin slumping or downfaulting since the end of the Early Miocene.

UTGD66534 — offshore eastern Tasmania

Lithology

Massive white chalk which yielded a relatively large, well-preserved residue coarser than 125 microns. Bryozoa dominant, with echinoids and foraminiferids constituting a small component. No obvious terrigenous detrital element.

Age

Approximately 20% of the foraminiferid fauna is composed of planktonic species, including *Praeorbulina glomerata* *circularis* (Blow), *Globoquadrina debiscens debiscens*

(Chapman, Parr & Collins), *Globorotalia miozea* Finlay, *Globigerina decoraperta* Takayanagi & Saito, and *G. woodi woodi* Jenkins. A single specimen of a form very similar to *Globorotalia puncticulata* (Deshayes) was found and appears to be out of place. No *Globigerinoides* spp. were recovered. Benthic forms include *Operculina victoriensis*, *O. sp.* (of Carter 1964), *Cibicides mediocris* Finlay, *C. perforatus* (Karrer) (dominant benthic), *Karrerella maoria* (Finlay), *Alabama tenuimarginata* (Chapman, Parr & Collins) etc. It is a diverse fauna with low dominance.

Both planktonic and benthic species indicate an age on the Early–Middle Miocene boundary, that is N8 (*Globigerinoides sicanus*–*Globigerinatella insueta* Partial-range Zone) or N9 (*Orbulina suturalis*–*Globorotalia peripheroronda* Partial-range Zone of Blow 1969).

Palaeoenvironment

UTGD66534 is a warm, clear water, inner continental shelf sediment deposited in a low energy environment off a coast of low sediment input. It seems to have been deposited during an episode of high sea level, represented by sediment around most of the Australian coastline. It was recovered from 870 m and, thus, appears to be considerably below where it was deposited, perhaps by as much as 800 m, indicative of tectonic subsidence of approximately that amount.

UTGD66535, 66536 — offshore eastern Tasmania

Lithology

UTGD66535 white chalk; 66536 indurated grey, non-bedded marl. Residue coarser than 125 microns from 66535 small and dominated by foraminiferids and sponge spicules, with minor bone fragments, ostracods and alcyonarian spicules. That from 66536 larger and dominated by bryozoa and two types of calcareous worm tubes. Echinoid spines and small gastropods subordinate.

Age

The samples are Quaternary in age, based on the presence in each of *Globorotalia truncatulinoides truncatulinoides* (d'Orbigny), the index species for the Quaternary. Differentiation of the two Quaternary zones in the Blow (1969) scheme is not possible with the material available. Both samples consist of high diversity, low dominance benthic faunas with 28% and 71% planktonics respectively. Pulleniatinids and sphaeroidinellids are absent.

Palaeoenvironment

While UTGD66535 and 66536 are both Quaternary in age, in other ways they are very different. UTGD66536 comes from farther offshore and from deeper water. Thus, it would be expected to contain a higher percentage of planktonic forms in the foraminiferid fauna and benthic

forms indicative of deeper water deposition. In fact the converse is true. It contains less than 30% planktonic species, and almost half the benthic fraction is composed of miliolid forms, normally associated with reasonably shallow, inner shelf conditions of deposition. *Textularia* cf. *hayi* Karrer is the dominant benthic.

In contrast, UTGD66536, which is at present closer inshore and in shallower water, contains over 70% planktonic forms and a diverse planktonic species list. The benthic forms are diverse, and dominance (Walton 1964, Quilty 1972) is low, consistent with an outer continental shelf-upper continental slope site of accumulation.

The differences between foraminiferid faunas in UTGD66535 and 66536 may have been caused by deposition during glacial intervals (when sea level was approximately 130 m lower than now, ocean waters cooler and planktonic faunas less diverse; UTGD66536) and interglacial (when sea level was high, the ocean warmer and planktonic faunas more diverse; UTGD66535). Such conditions alternated during the Quaternary on a regular 100–120 ka cycle, perhaps in response to Milankovich forcing (Imbrie 1984, Goodess *et al.* 1992).

ST HELENS HILLS

The sample was studied from one large thin section of UTGD124871.

Lithology

Buff-coloured, highly indurated, matrix supported, micritic limestone with abundant and diverse macro- and micro-fossil content. Fabric of the sample highly disturbed, suggesting severe bioturbation or slumping to present locality. Most macrofossils broken. Echinoderm debris common; highly overgrown. Internal detail largely destroyed.

Age

The foraminiferid fauna is dominated by small, thin-walled globigerinids which are quite well preserved. These include *Orbulina universa*, *Globoquadrina* sp., *Globigerinoides quadrilobatus* (d'Orbigny), *Globoquadrina altispira* s.l., *Sphaeroidinellopsis* sp. (this appears not to be *S. dehiscens*, as no second aperture could be seen on the many sections encountered and the most similar form is *S. subdehiscens* Blow), *Globorotalia* (probably *G. tumida* [Brady]), *Globorotalia* (of the *G. scitula* type), *Globigerina* (of the thick-walled, three-chambered type such as *G. woodi*), *G. venezuelana* and possibly *Pulleniatina* (of the *P. primalis* type). Kecked and nonkecked globorotalids are rare. Also present is an unidentified highly spinose *Globigerina*.

The composition of the fauna suggests a Late Miocene age (N18, *Globorotalia tumida tumida*–*Sphaeroidinellopsis subdehiscens* *paenedehiscens* partial-range zone of Blow 1969).

Palaeoenvironment

Deposition occurred in fully marine conditions adjacent to a source of coarse macrofauna, in water deep enough for the dominant sediment input to be pelagic. There is very little terrigenous material other than in the micritic fraction. This indicates either that runoff was low, or that the site of deposition was isolated from the mainland by a deeper water region. Water temperature was temperate, similar to the present-day environment.

AURORA AUSTRALIS SAMPLE

Site of deposition

Echo sounder information suggests that the site is on a flat-topped submarine plateau at about 800 m. Between the plateau and the continental shelf edge there is a deeper channel.

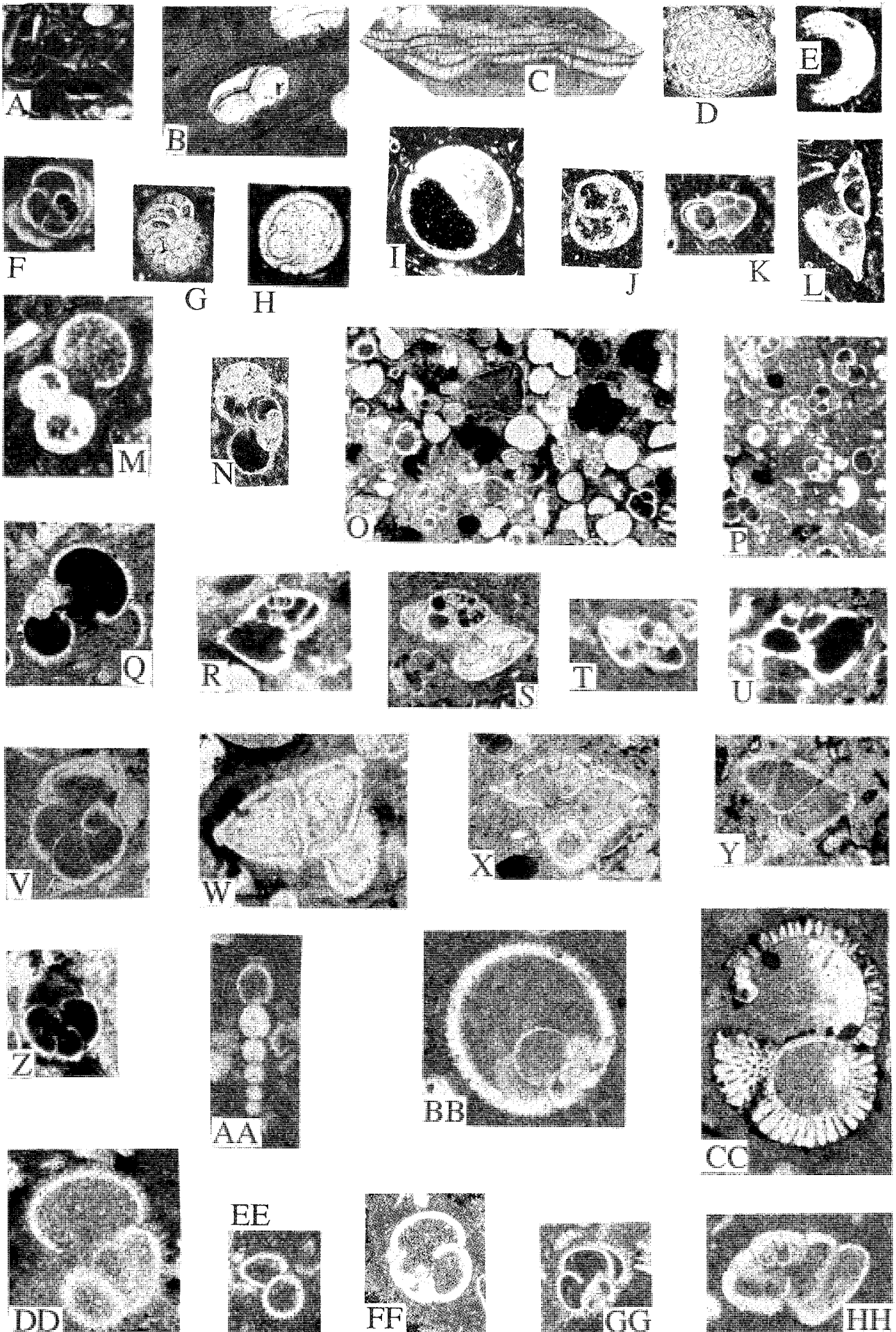
Lithology

A mixture of bryozoal calcarenite fragments, up to 30–40 mm in size, broken from parent rock during coring, and minor soft “modern” sediment. The more lithified sediment is compact, white, moderately lithified, well-sorted, bryozoal calcarenite, apparently unbedded. It contains abundant echinoderm debris, alcyonarian remains and bryozoa. Small, ribbed brachiopods rare. Most fossils well preserved but echinoderm debris commonly substantially overgrown. Terrigenous detritus a very minor component of the 125–250 micron fraction. Calcarenite surface marked by brown iron staining in zone about 5 mm thick, suggesting it marks a hardground on which younger sediment is accumulating. Because of the mixed nature of the sediment, samples reported here were carefully chosen and washed before crushing and processing, to ensure that there has been no mixing of the younger with the older.

The well-lithified sediment is overlain by soft sediment, which is carbonate rich with abundant foraminiferids.

Age

In the well-lithified sediment, foraminiferids constitute a small volume of the residue but are well preserved. Planktonic species are a very minor component (much less than 1%) of the fauna and only *Globigerina woodi*, *G. bulloides* and *Globorotalia nana* Bolli were recovered. Benthic forms are diverse and dominated by *Cibicides perforatus*. Few of the key species in the southeastern Australian biostratigraphic schemes of Carter (1958, 1964) are present, but *Astrononion centroplax* Carter, *Carpenteria rotaliformis* Chapman and Crespin, *Notorotalia howchini* (Chapman, Parr & Collins) and *Elphidium crespinae* Cushman, together with the planktonic species listed above, suggest that the fauna is from the earlier part of the Early Miocene (or perhaps very latest Oligocene). The problematic form *Triangulina aequilateralis* Quilty (Quilty 1970) was described from the earliest Miocene of Cape Grim and also is found here but is very rare.



The overlying younger sediment was not well sampled by the core, but planktonic species constitute over 90% of the foraminiferid fauna and include abundant *Globorotalia inflata* and rare *G. truncatulinoides*, indicating a Quaternary age. Otoliths include those from myctophids (lanternfish) and others.

This sample provides the first palaeogeographic evidence from the pre-Quaternary Cenozoic of southeastern Tasmania and is the first step in redressing the problem of lack of samples of much of the Tertiary, noted by Colhoun in Burrett & Martin (1989: 409).

Palaeoenvironment

The Early Miocene sediment was deposited in shallow water. It has a very low planktonic content and probably accumulated off a coast with low runoff. Water depth was probably less than 20 m, and that depth probably precludes the full diversity of planktonic forms being incorporated. There is not enough information to comment on water temperature at the time, other than that there are no indices of subtropical/tropical or even warm temperate conditions. This perhaps supports an earlier, rather than a later Early Miocene age determination.

The Quaternary sediment is characterised by sinistrally coiled *Globorotalia truncatulinoides*, which indicates deposition in cool water.

OCEAN BEACH SAMPLES

One thin section was studied from each of the six rock samples collected. This material was not recorded in the review of Macquarie Harbour Graben sediments contained in Baillie & Corbett (1985). Lithology is variable from bryozoal calcarenite to conglomerate with interstitial bryozoal debris. Three separate rock types appear to be present and a fourth is a mixture of two as a conglomerate.

UTGD124886

The most complex of six samples recovered. Conglomerate with well-rounded, high sphericity pebbles of calcarenite to about 30 mm, embedded in grey matrix which seems to represent significantly younger, shallower water phase.

Older material consists of yellowish to reddish-brown, uniformly medium-grained calcarenite. Foraminiferids the dominant fossil group, but some bryozoa, echinoid spines and rare calcareous algae also present. Benthic foraminiferids subordinate to planktonics.

The older material is early N9 in age, based on the presence *inter alia* of *Praeorbulina*, *Orbulina universa*, *Globoquadrina*, *Globorotalia scitula* and *Globigerina* of the *woodi* group. Small, thin-walled, four-chambered globigerinids also are common.

The grey matrix is much coarser, poorly sorted and highly porous. Where the porosity is low, it is due to the filling of the interstices by uniform, very fine, grey micrite. This phase consists of highly fragmented bryozoan calcarenite with common calcareous algae, serpulids and broken mollusc fragments. Foraminiferids are less common than in the reddish phase and benthics are dominant over planktonics.

This phase is much younger than the framework of the pebbles and the planktonic foraminiferid fauna less common. Benthic forms include *Elphidium* spp. (both large and small species), *Carpenteria* cf. *rotaliformis*, *Acervulina inhaerens*, *Notorotalia* and miliolids. This phase seems to be Late Miocene, N18 in age.

UTGD 124887

Grey, roughly laminated limestone dominated by calcareous algae, bryozoans and gastropods, with other minor molluscs and echinoids. Interstices filled with very fine (but not micritic) sediment, including some fine, angular, terrigenous material and sponge spicules. Foraminiferids identified, while uncommon, come from this lithology and include

PLATE 2

Early Middle Miocene, Ocean Beach Strahan, western Tasmania.

(A–G) From UTGD124487. (A) Sponge spicules in rock thin section, $\times 25^*$; (B) *Mesophyllum/Lithophyllum* sp., $\times 70$; (C) *Lithoporella* sp., $\times 65$; (D) *Gypsina globulus*, $\times 55$; (E) *Sherbornina* sp., $\times 65$; (F) *Globoquadrina dehiscens* (Chapman, Parr & Collins), $\times 65$; (G) *Elphidium* sp., $\times 65$.

(H–I) From UTGD124888. (H) *Praeorbulina glomerata* Blow, section through embryonic chambers, $\times 70$; (I) *Orbulina universa d'Orbigny*, $\times 45$.

(J–N) From UTGD124889. (J) *Globigerinita* sp., $\times 70$; (K) *Globorotalia scitula* (Brady), $\times 80$; (L) *Globorotalia* cf. *conoidea* Walters, $\times 65$; (M) *Globigerinoides quadrilobatus* (d'Orbigny), $\times 105$; (N) *Globigerina angustiumbilocata* Bolli, $\times 200$.

(O–Z) From UTGD124891. (O) Lithology showing phase with abundant glauconite grains, $\times 45$; (P) Lithology showing abundance of planktonic foraminiferids, $\times 50$; (Q) *Globigerina angustiumbilocata*, $\times 100$; (R, S) *Globorotalia conoidea*/miozea, vertical sections, $\times 120$ and $\times 150$ respectively; (T) *Globorotalia scitula* (Brady), vertical section, $\times 105$; (U) *Globorotalia conoidea* Walters, $\times 110$; (V–Y) *Globorotalia* (?) *conomiozea* Kennett, (V) equatorial section, $\times 110$, (W–Y) vertical sections, $\times 110$, 160 and 110 respectively; (Z) *Globoquadrina* sp., $\times 190$.

(AA–HH) All Late Miocene, St Helens Hills, UTGD124871. (AA) *Stilostomella* sp., longitudinal section, $\times 30$; (BB) *Orbulina universa*, $\times 110$; (CC) *Sphaeroidinellopsis* sp., $\times 105$; (DD, EE) *Globoquadrina* cf. *dehiscens* (Chapman, Parr & Collins), vertical sections, $\times 115$ and $\times 45$ respectively; (FF) *Globigerina venezuelana* (Hedberg), vertical section, $\times 45$; (GG) highly spinose globigerinid, vertical section, $\times 40$; (HH) *Globorotalia scitula*, $\times 110$.

* Most magnifications rounded to the nearest 5 \times .

Sherbornina, *Globoquadrina debiscens*, small *Elphidium* and *Gypsina globulus*. These are not age diagnostic but are consistent with the Middle Miocene age identified in some of the other Ocean Beach samples. This rock has been burrowed to a minor extent and the burrows are infilled with angular detrital material from which no fossils have been recovered.

UTGD124888-124890

Each of three samples consists of single lithology which is reddish or yellowish brown, highly calcareous with common bryozoans, minor calcareous algae, weak bedding accentuated by alignment of the bryozoans, and matrix supported with abundant, thin-walled globigerinids. Fine, curved fragments are common and may be ostracod or pteropod remnants. Fragmentation of components common, but rounding not evident.

UTGD124888 contains *Orbulina universa*, *Praeorbulina glomerosa*, *Globorotalia* cf. *miozea*, *G. scitula*, *Globoquadrina* etc.

UTGD124889 and 124890 very similar to 124888 but bedding less obvious and sponge spicules abundant in the matrix. Pteropods are identifiable in this slide only. Foraminiferids, while abundant, do not include age diagnostic forms. *Globorotalia* cf. *conoidea* is present. 124890 contains what appears to be *Globorotalia conomiozea*, which would indicate an age younger than the early Middle Miocene documented above for other samples from Ocean Beach.

UTGD124891

Sand-sized pellets or tubular structures, 2–5 mm in diameter, which have a marked concentric structure. Terrigenous material not abundant, but silt-sized grains are angular and coarser grains well rounded. Other fossil debris includes abundant but poorly defined small sponge spicules, echinoid spines and broken and rounded bivalve fragments. Sample also has patches dominated by rounded glauconite grains, interstitial between the concentric structures. *Globorotalia* (?) *conomiozea* also is present, even quite common, in this sample.

Age

Foraminiferid and other faunas vary greatly from sample to sample but are generally dominated by small, thin-walled globigerinids. Keeled globorotalids are rare. Benthic forms include *Elphidium*, *Karreria*, gavelinellids, and occasionally abundant miliolids. Pulleniatinids and other Late Miocene and Quaternary planktonic forms are absent. The foraminiferid fauna is listed on table 2. Calcareous algae are a feature of most specimens and include *Mesophyllum*/*Lithophyllum* and *Lithoporella*.

UTGD124887 contains *Orbulina universa* (several sections) and *Praeorbulina glomerosa*, showing that this specimen, at least, is very early Middle Miocene (early N9, *Orbulina suturalis*–*Globorotalia peripheroronda* Partial-range Zone of Blow 1969). *Praeorbulina* has also been seen in a thin section of UTGD124886. Other specimens contain abundant thin-shelled forms including a common five-

chambered globigerinid that is probably *G. angustiumbilitata*, and *G. woodi*, *Globorotalia scitula*, *G. cf. conoidea* Walters, *G. miozea*, *Sphaeroidinellopsis* sp., *Globoquadrina altispira*, *Globigerinita* sp. and the benthic forms, *Sherbornina* sp., *Elphidium* spp., *Karreria maoria*, *Gypsina globulus* (Reuss), *Cibicides* cf. *perforatus*, *Textularia* sp., miliolids and buliminids. The absence of pulleniatinids from all samples suggests an age older than Late Miocene for the entire specimen collection.

A form that appears to be *Globorotalia conomiozea* is present in UTGD124890 and 124891. It is possible that two ages are represented in both the sample collection and in individual samples. In addition to the early Middle Miocene age documented here, it is possible that lithified Middle Miocene fragments have been reworked into the grey limestone which is Late Miocene, probably N18 (*Globorotalia tumida tumida*–*Sphaeroidinellopsis subdehiscens paenedehiscens* Partial-range Zone of Blow 1969). However, any suggestion of Late Miocene is very tentative.

Palaeoenvironment

The variation in lithology and fossil content suggests an origin in a “shallow” water, fully marine environment, at a time of high energy. Abundant calcareous algae in some specimens indicate a depth limit in the photic zone, perhaps 70 m or shallower. Rounding and breakage of fossils and the abundance of coarse terrigenous material are also consistent with this hypothesis but probably support a depth of deposition considerably less than 70 m. Other specimens lack the algae and have high proportions of planktonic species, which suggests a deeper water, perhaps outer continental shelf depth of deposition. A significant part of the breakage seems due to postdepositional compaction effects.

The red/brown material has a higher planktonic foraminiferid content, suggesting deeper water deposition (still within the photic zone to judge from the calcareous algae) and perhaps a period of exposure to allow development of a ferruginous character and also erosion to generate rounding and redeposition. The grey, bryozoan/mollusc/algae rich content is a younger, shallower water, higher energy component.

COMPARISON WITH MODERN TASMANIAN SHELF SEDIMENTS

Jones & Davies (1983) summarised what is known of the distribution of modern sediments on the Tasmanian continental shelf and through most of Bass Strait. For that study, 365 localities were sampled and analysed for grain size, composition, heavy mineral content etc. This collection of samples has provided the basis for other studies such as that by Rao & Adabi (1992, and references therein). The modern material studied by Jones and Davies and by Rao and Adabi has in common with older Neogene sediments around Tasmania that it seems generally to be cold water carbonate dominated, with the exception of one interval at the close of the Early Miocene and earliest Middle Miocene, when conditions were much warmer. Unfortunately, little attention was given by Jones & Davies (1983) to biogenic content other than for molluscs and pollen (three samples

only), although reference was made to unpublished foraminiferid data of Taylor and Mee, which indicate that the benthic component is quite different from that recorded from the older samples. In contrast to the modern samples recorded by Jones & Davies (1983), the material recorded herein generally contains little molluscan debris. Jones & Davies' samples were generally from less than 100 m water depth, a few to about 200 m, and only one unsuccessful attempt (locality 2029) was made to obtain material from significantly deeper waters — 823 m. This latter sampling was within a few kilometres of UTGD66535 (see below). Similarly, sample location 2119 in 170 m was within a few kilometres of UTGD66532.

Jones & Holdgate (1980) referred to Miocene sediment from shallow depth in the oil exploration well Clam-1, off northwestern Tasmania, and it is probable that what has been recorded here from UTGD66532 is part of that sequence which outcrops on the seafloor.

Exon *et al.* (1992) recorded sediments from core, grab and dredge samples along the west coast of Tasmania. Dredge samples in areas close to those examined for this paper are Cretaceous. Cores 45 and 46 contained Late Pliocene sediments deposited under cold surface water conditions. Core 40 consisted of shallow water Early Miocene overlain by Quaternary. The grab samples contained only modern material and will be discussed no further.

TASMANIAN NEOGENE MARINE SEDIMENTATION PATTERNS

By the beginning of the Miocene, Australia and Antarctica had separated (Veevers *et al.* 1991) sufficiently to allow open circulation, both shallow and deep, between the continents from the Indian to Pacific Oceans, as part of a circumpolar system that exists today (see Kemp 1978,

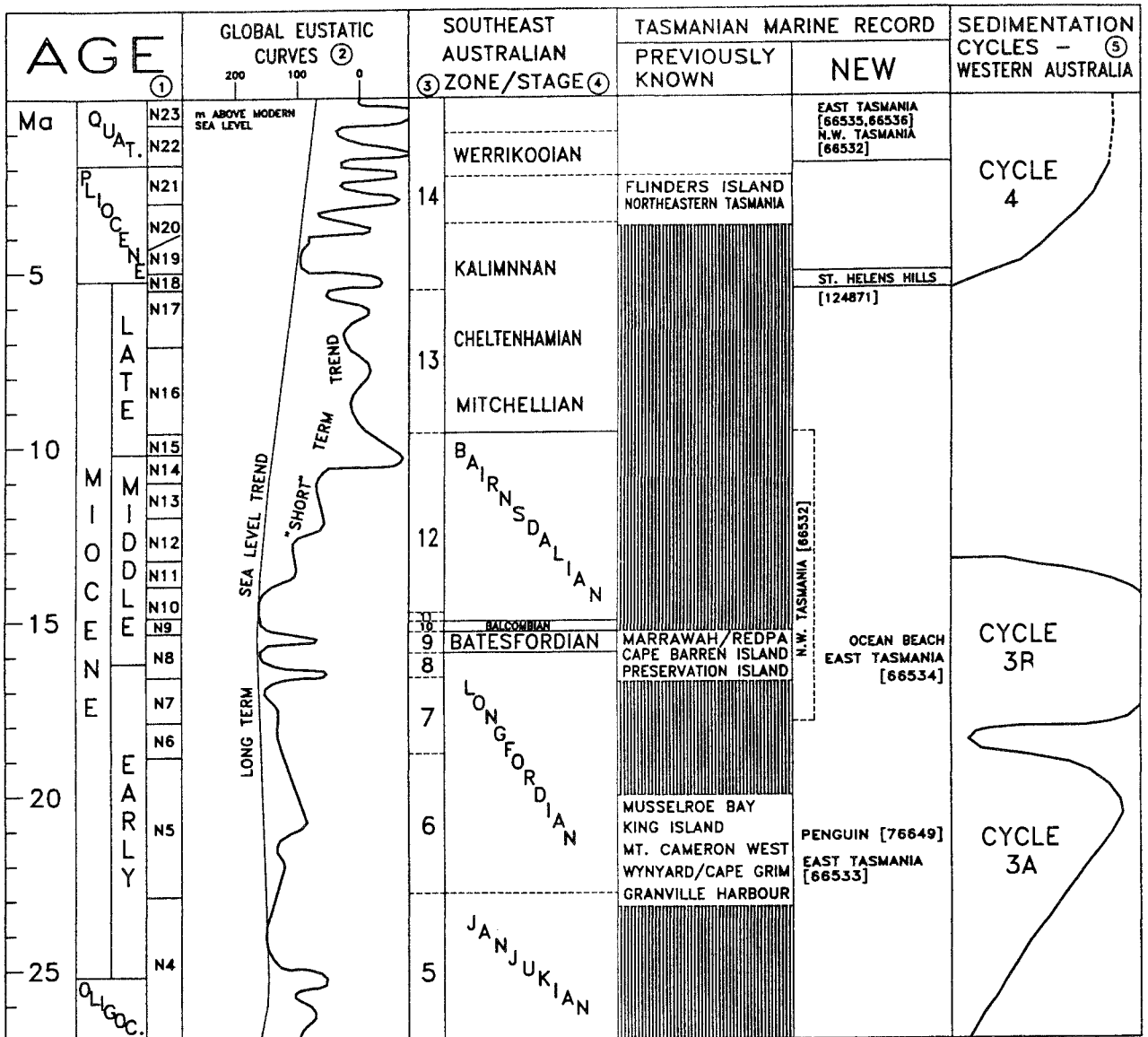


FIG. 3 — Integration of new data into general correlation scheme for all Tasmanian marine sediment sections. (1) Planktonic foraminiferid zonal scheme of Blow (1969). (2) Correlation of age and global eustatic curves taken from Haq *et al.* (1987). (3) Carter (1958) Faunal Unit scheme. (4) Correlation of Faunal Units and Australian stages from Abele in Douglas & Ferguson (1976). (5) Western Australian sedimentation cycles from Quilty (1977).

Veevers 1984). For the first time, Australia became independent of the direct influence of Antarctica, in contrast with conditions earlier. There were marine conditions and shallow water flow from west to east through Bass Strait. Tectonically, the region was relatively inactive, other than for changes in latitude due to seafloor spreading. Volcanism was active onshore in Tasmania during the Miocene (Sutherland & Wellman 1986) and also intruded into offshore marine sequences (Burrett & Martin 1989). It seems, therefore, that the principal influences on Tasmanian sea-level change and climate were global rather than purely local.

Only a small proportion of Neogene time is represented by marine sediments recorded here in and around Tasmania and, thus, any reconstruction of Neogene history based on the marine record alone is incomplete and biased towards short intervals of time. This is in contrast with the situation in much of southeastern Australia, where more continuous sections are known, and is probably due to the lack of basinal structures in the Cenozoic of Tasmania, other than graben, and control of marine sedimentation patterns by eustatic sea level variation.

Study of all known sections and records from many isolated sections reinforces the indications, outlined in Quilty (1972, 1985a, b), that the discontinuous Tasmanian marine record reflects a series of episodes of deposition in the earliest Miocene, very late in the Early Miocene and/or earliest Middle Miocene, Early and Late Pliocene and at different times through the Quaternary. Most of the pre-Quaternary episodes are represented by several sections and isolated samples. The Late Miocene is represented in only one sample seen to date and that was deposited in much deeper water conditions than sediments of other ages. The earlier part of the Middle Miocene is identified only from those samples deposited in N9 time, probably as a continuation of the episode of deposition in the latest Early Miocene. This study indicates that the latest Middle Miocene (N14/15 of Blow 1969) may be present. This is unusual in Australian Cenozoic sections.

The records appear to represent carbonate sedimentation during intervals of globally warmer water conditions and high sea level. These coincide generally with a similar sequence of episodes of deposition elsewhere around Australia, documented by Quilty (1977b, 1980b) and McGowran (1979) and McGowran & Li (1993). Figure 3 includes a compilation of the international eustatic sea-level curve produced by Haq *et al.* (1987), based on those of Vail *et al.* (1977). On what earlier authors have termed the short-term sea-level curve, there is shown to be a series of generally higher sea levels including one in the very Early Miocene (N4/5), a series of peaks at the Early/Middle Miocene boundary (including N8 and N9) and one in the Early Pliocene (N19/20). The Early/Middle Miocene events seem to represent the interval of highest Neogene sea level that also coincides, from the Tasmanian and other southern (McGowran & Li 1993), eastern (Quilty 1993) and western Australian evidence, with a time of very warm marine conditions, marked by carbonates and the presence, even in Tasmania, of large, subtropical or warmer foraminiferids such as *Lepidocyclina*. This probably was the interval of warmest conditions that surrounded Australia during the Cenozoic. Figure 3 also shows the Western Australian sedimentation cycles described by Quilty (1977b, 1980b). Cycles 3A and 3B have been identified in the Gippsland

Basin (McGowran & Li 1993) and have been resolved into a more detailed transgression/regression record. This level of differentiation is at yet impossible in the Tasmanian sequence. The N14/15 record does not fit the pattern at all.

The earlier Miocene high sea-level event is not marked by warm water genera, such as *Lepidocyclina*, but does include the warm temperate (and warmer) genus *Operculina* at Penguin and at Doctors Rocks near Fossil Bluff. The fauna from southeastern Tasmania suggests cooler water than at Penguin/Doctors Rocks, perhaps due to different water masses operating. Kennett (1977) developed a scenario of circulation for the latest Oligocene, of cooler water from the south in southeastern Tasmania and warmer water from the west through Bass Strait. The results here indicate that this may have continued into the earliest Miocene. Kennett *et al.* (1985) suggested that the region was temperate in the Early Miocene, which is consistent with this interpretation. Sedimentation during this interval includes a significant noncarbonate component in the Fossil Bluff–Penguin area. Elsewhere, for example southeast of Tasman Island, and in Musselroe Bay (northeastern Tasmania), this was an interval of carbonate sedimentation.

The Pliocene sea-level high is relative only to sea levels immediately before and since and seems not to have been as high as during any of the Miocene events; nor is it represented by larger foraminiferid species of warm water aspect.

Thus, the Tasmanian marine sediment record, as far as it is known, is typical of what would be expected of a passive margin influenced by variations in sea level. The gaps in the sediment record dominate the stratigraphic column and appear to represent times of regionally low sea level. In most sedimentation cycles, the sediments seem to represent warm or relatively warm water sedimentation, and this seems to be regional in extent as noted above.

Loutit *et al.* (1983) and Kennett & Von der Borch (1985) summarised the Deep Sea Drilling Project contribution to palaeoceanography and water temperature for the southwest Pacific Ocean. Loutit *et al.* included data from Sites 279 and 281, which are southeast and south of Tasmania respectively, and quoted convincing evidence for an Early Miocene that was warmer than the Middle and Late Miocene, with a major cooling event during the interval 15–13 Ma, consistent with the evidence preserved around Tasmania. They also differentiated two warm phases within the Early Miocene, at 20.5 Ma and 16.5 Ma although their data began at about 20.5 Ma, younger than the oldest material included in this paper. Kennett *et al.* (1985) referred to the lowest $\delta^{18}\text{O}$ of the Neogene as being in the latter part of the Early Miocene and, thus, consistent with this being the warmest water of the Neogene, in turn consistent with the indications for Tasmania of the *Lepidocyclina* fauna.

Sediments marking the earliest Miocene transgression (N4/5; Faunal Unit 6) are known from north (both west and east parts) and from offshore southeastern and northeastern Tasmania. In contrast, the latest Early Miocene–Middle Miocene (N8/9; Faunal Unit 8/9) sediments are recorded onshore only from Marawah in far northwestern Tasmania, through CSIRO sample 66534, to Ocean Beach. Late Miocene and younger sections are poorly known, and more samples are needed before generalisations can be made. So far, they are known from Flinders Island and offshore northeastern Tasmania only, perhaps largely because of sampling peculiarities.

IMPLICATIONS FOR NEOGENE TECTONISM

Several of the samples examined in this study contain evidence of the depth of water at the time and site of deposition. The present water depth is often inconsistent with an hypothesis that suggests there has been no postdepositional vertical movement. For example, UTGD66534 was deposited in about 50 m water depth but now lies in 870 m and the *Aurora Australis* sample was deposited in less than 20 m but now lies in 810 m. Differences due to eustasy are much less than 800 m, suggesting that sediments at the locality have moved into deeper water either by slumping or continental margin downwarp or faulting. The differences are of the order of 400-1000 m, but no consistent trend with age is obvious. It is clear, however, that significant movement has taken place. Many more locations need to be sampled before any trend can be found reliable.

CONCLUSIONS

Samples studied in this paper all were deposited in the Neogene. The more samples are collected, the more it becomes clear that this interval is the one which is most important around Tasmania for marine Cenozoic deposition, because no marine foraminiferid faunas older than this are known from Tasmania onshore or offshore, except in sections penetrated during hydrocarbon exploration. These are from Bass Strait and from offshore west coast Tasmania (fig. 1).

The sediment record is consistent with intermittent deposition during intervals of high sea level on the global eustatic sea-level curves, such as those compiled by Vail *et al.* (1977) and Haq *et al.* (1987). It is further consistent with the history of deposition recorded from elsewhere around Australia. It further highlights the lack of information from the marine environment for most of the Middle and Late Miocene across southern Australia.

The warmest water conditions were at the close of the Early Miocene and earliest Middle Miocene, consistent with indications from earlier onshore studies (Quilty 1972).

None of the earliest Miocene faunas documented from the samples studied here represents a warm interval, although the presence of *Operculina* at Penguin and in UTGD66534 does indicate warmer conditions during deposition of those sediments than exist at present.

Neogene carbonate sedimentation occurred farther south on both eastern and western Tasmanian coasts than has been recorded previously.

Water temperature conditions during deposition varied from time to time, and the results available are consistent with southwest Pacific Ocean temperature history as documented by Kennett *et al.* (1985).

There has been significant postdepositional vertical movement of several hundred metres of some of the sediment sections.

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