

**Transgressions in the Gambier Limestone,
Gambier Basin, S.A.**

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ABSTRACT

A detailed foraminiferal profile of the Late Eocene-Early Oligocene boundary in the Gambier Limestone was investigated by local and regional biostratigraphic correlations together with foraminiferal biofacies analysis. Occurrences of important planktonic species were used to produce chronostratigraphic charts to interpret the duration of the unconformable Eocene/Oligocene boundary.

Deposition of the Early Oligocene basal Gambier Limestone is coeval with the Aldinga Transgression and is characteristic of an isochronous flooding event at sequence boundary Pr4/Ru1. The Late Eocene Narrawaturk Marl, where present, correlates to the Tuit regional biofacies member, and the Late/Middle Eocene sand unit is coeval to the Tortachilla unit.

Hiatuses are represented by erosional surfaces at sequence boundaries. The maximum estimated duration of the hiatus ranges from Pr1 to Pr4/Ru1 indicating an age gap of approximately 3 Ma, with the majority of samples showing a hiatus between Pr3 to Pr4/Ru4, representing a time slice of approximately 2 Ma. The unconformable Eocene/Oligocene contact therefore parallels the Chinaman Gully downcut in the St Vincent Basin, indicating a regional event coeval with and in response to the oceanic-oxygen isotopic glaciation.

CHAPTER 1

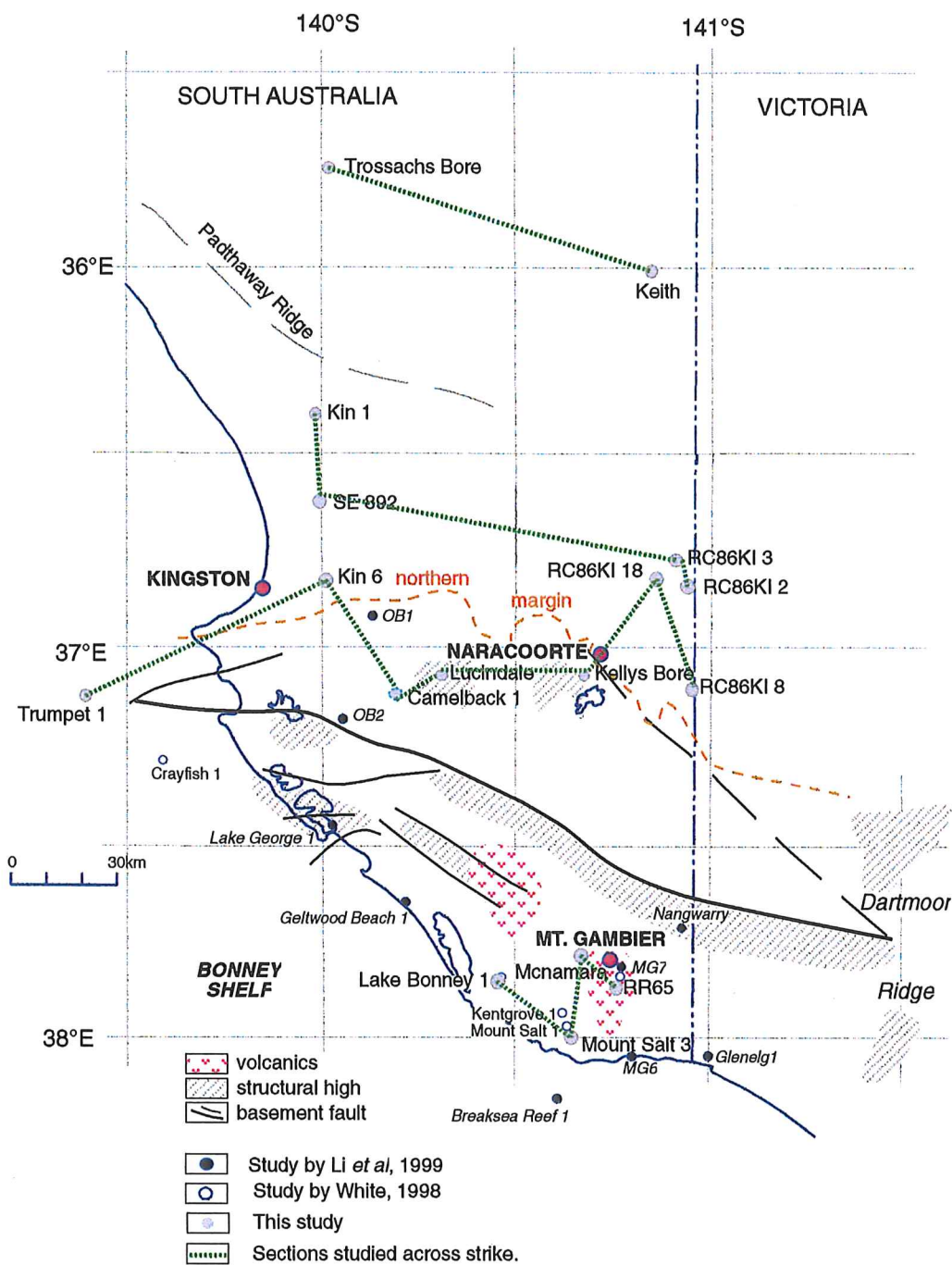
INTRODUCTION

Neritic, extratropical carbonates have been deposited along the southern Australian margin since Middle Eocene times (McGowran, *et al.*, 1997). They accumulated most extensively during several marine transgressions between the late Middle Eocene and the Middle Miocene. Marine transgressions progressively introduce deeper-water facies, thus in the stratigraphic record shallow sediment will be overlain by sediment characteristic of deeper-waters. By combining lithostratigraphy, physical stratigraphy and foraminiferal biostratigraphy, variations in sea level can be easily identified.

Foraminifera are unicellular protists widely employed in stratigraphy and marine geology for age-dating and paleoenvironmental interpretation (Li & McGowran, 1995). They occur in a wide variety of substrates at all depths in the marine realm. Planktonic foraminifera are most common in open marine facies, whereas benthic forms are more abundant in shallow water environments.

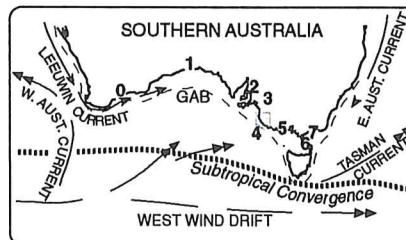
The Gambier Limestone in southeastern South Australia is one of the purest and temporally most persistent neritic carbonate province along southern Australia. With samples taken across strike of the Basin (Figure 1), this project involves sequence biostratigraphy and paleoenvironmental analysis of the Late Eocene Narrawaturk Marl (where present) and Early Oligocene basal Gambier Limestone at local and regional scales.

Figure 1 : Location of drilled sections analysed



Inset: Present day circulation and distribution of Cainozoic basins in southern Australia.

- 0: Bremer
- 1: Eucla
- 2: St Vincent
- 3: Murray
- 4: Gambier
- 5: Otway
- 6: Bass
- 7: Gippsland



(modified from Cockshell, 1995 & Li, 2000)

1.1. AIMS OF THIS STUDY

This project has several main aims that are listed below:

- 1) To complete foraminiferal profiles across strike of the Gambier Basin at the Eocene/Oligocene contact.
- 2) To extract environmental patterns or shifts between faunas from these sections.
- 3) To determine a specific age for the deposition of the Basal Gambier Limestone member using datums and events of basinwide and regional significance.
- 4) To identify and define the Late Eocene/Early Oligocene boundary.
- 5) To define boundaries based on differences between abundances of shallow and deeper water species.
- 6) To identify duration of hiatuses at the unconformable surface of the boundary.
- 7) To strengthen local correlations to a regional context, by integrating other sections from previous work on the Gambier Basin.
- 8) To relate the neritic record of southern Australia (Gambier Basin) during the Late Eocene/Early Oligocene to global glacioeustatic patterns.

Studies of foraminiferal biofacies and biofacies shifts relating to environmental changes especially fluctuations in sea level through the Eocene to Miocene of southern Australia have been undertaken in the Eucla Basin (Li *et al.*, 1996), St Vincent Basin (McGowran & Beecroft, 1986; McGowran, 1992; Moss, 1995), western Murray Basin (Navidad, 1997; Li & McGowran, 1999), Gippsland Basin (Li & McGowran, 1997) and Torquay Subbasin (Li *et al.*, 1999). From these studies it can be noted that packets of strata are better recognised by their foraminiferal biofacies than their lithofacies; also neritic shallowing and the stratigraphic levels of unconformities are correlative with successions of global third-order sequences. This suggests that the regional

or local packages of biofacies are manifestations of eustatic fluctuations at 10^6 yr time scale. Implying these results to that of the Eocene/Oligocene contact was imperative to verify regional correlation to the Gambier Basin.

Several transgressions occurred through the Middle to Late Eocene, with the best defined hiatus occurring at the Eocene/Oligocene contact. The unconformable boundary is well represented in the St Vincent Basin with a downcut of up to 50 m observed by Lindsay (1981). Such downcuts or hiatuses should also be evident in the neighbouring Gambier Basin, suggesting a regional event coeval with and in response to the oceanic-isotopic glaciation (Miller *et al.*, 1991). This holds significance in determining the duration of the Eocene/Oligocene boundary across the Gambier Basin, providing detail of the hiatus in a chronostratigraphic time scale.

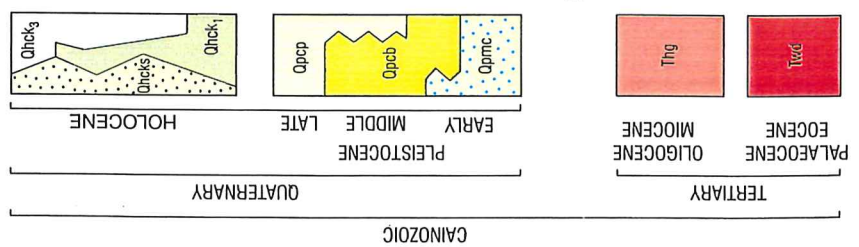
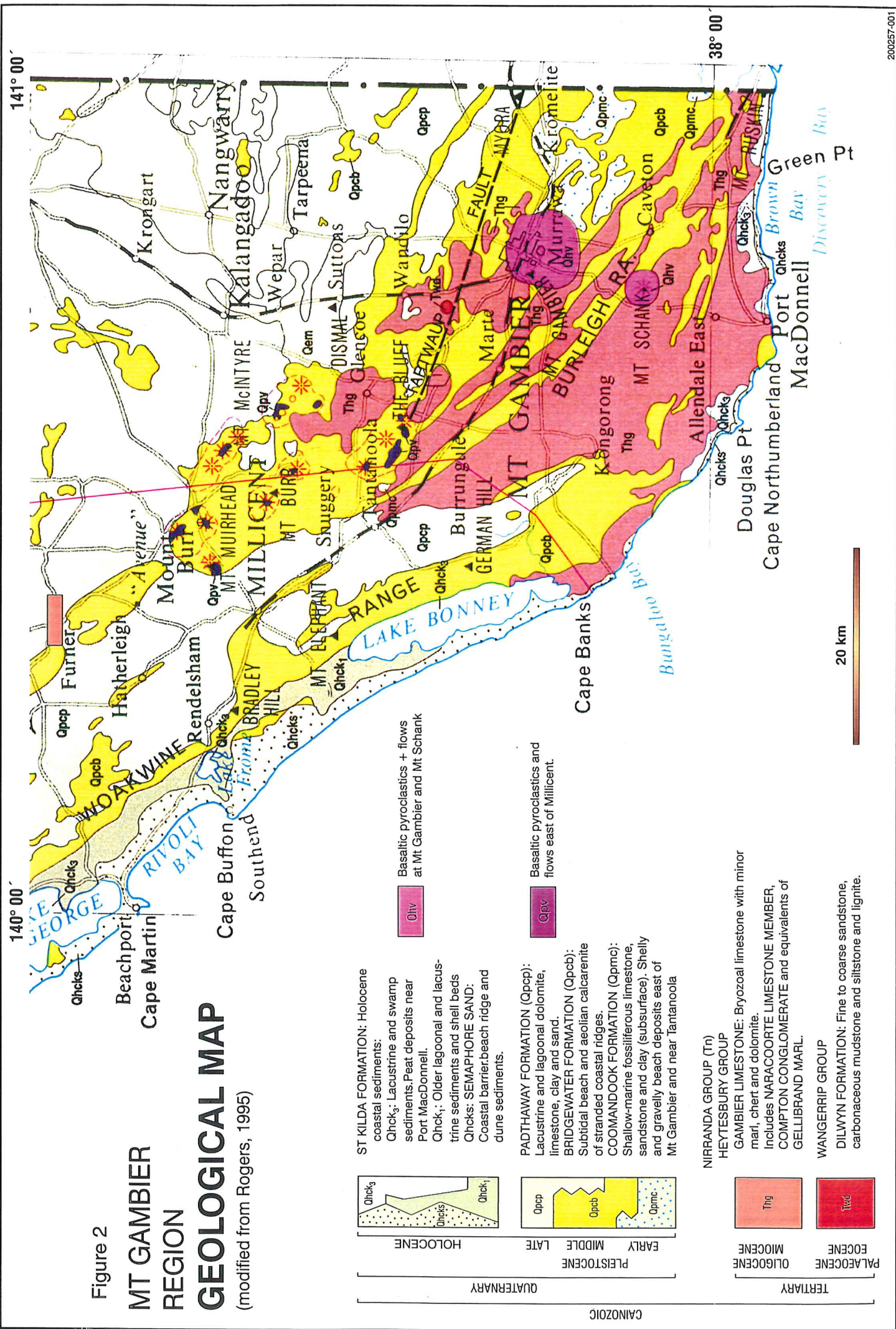
The threefold subdivision of the Gambier Limestone reflect variations with implicitly diachronous boundaries (White, 1996). Is the erosional surface at the Eocene/Oligocene boundary part of this diachronous trend or is it an isochronous flooding event? Detailed foraminiferal biostratigraphy at the contact will enable a more confident proxy to be drawn for the depositional environment at the time.

Figure 2

MT GAMBIER REGION

GEOLOGICAL MAP

(modified from Rogers, 1995)



- ST KILDA FORMATION:** Holocene coastal sediments:
 - Qhck₃: Lacustrine and swamp sediments. Peat deposits near Port MacDonnell.
 - Qhck₂: Older lagoonal and lacustrine sediments and shell beds
 - Qhck₁: SEMAPHORE SAND: Coastal barrier beach ridge and dune sediments.
- PADTHAWAY FORMATION (Qpcc):** Lacustrine and lagoonal dolomite, limestone, clay and sand.
- BRIDGEWATER FORMATION (Qpbc):** Subtidal beach and aeolian calcarenite of stranded coastal ridges.
- COOMANDOOK FORMATION (Qpmc):** Shallow-marine fossiliferous limestone, sandstone and clay (subsurface). Shelly and gravelly beach deposits east of Mt Gambier and near Tantanoola
- NIRRANDA GROUP (Tr)**
- HEYTESBURY GROUP**
- GAMBIER LIMESTONE:** Bryozoal limestone with minor marl, chert and dolomite. Includes NARACOORTE LIMESTONE MEMBER, COMPTON CONGLOMERATE and equivalents of GELLIBRAND MARL.
- WANGERRIP GROUP**
- DILWYN FORMATION:** Fine to coarse sandstone, carbonaceous mudstone and siltstone and lignite.

- Qhvc**: Basaltic pyroclastics + flows at Mt Gambier and Mt Schank
- Qpv**: Basaltic pyroclastics and flows east of Millicent.

CHAPTER 2

BACKGROUND THEORY

INTRODUCTION

Cainozoic strata are widespread in South Australia, occupying gently downwarped cratonic basins, palaeochannels, and occurring as extensive thin sheets in the interior (Alley and Lindsay, 1995). Thicker successions accumulated in passive continental margin basins, where they unconformably overlie Mesozoic rift-basin sediments. Exposed sediments on the inland are heavily weathered and are sometimes capped by siliceous and ferruginous duricrusts. The Gambier basin is a classic example of Tertiary strata.

2.1 TERTIARY FORAMINIFERAL RESEARCH

The southern, extratropical, Indo-Pacific region comprises of southern Australia and New Zealand. The stratigraphic record in southern Australia is a thin, poorly outcropping cap on a relatively stable passive continental margin (McGowran *et al.*, 1997).

Crespin (1943) initiated the use of foraminifer and lithostratigraphy in the characterisation of regional stages. Glaessner (1951) provided the future framework for correlations and age determination in the Tertiary with erection of zones based on identification of *Hantkenina alabamensis*, *Victoriella plecte* and *Austrotrillina howchini*. Jenkins (1960) pioneer research resulted with the identification of 11 planktonic foraminiferal biozones from a Lakes Entrance oil shaft in east Gippsland, Victoria, thus contributing to modern understanding of the southern temperate planktonic foraminiferal succession of the mid Tertiary. McGowran (1971) held success with the first comprehensive correlation of local biozones to a modern global geochronology. These

correlations are discussed in depth in Abele *et al* (1976), Heath & McGowran (1984) and Carter (1990).

McGowran and Li (1993) identified 16 planktonic assemblages spanning 20 Ma. First and last appearances of planktonic taxa were used to correlate southern Australian stages to the zones specified by Berggren *et al.* (1995). From this, McGowran and Li (1997) established a chronological series for taxa variations and relative abundance of benthic foraminifer at Lakes Entrance. In re-examination of Waikerie core material (2W), Li (1997) uncovered important biostratigraphic and ecostratigraphic datums.

2.2 THE GAMBIER BASIN

The Gambier Basin (previously defined as the Gambier Embayment of the Otway Basin) is located in southern Australia, adjacent to and partially overlying the Otway Basin. The basin straddles the Victorian and South Australian coastline with the western two-thirds located in southeastern South Australia and the eastern third located in southwestern Victoria. The sub-basin covers an area of more than 150,000 km², two-thirds of which is located offshore (Yu, 1988).

The boundary of the Gambier Basin approximately follows the depositional limit of Cainozoic sediments. The northern limit of the basin is the E-W trending Padthaway Ridge (Sprigg, 1952; Morton and Drexel, 1995). This submerged basement high separates the Gambier Basin from the Murray Basin and is marked by a steep gravity gradient (Wopfner and Douglas, 1971). The Merino Uplift marks the eastern limit of the basin and the southern margin represents the present day continental shelf in water depths of 2500m. The Gambier Limestone unit is located to the southwest of the Tartwaup Fault, which trends approximately northwest-southeast through the northern half of the basin (Figure 2). Although there are excellent coastal sections in

this region, understanding of the Cainozoic stratigraphic record relies heavily on drill hole data.

2.3 GEOLOGICAL HISTORY

The Gambier Basin has been defined as consisting of Cainozoic sediments (Wopfner and Douglas, 1971).

Early Cambrian rifting associated with the Cambro-Ordovician Delamerian Orogeny produced a series of northwest trending depressions into which fluvio-lacustrine conglomerates, sandstones and siltstones were later deposited from the Late Devonian to Early Carboniferous (Wopfner and Douglas, 1971).

Glaciation was wide spread in the Late Carboniferous and Early Permian (Bourman, 1987; Wopfner, 1980), which scoured the basement, leaving depressions that infilled with shale diamictite, sand and laterites (Flottman and Cockshell, 1995).

Triassic and Jurassic sediments are rare, a result of major planation of the Paleozoic basement. Evidence that these sediments were deposited and subsequently eroded is suggested by the presence of reworked Triassic spores (Morton and Drexel, 1995; Yu, 1988).

Thermal doming, signifying the onset of an extensional regime, began in the Late Jurassic and Early Cretaceous, which later led to the separation of Antarctica and Australia (Middleton and Falvey, 1983; Yu, 1988; Pettifer *et al.*, 1991; Morton and Drexel, 1995; Finlayson *et al.*, 1998). The rifting was progressive from east to west, forming east-west trending grabens. Fracturing over the crest of the domed surface induced a fluvial environment of deposition within the fractures (Morton and Drexel, 1995). During the Early

Cretaceous, the rate of infilling increased, forming grabens and half grabens in which fluvial and lacustrine environments formed (Yu, 1988). Rift volcanism was also active at this time, providing a source of lithic debris (Morton and Drexel, 1995; Wopfner and Douglas, 1971; Yu, 1988).

Late in the Cretaceous there was a sag-rift phase in basin formation (Middleton and Falvey, 1983; Morton and Drexel, 1995). Extension was orientated in a northeast-southwest direction, causing the basin's depocentre to move southward (Morton and Drexel, 1995). At ~95 Ma, a major uplift occurred prior to breakup, producing the unconformity at the top of the Otway Group (Yu, 1988).

Christ (1984) suggested a rotational, scissor-like separation of Australian and Antarctic plates with the Australian mainland pivoting around a point of Cape Howe, on the eastern coast of Australia. This implies that the Tasman Sea and Southern Ocean broke up at the same time during the Early Cretaceous (Yu, 1988). However, Yu (1988) states that available evidence does not support simultaneous opening of the Southern Continents.

Continental separation started during the Middle Cretaceous and drifting occurred at a relatively slow rate for the next 40-50 Ma (Cande and Mutter, 1982; Morton and Drexel, 1995). As drifting continued the sea progressively transgressed from the east over a subsidising margin producing deltaic and marginal marine environments (Deighton *et al.*, 1976; Yu, 1988). Lowry (1987) states that during the Middle Cretaceous time, in addition to slow spreading between Australia and Antarctica, the picture is complicated by the opening of the Tasman Sea, which resulted in the eventual separation of the New Zealand and Australian plates and formation of the Gippsland Basin. The Tasman Sea break up occurred between 82-52 Ma (Weissel *et al.*, 1977) and the Otway Basin, being in close proximity, would have felt the effects (Yu, 1988).

The Tasman Sea Transform Fault Zone associated with the spreading centre would have subjected the Otway Basin to a right lateral stress regime (Sprigg, 1985; Yu, 1988). This east-west stress would have progressively uplifted the Otway Basin and formed the Port Campbell and Gambier Embayments and the various structural highs (Yu, 1988). Overall, the Southern Ocean Transform Fault Zone only had a small influence on the development of the structural feature of the Otway Basin because the rate of spreading was slow as was movement on the transform faults (Yu, 1988).

From 42 Ma, the spreading rate between Australia and Antarctica was significantly greater (Yu, 1988; Deighton *et al*, 1976; Morton and Drexel, 1995)(Figure 3). The Southern Ocean spreading centre formed the more dominant arm of the rift system and continued spreading at an increased rate while the Tasman Sea spreading centre aborted its spreading activity (Yu, 1988). Increase in spreading rate caused thermal subsidence and the initiation of marine transgressions into the southern marine basins. Deposition of large amounts of marine sediments followed with the Cainozoic sediments passed upwards and seawards from early-Tertiary non-marine clastic sediments into marine temperate water limestone (i.e. Gambier Limestone).

Introduction of the Leeuwin Current (Figure 1, inset) along with marine transgression and plate reorganisation lead to the starvation of clastic sediments and allowed the progradation of carbonates across the shelf (Morton and Drexel, 1995; Deighton *et al*, 1976).

A comprehensive wrench regime then prevailed in the area from the Miocene to Recent. The wrenching was dextral (right lateral) and orientated in an east-west direction and this lead to northeast-southwest trending anticlines and inversion of faults (Morton and Drexel, 1995). This late compressive phase in the Otway Basin corresponds to the situation where structures that originally

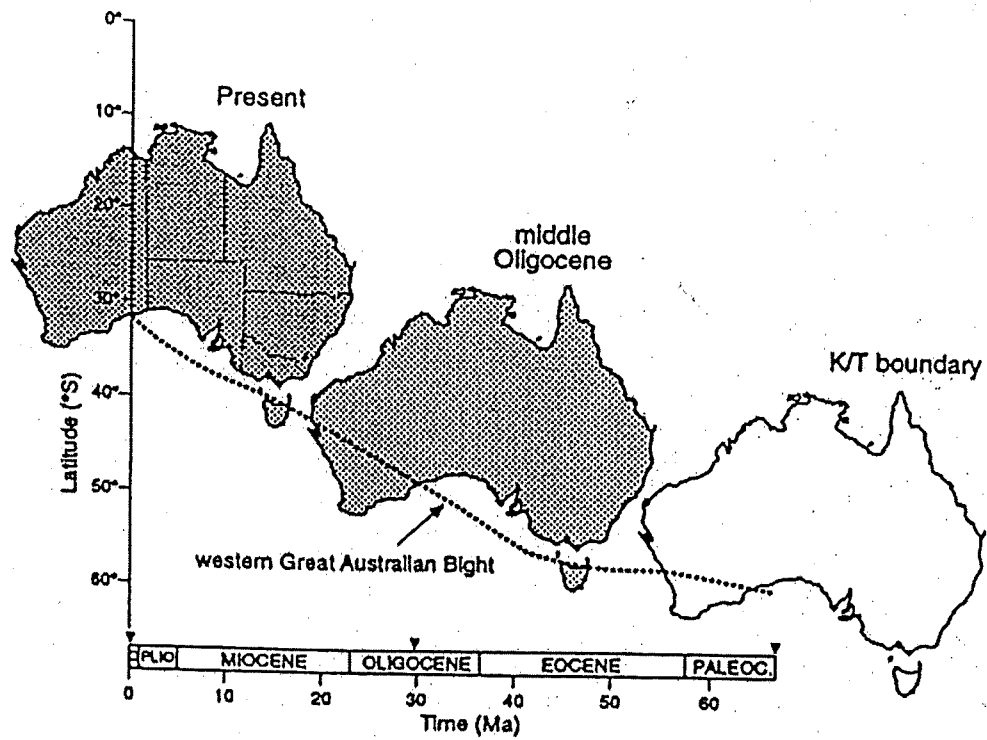


Figure 3 : Australia's migration on a time-latitude grid, adapted from a sketch by D.A. Feary (Feary *et al.*, 1994). The dog-leg in the path of the Bight is at the onset of rapid spreading followed shortly by the onset of neritic carbonate accumulation. (Mcgowran *et al.*, 1997)

had fault movement subsequently show late reverse movements at younger stratigraphic horizons (Yu, 1988; Laing *et al.*, 1989; Morton and Drexel, 1995).

A period of eustatic sea-level fall and tectonism during the remainder of the Miocene resulted in subaerial exposure, karstic weathering and erosion of the Gambier Limestone (Smith *et al.*, 1995).

Apart from Quaternary volcanism and associated uplift, the Gambier Basin has been relatively stable since this time. Volcanism was active from Pliocene to Recent times. The extrusive volcanics increase the risk for petroleum occurrences by introducing magmatic carbon-dioxide (Morton and Drexel, 1995). The current landscape is a low-relief doline and uvala, multigenerational, karst terrain (Twidale *et al.*, 1983).

2.4 STRATIGRAPHIC FRAMEWORK

2.4.1 CAINOZOIC STRATIGRAPHY

When the Cainozoic stratigraphic record around the southern margins of Australia is plotted against a geochronological scale, it falls into four packets or second-order sequences, termed 'super sequences', with intervening hiatuses, regression or non-deposition events (McGowran, 1979; McGowran *et al.*, 1997).

- IV – Latest Miocene to Quaternary
- III – Late Oligocene to middle Miocene
- II – Late-middle Eocene to early Oligocene; and
- I – Late Paleocene to early Eocene.

These four stratigraphic sequences ride on the first-order trajectory from the mid-Cretaceous high to the Neogene. The second super sequence includes

the Gambier Limestone, hence it is relevant to this study. The biogeohistory record in southern Australia correlates with these four packages, including evidence that increasing sea level accompanies increased humid conditions at the second and third-order (McGowran *et al.*, 1997).

2.4.2 GAMBIER BASIN STRATIGRAPHY

The Cainozoic (Paleocene-Recent) sediments of the Gambier Basin unconformably overlie the Late Cretaceous succession of the Otway Basin. Sedimentation in the Late Paleocene to Middle Eocene has been identified as forming part of the paralic Wangerrip Group (i.e. *L.balmei* to *M.diversus* palynozones)(White, 1995). These sediments were deposited at a slow rate in a marginal marine environment and the presence of ooids suggests a low energy environment (Morton and Drexel, 1995).

Sediments deposited during the Late Paleocene to Middle Eocene (i.e. *L.balmei* to *P.asperopolus* palynozone), partially representing the Dilwyn Formation (White, 1995) in which Holdgate (1981) recognised up to seven cycles. The cycles commence with a sudden change to shale or silty-shale from sand, evident on the gamma ray log, consistent with deltaic cycles described by Galloway (1968), Weber (1971), and Selley (1976).

Increasing marine influence led to sediment deposition of the marginally marine Nirranda Group, ranging in age from Middle to Late Eocene (ie *P.pachypolus* to *N.asperus* palynozone, which correlates to latest P14 to P17 planktonic foraminiferal zone)(White, 1995). Sediments representing this group are present in wells north of the Tartwaup Fault, but cannot be identified with any certainty in wells in the southern part of the basin (White, 1995).

During the Early Oligocene, starvation of clastic sediment, plate reorganisation and marine transgression lead to deposition of platform carbonates, which are classified by some authors as forming part of the Heytsbury Group (Figure 4)(Morton and Drexel, 1995; Mehin and Link, 1994; White, 1995,1996, Finlayson *et al.*, 1998; James *et al.*, 1993).

2.4.3. REGIONAL AND GLOBAL SUCCESSIONS

Neritic, extratropical carbonates have been deposited along the southern Australian margin since Middle Eocene times. They accumulated most extensively during several well-documented marine transgressions between the late Middle Eocene and the Middle Miocene and recorded the development of the nascent Southern Ocean (McGowran *et al.*, 1997). The Eocene-to-Miocene record has been documented as a second-order, unconformity-bounded package of strata consisting of unconformity-bounded packages successively at the third and fourth orders which can be correlated to neritic and regional examples of relative global successions (Li *et al.*, 1999). Third-order glaciations, identified by oxygen-isotope fluctuations in pelagic carbonates, can be correlated to package-bounding unconformities on continental margins, thereby suggesting glacioeustasy as the mechanism (Miller *et al.* 1998; Hardenbol *et al.* 1998). McGowran *et al.* (1997a) reassessed the neritic patterns of the region in terms of global theories of pattern. Feary & Loutit (1997) demonstrated that seismically recognised packages of strata in the offshore, deep water Gippsland Basin are consistent with the global pattern. Holdgate & Gallagher (1997) and Gallagher *et al.* (2000) have combined stratigraphy with foraminiferal biostratigraphy and ecostratigraphy to identify and date third order sequences in the carbonate-rich neritic facies of the Gippsland and Otway Basins.

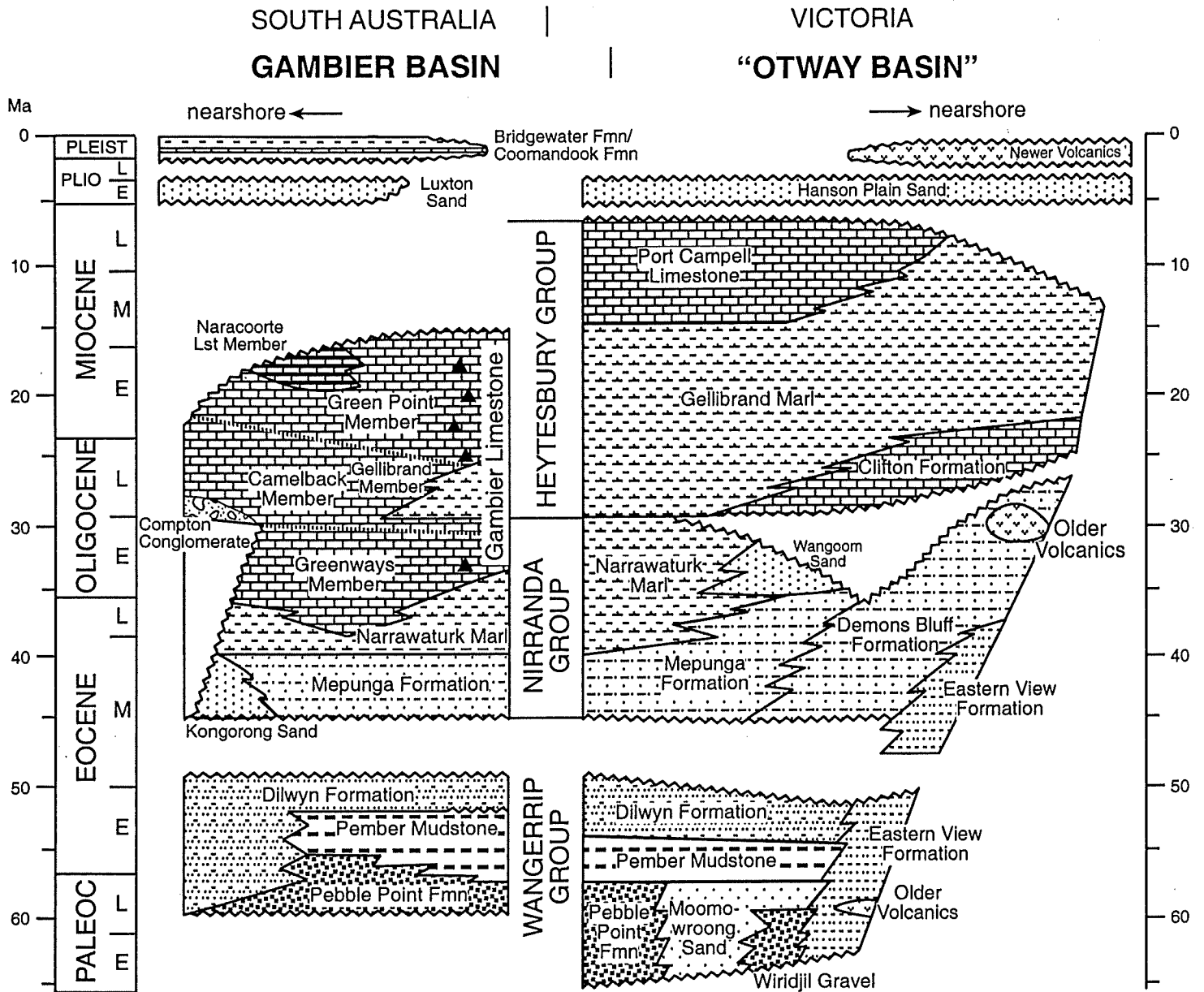


Figure 4: Lithostratigraphy of the Gambier and Otway Basin. Note the Diachronous boundaries. Data from Abele *et al.* (1976), Morton *et al.* (1995), White (1995) and Abele (1997).

2.5. GAMBIER LIMESTONE

The Gambier Limestone is a major fossiliferous carbonate, varying in thickness up to 400m offshore, deposited on an open-water marine shelf. The Gambier Limestone can be subdivided into three members (Figure 4). Subdivisions of the Gambier Limestone have been made by previous authors (e.g. Ludbrook, 1962,1971; Lindsay, 1967,1985; McGowran, 1973), but were based on a limited number of successions and had not formally been defined. A recent examination of 26 petroleum wells by White (1995) confirms the value of a three-fold division of the Gambier Limestone. The type section of the Gambier Limestone is located in the sinkhole in the town centre of Mount Gambier, South Australia (White, 1996).

The basal Greenways Member is of latest Eocene to Early Oligocene age (White, 1996)(i.e. P15 to no younger than P20 planktonic foraminiferal zones, correlative with Middle *N.asperus* to *P.tuberculatus* palynozones) and typically comprises of grey limestone, marly limestone and marl with glauconite. The Greenways member includes the 'sponge spicule zone' noted by Ludbrook (1962) in Mount Salt where the member is up to 70m thick. Accessories include bioclasts, chert, quartz and glauconite (Figure 5).

The Camelback Member ranges in age from Early Oligocene to Early Miocene (White, 1996)(i.e. no younger than top P20 to no older than at least basal N5 planktonic foraminiferal zones, which is correlative with *P.tuberculatus* palynozone)(White, 1995). It is ~10-250 m thick, off-white, white or fawn limestone with bryozoal calcarenite, chert, quartz, rock fragments, forams, macrofossils and glauconite (White, 1996)(Figure 6). The boundaries with the Greenways Member and the Gellibrand Marl are apparently conformable (White, 1996). The environment of deposition is interpreted to be inner and middle shelf (White, 1995). This member is quarried extensively for building stone.

The Green Point Member (White, 1996) ranges in age from Early Miocene to at least Middle Miocene (i.e. no younger than N4 to at least N9 planktonic foraminiferal zones, which is correlative with *P.tuberculatus* to at least Lower *T.bellus* palynozones)(White, 1995). It is at least 193 m thick and is characterised by its grey colour and abundant chert. The limestone is also comprised of macrofossils, forams, quartz, glauconite and pyrite (White, 1996)(Figure 7). The Green Point Member conformably overlies the Camelback Member, and is partly equivalent to the Naracoorte Member. It is commonly absent north of Mount Gambier due to erosion.

Li *et al* (2000) alternatively divided the Gambier Limestone on the basis of biostratigraphy and unconformities instead of lithologically. Figure 8 shows the sub-divisions of the Gambier Limestone into 7 unconformity bounded sequences, or allostratigraphic units corresponding to third-order sequences.

Regional warping has been dominant over faulting since the Late Cretaceous, although seismic sections indicate that many faults displace the Gambier Limestone. Sprigg (1952) described gentle folding in the Gambier Limestone, which he related to differential movement of fault-bounded basement blocks, and noted zones of dolomitisation in the same unit which appear to be associated with faults. Consequently the dolomitised zones in the Gambier Limestone are associated with the Tartwaup and Nelson Faults. A deposit near Tantanoola is quarried for high-grade dolomite used in the glass industry. Intervals of primary dolomite at the base of the Gambier Limestone could be a source of magnesium for the zones of secondary dolomitisation (Morton and Drexel, 1995).

James and others (1993) conducted a petrographic and geochemical study on dolomites present within the Gambier Limestone. They drew the conclusion that the dolomites replaced the diagenetically stabilised Gambier Limestone at some time during an uplift event in the Middle-Late Miocene. Geochemistry suggests that dolomitisation was predominantly by seawater, but admixing of

continental, possibly fresh groundwater is consistent with the stable isotope and trace element data (James *et al.*, 1993). Fabric selective dissolution of the dolomite crystal core and the Iron-rich zone and later precipitation of calcite within dolomite crystals was also observed in samples of Gambier Limestone (James *et al.*, 1993).

Overlying the Naracoorte Limestone is a thin unit called the Gellibrand Marl (White, 1995), which is only present in the northern parts of the basin. The sandy, Pleistocene aged Bridgewater Formation unconformably overlies the Camelback and Green Point Members of the Gambier Limestone (White, 1995).

Deposition of the Gambier Limestone ended in the Middle Miocene during a period of global eustatic fall in sea level and tectonic uplift of the southern Australian continental margin. During the remainder of the Miocene, the formation was exposed to extensive karstic weathering and erosion, which has continued intermittently to the present day.

2.5.1. TERTIARY SEDIMENTARY FEATURES IN GAMBIER LIMESTONE

The Gambier Sub-basin experiences a Mediterranean climate, with hot, humid, dry summers and variably wet winters. Surface expression is minimal within the Gambier Sub-basin with only a handful of outcrops visible. A large part of the basin is expressed as a coastal plain with extinct volcanoes and ridges of sub-parallel northwest trending dunes. These dunes are 15-30 m high and are associated with Pleistocene stranded shorelines (Wopfner and Douglas, 1971).

Spectacular karst features have developed throughout the region within the Gambier Limestone. Overall, this karst region extends as a broad band southwards from Naracoorte towards and beyond the present coastline,

reaching a maximum width of more than 60 km (Marker, 1975). Karst in the Gambier Limestone is more spectacular and extensive, and includes large cenotes (e.g. Little Blue Lake and Hell's Hole), complex joint controlled cave systems and dolines. The depth to which karst features have developed increases towards the coast due to an increasing thickness of Gambier Limestone due to lower sea levels and water tables during the Pleistocene glacial periods.

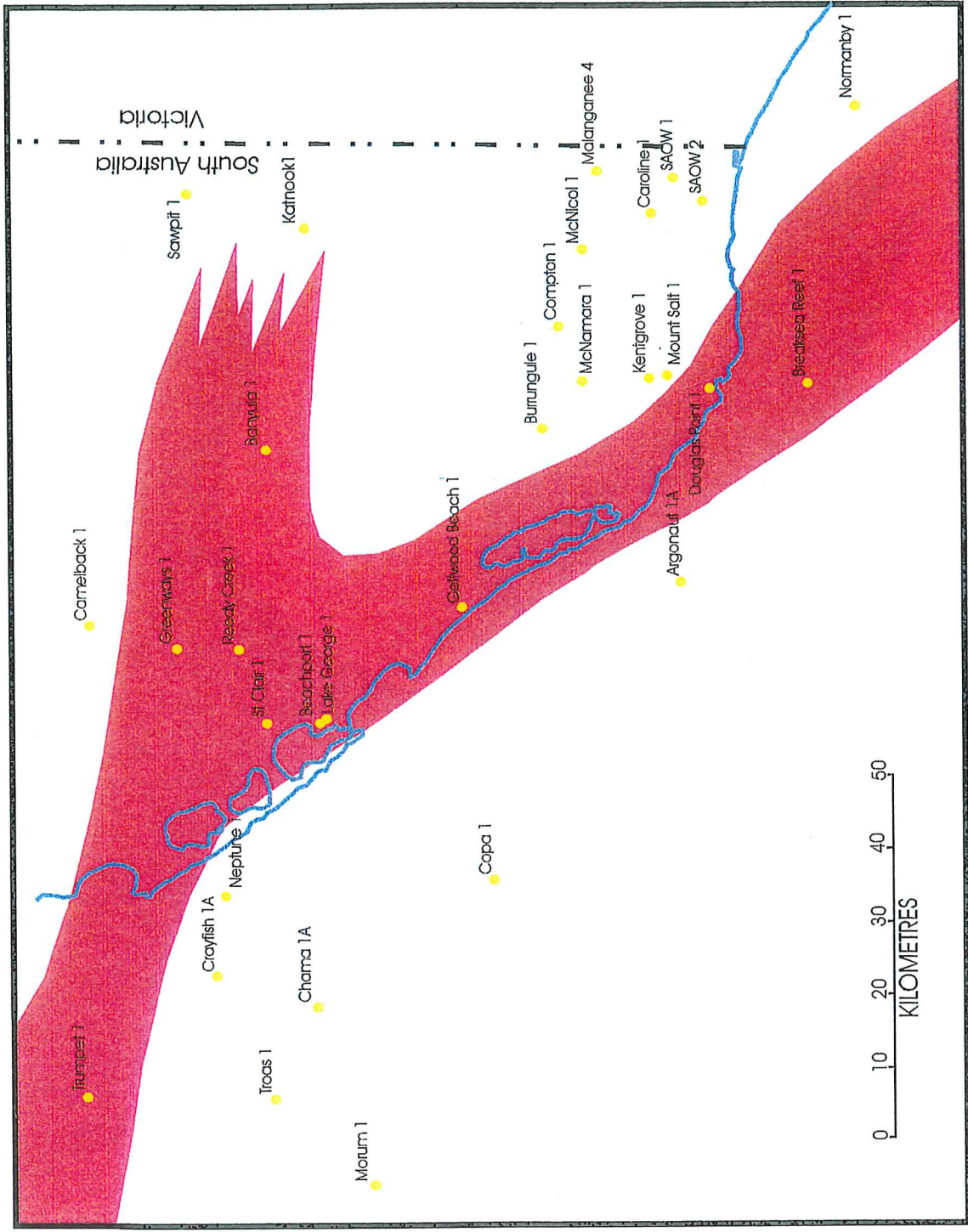
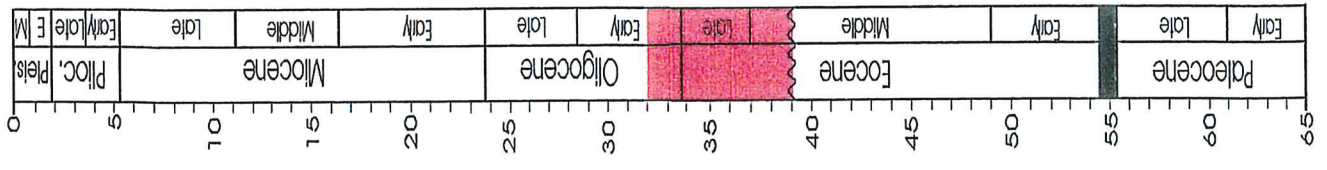


Figure 5 Approximate distribution of the Lower Gambier Limestone, Greenwatts Member of the Gambier Limestone (after White, 1995).



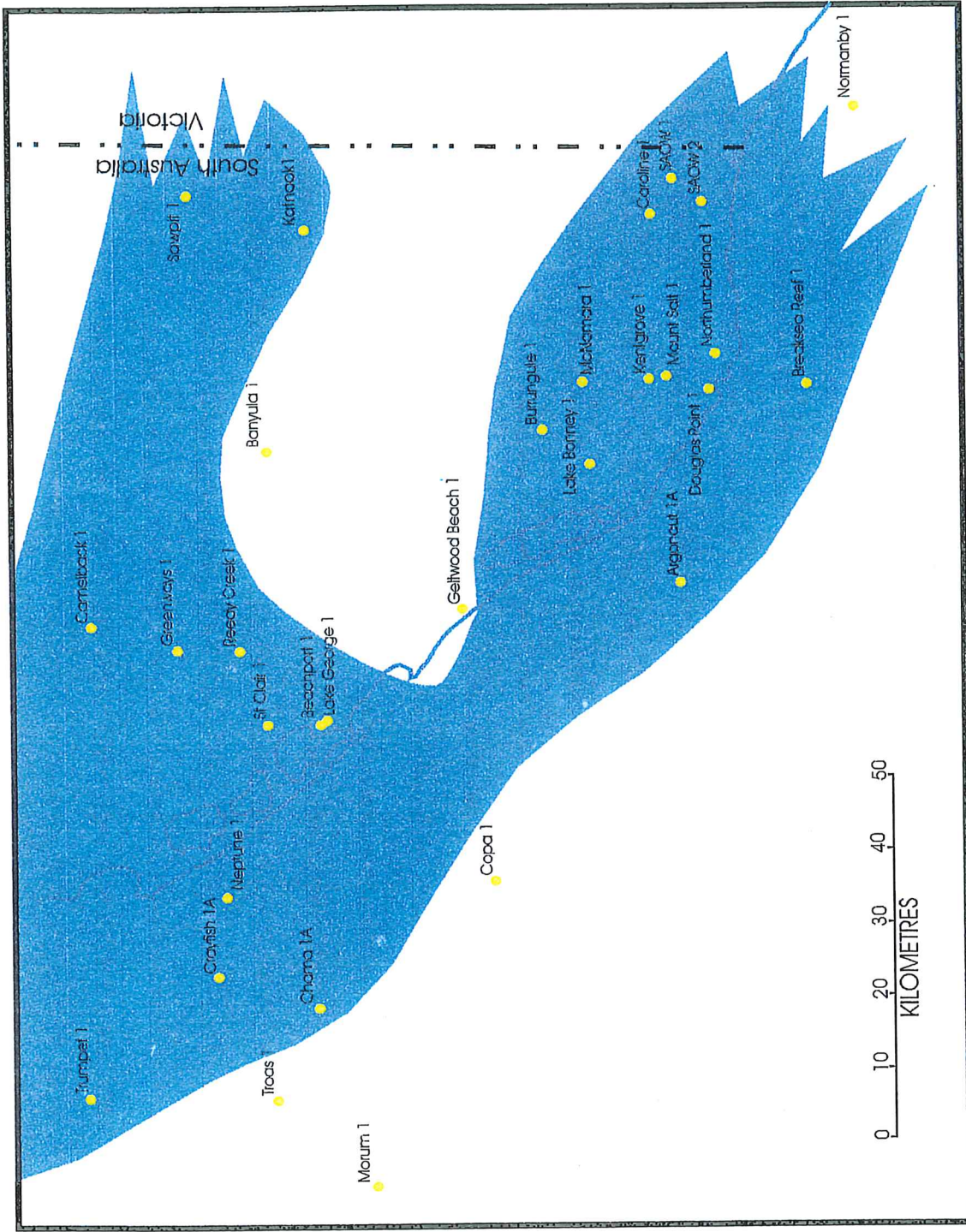
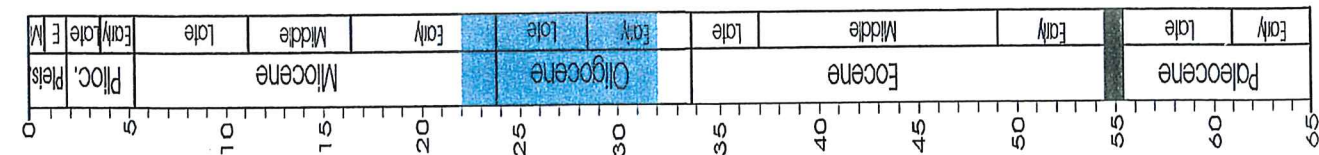
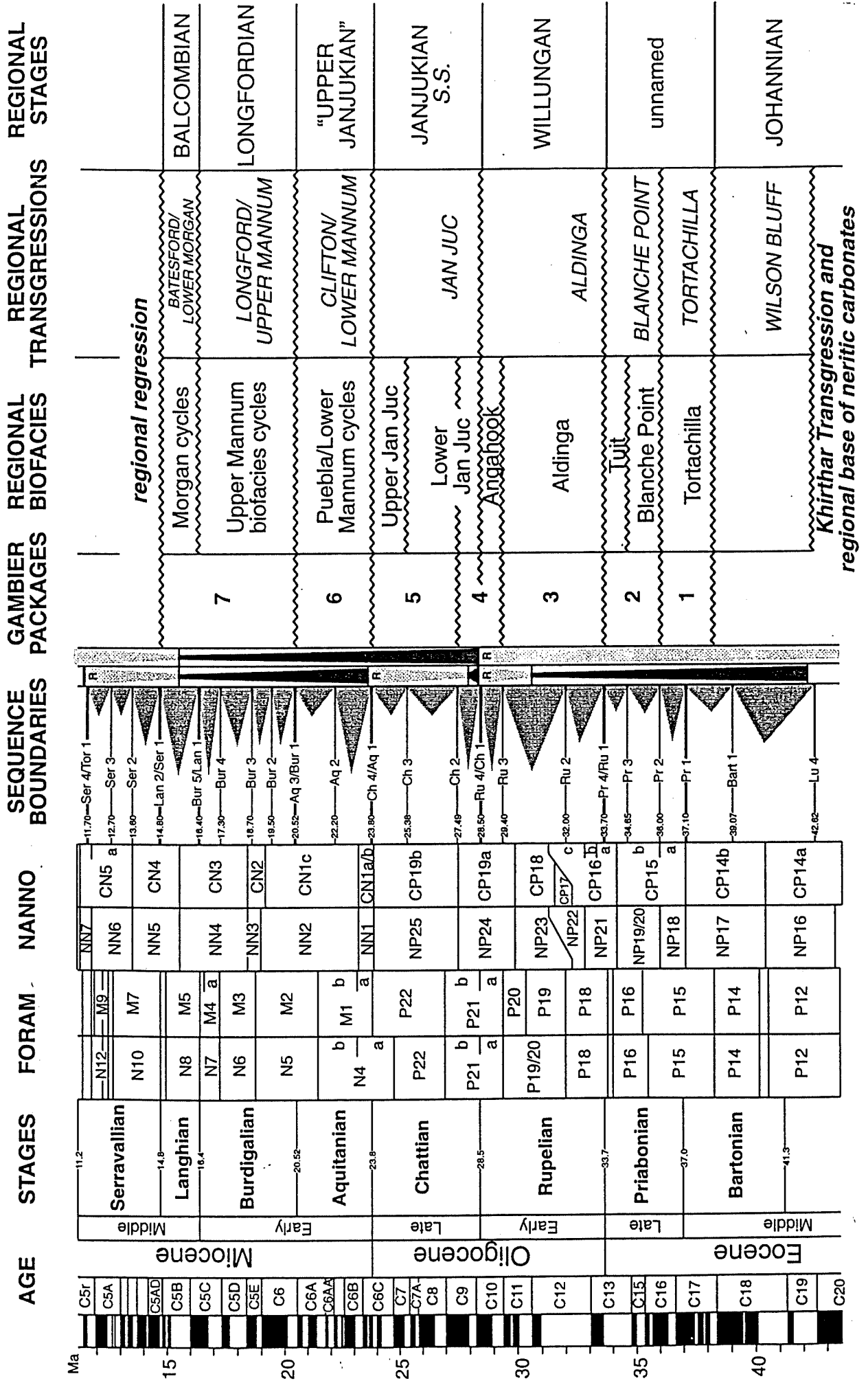


Figure 6 Approximate distribution of the Middle Gambier Limestone Camelback Member of the Gambier Limestone (after White, 1995).

Figure 8. The lithological units of the Gambier Limestone in a regional and global context.



CHAPTER 3

FORAMINIFERAL PROFILE

INTRODUCTION

A detailed foraminiferal profile has been established for the base of the Gambier Limestone across strike of the Gambier Sub-basin. This chapter aims to describe the characteristics of the profile by analysis of planktonic and benthic foraminiferal assemblages affirming correlation between cores.

For the description of the foraminiferal profile the sections have been divided into two main parts across the Eocene/Oligocene boundary, where the most significant faunal change has occurred (ie. above and below the base of the Gambier Limestone).

Planktonic and benthic abundance charts are located in Figure 9 (1-25).

3.1 PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

The planktonic to benthic (P/B) ratio shows planktonic foraminiferal abundances range from 5% to >90%, generally being more abundant in the samples taken from the Narrawaturk Marl, beneath the Gambier Limestone. In the basal Gambier Limestone planktonic abundance is 35% and benthic 65% in comparison to the planktonic abundance in the Eocene marl, 22% and benthic 78%. These figures indicate a defined shift in environmental conditions with the Eocene marl being deposited in shallower water and the basal Gambier Limestone accumulating in deeper water conditions. High planktonic abundances (P/B ratio) indicate increased oceanic influence implying high sea level, as at maximum flooding surfaces, and conversely for low values near sequence boundaries (Li *et al.*, 2000).

The oldest planktonic assemblages included *Gloigerinatheka index*, *Acarinina aculeata*, *A. collactea*, *Subbotina linaperta* and *S. angiporoides*, characterising later Middle to Late Eocene, Zones P14-P16 (McGowran 1989; McGowran *et al.* 1997a). Kin 6 was sampled from the marl and an age determination of Late Eocene is characterised by coexistence of *S. linaperta* and *Turborotalia increbescens*. The presence of *G. index* only in the marl sediment verifies the Late Eocene age. Classic index species, *G. index* and *S. linaperta* found in the marl of SE 892, and *G. index* with *Globorotalia euapertura* in RR65 are indicative of Late Eocene deposition. Kellys Bore marl is also consistent with the age determination of Late Eocene with the coexistence of *S. linaperta* and *T. increbescens*.

Chiloguembelina cubensis is present only in the lower sample of the Camelback drillhole and ranges from Late Eocene into the Early Oligocene. The presence of *C. cubensis* with *Globigerina brevis* in Camelback basal Gambier Limestone is indicative of deposition in the Early Oligocene. *T. increbescens* and *T. pseudoampliapertura* also range into the Early Oligocene, but cease to be good age determinates when compared to coexistence of species from the Late Eocene through the Early Oligocene, as seen in Camelback, Kin 6 and Kellys Bore.

The presence of both *Globigerina praebulloides* and *Globigerina ciperoensis* in Keith 1 basal Gambier Limestone indicates that it is of Early Oligocene age. Determination of Early Oligocene age is also consistent in samples RC86KI 3 and RC86KI 2, with the coexistence of *Subbotina angiporoides* and *Globigerina labiacrassata*.

The Early Oligocene is characterised by increased presence of *Subbotina angiporoides* and *Globorotaloides* spp. *Tenuetella munda* is present in Lucindale 1 and its presence along with *G. praebulloides* is indicative of the Early Oligocene. In SE 892, coexistence of *T. munda*, *Globorotaloides suteri*

and *G. brevis* also correlates well with the Early Oligocene age for the basal Gambier Limestone.

In Keith 1, the presence of *G. praebulloides* and *G. ciperensis* in the basal Gambier Limestone provides an age determination of Early Oligocene. This trend of age determination is consistent across the basin for the basal Gambier Limestone, indicating that deposition is characteristically Early Oligocene.

The Narrawarturk Marl is consistently Late Eocene across the basin with the exception of the presence of *G. ciperensis* in Lake Bonney, and coexistence of *G. labiacrassta* and *S. angiporoides* (Early Oligocene in age) in Kin 1.

These results may well be due to error in sampling or contamination down the core cutting. Closer inspection would need to be carried out in these samples before any conclusive remarks were made.

3.2 BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY

Benthic foraminifers are markedly more abundant than their planktonic counterparts with the exception of five samples, from the basal Gambier Limestone of Camelback and the Eocene marl of RC86KI 8, Kellys Bore and McNamara. Dominance of benthic species, as shown by a low P/B ratio is indicative of a shallow water biofacies (McGowran & Li, 1997).

The most abundant taxa are cibicidids (~30%), *Globocassidulina subglobosa* (~25%) and other species commonly found on the middle to outer shelf, 50-200m water depths. For example, *Gyroidinoides* attains 10% of the total benthic assemblage, *Cibicidoides* attains 5% and *Heterolepa*, 3%. The trochospiral rotaliid, *Sphaeroidina* (~4%), as well as discorbids and elphidiids are uncommon to rare. They appear to concentrate in the mid-Oligocene through earlier Miocene sections that is considerably younger than the sections analysed. Their presence as well preserved specimens in the basal

Gambier Limestone samples (Lucindale, Kellys Bore and RC86KI 18) and in marl samples (Kin 6, Kin 1, RC86KI 3 and Keith) can only suggest contamination in acquisition.

Cassidulinids, cibicidids and lagenids are well represented across section. In contrast millolids, nonoidids, agglutinated and larger benthics are less common or rare. A possible explanation for lack of these species is the presence of nutrient rich waters as a result of upwelling of cooler bottom waters.

Robertina and other aragonitic tests are common in the Eocene section of Camelback and Keith holes. This represents an assemblage widely found in southern Australia margin during the Palaeocene-Eocene (McGowran 1965). In other holes *Cibicides perforatus* is common, as are *Cibicides pseudoungerianus* and *Cibicides pseudoconvexus*.

Gyroidinoides zelandicus, *Sphaeroidina bulloides*, *Alabamina tenuimarginata* and *Svratkina* sp. represent deeper-water species. Their combined high abundance in basal Gambier Limestone samples (Camelback, RC86KI 8, Lucindale, RC86KI 2, McNamara and Mt Salt 3) is indicative of the Early Oligocene interval. *Svratkina* sp and *A. tenuimarginata* are present in the marl sediment of Kin 6 providing evidence that environmental conditions were shifting from shallower to deeper water regime, or from a protected to an open water environment.

Abundance of epifaunal benthos (10-50%) is substantially greater than the general trend of abundance for infauna (0-10%) across the drillholes sampled. This is attributed to the relative low abundance of various infaunal groups such as nonionids and lenticulids, and the lack of bolivinids and buliminids. The infauna is quite heterogeneous, consisting of a succession of dominances including lagenid, nodosariids and casidulinids. Changes in benthic abundance parallel the infaunal/epifaunal ratio. A marginal increase

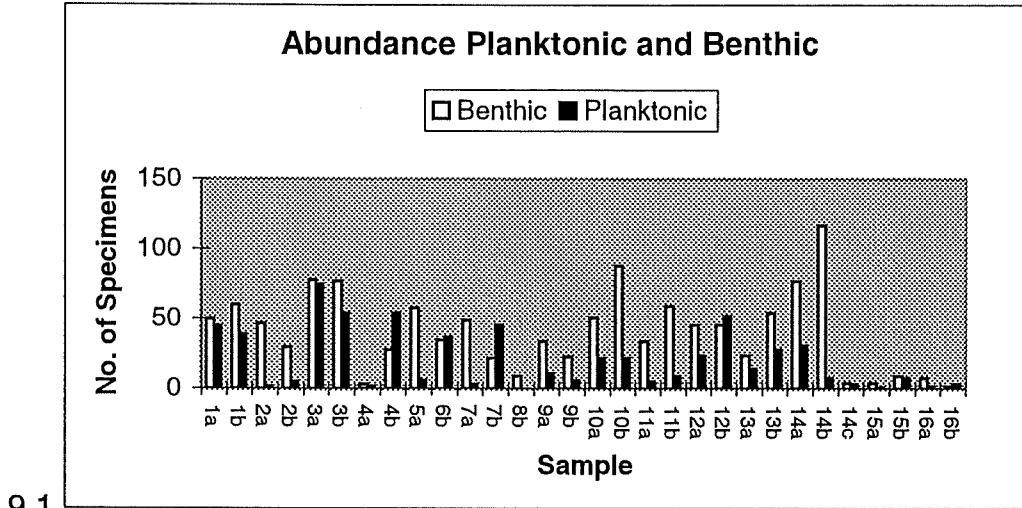
of infauna species is represented in samples from the basal Gambier Limestone in comparison to those from the Late Eocene.

The presence of lagenids, discorbids and miliolid species is used as a measure of the benthic diversity of the samples as they prove to be more sensitive to facies changes than other species (Li, 1997). Murray (1991) provided ecological data for selected modern genera, generalising the water depth preferences of particular species. From this study, the genera can be divided into two groups: inner neritic (less than 50m) and outer neritic (greater than 50m), based on the assumption that the ecologies of the Eocene/Oligocene boundary were similar to their modern counterparts. Inner neritic forms include *Operculina*, *Elphidium*, *Discorbis*, *Notorotalia* and miliolid forms, whereas the middle to outer neritic forms include species of *Pullenia*, *Globocassidulina*, *Sphaeroidina*, *Cibicidoides*, *Heterolepa*, *Eponides* and *Lenticulina*. Generally, the deeper water species tend to dominate in the late Eocene sediment, whilst the shallower water species dominate in the Early Oligocene basal Gambier Limestone.

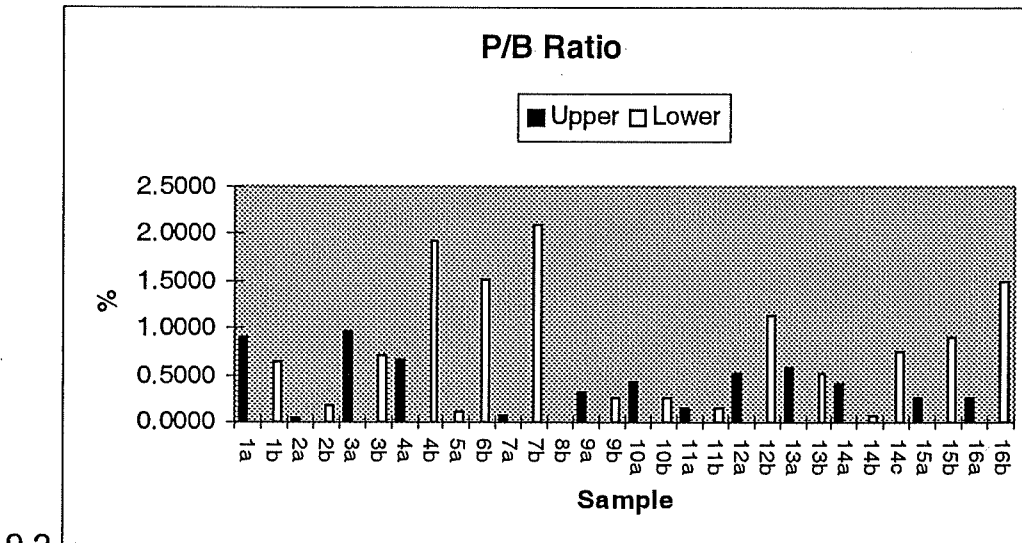
Figure 9 ABUNDANCE CHARTS

Upper - Early Oligocene basal Gambier Limestone Unit
 Lower - Late Eocene Unit

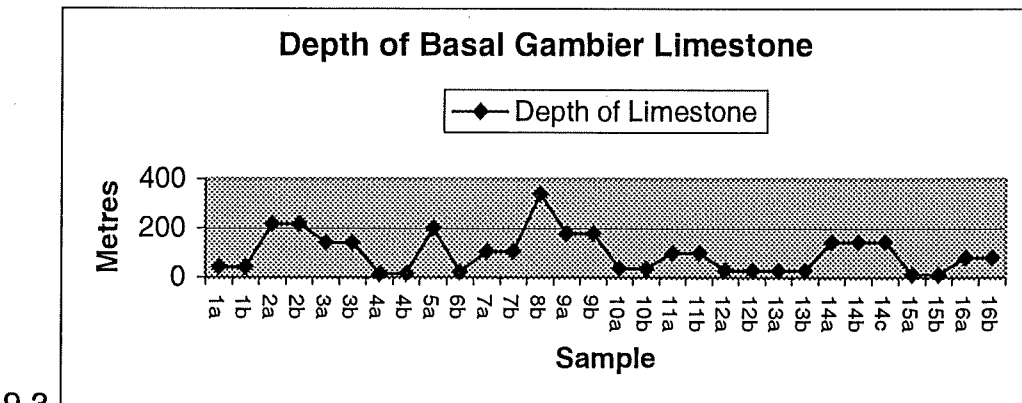
N.B. Sample Numbers correlate to chart drill hole # in database (Appendix B, pp 75)



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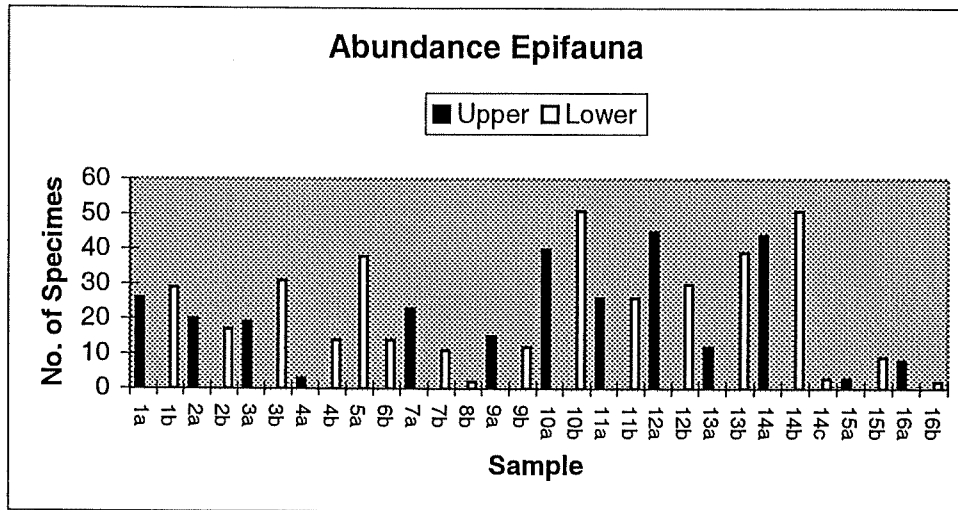


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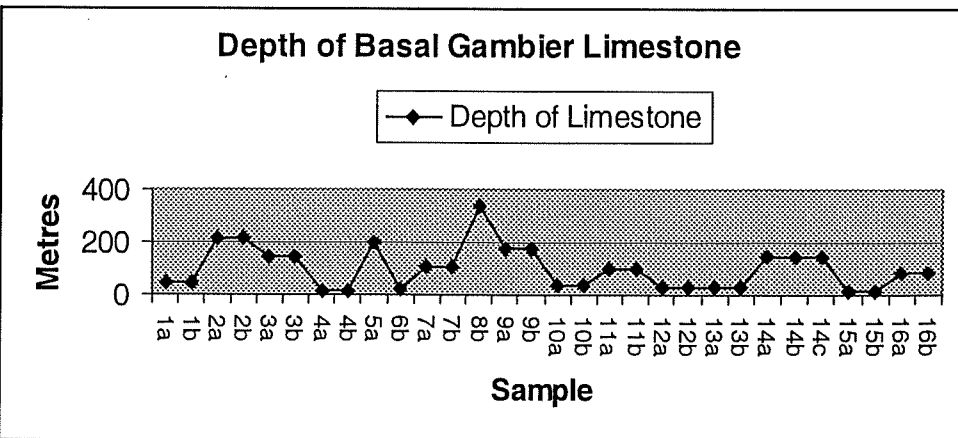
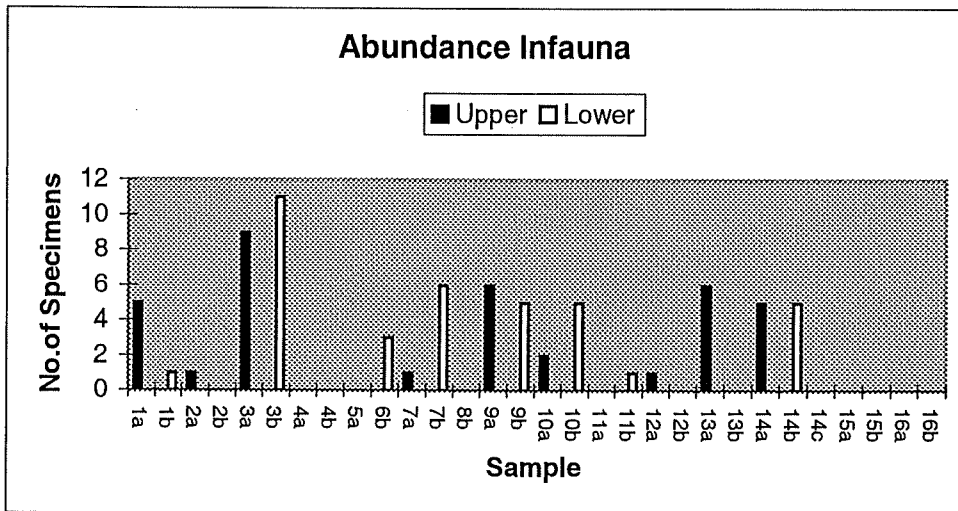


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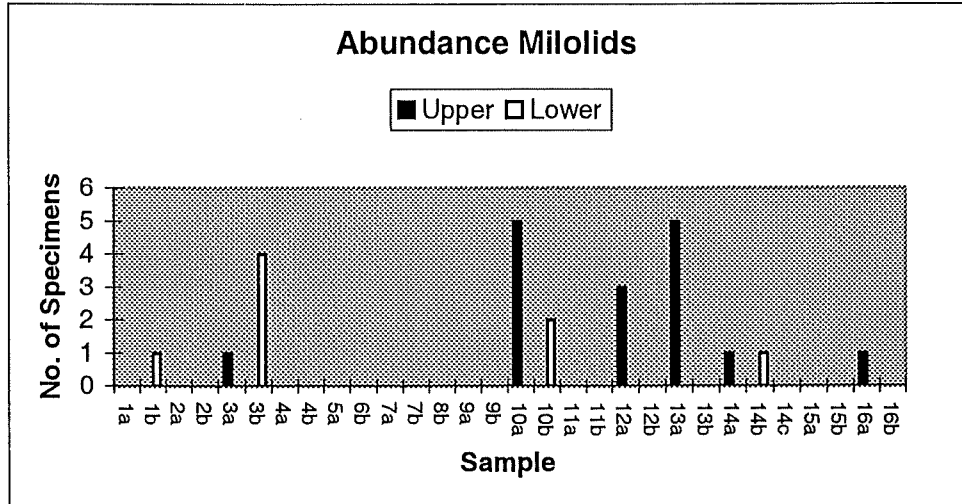
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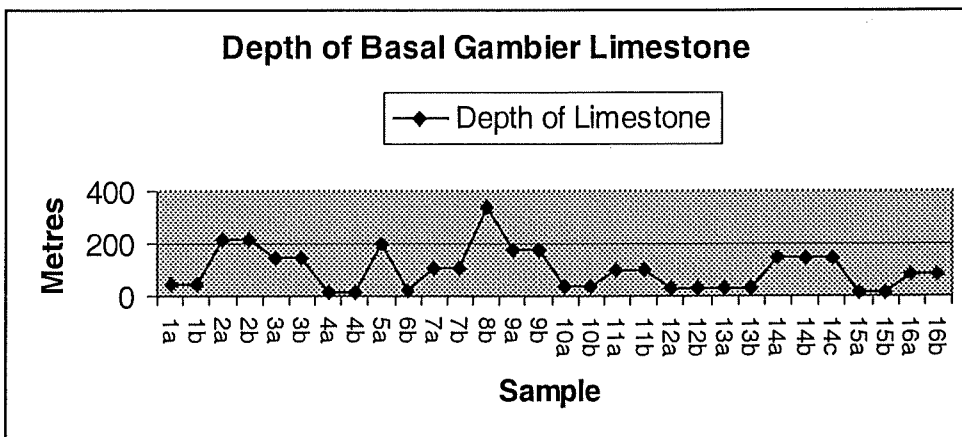
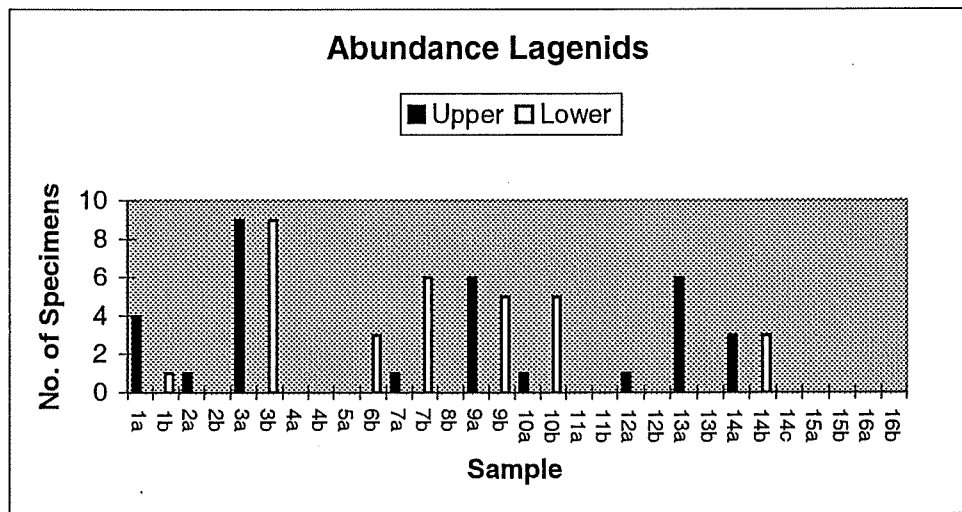
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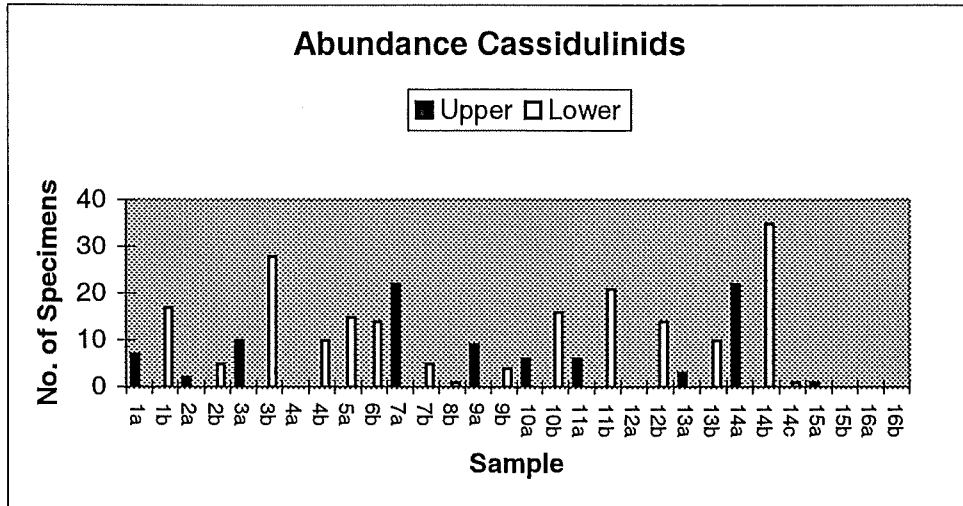
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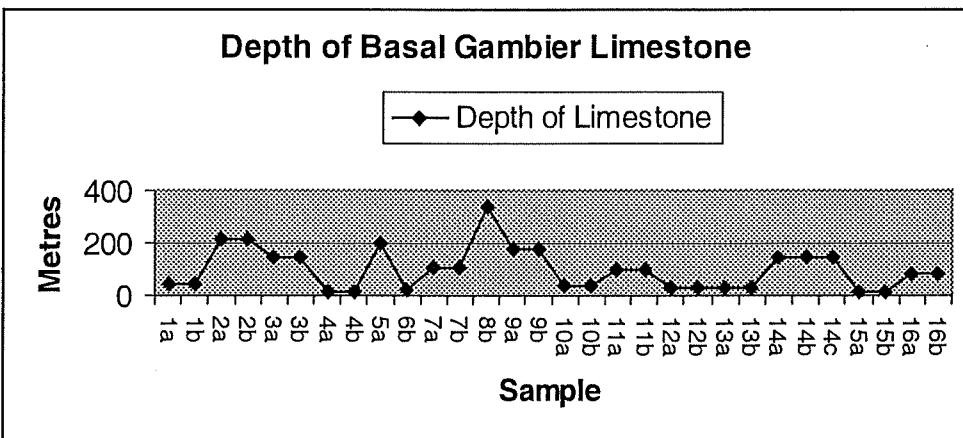
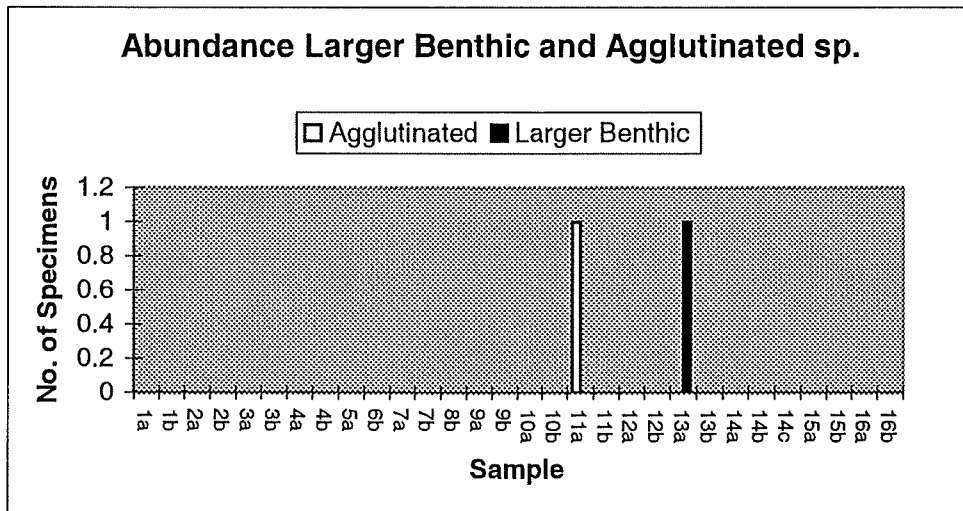
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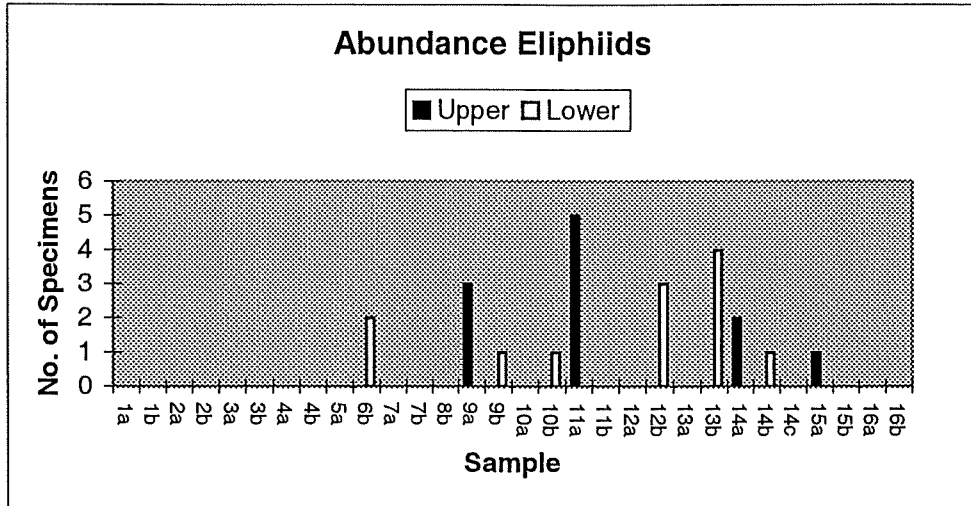


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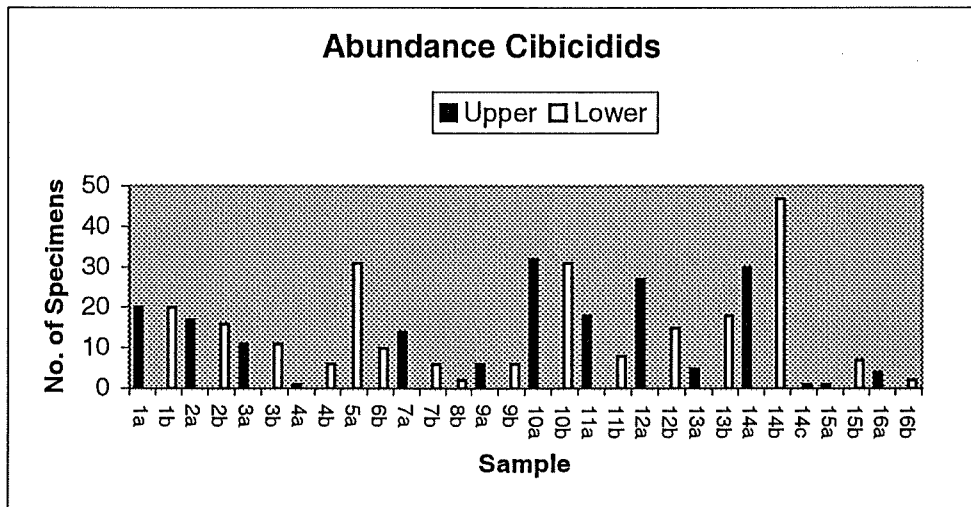


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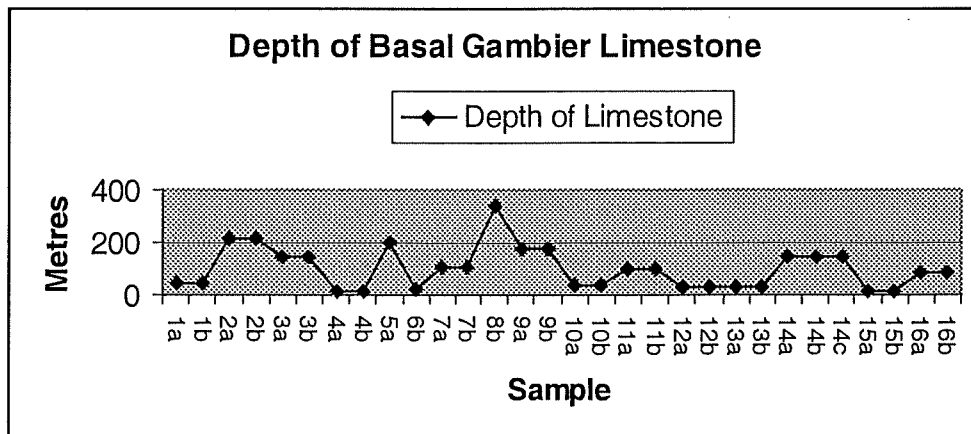




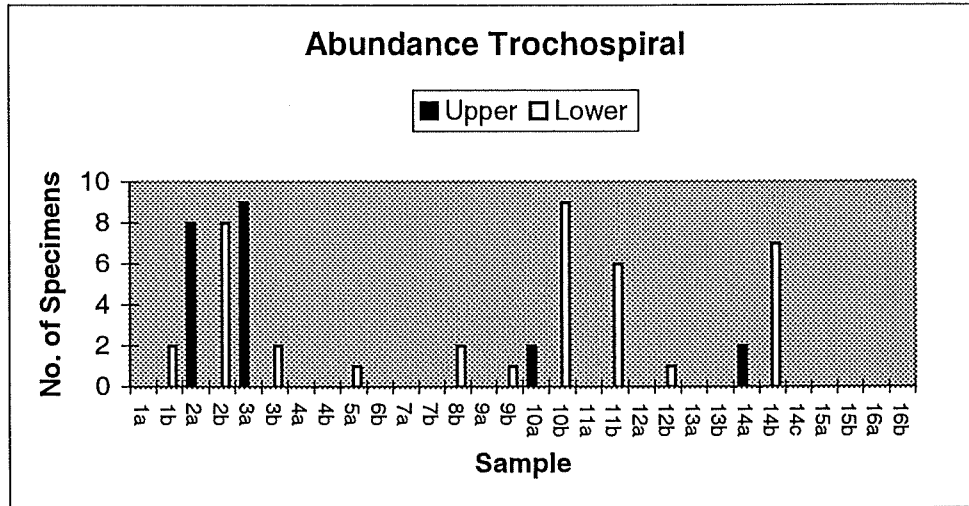
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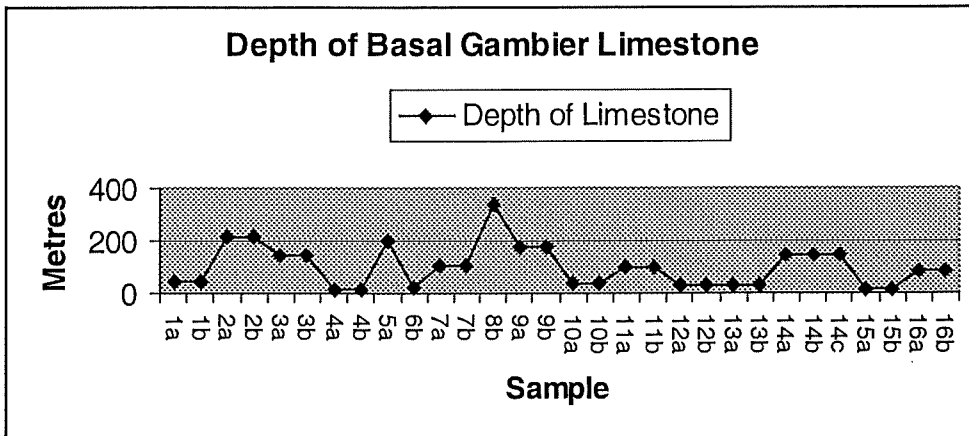
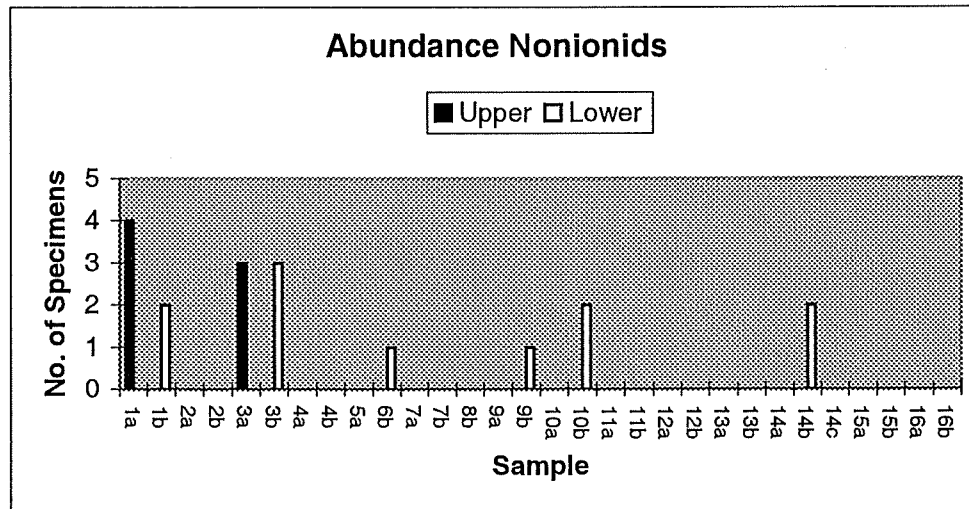
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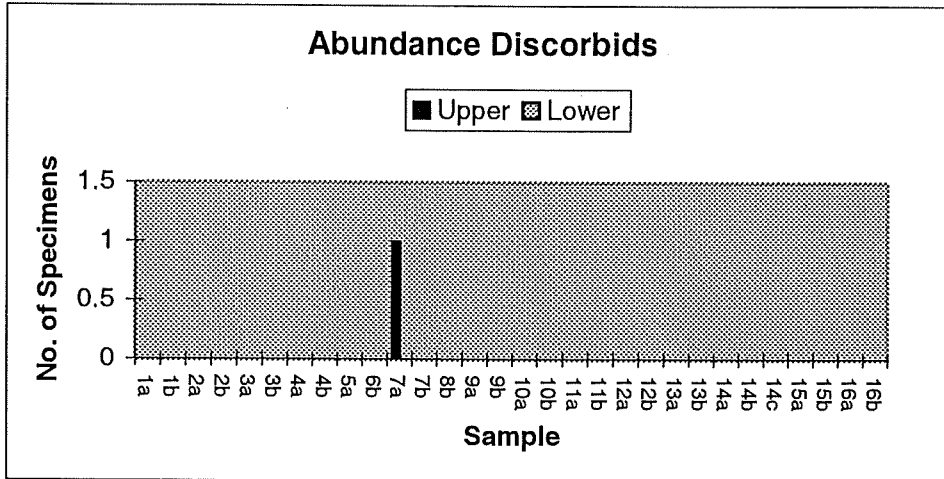


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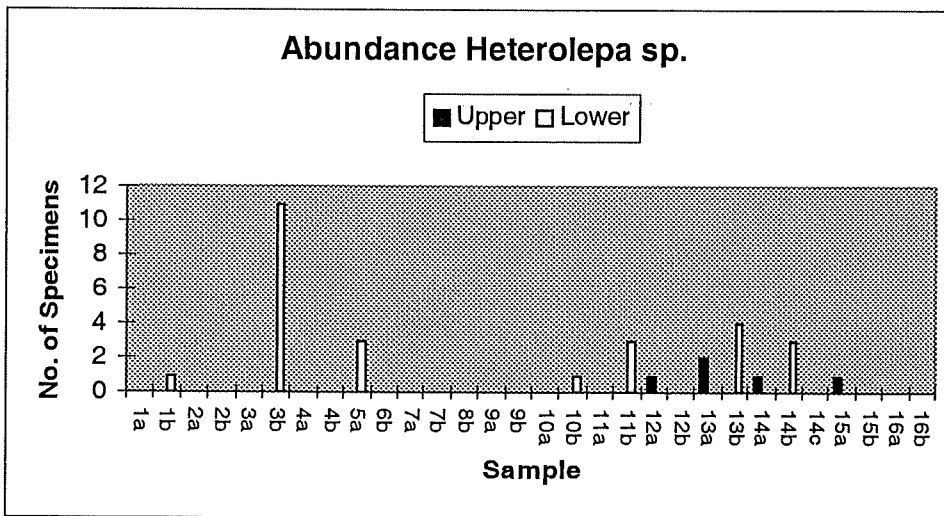


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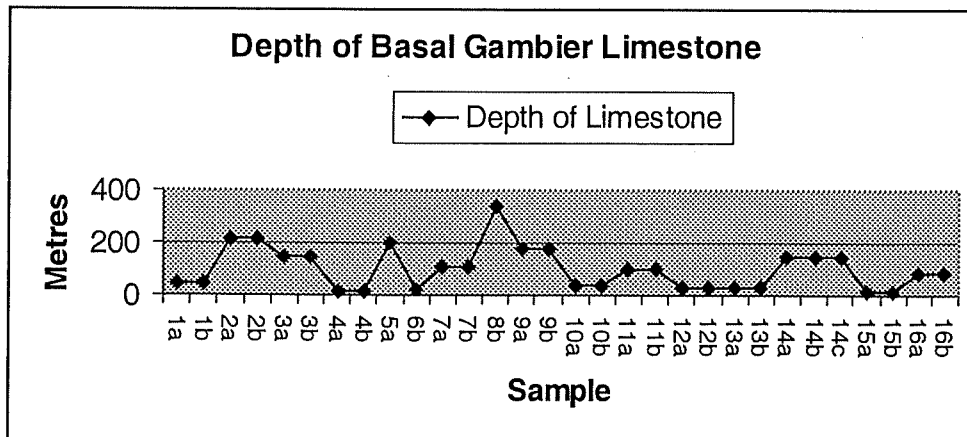


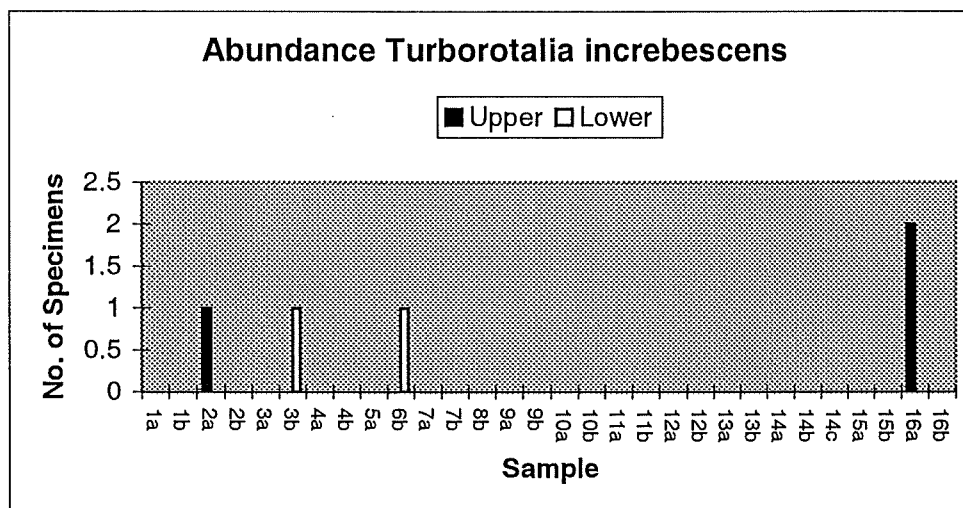


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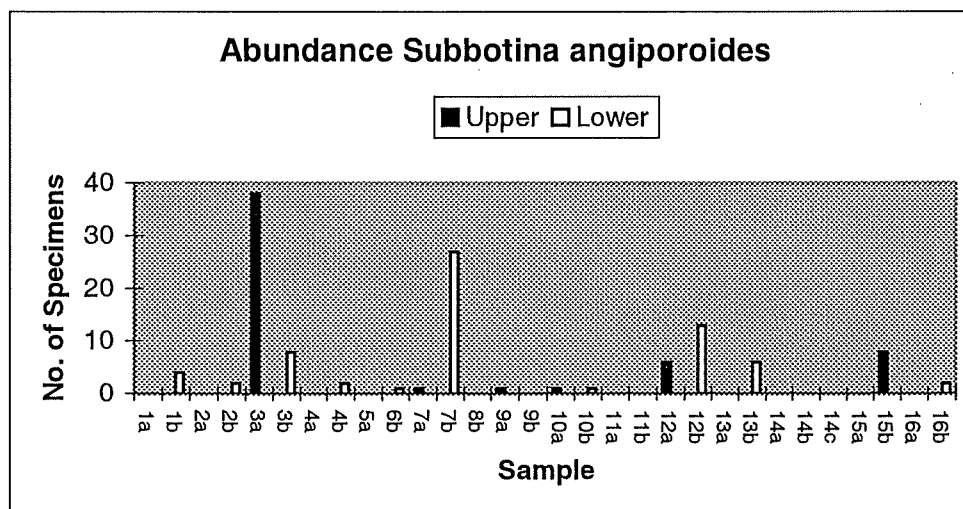


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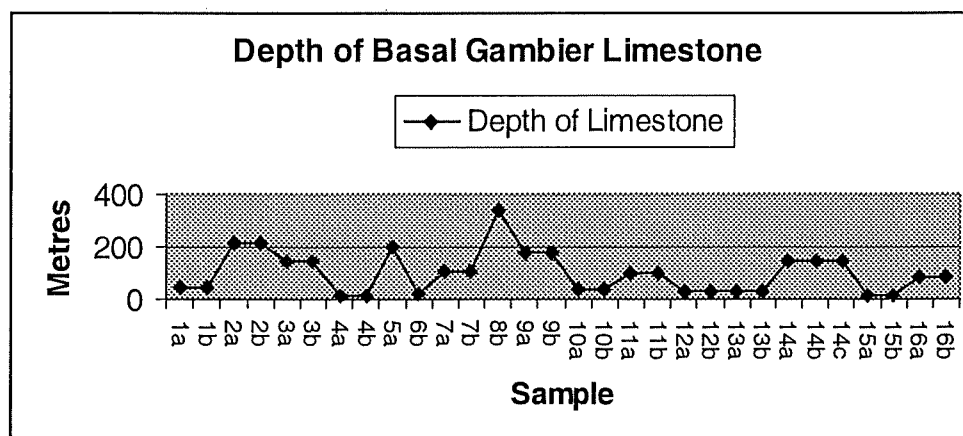




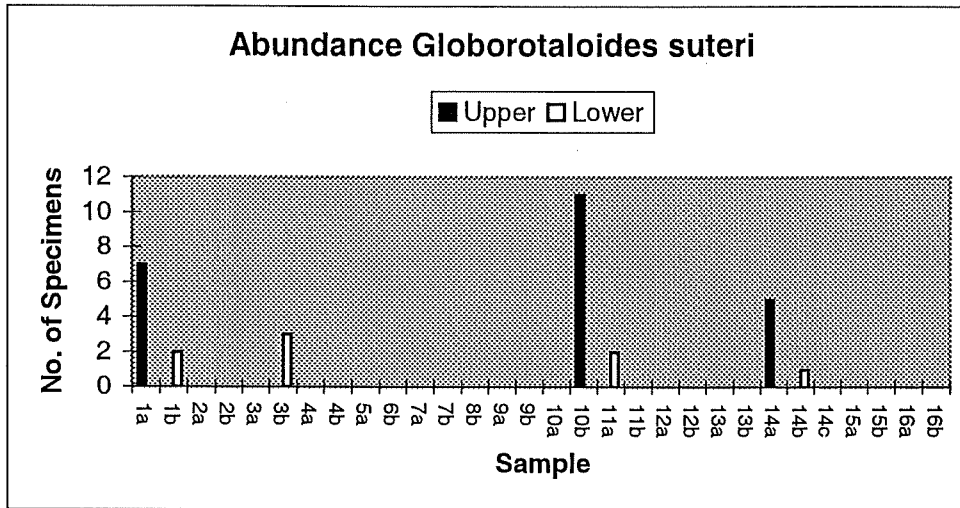
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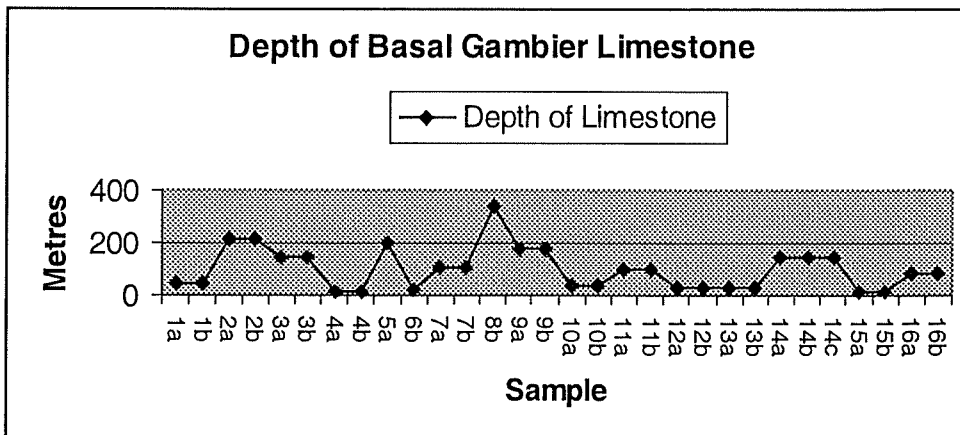
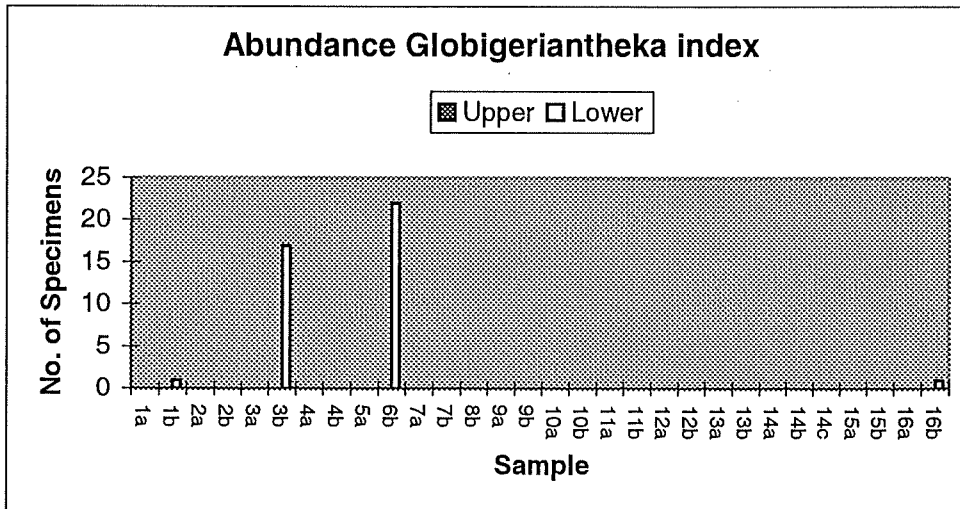
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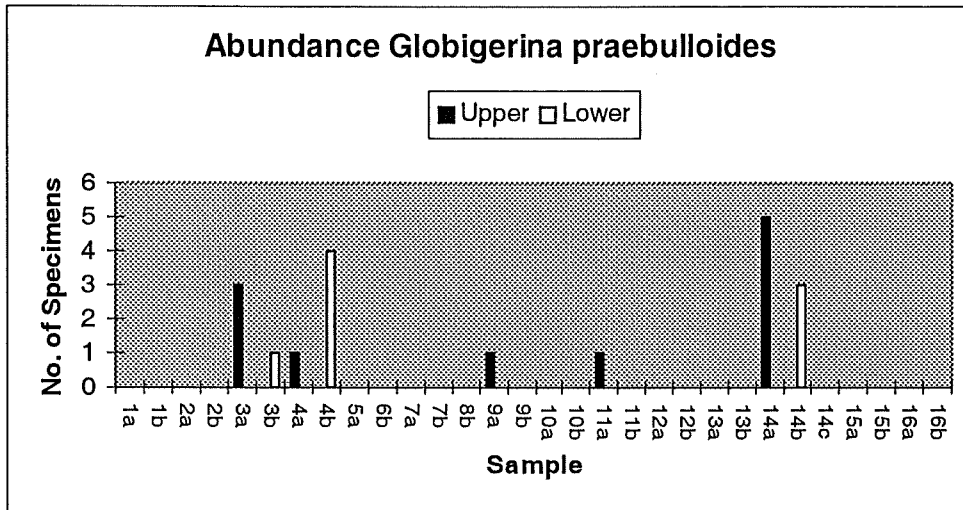


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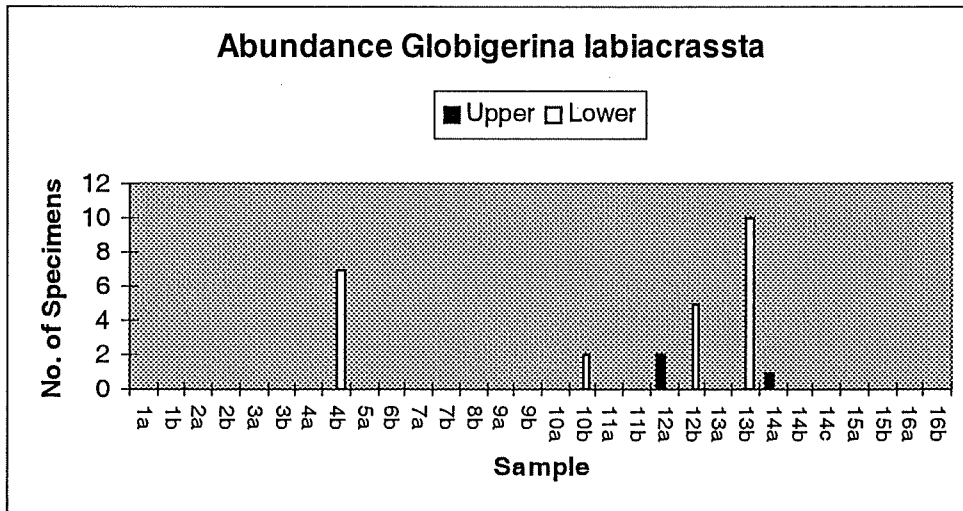


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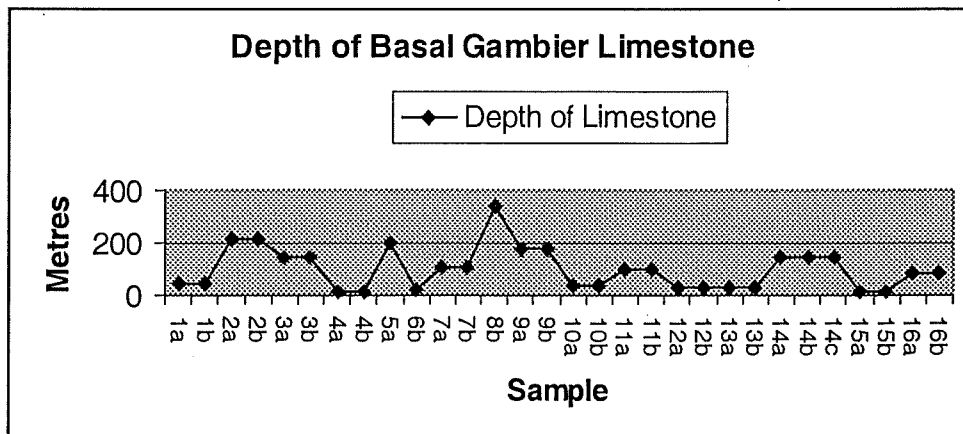




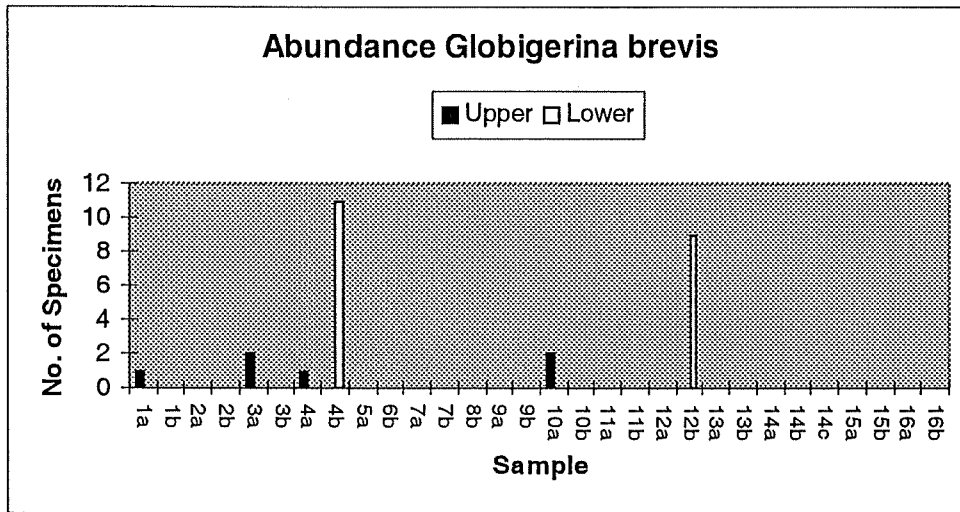
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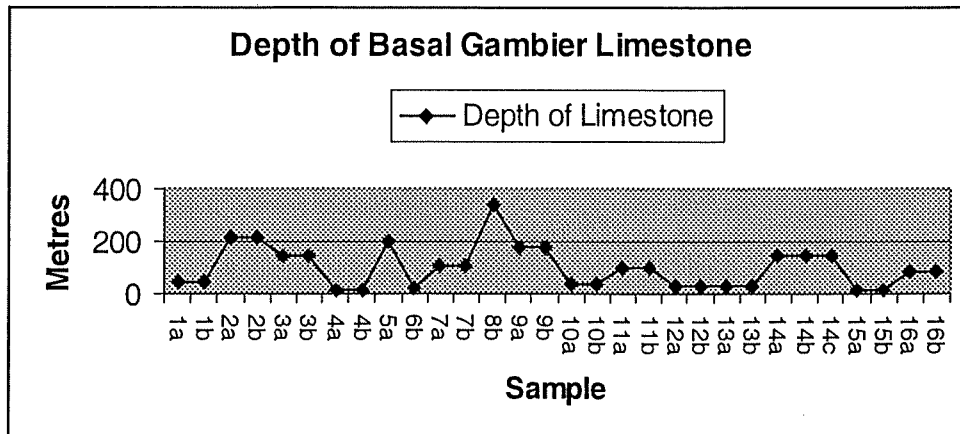
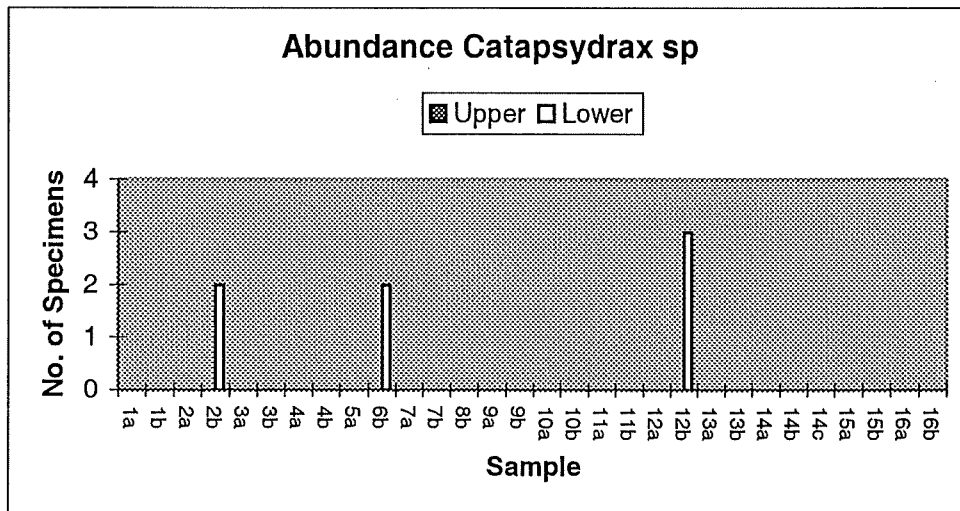
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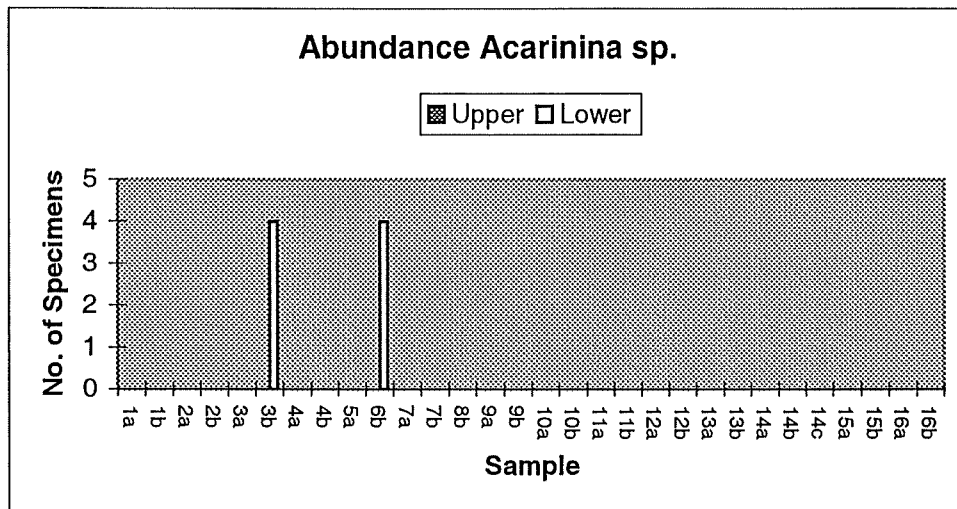


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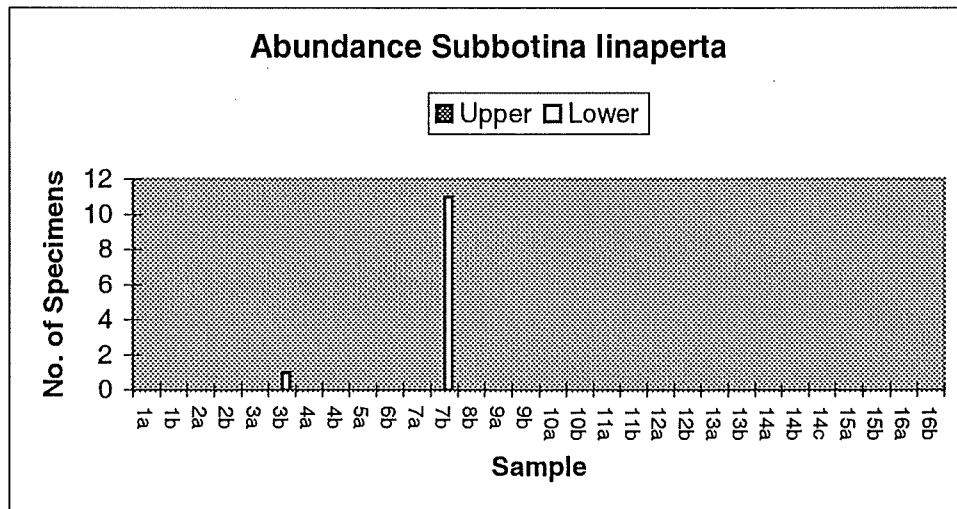


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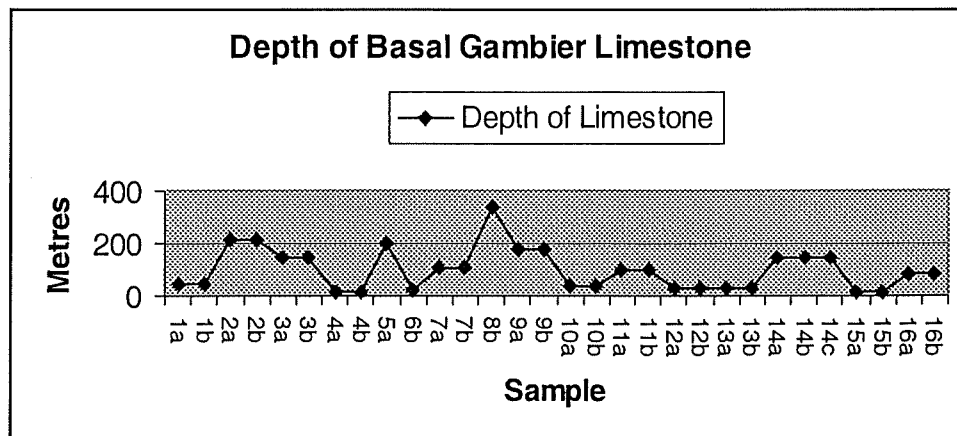




9.24



9.25



3.3. ENVIRONMENTAL INTERPRETATION

From these observations it can be noted that:

- 1) In deep marine open waters plankton and deepwater benthos are abundant;
- 2) In deep water protected marine environments, there are abundant deepwater benthos and less plankton; and
- 3) In shallow conditions, only the benthos prevails.

3.3.1 LATE EOCENE MARL vs EARLY OLIGOCENE GAMBIER LIMESTONE

The flooding event, or transgression, that occurred at time of the Eocene/Oligocene contact decreased the stress in the basin by expanding environmental niches and increasing competition amongst species.

Foraminiferal evidence indicates that the Gambier Limestone, where studied, was deposited in cool water open marine environment, corresponding to the inner and middle shelf. An increase in abundance of infauna signifies a nutrient rich environment with high productivity due to the increase in accommodation space provided due to the rise in sea level. Increased nutrient supply into the oceans was due to upwelling of bottom waters stimulated by Antarctic Circumpolar Current (Li, *et al*, 2000). This is mimicked by the presence of chert nodules in the Early Oligocene Gambier Limestone units.

The Late Eocene Narrawaturk Marl was deposited in a warm protected marine environment on the middle shelf. The presence of glauconitic facies and increased abundance of epifauna parallel the low productivity rates and nutrient depleted conditions.

The relative increase in abundance of *Globocassidulina subglobosa* and *Heterolepa brevoralis* in the Early Oligocene is indicative of a rise in sea level at this interval (Li & McGowran, 1997).

The planktonic and benthic abundances indicate a change in environmental conditions and this is coeval with the change in lithology at the Eocene/Oligocene boundary. A change of facies from a warm, protected facies to a cooler, open marine environment, resulted in an increase in abundance of planktonic species and the deposition of the Gambier Limestone.

3.4. BIOFACIES IMPLICATIONS OF DEPOSITIONAL ENVIRONMENTS

A high abundance of cibicidids and other middle to outer shelf foraminifers suggests that the Gambier Limestone carbonates accumulated at 50-150m depth (Li *et al.* 2000). A greater water depth may have existed near the central part of the troughs, supported by an assemblage dominated by planktonic specimens (White 1995).

Marine transgressions in the later Eocene led to a widespread deposition of carbonates in many southern Australian basins (McGowran *et al.* 1997a). A warm temperate environment for deposition of packages 1 and 2 is indicated by the warm-water species *G.index*. This was probably driven by the initial flow of a warm, saline water system similar to the present day Leeuwin Current from the northwestern to the southern margins (McGowran *et al.*, 1997b). Li (1999) noted that the benthic assemblage in the Gambier Basin included two main associations: *Angulogenerina - Cibicides pseudoconvexus* (RR65) and *Robertina-Hoegludina* (OB2), suggesting different topographic settings with considerable variations in the bottom environment. The sedimentation break at the Eocene/Oligocene boundary represents a fall of at

least 30-50 m in sea level, as estimated from the erosional surface and biofacies from below.

The faunal evidence for a cooler Early Oligocene and the beginning of a new water regime includes a planktonic assemblage dominated by temperate species, a major increase of deep-water benthic forms, and a change of biofacies composition (Li *et al.*, 2000). Siliceous content increased dramatically in the sediment from package 3, within which a marly layer of up to ~ 100 m containing vast quantities of sponge spicules can be observed (Ludbrook 1971) and chert started to become common. This shift may correspond to initial flow of the Antarctic Circumpolar Current after the opening of the Tasman Gateway, and the advent of thermohaline circulation in Proto-oceanus (Kennett 1977; Kennett & Scott 1990; Wright & Miller 1993).

Towards the mid-Oligocene, chert was rare or totally absent from package 4 at many localities (Li *et al.*, 2000). Foraminifers were rare and poorly preserved, with minor plankton or deep water benthic forms, probably accumulated at <50 m water depths (Li *et al.*, 2000). In other areas, the Compton Conglomerate unconformably overlies Eocene sediments and at least part of the Early Oligocene is missing, suggesting that the mid-Oligocene glacioeustatic fall may have been coupled with tectonic uplift in the region (Li *et al.*, 2000).

Faunal variations during warm periods may be due to a higher level of upwelling (Li *et al.*, 2000). This is evident from increased concentrations of cassidulinids, especially *Globocassidulina subglobosa*. In dredge samples from offshore of South Australia, *G.subglobosa* often constitutes about 1-5% of total benthic foraminifers but may increase to ~ 20% in areas affected by seasonal cold water (13-14°C) upwelling, such as Bonney Shelf (Figure 1) (Schahinger 1987; Li *et al.*, 1996b, fig 8). Therefore, the observation that *G. subglobosa* flourished while other deep-sea taxa declined supports the notion that this species has a positive relationship with nutrient-rich, cooler waters of

the Early Oligocene (Li & McGowran 1994; Brasier 1995; Murray 1995). The intervals with frequent *G. subglobosa* also coincide with periods of generally increased deep-water production as signalled isotopically (Wright & Miller 1993).

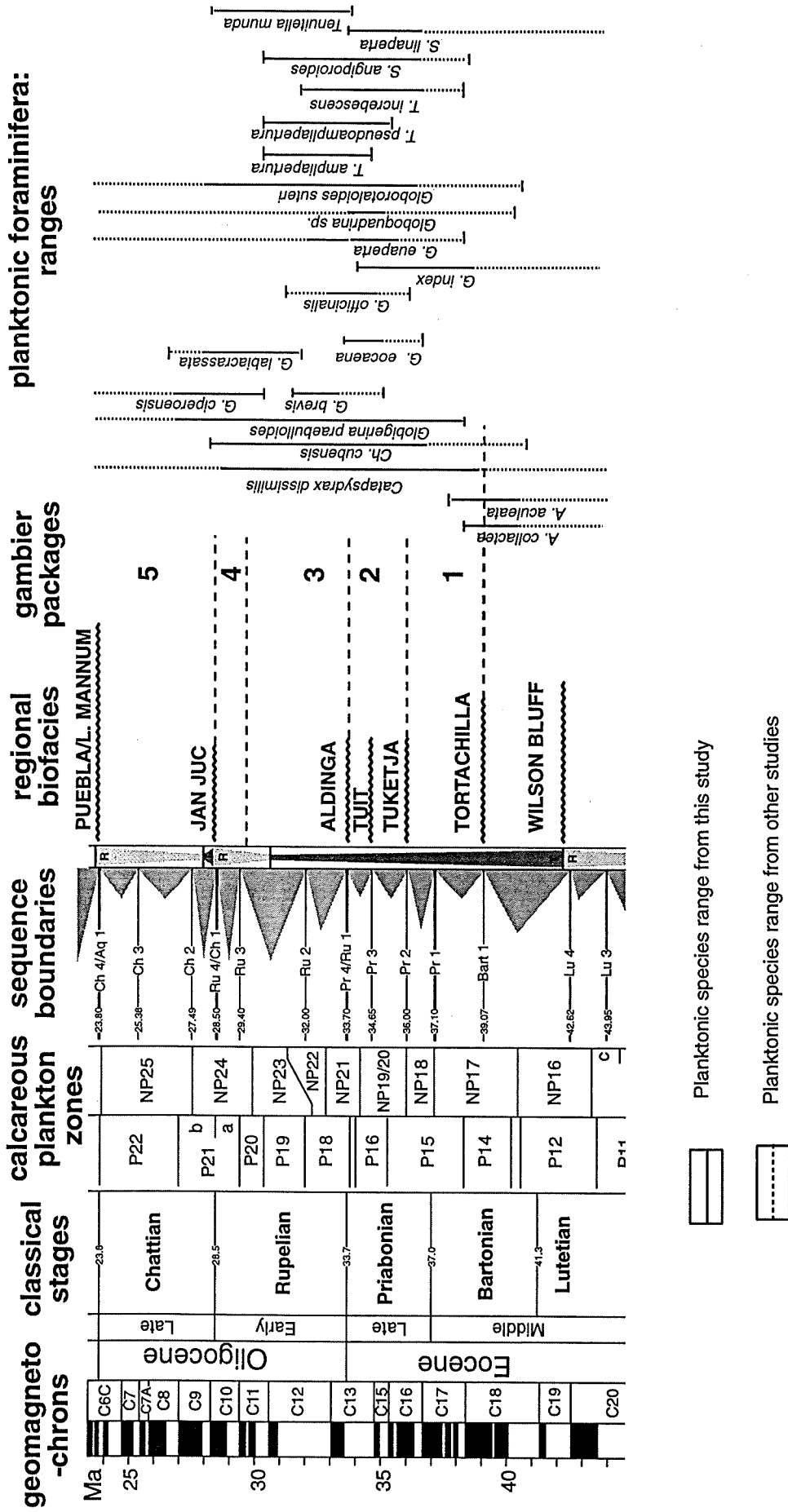


Figure 10 : Ranges of Diagnostic Planktonic species found in samples across the Gambier Basin

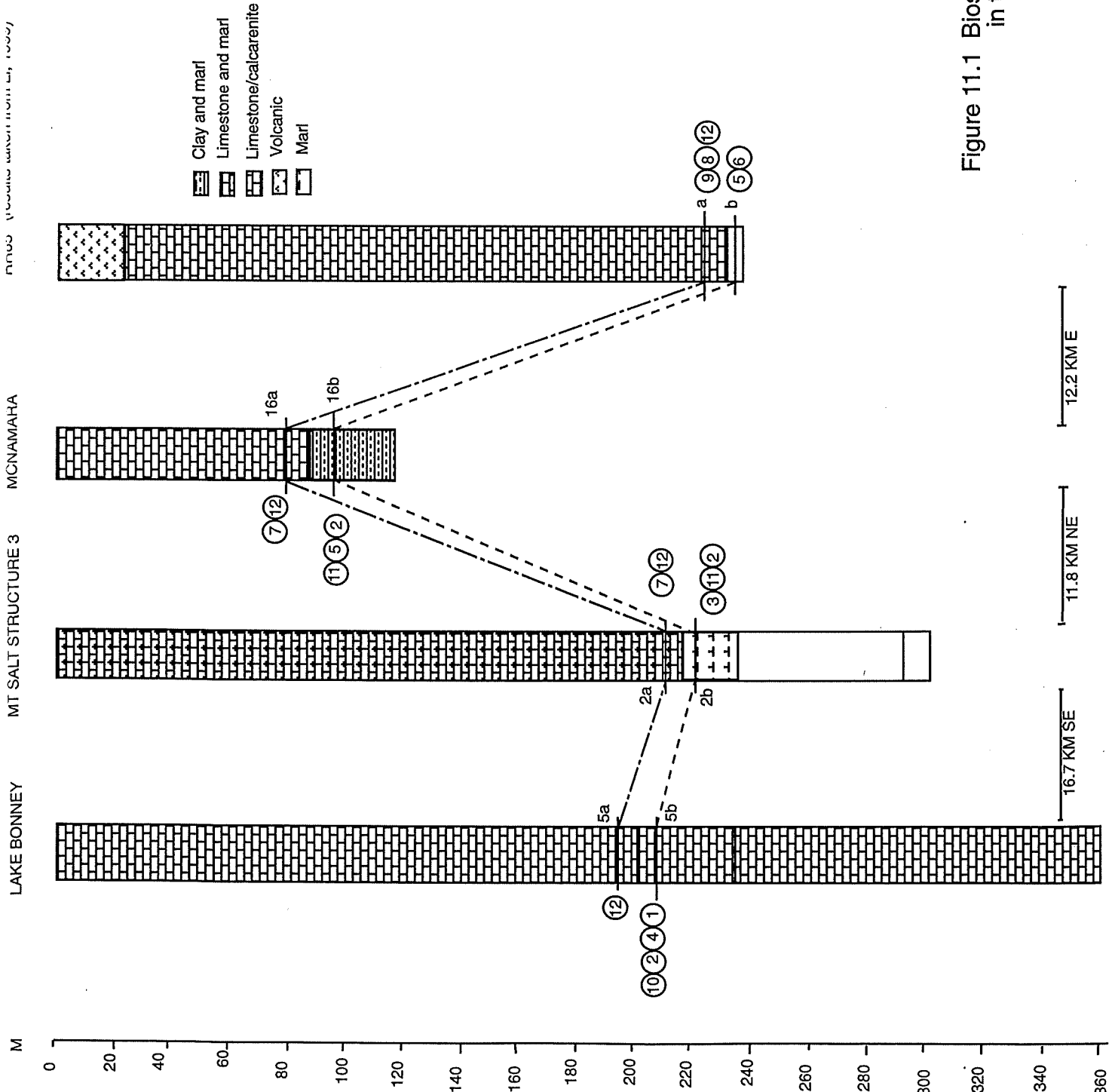


Figure 11.1 Biostratigraphic Correlation of drilled sections in the Gambier Basin

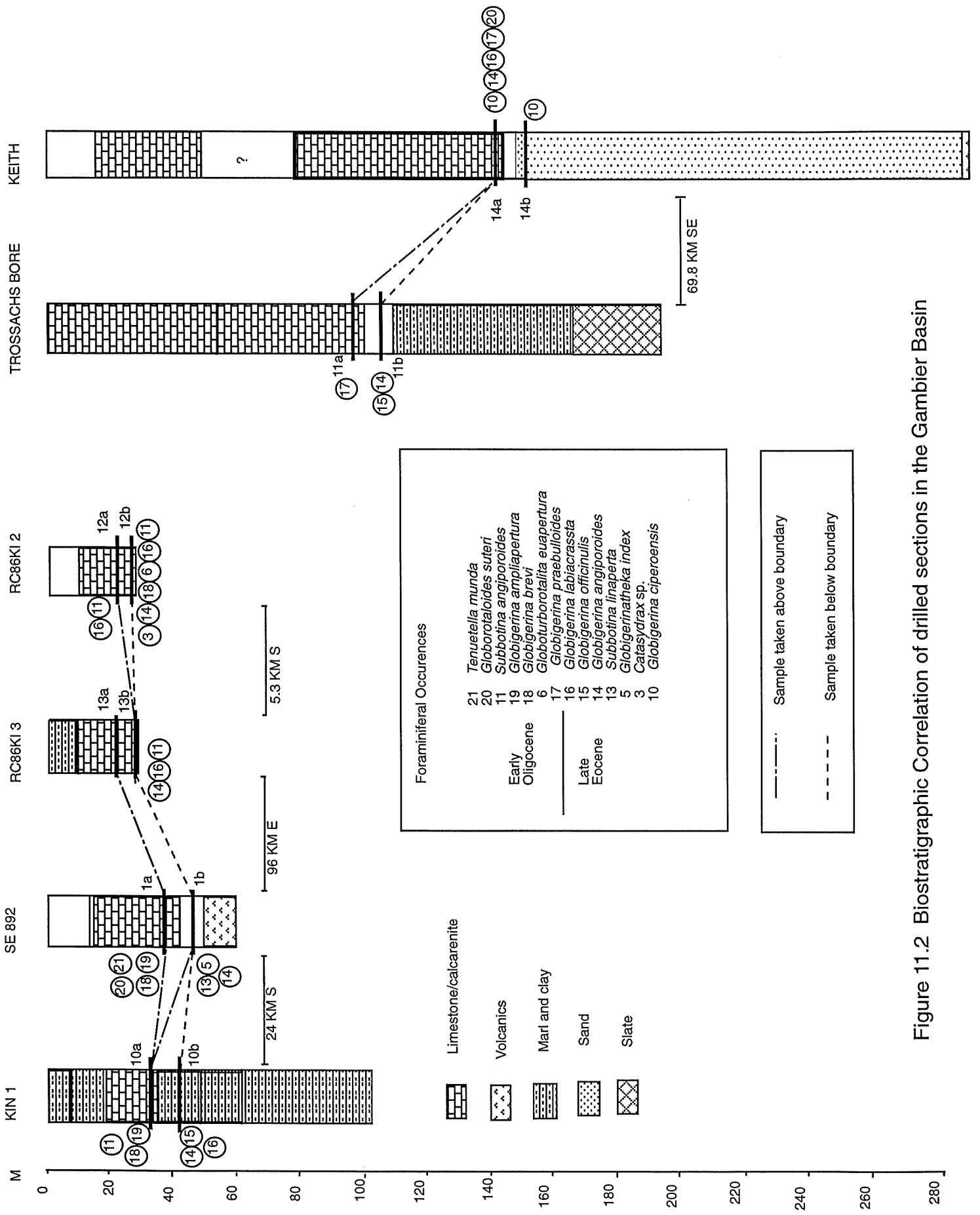


Figure 11.2 Biostratigraphic Correlation of drilled sections in the Gambier Basin

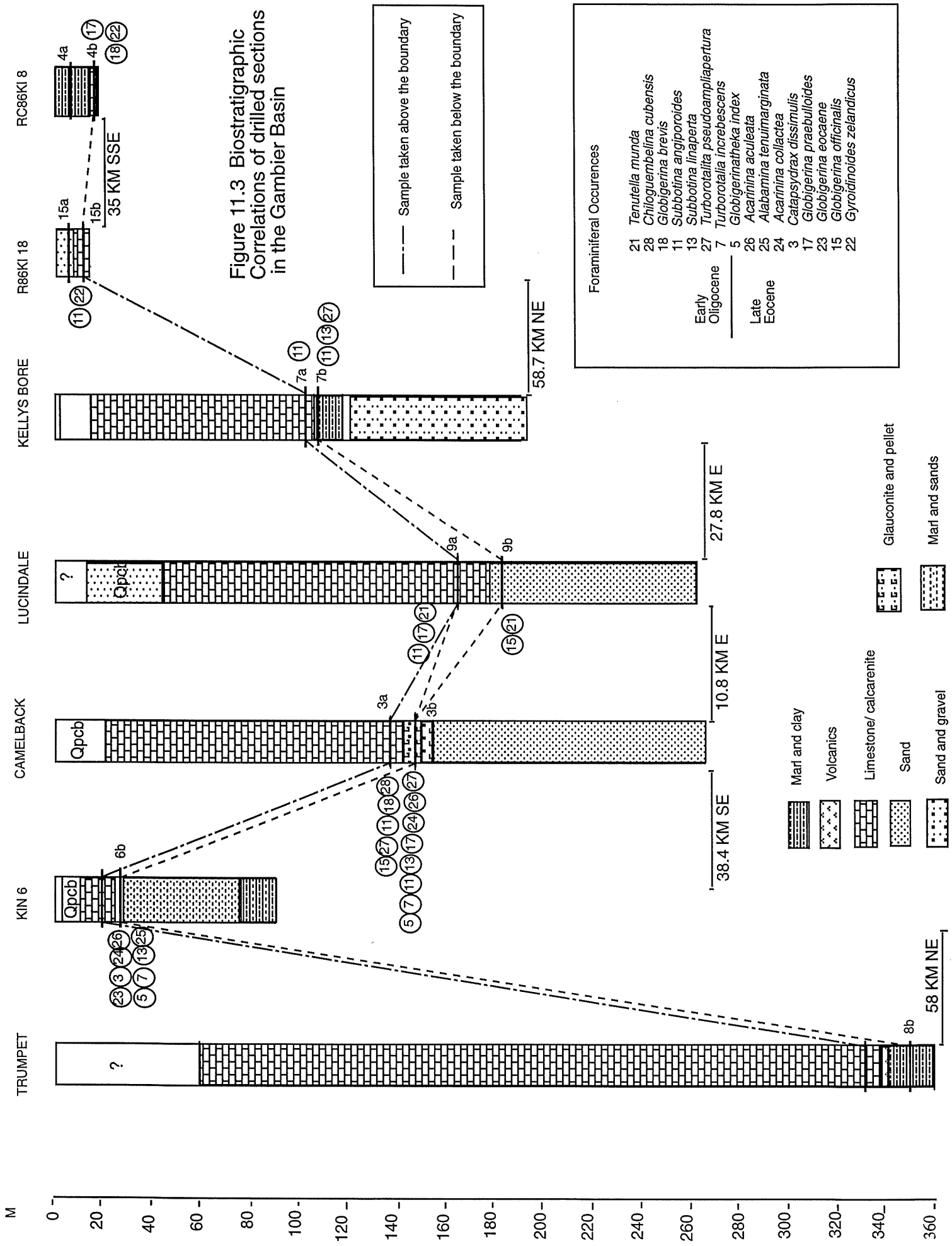


Figure 11.3 Biostratigraphic Correlations of drilled sections in the Gambier Basin

Foraminiferal Occurrences

21	<i>Tenutella munda</i>
28	<i>Chiloguembelina cubensis</i>
18	<i>Globigerina brevis</i>
11	<i>Subbotina angiporoides</i>
13	<i>Subbotina linaperta</i>
27	<i>Turbototalita pseudoampliapertura</i>
7	<i>Turbototalita increbescens</i>
5	<i>Globigerinatheka index</i>
26	<i>Acarina aculeata</i>
25	<i>Alabamina tenuimarginata</i>
24	<i>Acarina collectea</i>
3	<i>Catapsydrax dissimulilis</i>
17	<i>Globigerina praebulloides</i>
23	<i>Globigerina eocaena</i>
15	<i>Globigerina officinalis</i>
22	<i>Gyroloides zelandicus</i>

Early Oligocene

Late Eocene

M
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

CHAPTER 4

STRATIGRAPHIC CORRELATIONS

Stratigraphic correlation between all sections studied (Figure 11) is based on the datum levels of planktonic and benthic species listed in Figure 9. Several of these datum levels are regional events, having been recorded across southern Australia and New Zealand (Lindsay 1985; Jenkins 1993; McGowran *et al.* 1997a). Whether they are entirely coeval with those recorded in the pelagial (e.g. Berggren *et al.* 1995) is not evident in this neritic context; even so, their succession provides a sound biostratigraphy.

By comparison of drillholes sampled across strike, biostratigraphy concludes that the Gambier Limestone began to be deposited at the Eocene/Oligocene sequence boundary Pr4/Ru1. Some vital forams are absent from certain holes, suggesting absent lithology due to the unconformable contact. Variations in lithology between holes may be indicative of change in depositional settings either in a trough or on palaeohighs (eg: between Trumpet 1 and Kin 6).

4.1. SEQUENCE STRATIGRAPHIC CORRELATION

The subdivision of the Gambier Limestone based on lithology and presence or absence of chert has proven useful for logging and mapping the carbonate section (Li *et al.*, 2000). The Greenways, Camelback and Green Point members (White, 1996) reflect changes in lithology with diachronous boundaries, although the Greenways/Camelback contact may coincide with a local magnification of the TA4.4/4.5 sequence boundary at ~30Ma (Li *et al.*, 2000). Lithological boundaries contrast sharply with erosional surfaces that cut across different lithologies. Chert nodules are often abundant in the basal Gambier Limestone member (e.g. Lake Bonney sample). Chert-carbonate

facies accumulated in a more fertile environment, which was either cooler and deeper or under upwelling (Villamil *et al.* 1999).

In contrast to diachronous lithostratigraphic members, the seven sedimentary packages proposed by Li *et al.* (2000) are unconformity-bounded allostratigraphic units and have chronostratigraphic significance in a broader regional context. Li (2000) has described each of these packages as including two or more third-order sequences on the basis that lithostratigraphic and biofacies distinctions are more distinct at these third-order boundaries. The packages are thus comparable ecostratigraphically and correlated biostratigraphically with biofacies in the Upper Eocene and Lower Oligocene sections of the St Vincent Basin (McGowran & Beecroft 1986; Moss 1995).

The biofacies patterns in the Gambier Basin fit excellently into regional transgressions (McGowran *et al.*, 1997) which, in turn, matches the "global" sequences (Figure 12). Hence, the regional packages are manifestations of the global configuration and their accumulation was controlled primarily by glacioeustatic fluctuations in sea level (Li *et al.*, 2000).

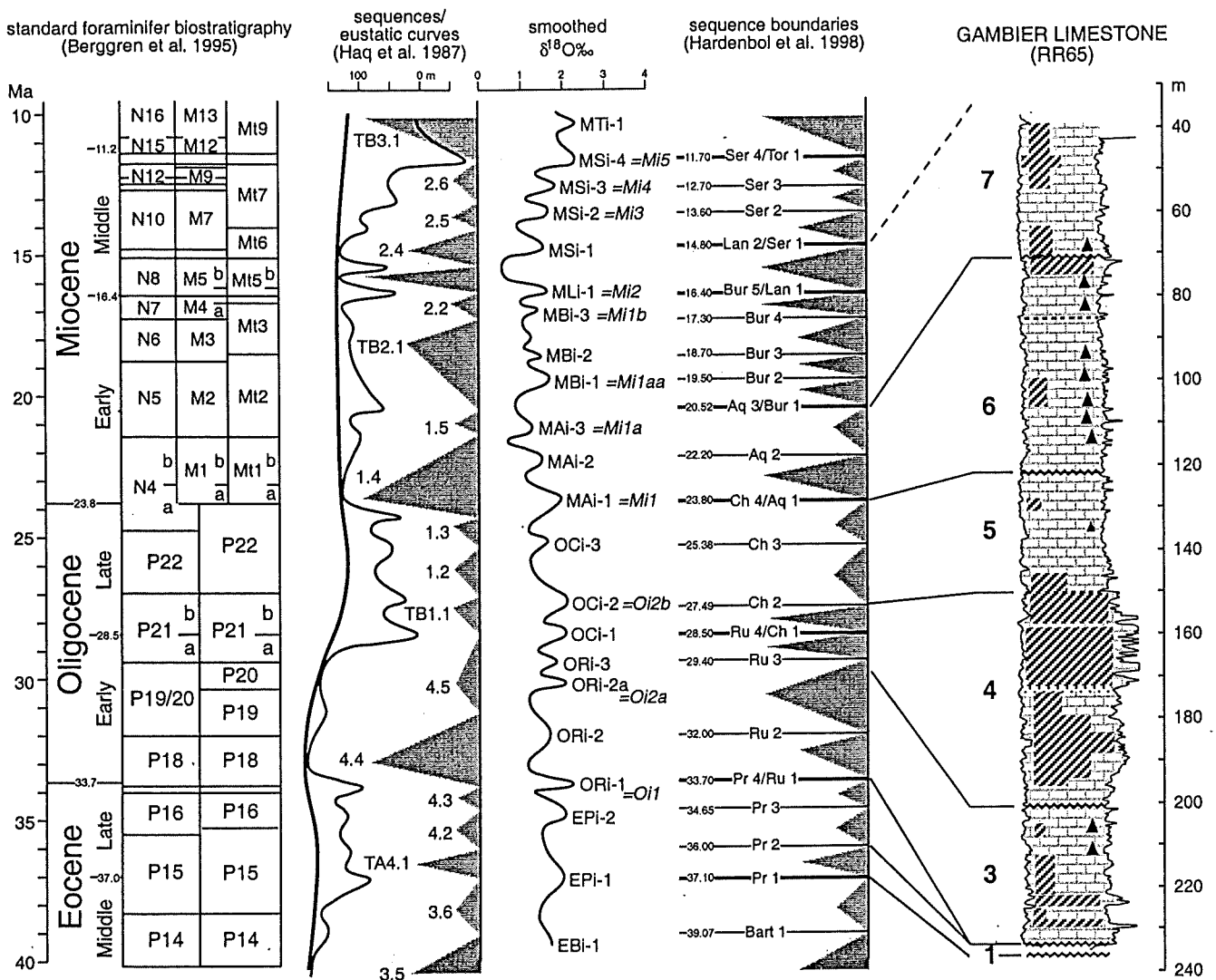


Figure 12. The position of the Gambier Limestone in the global stratigraphic and depositional hierarchy. The stratal units 1 to 7 represent sediment packages at the third order separated by surfaces corresponding to glacioeustatic events as measured by oxygen isotopes. Correlation between geochronobiostratigraphy, third-order sequences and oceanic oxygen-isotopic events was based on Hardenbol *et al.* (1988), including the previous (Haq *et al.*, 1987) sequences grouped into the second-order TA4 to TB3.

CHAPTER 5

DISCUSSION

5.1. BASINAL CONTEXT

From biostratigraphic correlations across strike of the Gambier Basin, it can be said that:

1. High planktonic abundances (P/B ratio) in samples of the basal Gambier Limestone are indicative of cold, deep water open marine settings.
2. Low planktonic abundances (P/B ratio) in Late Eocene sediment are coeval with warm, deep water protected environments.

This evidence correlates with the six successional units (1-7) that Li, *et al* (2000) proposed for holes RR65 and OB2. The successional boundaries fall at changes in lithology, which correlate well with unconformity bounded erosional surfaces. Table 1 summarises the seven units and implies that they are allostratigraphic units corresponding with third-order cycles. The boundary of interest is 1/3, representing the Eocene/Oligocene contact, which is clearly erosional (Figures 13 & 14).

Li, *et al.* (2000) defined boundary 1/3 as equal to Pr2 to Pr4/Ru1 (Hardenbol *et al.* 1998), or TA4.1/Ta4.4 (Haq *et al.* 1987). This is indicated by a decrease in deep-water benthics and a collapse in P/B ratio, defining an unconformable contact.

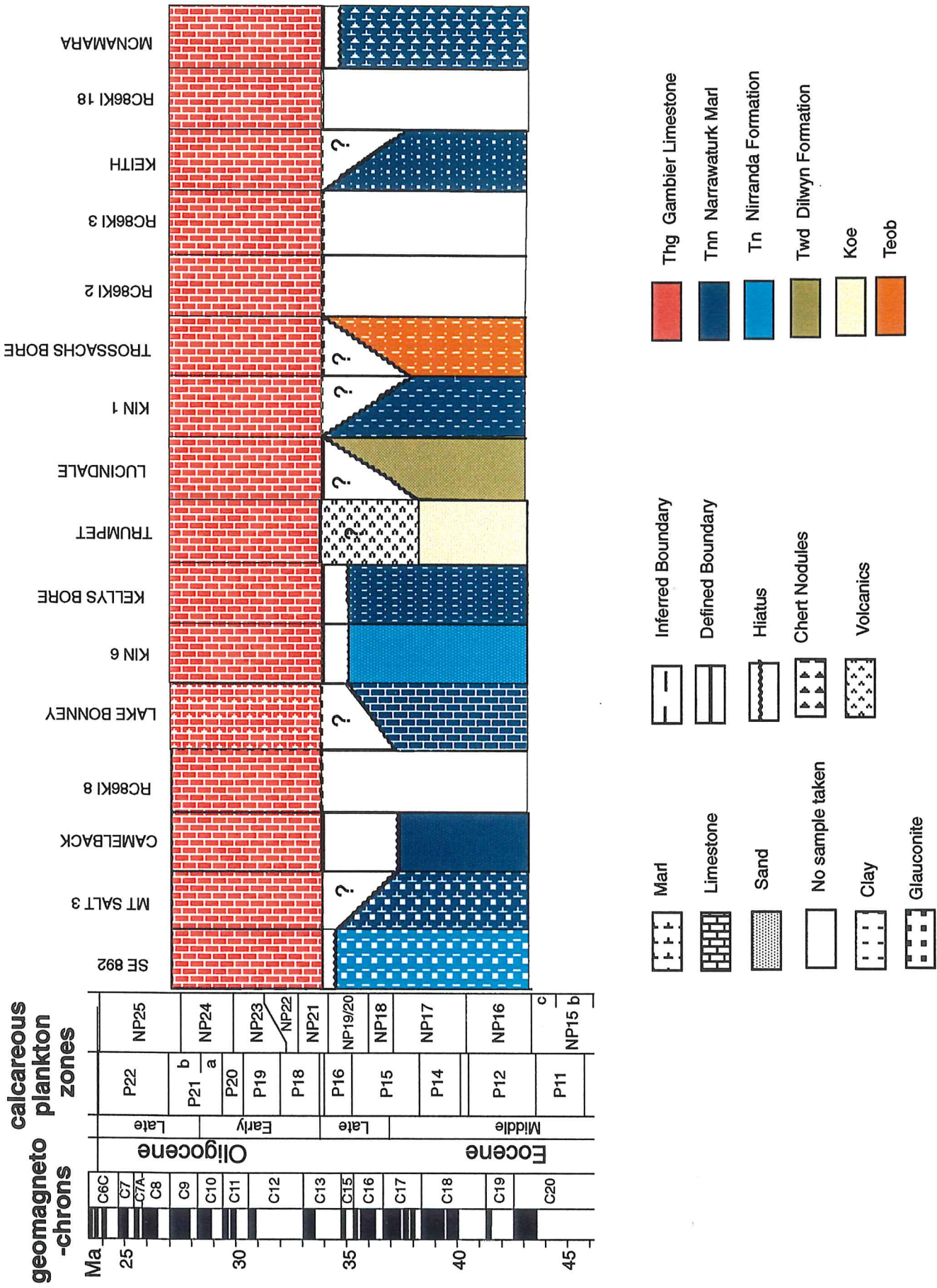


Figure 13 Chronostratigraphy of Gambier Samples

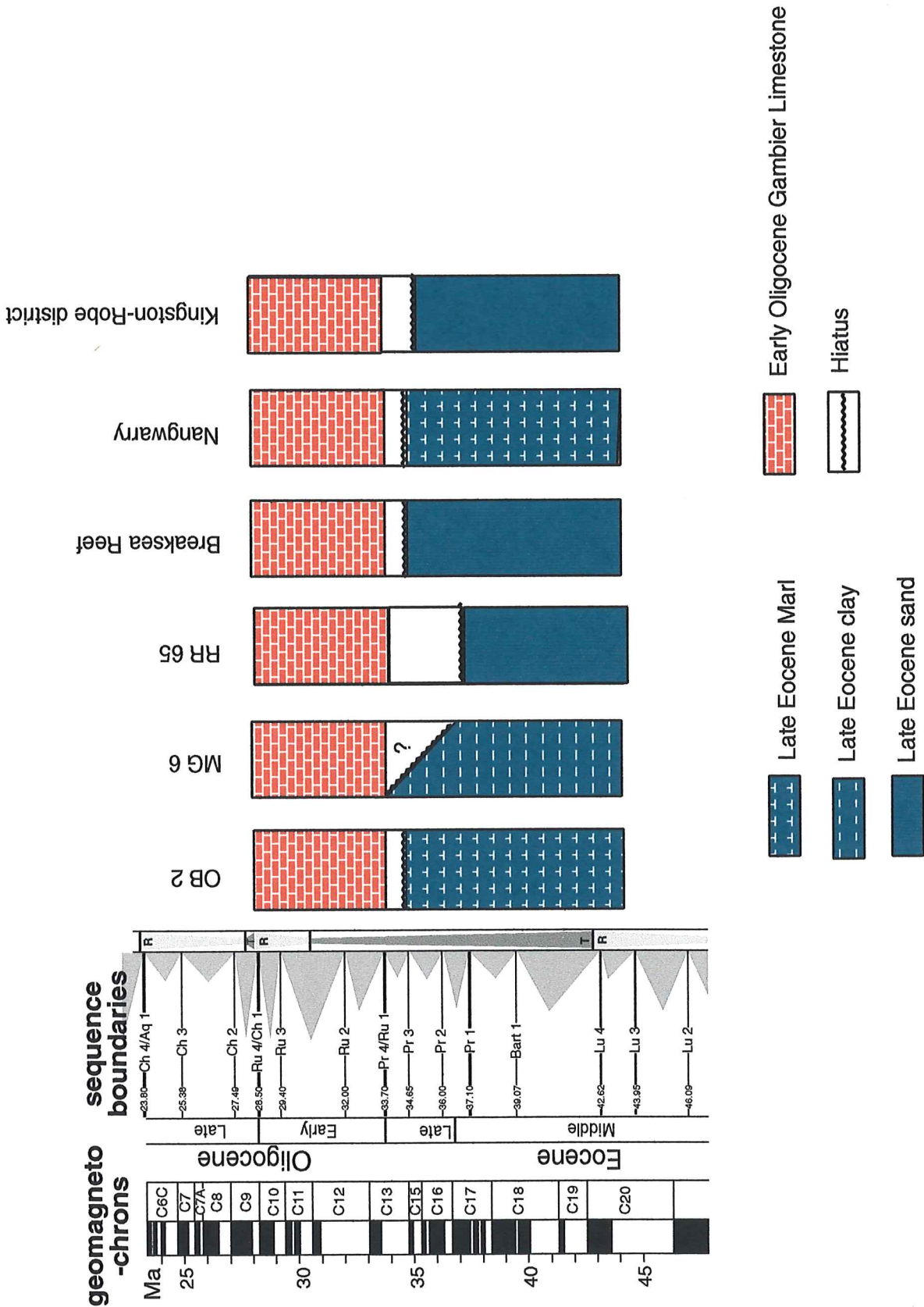


Figure 14 Chronostratigraphy of Gambier Samples (from previous studies)

Table 1 Stratigraphic units proposed for subdivision of the Gambier Limestone and related strata

Unit	Major characteristics	Sequence equivalent	Sequence boundary	Benthic association	Age & planktonic zone	McGowran 1973	White 1995
7	Cream to light grey bryozoan limestone, marly in places, with or without chert, abundant mollusc remains in places, common warm-water biofacies	TB2.4-2.1		<i>Operculina-Cibicides medicris</i>	Early to Middle Miocene (N5-N10)	(not observed)	Green Point Member
6	Erosional contact Mainly grey bryozoan limestone, with abundant chert	TB1.5-14	Aq3/Bur1	<i>Siphonina-Discorbinella scopus</i>	Early Miocene (N4-N5)	Upper Member	
5	Erosional contact Light grey to creamy bryozoan limestone, with chert and warm-water biofacies	TB1.3-1.2	Ch4/Ag1	<i>Alabamina-Cibicidoides wuellerstorfi</i>	Late Oligocene (P22)		
4	Erosional contact Grey to creamy bryozoan marl and limestone, or grey to pink dolomite, often without chert, microfaunas poor and poorly preserved	TB1.1- TA4.5	Ch2	(rare) <i>Notorotalia-Cassidulina carapitana</i>	Early to Late Oligocene (P19-P21)	Middle Member	Camelback Member
3	Erosional contact Grey bryozoan limestone or marl, with frequent chert, often glauconitic in the lower part	TA4.4	Ru3	<i>Trifarina-Gyroïdina</i>	Early Oligocene (P18-P19)	Lower Member	Greenways Member
2	Erosional contact Green to brown marl and limestone, very glauconitic, with limonite pellets in parts	TA4.3-4.2	Pr4/Ru1	<i>Robertina-Hoeglundina</i>	Late Eocene (P15-P16)	Lacepede Formation	Narrawaturk Marl
1	Erosional contact Grey to brown limestone, marly in places, glauconitic or limonitic, sandy	TA4.1- TA3.6	Pr2		Middle to Late Eocene (P14-P15)		

(Li *et al.*, 2000)

5.2 THE BOUNDARY

The hiatuses represented by erosional surfaces at sequence boundaries are mostly too short to be measured by foraminiferal dating. The Eocene/Oligocene contact provides the best-defined hiatus, with part of the Late Eocene missing from almost all of the samples studied. In OB2 and SE 892, the hiatus appears to have been truncated due to the presence of *Globoturborotalita brevis* (earliest Oligocene) appearing soon after the disappearance of *G. index* (late Eocene P16 and older). The unconformable Eocene/Oligocene contact therefore parallels the Chinaman Gully downcut/incised valley of up to 50 m observed by Lindsay (1981) in the St Vincent Basin; suggesting a regional event coeval with and in response to the oceanic-oxygen isotopic glaciation (Miller *et al.* 1991)(Figure 12).

The presence of both *G. index* and *A. aculeata* in the basal Gambier Limestone sample of Camelback, representing mid Eocene, indicates that a substantial slice of sediment has disappeared from this section. For these two planktonic species to co-exist in the same time interval, the equivalent to the Late Eocene section (P16) must have been truncated, implying a hiatus of about 3.5 Ma. This too can be attributed to the unconformably bounded, highly erosional nature of the Eocene/Oligocene contact. As outlined previously, the incised valleys/downcuts uncovered in this study correlate with those found in the St Vincent Basin. This has always thought to be evident in theory, but has now been identified by actual evidence.

The boundary between the Eocene and Oligocene is a highly unconformable erosional surface. Two samples show a hiatus of 3.5 Ma, representing the removal of the entire late Eocene from Camelback and RR65. In Kin 6, Kellys Bore, and the Kingston-Robe district calcareous zone P16 is absent, equivocating to ~ 1.5 Ma. Se 892, McNamara, OB2, Breaksea Reef and Nangawarry all exhibit smaller hiatuses with sediment missing between sequence boundaries Pr3 and Pr4/Ru1, ~ 0.5 Ma. The remainder of the

samples could not have a time constraint fixed for duration of the hiatus through lack of foraminiferal evidence.

It does not seem apparent that the Gambier Limestone is missing any sediment from the Early Oligocene biostratigraphy. Deposition of the Gambier Limestone appears uniformly across all samples analysed, at the Early Oligocene, 34 Ma. This infers that the transgression at this time was an isochronous flooding event and resulted in the deposition of open marine, cool water carbonates across the Gambier Basin.

CHAPTER 6

CONCLUSIONS

1. The deposition Gambier Limestone commenced at the time of Eocene/Oligocene boundary and correlates to the sequence boundary Pr4/Ru1. The presence of planktonic and benthic foraminiferal species and mid- to outer shelf assemblages justifies definition of biostratigraphy and biofacies packages.
2. Unveiling of large-scale downcuts, or hiatuses in the stratigraphic framework surpasses the correlation between adjacent basins. The uppermost Eocene sediments are largely missing as a result of the Eocene/Oligocene contact being an unconformity and thus a highly erosional surface.
3. Deposition of the Gambier Limestone is coeval with the Aldinga transgression (St Vincent Basin); thus the transgression evident at the base of the Gambier Limestone must be linked with this adjacent basin and also other Southern Australian basins.
4. Seven stratal units or allostratigraphic packages can be related to sequence biostratigraphy. The Late Eocene marl correlates to the upper portion of package 2, the 'Tuit Member'. The Early Oligocene basal Gambier Limestone correlates to the lower part of package 3, coeval with the regional biofacies 'Aldinga Member'. They are time constrained, and each display a combination of lithological and biofacies properties (Table 1).

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5. Chert nodules are rare to common in the Early Oligocene and are mimicked by changes in benthic foraminiferal assemblages. They reflect input of nutrient due to upwelling of bottom water stimulated by Antarctic Circumpolar Current. Glauconitic facies represent the Late Eocene package, deposited in nutrient depleted, warm water protected environment.
 6. The estimated duration of hiatus below the boundary ranges between 0.5 to 3.5 Ma.
 7. The Eocene/Oligocene contact is coeval to an isochronous flooding event that stimulated the deposition of cool water neritic carbonates in the Gambier Basin.
 8. The timing and frequency of deposition of Gambier Limestone Basin closely follows the global glacioeustatic patterns (Fig 12). Local tectonic effects on sequence packaging were minor.

CHAPTER 7

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APPENDIX A

**METHODOLOGY – COLLECTION, PREPARATION AND
EXAMINATION.**

Foraminifera are present in most sedimentary rocks but particularly in the finer clastics. Few can be examined in hand specimens, so collection must be systematic and planned accordingly. Great care must be taken to avoid contamination, to bag samples securely and to provide full documentation. Simple washing should be tried before more elaborate methods are tried. Decanting is achieved through a sieve with a mesh opening of 63 microns and the residual picked after sieving into fractions on mesh openings of 500, 250 and 125 microns. A labelling system is used throughout the washing, drying and picking process.

Special techniques are required for sections of individual foraminiferal tests and for preparation of sections for examination by Scanning Electron Microscope (SEM). Fine details of the test surface and ultra-structures are best observed and photographed by SEM, while smooth, lamellar forms give better results by light photomicrography.

FIELD SAMPLING

No field samples were collected, as the base of the Gambier Limestone does not outcrop. Sufficient quantities of bore holes from the Gambier embayment are stored at Primary Industries and Resources of South Australia (PIRSA) Core Library, from which samples were collected within a parameter of ten meters above and below the basal Gambier Limestone. The cores were chosen from a drill hole map of the south-east region, taking equivalent sections along the strike so that full basin analysis could be undertaken. The availability of the samples was the only restriction in the collection procedure.

Cores yield the best samples for foraminiferal analysis because the depth at which the sample is taken is accurately known and the material is uncontaminated.

SAMPLE PREPARATION

Recovery from limestone can be more difficult than from softer clastic material. However, chalks and soft marly limestone may be crushed and boiled with successful release of microfossils. This is particularly the case where the grain size is the same as that of the fossil.

After the sample has been successfully washed and dried, the residual sand and mineral grains are sieved into fractions to be examined by reflected light under the binocular microscope. Mesh sieves aperture 250, 150 and 100 microns, are used with most of the foraminifer found in the 100 microns. The residue is tapped gently out of the sieve on to a matt black board so that the grains are evenly spread out. The board has raised sides to prevent specimens rolling off and is marked with squares of approximately the area of the field of the microscope, allowing the residue on the tray to be looked over systematically.

The foraminifer are picked up by a small artist's brush and transferred to gummed cavity slide for examination. This allows the foraminifer from different fractions to be kept separate. The samples are mounted with a wet brush onto the slide.

Preparation of specimens for examination by SEM is relatively simple. The uncontaminated specimen is cleaned with alcohol and mounted on an aluminium stub with double-sided transparent adhesive tape. Finally it is plated with gold or aluminium evaporated under vacuum. An even, complete

metal coating is required together with secure mounting to prevent build up of electrons in the specimen and charging effects.

A disadvantage of examination by SEM is that, although it allows the mapping of surface features in detail, internal features are obscured and smooth opaque specimens show less detail than by optical microscope.

IDENTIFICATION OF FORAMINIFER

Identification of species requires careful comparison with published figures and descriptions, or on strata of the same age in adjacent areas. Regional and global comparisons are absolute for the construction of biostratigraphic and chronostratigraphic charts. The Willunga Basin holds good correlation to the Gambier Basin, linking the Gambier Limestone with such strata as the Blanche Point Formation (mid-late Eocene); as does the St Vincent Basin, i.e. Aldinga Transgression (Eocene/Oligocene contact).

APPENDIX B

THE DATABASE

A total of 15 cores were examined, with two samples collected from each core. The upper sample was taken from directly above the basal Gambier Limestone unit and the other taken from immediately below. The upper samples are labelled (a) and the lower (b) as seen in the database and the abundance charts.

Results from previous studies consistent with the findings of this study have been included. The samples used for this study are listed in Table 2.

The Database contains nearly 2000 specimens comprising of approximately 70 benthic and 40 planktonic species. Where preservation was optimum, over a hundred foraminiferal specimens were picked from the samples. The specimens were then sorted into morphologically similar groups and identified to the genus level, with the majority being identified at the species level also. Reference slides were produced for each sample, and a database of all samples recorded.

SEM was carried out to aid with identification of particular species. Plates showing the different planktonic and benthic species found have been included.

Table 2. Gambier samples examined in this study.

Sample	Drillhole #	Longitude/ Latitude	Author
SE 892	81358	139.878874 ⁰ -36.626346 ⁰	This study
Trumpet	69941	139.413143 ⁰ -37.095017 ⁰	This study
Camelback	94914	140.189422 ⁰ -37.103131 ⁰	This study
RC86KI 8	117714	140.945206 ⁰ -37.113748 ⁰	This study
Lake Bonney	88257	140.473184 ⁰ -37.841991 ⁰	This study
Kin 6	158332	139.960184 ⁰ -36.809798 ⁰	This study
Kelly's Bore	116482	140.621820 ⁰ -37.083645 ⁰	This study
Lucindale	91857	140.310310 ⁰ -37.093600 ⁰	This study
Kin 1	158327	139.842564 ⁰ -36.408664 ⁰	This study
Trossach's Bore	101623	140.029964 ⁰ -35.789515 ⁰	This study
RC86KI 2	122322	140.934227 ⁰ -36.831336 ⁰	This study
RC86KI 3	122324	140.928687 ⁰ -36.783231 ⁰	This study
Keith	122487	140.751357 ⁰ -36.015191 ⁰	This study
RC86KI 18	122323	140.630887 ⁰ -36.802280 ⁰	This study
McNamara	112182	140.630887 ⁰ -37.835794 ⁰	This study
RR 65	112062	140.766867 ⁰ -37.850662 ⁰	Li 2000
RR 65			Moss 1995
Nangwarry		140.949054 ⁰ -37.551765 ⁰	Li 2000

cont. Table 2.

Sample	Drillhole #	Longitude/ Latitude	Author
Observation Bore 1 (OB2)		140.056426 ⁰ -37.176883 ⁰	Li 2000
Breaksea Reef 1	105475	140.612306 ⁰ -38.158583 ⁰	White 1995
Kingston and Robe District			McGowran 1989
MG 6	105154	140.807588 ⁰ -38.048111 ⁰	Li 2000

PLATE 1

- Fig 1: *Catapsydrax unicavus*
(Bolli, Loeblich & Tappan) Trossachs Bore 300-310'
- Fig 2: *Catapsydrax* sp.
(Bolli, Loeblich & Tappan) Kin6 26-28m
- Figs 3-4: *Catapsydrax dissimulis* Kin 6 26-28m RC86KI 2 29-30m
- Figs 5-6: *Acarinina aculeata* Kin 6 26-28m
- Figs 7-8: *Acarinina collactea* Camelback 510' Kin 6 26-28m
- Figs 9-10: *Subbotina angiporoides* RC86KI 29-30m Camelback 450-480'
- Figs 11-12: *Subbotina linaperta* Kellys Bore 104-106m Camelback 510'
- Fig 13: *Globigerina angiporoides group* RC86KI 3 29-30m
- Fig 14-15: *Globigerina* sp. SE 892 45-48m Trossachs Bore 330-340'
(d'Orbigny)
- Fig 16: *Globigerina angiporoides minima* Trossachs Bore 330-340'
- Fig 17: *Globigerina euapertura* RC86KI 2 29-30m
- Fig 18: *Globigerina eocaena* Kin 6 26-28m

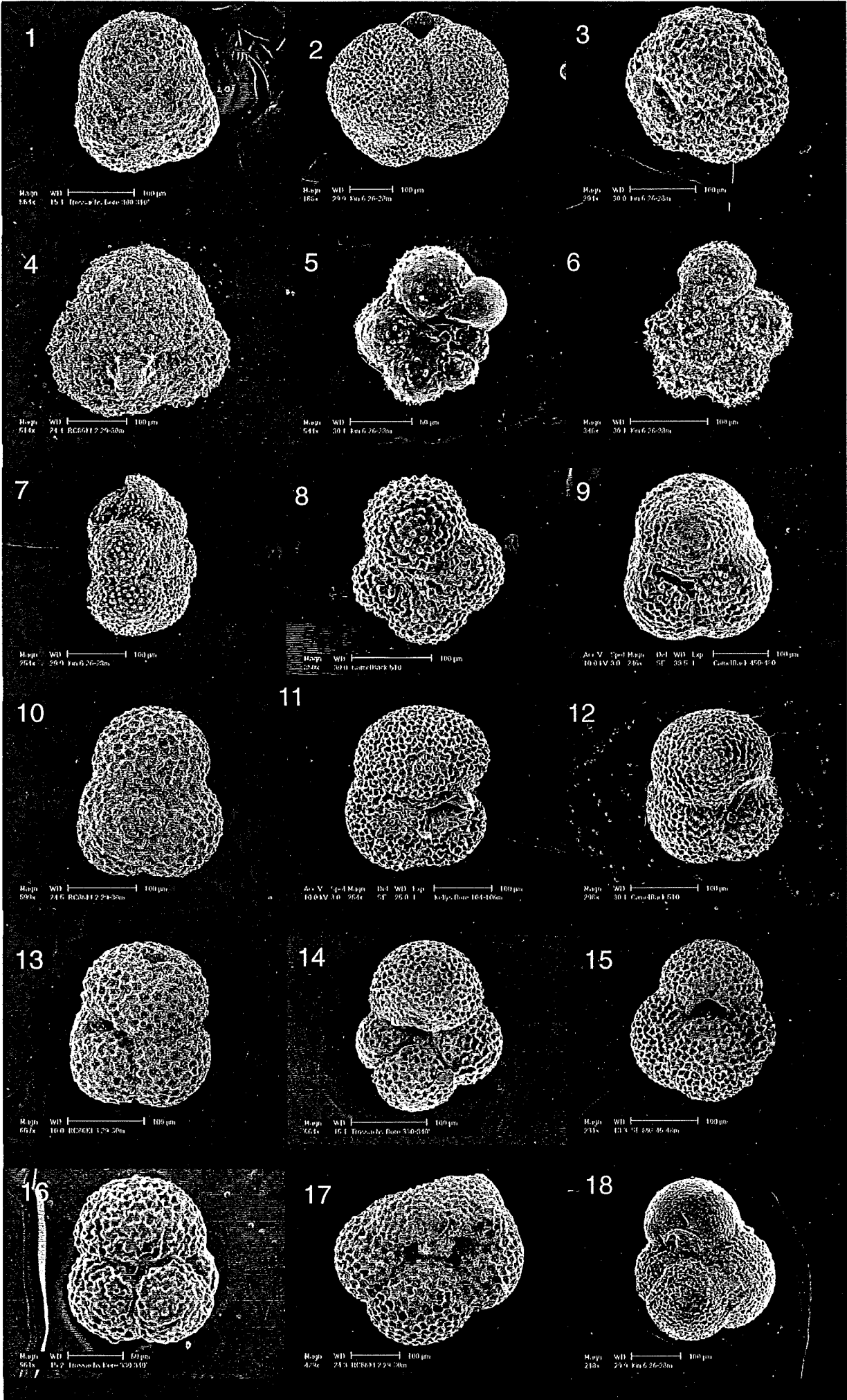


PLATE 2

- Figs 1-2: *Globigerinatheka index*
(Bronnimann) Camelback 510' SE 892 46-48m
- Fig 3: *Globigerina brevis* Camelback 450-480'
- Figs 4-5: *Globorotaloides suteri*
(Bolli) SE 892 36-38m Camelback 510'
- Figs 6-7: *Globigerina praebulloides*
(Blow) RC86KI 8 17-18m Camelback 450-480'
- Figs 8-10: *Globigerina labiacrassta* RC86KI 2 29-30m RC86KI 8 17-18m
- Figs 11-12: *Globigerina ciperoensis*
(Bolli) Keith 468-479'
- Fig 13: *Globigerina cf officinalis* Trossachs Bore 330-340'
- Fig 14: *Globorotaloides* sp.
(Bolli) Kellys Bore 104-106m
- Figs 15-16: *Globoturborotalita* sp
(Hofker) RC86KI 8 17-18m
- Figs 17-18: *Tenitella munda*
(Jenkins) SE 892 36-38m Lucindale 540'

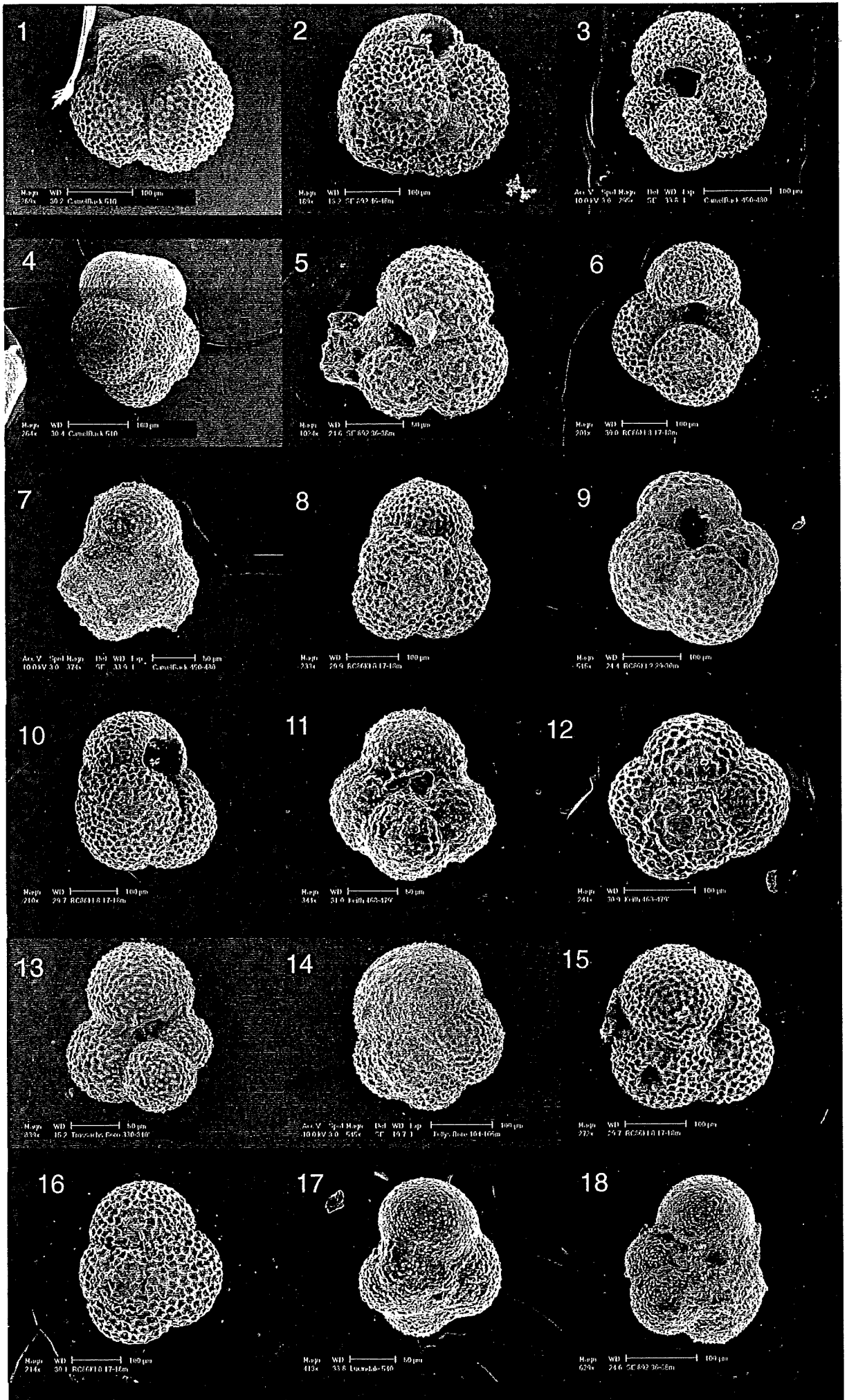


PLATE 3

- Figs 1-2: *Turborotalia* sp
(Cushman & Bermudez) Kellys Bore 104-106m Camelback 510'
- Fig 3: *Turborotalia pseudoampliapertura* Camelback 450-480'
- Fig 4: *Turborotalia increbescens* Kin 6 26-28m
- Fig 5: *Alabamina tenuimarginata*
(Chapman, Parr & Collins) Kin 6 26-28m
- Fig 6: *Discorbinella scopos*
(Finlay) Keith 468-479'
- Fig 7: *Discorbinella* sp
(Cushman & Martin) Lake Bonney 676'
- Fig 8: *Discorbis* sp
(Lamarck) Kellys Bore 104-106m
- Fig 9: *Dridosalis* sp. SE 892 46-48m
- Fig 10: *Notorotalia howchini*
(Chapman, Parr & Collins) Keith 468-479'
- Fig 11: *Gaudryina* sp.
(d'Orbigny) Trossachs Bore 300-310'
- Fig 12: *Gyroidina* sp.
(d'Orbigny) Camelback 450-480'
- Fig 13: *Globulina* sp.
(d'Orbigny) Camelback 450-480'
- Fig 14: *Globulina minuta*
(Roemer) Lucindale 540'
- Figs 15-16: *Guttulina* sp.
(d'Orbigny) Kellys Bore 104-106m Lucindale 600'

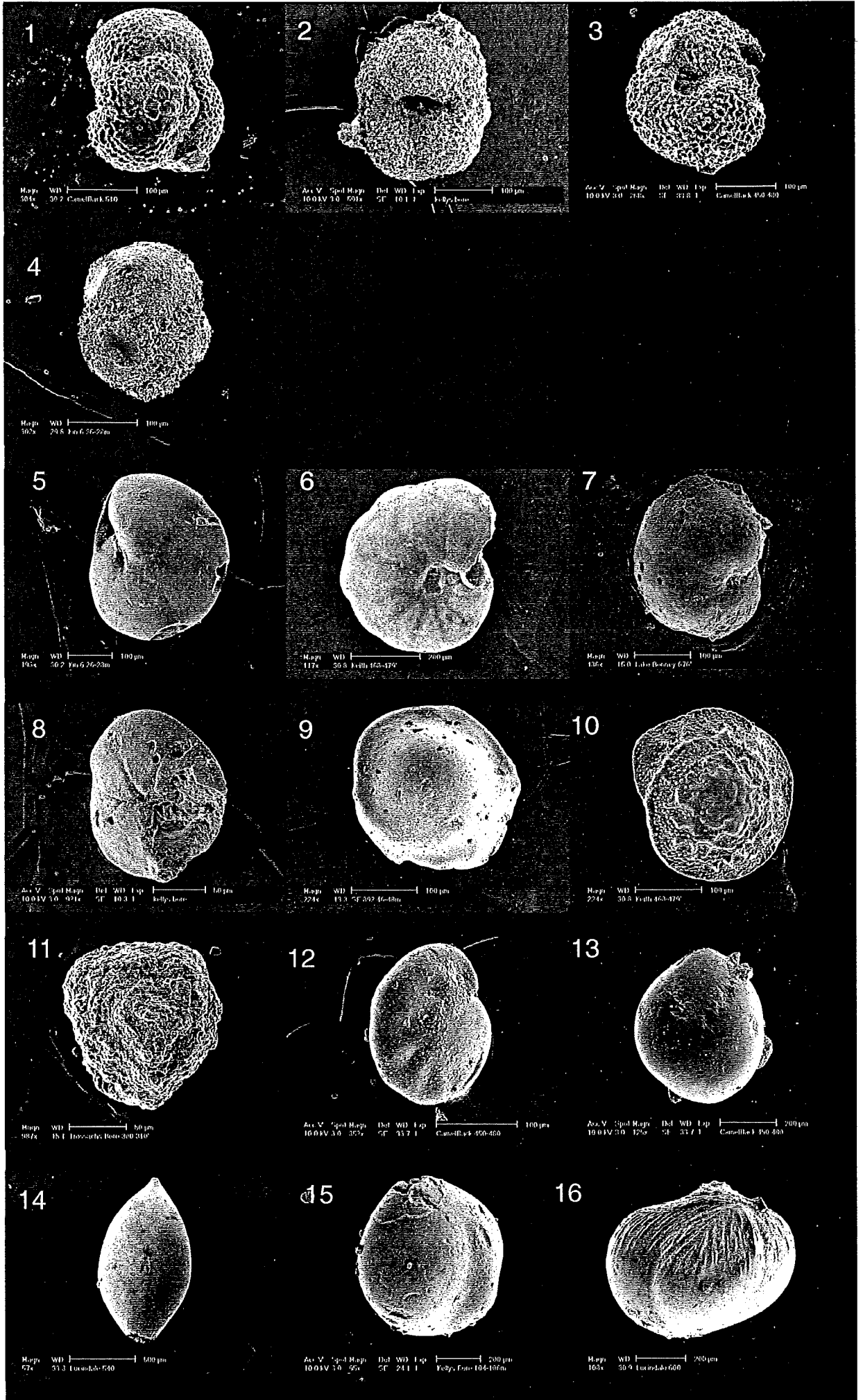


PLATE 4

- Figs 1-2: *Cibicides perforatus* Keith 468-479' Trossachs Bore 300-310'
- Figs 3-4: *Cibicides pseudoconvexus*
(Parr) Camelback 450-480' Camelback 510'
- Fig 5: *Cibicides cf pseudoconvexus*
(Parr) Keith 480'
- Figs 6-7: *Cibicides pseudoungeranus* Kin 1 40-42m
- Fig 8: *Cibicides* sp.
(de Montfort) SE 892 36-38m
- Fig 9: *Cibicidoides pseudoungeranus*
(Cushman) RC86KI 2 29-30m
- Figs 10-11: *Cibicidoides perforatus*
(Karrer) Mount Salt Structure 3 700-710' Keith 480'
- Figs 12-13: *Cibicidoides* sp.
(Thalman) Kin 1 40-42m Kin 6 26-28m
- Fig 14: *Gyroidinoides zelandicus*
(Finlay) Camelback 450-480'
- Fig 15: *Gyroidinoides danvillensis*
(Howe & Wallace) Trossachs Bore 330-340'
- Fig 16: *Gyroidinoides* sp.
(Brotzen) Kin 1 40-42m
- Figs 17-18: *Anomalinoides* sp.
(Brotzen) RC86KI 3 29-30m

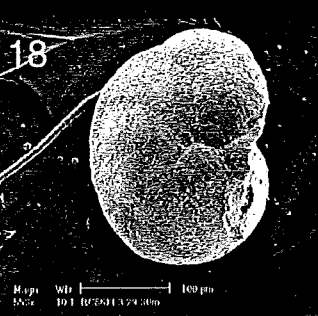
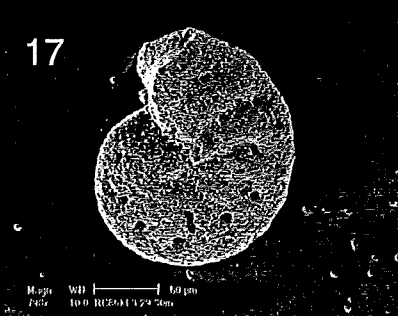
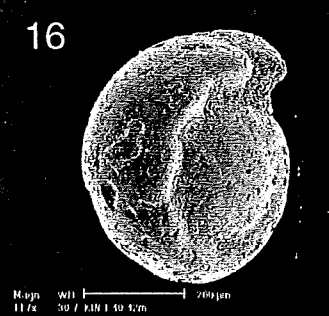
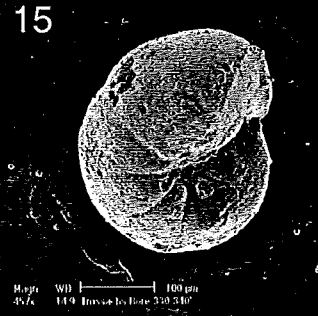
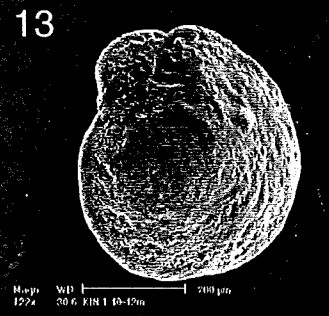
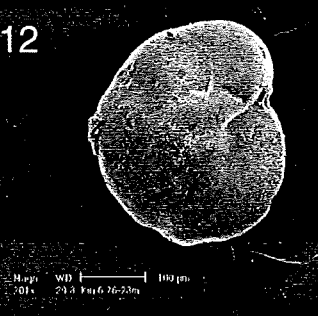
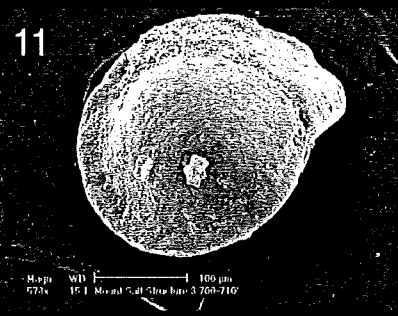
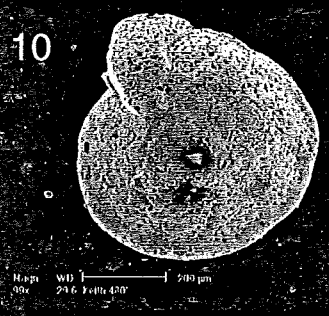
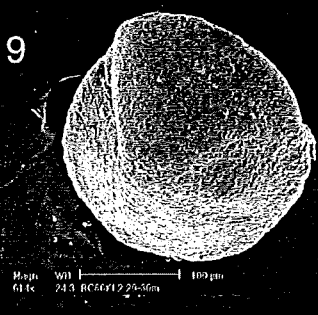
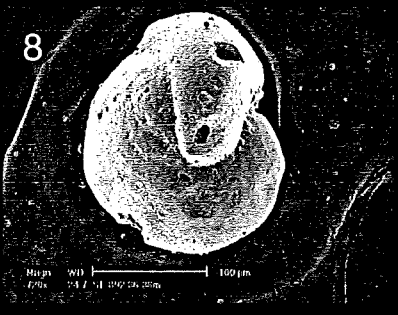
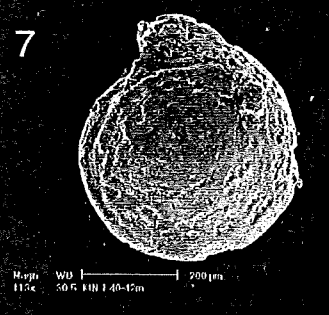
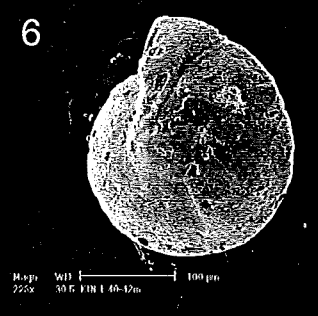
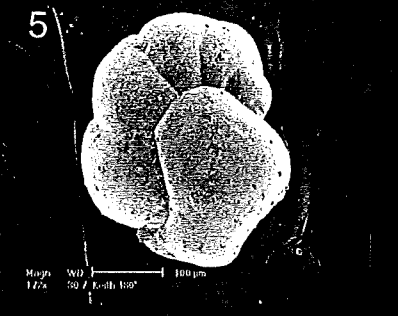
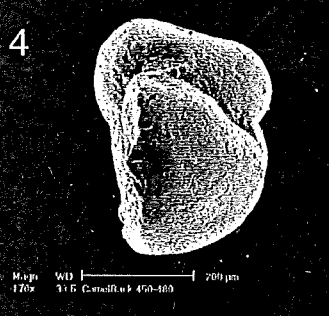
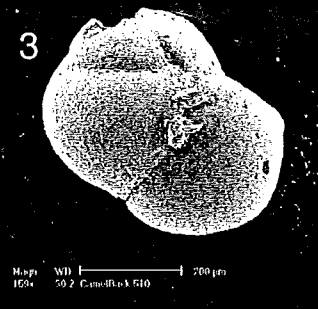
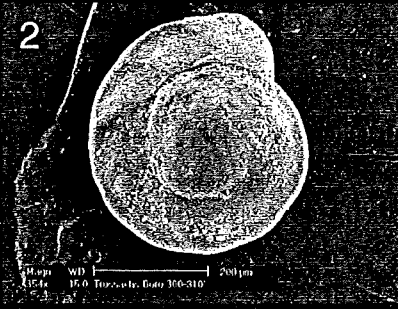
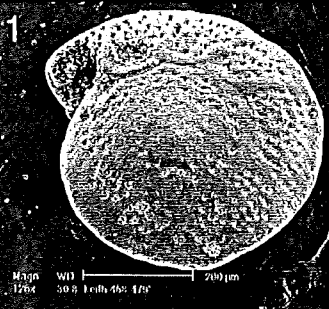


PLATE 5

- Fig 1: *Globocassidulina pacifica*
(Cushman) Kin 1 32-34m
- Figs 2-3: *Globocassidulina subglobosa*
(Brady) Trossachs Bore 330-340'
- Fig 4: *Evolvocassidulina subglobosa*
(Eade) Keith 468-479'
- Figs 5-6: *Cassidulina crassa*
(d'Orbigny) Keith 468-479' Trumpet 1080-1101'
- Fig 7: *Cassidulina* sp.
(d'Orbigny) Keith 480'
- Figs 8-9: *Sphaeroidina bulloides*
(d'Orbigny) Keith 480' Trumpet 1080-1101'
- Figs 10-11: *Pullenia bulloides*
(d'Orbigny) Lucindale 600' SE 892 46-48m
- Figs 12-13: *Heterolepa brevoralis*
(Carter) Keith 480' Lake Bonney 676'
- Figs 14-15: *Heterolepa* sp.
(Franzenau) Camelback 510' Trossachs Bore 330-340'
- Figs 16-17: *Melonis obesus*
(Carter) Trossachs Bore 330-340'
- Fig 18: *Elphidium* sp.
(de Montfort) Kin 6 26-28m

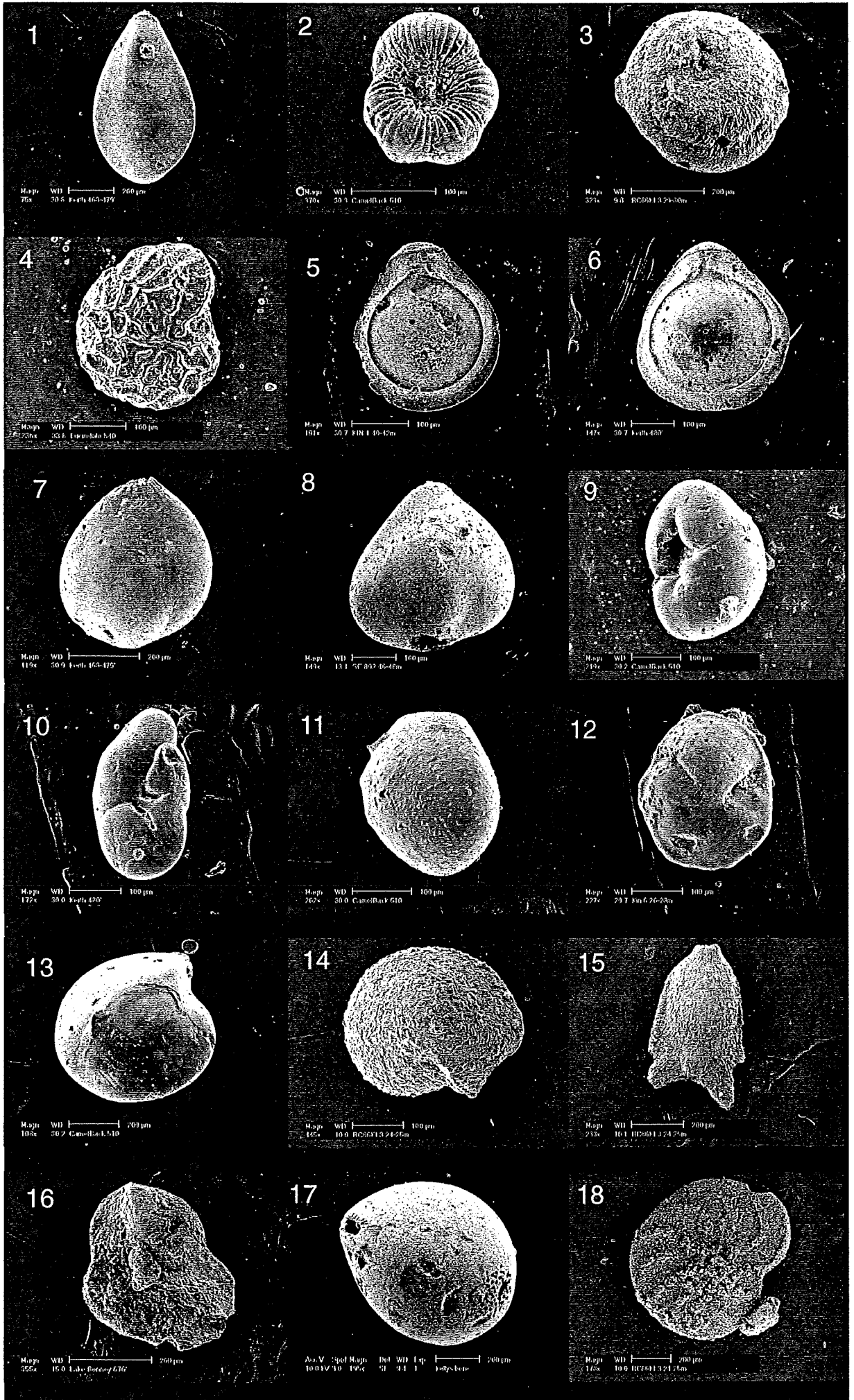


PLATE 6

- Fig 1: *Glandulina* sp.
(d'Orbigny) Keith 468-479'
- Fig 2: *Glabratella crassa*
(Dorreen) Camelback 510'
- Fig 3: *Patellina* sp. (Williamson) RC86KI 3 29-30m
- Fig 4: *Parrellina* sp.
(Thalman) Lucindale 540'
- Fig 5: *Palliotella laevis*
(Seguenza) Kin 1 40-42m
- Fig 6: *Palliotella pterocephala*
(Seguenza) Keith 480'
- Fig 7: *Sigmoidella elegantissima*
(Parker & Jones) Keith 468-479'
- Fig 8: *Sigmoidella* sp.
(Cushman & Ozawa) SE 892 46-48m
- Fig 9: *Robertina* sp.
(d'Orbigny) Camelback 510'
- Fig 10: *Robertinoides* sp.
(Hoglund) Keith 480'
- Fig 11: *Polymorphina* sp.
(d'Orbigny) Camelback 510'
- Fig 12: *Svratkina* sp. (Pokorny) Kin 6 26-28m
- Figs 13-14: *Lenticulina* sp. Camelback 510' RC86KI 3 24-25m
(Lamarck)
- Fig 15: *Fissurina kerguelensis* RC86KI 3 24-25m
- Fig 16: *Karrerria maoria* (Finlay) Lake Bonney 676'
- Fig 17: *Fissurina* sp. (Reuss) Kellys Bore 104-106m
- Fig: 18: *Operculina* sp. (d'Orbigny) RC86KI 3 24-25m

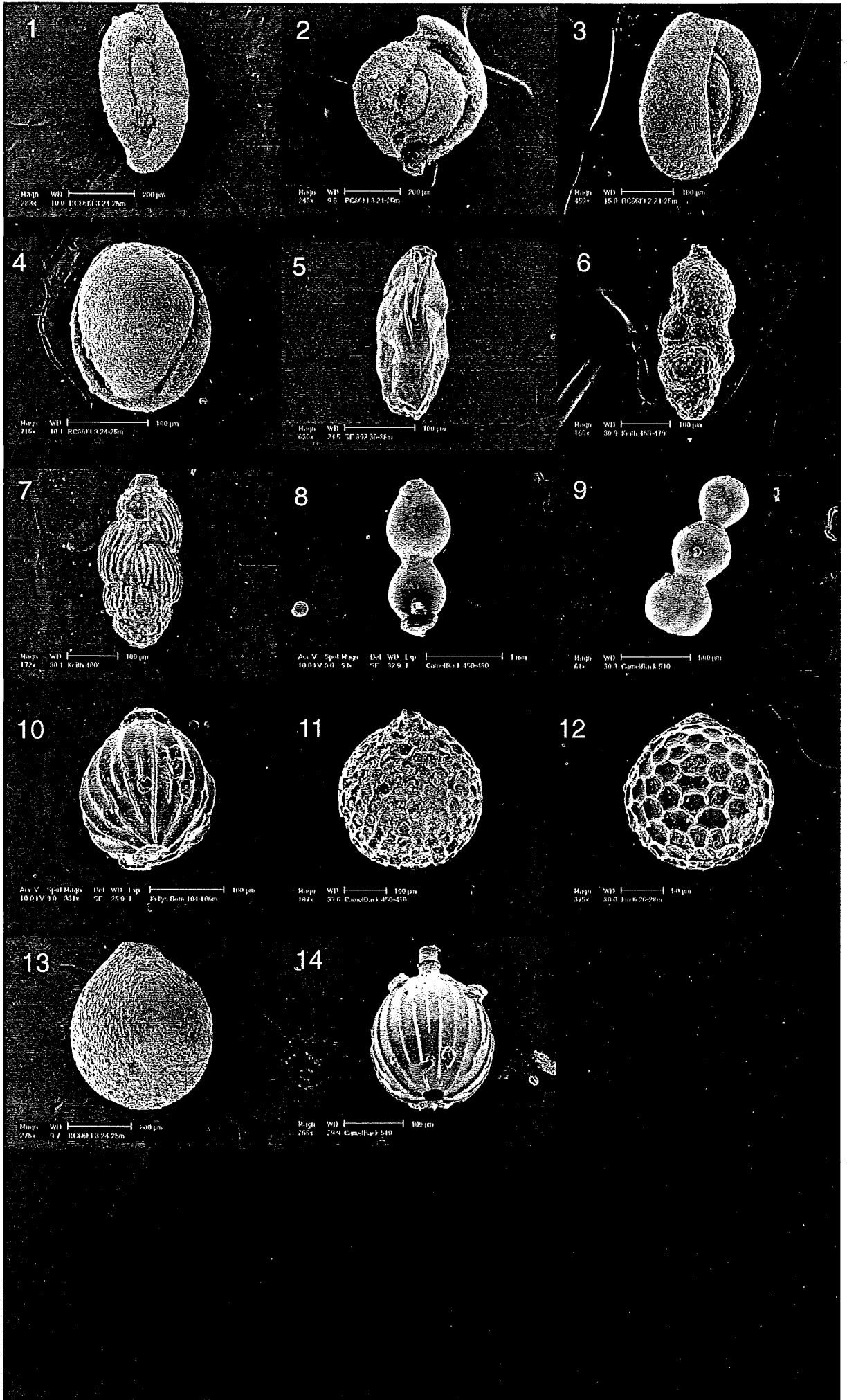
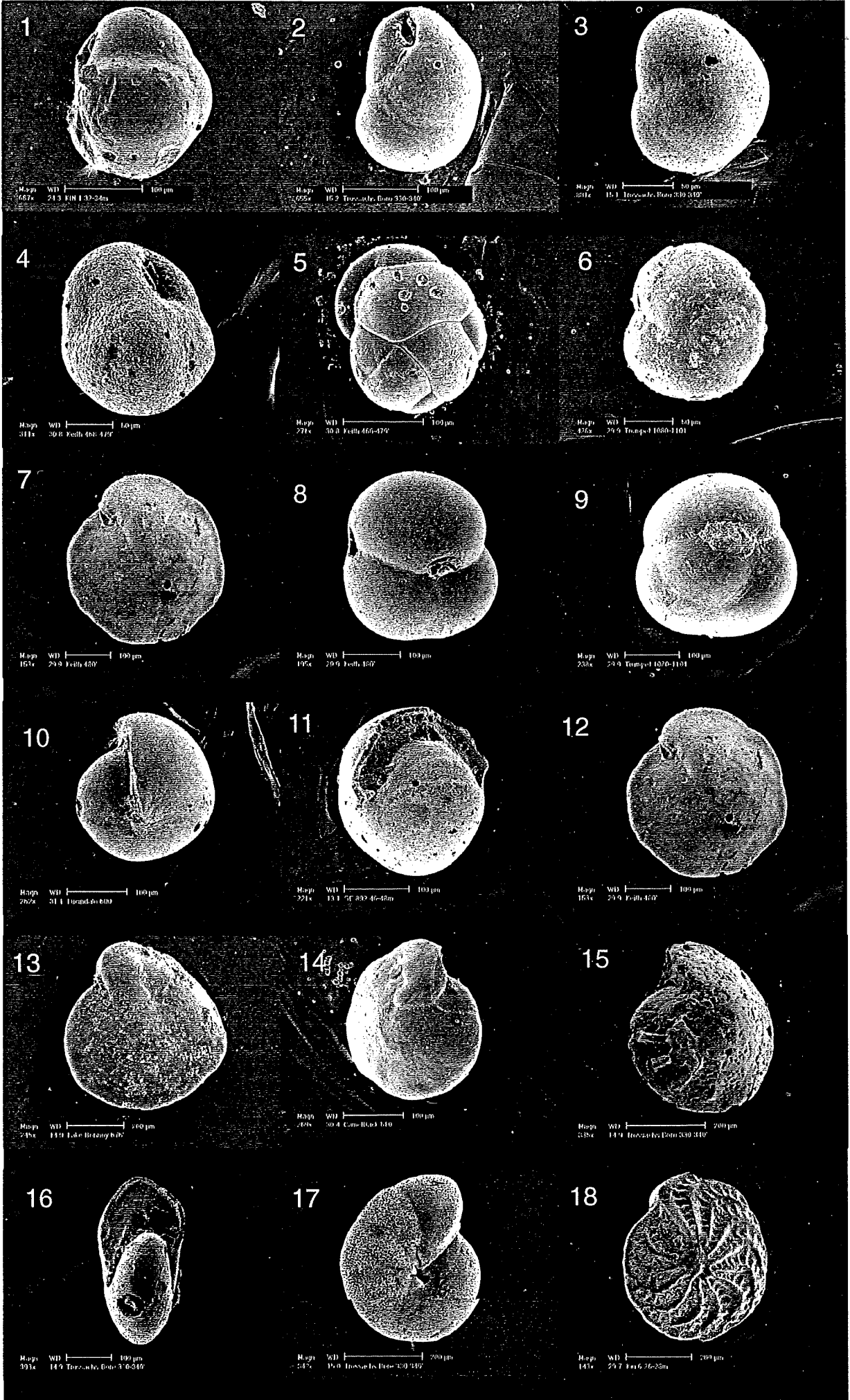


PLATE 7

- Fig 1: *Quinqueloculina* sp 1
(d'Orbigny) RC86KI 3 24-25m
- Fig 2: *Quinqueloculina* sp 2.
(d'Orbigny) RC86KI 2 24-25m
- Fig 3: *Quinqueloculina* sp 3
(d'Orbigny) RC86KI 3 24-25m
- Fig 4: *Triloculina* sp.
(d'Orbigny) RC86KI 3 24-25m
- Fig 5: *Trifarina parva*
(Hornibrook) SE 892 36-38m
- Fig 6-7: *Uvigerina* sp.
(d'Orbigny) Keith 480' Keith 468-479'
- Figs 8-9: *Nodosaria* sp.
(Lamarck) Camelback 510' Camelback 450-480'
- Fig 10: single chamber of *Nodosaria* sp.
(Lamarck) Kellys Bore 104-106m
- Fig 11: *Favulina hexagona*
(Williamson) Camelback 450-480'
- Fig 12: *Favulina squamosa*
(Montagu) Kin 6 26-28m
- Fig 13: *Lagena* sp.
(Walker & Jacob) RC86KI 3 24-25m
- Fig 14: *Lagena sulcata*
(Walker & Jacob) Camelback 510'



APPENDIX C

FAUNAL CHECKLIST

Species are organised into families according to Loeblich and Tappan (1988).

Kingdom PROTISTA

Phylum SACODINA

Class RHIZOPODA

Order FORAMINIFERA

Family VERNEUILINIDAE Cushman, 1911

Subfamily VERNEUILININAE (Cushman, 1911)

Gaudryina sp. (d'Orbigny, 1839)

Family HAUERINIDAE Schwager, 1876

Subfamily HAUERININAE (Schwager, 1876)

Quniqueloculina sp. (d'Orbigny, 1826)

Subfamily MILIOLINELLINAE (Vella, 1957)

Triloculina sp. (d'Orbigny, 1826)

Family VAGINULINIDAE Reuss, 1860

Subfamily LENTICULININAE (Chapman, Parr and Collins, 1934)

Lenticulina sp. (Lamarck, 1804)

Family **NODOSARIIDAE** Ehrenberg, 1838

Subfamily NODOSARIINAE (Ehrenberg, 1838)

Nodosaria sp. (Lamarck, 1812)

Family **POLYMORPHINIDAE** d'Orbigny, 1839

Subfamily POLYMORPHININAE (d'Orbigny, 1839)

Guttulina sp. (d'Orbigny, 1839)

Globulina minuta (Roemer)

Roemer, 1838: pp 386, pl. 3: figs 35a-b.

Globulina sp. (d'Orbigny, 1839)

Sigmomorphina sp. (Cushman and Ozawa, 1928)

Sigmoidella elegantissima (Parker and Jones)

Parker and Jones, 1865: pp 438.

Quilty, 1974: pp 85, pl. 4: fig 142.

Sigmoidella victoriensis

Sigmoidella sp. (Cushman and Ozawa, 1928)

Polymorphina sp (d'Orbigny, 1826)

Family **ELLIPSOLAGENIDAE** A.Silvestru, 1923

Subfamily OOLININAE (Loeblich & Tappan, 1961)

Oolina sp. (d'Orbigny, 1839)

Favulina hexagona (Williamson)

Williamson, 1848: pp 20, pl. 2:fig. 23.

Quilty, 1974:pp 66, pl. 3: fig. 98.

Favulina squamosa (Montagu)

Montagu, 1803: pp 526, pl. 14: fig 2.

Hayward and Buzas, 1979: pp 68, pl. 23: fig 292.

Favulina sp. (Patterson and Richardson, 1987)

Subfamily ELLIPSOLAGENINAE (A.Silvestri, 1923)

Fissurina sp (Reuss, 1850)

Palliolatella laevis (Seguenza)

Seguenza, 1862: pp 66, pl. 2: figs 22-23.

Palliotella pterocephala (Seguenza)

Seguenza, 1862: pp 64, pl. 2: fig 17.

Family LAGENIDAE Reuss, 1862

Lagena sp. (Walker and Jacob, 1798)

Family UVIGERINIDAE Haeckel, 1894

Subfamily UVIGERININAE (Haeckel, 1894)

Uvigerina proboscidea (Schwager)

Schwager, 1866: pp 250, pl. 7: fig 96.

Uvigerina sp. (d'Orbigny, 1826)

Trifarina parva (Hornibrook)

Hornibrook, 1961: pp 71, pl. 9: figs 161-162.

Family **CASSIDULINIDAE** d'Orbigny, 1839

Subfamily **CASSIDULININAE** (d'Orbigny, 1839)

Cassidulina sp. (d'Orbigny, 1826)

Cassidulina crassa (d'Orbigny)

D'Orbigny, 1839: pp 56, pl. 7: figs 18-20.

Globocassidulina subglobosa (Brady)

Brady, 1881: pp 60; 1884: pp 430, pl. 54: fig. 17.

Quilty, 1982: pp 29, pl. 4: figs 23-24.

Globocassidulina subconglobosa

Globocassidulina sp. (Voloshinova, 1960)

Evolovocassidulina subglobosa (Eade, 1967)

Family **DISCORBIDAE** Ehrenberg, 1838

Discorbis sp. (Lamarck, 1804)

Family **GLABRATELLIDAE** Loeblich and Tappan, 1964

Glabratella crassa (Dorreen)

Dorreen, 1948: pp 294, pl. 39: fig 1.

Hornibrook, 1961: pp 108, pl. 14: fig. 289.

Quilty, 1977: pp 92, pl. 5: figs 3-4.

Family **GAVELINELLIDAE** Hofker, 1956

Subfamily GAVELINELLINAE (Hofker, 1956)

Gyroidina sp. (d'Orbigny, 1826)

Subfamily GYROIDINOIDINAE (Saidova, 1981)

Gyroidinoides danvillensis (Howe and Wallace)

Howe and Wallace, 1932: pp 69, pl. 13: figs 3a-c.

Hayward and Buzas, 1979: pp 59, pl. 18, figs 224-225.

Gyroidinoides zelandicus (Finlay)

Finlay, 1939: pp 323, pl. 28: figs 138-140.

Hayward and Buzas, 1979: pp 60, pl. 18: figs 221-223.

Quilty, 1982: pp 35, pl. 6: figs 1-3.

Gyroidinoides sp. (Brotzen, 1942)

Family **DISCORBINELLIDAE** Sigal, 1952

Subfamily DISCORBINELLINAE Sigal, 1952

Discorbinella scopos (Finlay)

Finlay, 1940: pp 466, pl. 67: figs 212-213.

Carter, 1958: pp 41, pl. 4: figs 34-36.

Discorbinella sp. (Cushman and Martin, 1935)

Family **ELPHIDIIDAE** Galloway, 1933

Subfamily **ELPHIDIINAE** (Galloway, 1933)

Elphidium sp (de Montfort, 1808)

Subfamily **NOTOROTALIINAE** (Finlay, 1939)

Notorotalia howchini (Chapman, Parr and Collins)

Chapman, Parr and Collins, 1934: pp 566, pl. 9: figs. 20a-c.

Carter, 1958: pp 65, pl. 10: figs 104-106.

Quilty, 1982: pp 23, pl. 4: figs 1-3.

Notorotalia sp. (Finlay, 1939)

Parrellina sp (Thalmann, 1951)

Family **CIBICIDIDAE** Cushman, 1927

Subfamily **CIBICIDINAE** (Cushman, 1927)

Cibicides perforatus

Cibicides pseudoconvexus (Parr)

Parr, 1938: pp 86, pl. 3: fig. 5.

Cibicides pseudoungerianus

Cibicides westi

Cibicides sp. (de Montfort, 1808)

Family **PARRELLOIDIDAE** Hofker, 1956

Cibicoides perforatus (Karrer)

Li and McGowran, 1995: pp. 102: fig. 4, no. 11.

Cibicoides pseudoungerianus (Cushman, 1922)

Cibicoides sp. (Thalman, 1939)

Family **HETEROLEPIDAE** Gonzales-Donoso, 1969

Anomalinoides (Brotzen, 1942)

Heterolepa brevoralis (Carter)

Carter, 1958: pp 47, pl. 6: figs. 54-56.

Heterolepa sp. (Franzenau, 1884)

Family **SPHAEROIDINIDAE** Cushman, 1927

Sphaeroidina bulloides (d'Orbigny)

D'Orbigny, 1826: pp 267.

Quilty, 1977: pp 75, pl. 1: figs. 23-24.

Family **EPONIDIDAE** Hofker, 1951

Subfamily **EPONIDINAE** (Hofker, 1951)

Eponides sp. (de Montfort, 1808)

Family **PLANULINIDAE** Bermudez, 1952

Planulina sp (d'Orbigny, 1826)

Family **ALABAMINIDAE** Hofker, 1951

Alabamina tenuimarginata (Chapman, Parr and Collins)

Carter, 1964: pp. 114, pl. 11: figs. 220-222.

Quilty, 1982: pp. 33, pl. 5: figs. 11-12.

Svratkina sp. (Pokorny, 1956)

Family **NUMMULITIDAE** de Blainville, 1827

Operculina sp. (d'Orbigny, 1826)

Family **GLANDULINIDAE** Reuss, 1860

Subfamily **GLANDULININAE** (Reuss, 1860)

Glandulina sp. (d'Orbigny, 1839)

Family **HERONALLENIIDAE** Loeblich and Tappan, 1986

Heronallenia parri (Carter)

Carter, 1958: pp 43, pl. 5: figs 43-45.

Quilty, 1977: pp 93, pl. 5: figs 15-16.

Family **KARRERIIDAE** (Saidova, 1981)

Karrereria maoria (Finlay)

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Finlay, 1939: pp 326, pl. 29: figs 148-151, 158.

Carter, 1964: pp 90, pl. 6: figs 116-120.

Quilty, 1982: pp 38, pl. 6: figs 22-23.

Family **NONIONIDAE** Schultze, 1854

Subfamily **PULLENIINAE** (Schwager, 1877)

Melonis obesus (Carter)

Carter, 1964: pp 112, pl. 10: figs 205-206.

Pullenia bulloides (d'Orbigny)

d'Orbigny, 1846: pp 107, pl. 5: figs 9-10.

Carter, 1964: pp 71, pl. 2: figs 46-47.

Hayward and Buzas, 1979: pp 72, pl. 24: figs 303-304.

Family **PATELLINIDAE** Rhumbler, 1906

Subfamily **PATELLININAE** (Rhumbler, 1906)

Patellina sp (Williamson, 1858)

Family **ROBERTINIDAE** Reuss, 1850

Subfamily **ROBERTININAE** (Reuss, 1850)

Robertina sp. (d'Orbigny, 1846)

Robertinoides sp. (Hoglund, 1947)

Family **GLOBIGERINIDAE** Carpenter, Parker and Jones, 1862

Subfamily PORTICULASPHAERINAE (Banner, 1982)

Globigerinatheka index (Bronnimann, 1952)

Bronnimann, 1952: pp 27.

Subfamily GLOBIGERININAE (Carpenter, Parker and Jones, 1862)

Globigerina angiporoides

Globigerina angiporoides minima

Globigerina brevis

Globigerina ciperensis (Bolli)

Bolli, 1957: pp 109, pl. 22, figs 10a-c.

Carter, 1964: pp 105, pl. 9: figs 180-182.

Kennett and Srinivasan, 1983: pp 28, pl. 4: figs 6-8.

Globigerina eocaena

Globigerina euaperta

Globigerina labiacrassata

Globigerina linaperta

Globigerina officinalis

Globigerina praebulloides (Blow)

Blow, 1959: pp 180, pl. 8: fig. 47a-c, pl. 9: fig 48.

Kennett and Srinivasan, 1983: pp 36, pl. 6: figs 1-3.

Globigerina sp (d'Orbigny, 1826)

Globoturborotalita sp. (Hofker, 1976)

Family **CATAPSYDRACIDAE** Bolli, Loeblich and Tappan, 1957

Globorotaloides suteri (Bolli)

Bolli, 1957: pp 117, pl. 27: figs 9a-13b.

Kennet and Srinivasan, 1983: pp 214, pl. 53: figs 1, 3-5.

Globorotaloides sp (Bolli, 1957)

Globoquadrina sp. (Finlay, 1947)

Catasydrax dissmilus

Catasydrax unicavus (Bolli, Loeblich and Tappan)

Bolli, loeblich and Tappan, 1957: pp 37, pl. 7: figs 9a-c.

Kennett and Srinivasan, 1983: p 26, pl. 3: figs 1-3.

Catasydrax sp. (Bolli, Loeblich and Tappan, 1957)

Subbotina angiporoides

Subbotina linaperta

Family **GLOBOROTALIIDAE** Cushman, 1927

Turborotalia amplitoture

Turborotalia increbscens

Turborotalia pseudoampliapertura

Turborotalia sp. (Cushman and Bermudez, 1949)

Family **CANDEINIDAE** Cushman, 1927

Subfamily **TENUITELLINAE** (Banner, 1982)

Tenuitella munda (Jenkins)

Jenkins, 1966: pp 1121, fig. 14, nos. 126-133:pl. 13,
figs 152-156.

Li, 1987: pp 309, pl. 3, figs 6-9, 11-12.

Li, Radford and Banner, 1992: pp 579, pl. 1: figs 6-7.

Family **TRUNCOROTALOIDIDAE** Loeblich and Tappan, 1961

Acarinina aculeata

Acarinina collactea

APPENDIX D

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APPENDIX E

This Appendix contains biostratigraphic correlations and foraminiferal datums referred to in this study, produced by Li *et al.*, (2000).

Figure 1: Correlation of drilled sections in the Gambier Basin with some datum levels listed in Table 2. Note a different scale for the three petroleum wells on the right, from which sparse samples provided a poor biostratigraphic control. Additional data for Glenelg 1 were from Gallagher *et al.* (2000).

Figure 2: Ranges of diagnostic planktonic and benthic species, zones and stratal units in hole MG 6

Figure 3: Hole OB2: ranges of diagnostic planktonic and benthic species, P/B ratio, sequences and units. Unit 2, not recognised in RR65, occurs here with distinctive lithology and foraminiferal assemblage (Table 3). The planktonic abundance was based on Moss (1995).

Table 3: Important planktonic and benthic foraminiferal datum levels from the Gambier Basin.

Figure 1

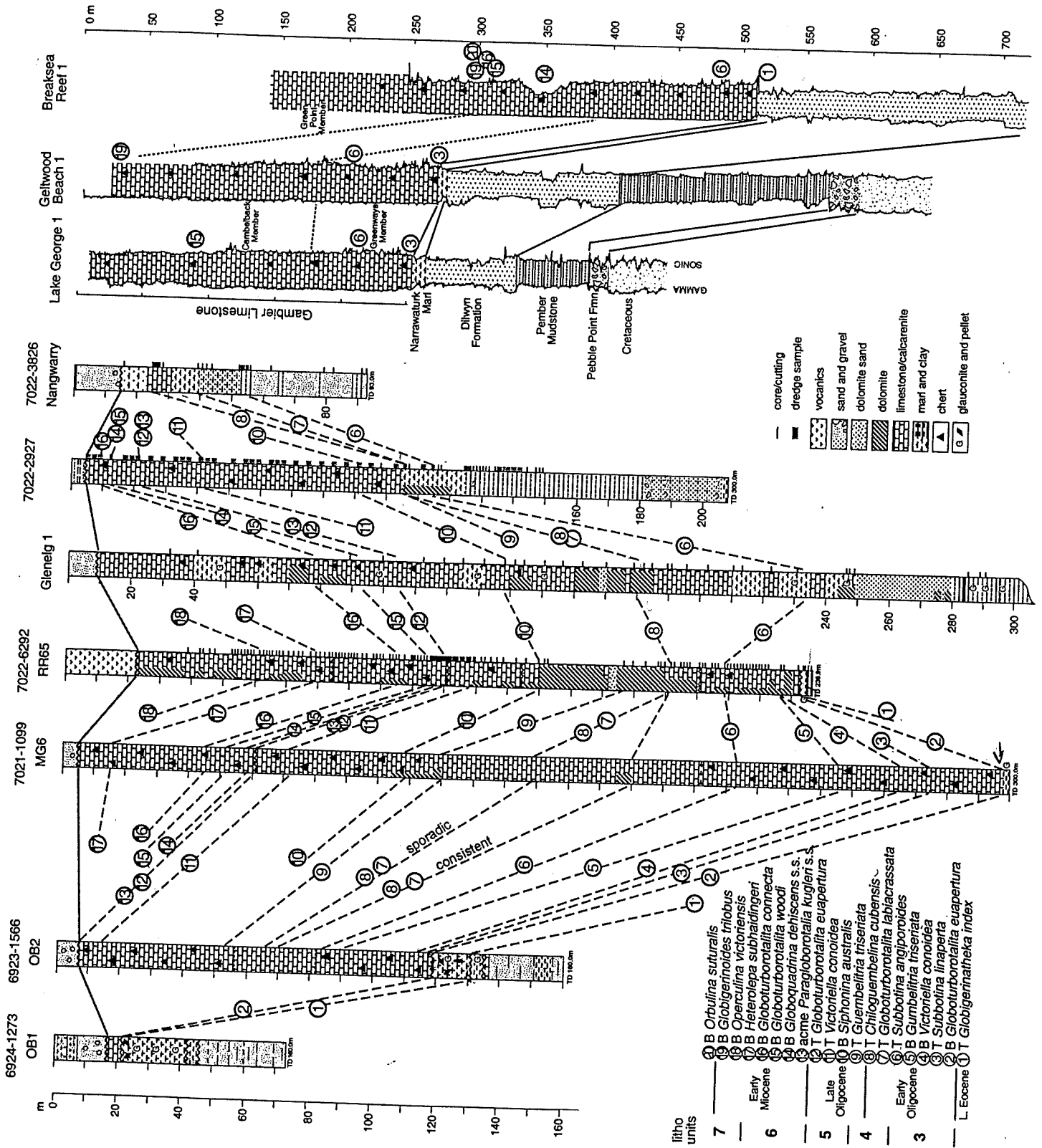


Figure 2

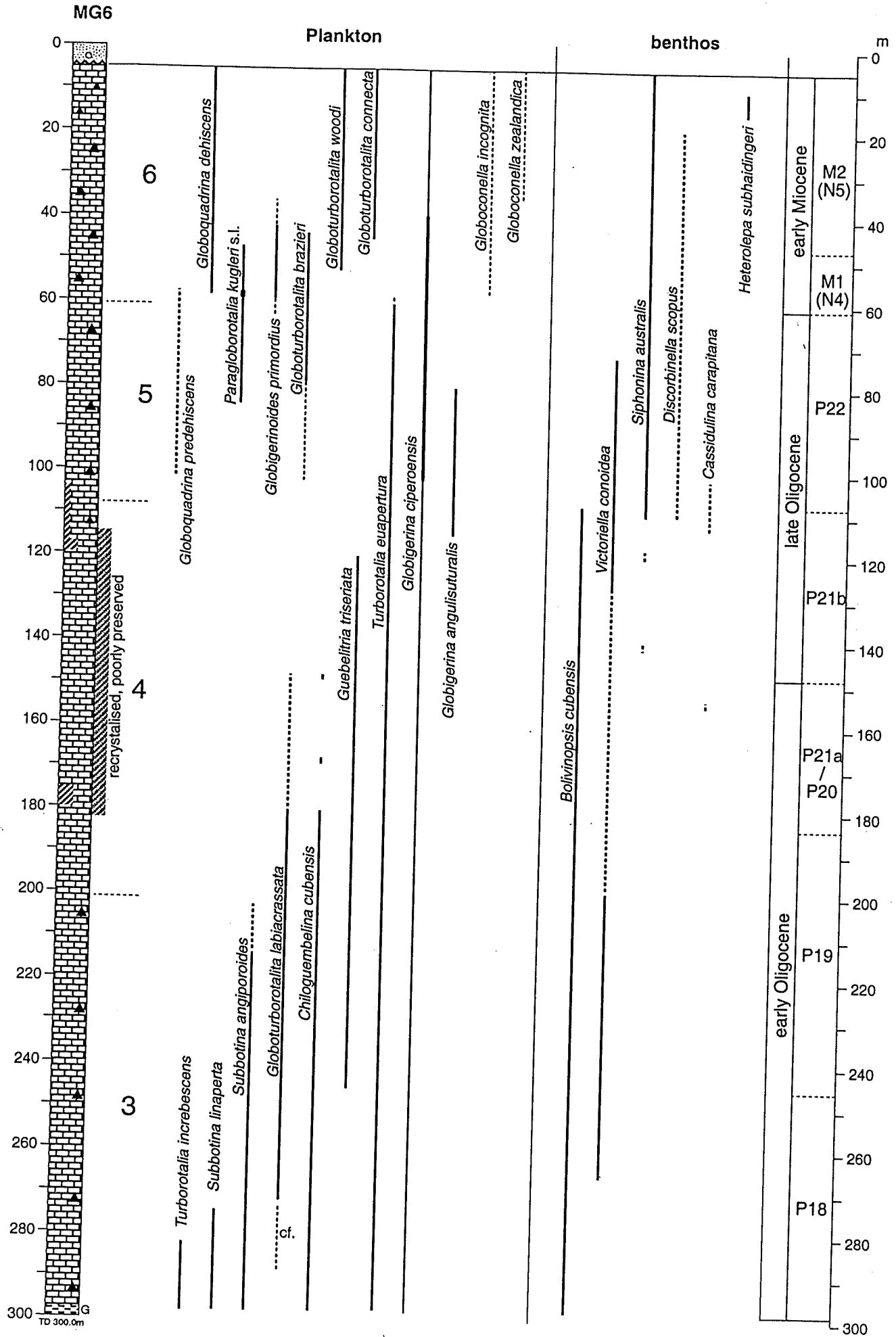


Table 3. Important planktonic and benthic foraminiferal datum levels from the Gambier Basin region.

Epoch	Datum level	Age (Ma)*	Occurrence	
Middle Miocene	Base <i>Orbulina suturalis</i>	16.1	300m, Breaksea Reef 1	
	Base <i>Praeorbulina glomerosa</i>	15.1	300m, Breaksea Reef 1	
Early Miocene	Base <i>Globigerinoides trilobus</i>	18.5	38m, RR65	
	Base <i>Ehrenbergina marwicki</i>	20.0	58m, RR65	
	Base <i>Operculina victoriensis</i>	20.0	61.2m RR65	
	Top <i>Heterolepa subhaidingeri</i> acme	20.0	67.7m, RR65; 9m, MG6	
	Base <i>Heterolepa subhaidingeri</i>	21.0	79m, RR65; 16m, MG6	
	Top large <i>Discorbinella scopus</i>	21.0	82m, RR65	
	Base <i>Globoturborotalita connecta</i>	21.8	107m, RR65; 46m, MG6	
	Base <i>Globoturborotalita woodi</i>	22.0	114m, RR65; 53m, MG6	
	Base consistent <i>Cibicides mediocris</i>	22.0	114m, RR65	
	Base <i>Globoquadrina dehiscens</i>	23.2	119m, RR65; 58m, MG6	
	Base <i>Paragloborotalia kugleri</i> s.s.	23.8	119m, RR65; 60m, MG6	
	Top consistent <i>Turborotalia euapertura</i>	23.8	60m, MG6	
	Late Oligocene	Frequent <i>Globigerinoides primordius</i>	24.3	64m, MG6; 30m, 7022-2927
		Top <i>Alabamina tenuimarginata</i>	25.5	125.5m, RR65; 22m, OB2
		Top <i>Victoriella conoidea</i>	25.5	72m, MG6
Top <i>Globigerina angulisuturalis</i>		26.0	80m, MG6; 35m, OB2	
Base <i>Paragloborotalia kugleri</i> s.l.		26.2	84m, MG6; 37m, OB2	
Base <i>Palliatella laevis</i>		26.3	128m, RR65; 39m, OB2	
Top <i>Bolivinopsis cubensis</i>		26.5	41m, OB2	
Top <i>Paragloborotalia opima</i>		27.1	142m, RR65; 44m, OB2	
Top <i>Cassidulina carapitana</i>		27.1	142m, RR65; 100m, MG6	
Base large <i>Discorbinella scopus</i>		27.2	149m, RR65, 110m, MG6	
Base typical and large <i>Siphonina australis</i>		27.2	149m, RR65, 110m, MG6	
Base consistent <i>Paragloborotalia opima</i>		27.5	65m OB2	
Top <i>Gumbelitra triseriata</i>		27.5	176.6m, RR65; 120m, MG6; 53m, OB2	
Early Oligocene		Top <i>Chiloguembelina cubensis</i>	28.5	168m, MG6; 70m, OB2
		Top <i>Globoturborotalita labiacrassata</i>	29.0	180m, MG6; 75m, OB2
	Base " <i>Astranonion</i> " <i>centroplax</i>	30.5	202.2m, RR65	
	Top good <i>Subbotina angiporoides</i>	31.0	208.5m, RR65; 214m, MG6; 84m OB2	
	Base <i>Gumbelitra triseriata</i>	32.0	226.5m, RR65; 246m, MG6	
	Base <i>Victoriella conoidea</i>	32.0	226.5m, RR65; 114m, OB2	
	Top <i>Subbotina linaperta</i>	33.0	117m, OB2	
	Top <i>Turborotalia increbescens</i>	33.0	117m, OB2	
	Base <i>Turborotalia euapertura</i>	33.5	232.2m, RR65	
Late Eocene	Top <i>Pseudohastigerina micra</i>	34.0	233.8m, RR65	
	Top <i>Globigerinatheka index</i>	34.3	233.8m, RR65	
	Top <i>Praetenuitella insolita</i>	35.0	234.2m, RR65	
Middle Eocene	Top <i>Acarinina</i> spp.	37.0	235.2m, RR65	

*Age in bold mainly after Berggren et al. (1995), others estimated.

(Li et al., 2000)