

## Early Palaeogene planktic foraminiferal and carbon isotope stratigraphy, Hole 762C, Exmouth Plateau, northwest Australian margin

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**ABSTRACT** – Although the northwest margin of Australia is an important region for petroleum exploration and palaeoceanographic investigations, its Palaeogene stratigraphy is poorly documented, especially in terms of a foraminiferal biozonation. Early Palaeogene cores from 502.96 to 307.80 m below sea floor at Ocean Drilling Program Site 762 on the Exmouth Plateau were examined in this study for their planktic foraminiferal assemblages and the carbon isotopic compositions of *Subbotina* spp. Planktic foraminifera are generally well preserved and belong to 74 species and 17 genera. In spite of a mid-latitude palaeolatitude (*c.* 40°S) the sequence, deposited between the early Paleocene and Middle Eocene, contains all planktic foraminiferal Zones P1c through P10 of the current global scheme for tropical locations, except for Subzone P4b. Most zones are well defined by the datums of primary marker species except P3a and P9, which have boundaries that probably occur in core gaps, and the P9 zonal boundaries are defined by secondary marker species. Overall, variations in  $\delta^{13}\text{C}$  based on sequential samples of *Subbotina* are similar in pattern and magnitude to global summary isotope curves spanning the early Palaeogene. However, the prominent  $\delta^{13}\text{C}$  excursion that characterizes the Palaeocene/Eocene transition is mostly missing and appears to lie in a core gap. The planktic foraminiferal zonation, linked with that based on nannofossils, a recalibrated magnetostratigraphy and carbon isotope records, provides a robust temporal framework for the Early Palaeogene of the northwest margin of Australia. *J. Micropalaeontol.* 21(1): 29–42, May 2002.

### INTRODUCTION

The Early Palaeogene *c.* 65 to 49 Ma (Fig. 1) is an especially significant interval of time because of profound changes in climate, ecosystems and the global carbon cycle (e.g. Zachos *et al.*, 1993, 2001; Corfield, 1994; Thomas & Shackleton, 1996; Dickens *et al.*, 1997; Norris & Röhl, 1999). Indeed, documentation of Palaeogene paleoceanography is now a high priority for stratigraphic research. However, to resolve outstanding questions of global change, early Palaeogene marine successions must be located that meet certain criteria. These targets must be: (1) thick so as to maximize the temporal quality of the record and time resolution; (2) buried with little overburden to reduce the logistical demands of drilling and diagenetic effects; (3) rich in well-preserved biogenic carbonate for geochemical evaluation; and (4) hosted in stratal geometries which permit construction of detailed depth and latitudinal transects. To date, one of the few investigated locations which meets these criteria is the recently drilled Blake Nose in the western North Atlantic. Studies of this region have already advanced our knowledge of Palaeogene environmental change significantly (e.g. Bains *et al.*, 1999; Katz *et al.*, 1999; Norris *et al.*, 1999; Norris & Röhl, 1999).

The Exmouth Plateau (Fig. 2) is a submerged platform extending 150–500 km off northwest Australia that consists of thinned and tilted continental crust with a Phanerozoic sedimentary sequence exceeding 10 km (Barber, 1988; Stagg & Colwell, 1994). The stratigraphic succession on the plateau is particularly significant because it contains a somewhat expanded Palaeogene sequence deposited in moderate water depths and within the southern subtropical zone (Exon *et al.*, 1992). Moreover, unlike

many other regions in the world, the Exmouth Plateau has extensive seismic coverage because of petroleum exploration. Seismic records indicate a substantial Palaeogene record which includes thick successions in both offshore and inshore locations making the Exmouth Plateau a potential location for detailed Palaeogene oceanographic reconstructions.

Current understanding of Palaeogene stratigraphy for the northwest margin of Australia is mostly a conglomeration of data from sidewall cores and ditch-cuttings largely held outside of the public domain. Ocean Drilling Program (ODP) Sites 762 and 763 were drilled by Leg 122 in 1988 on the Exmouth Plateau in part to provide an accessible stratigraphic framework for the Tertiary and Cretaceous. Although Neogene and Cretaceous intervals are now well documented for these sites (Wonders, 1992; Zachariasse, 1992), other than the ranges of calcareous nannofossils (Siesser & Bralower, 1992), and analyses of bulk carbonate carbon isotopes (Thomas *et al.*, 1992), the Palaeogene stratigraphic record has been given little attention. Planktic foraminifera have not been rigorously examined, carbon isotopes have not been measured on foraminiferal species or calibrated against other time markers, and the interpretation of polarity chrons (Galbrun, 1992) is inconsistent with the nannofossil stratigraphy (Siesser & Bralower, 1992). Moreover, the timescale used in previous work (Shipboard Scientific Party, 1990) is now outdated, precluding direct age comparisons with other regions. This study addresses these deficiencies by examining planktic foraminifera and their isotopic composition in sediment from ODP Site 762. The new dataset is combined with the results of previous studies to construct the first detailed early Palaeogene record for the Exmouth Plateau.

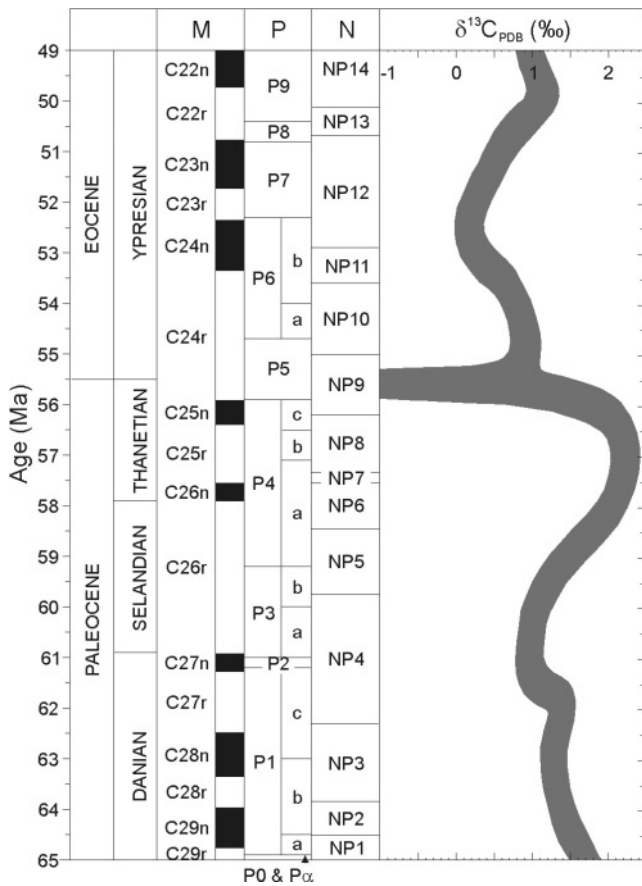


Fig. 1. Early Palaeogene global stratigraphy including magnetostratigraphy (M), planktic foraminifera (P) and nannofossil biozones (N) (adapted from Berggren *et al.*, 1995) and the global benthic foraminifera carbon isotope curve (adapted from Shackleton & Hall, 1990 and Zachos *et al.*, 2001).

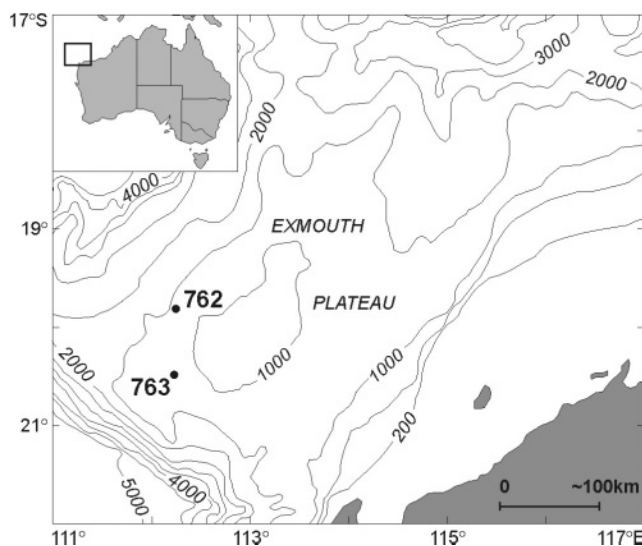


Fig. 2. Map of the Exmouth Plateau including ODP Sites 762 and 763 of Leg 122 (adapted from Exon *et al.*, 1992). Bathymetry in metres.

## MATERIALS AND METHODS

### Samples

Ocean Drilling Program Hole 762C (Fig. 2) was drilled on the central Exmouth Plateau (19°53.24'S, 112°15.24'E) in 1360 m of water depth. Preliminary shipboard work (Shipboard Scientific Party, 1990) and shore-based nannofossil investigations (Siesser & Bralower, 1992) documented 550 m of Middle Eocene to Lower Campanian nannofossil chinks and oozes from the recovered core. This study investigates 83 samples taken from some 200 m of sediment deposited between the late Early Palaeocene and the early to Middle Eocene. Bulk sediment in this interval consists predominantly of white to pale yellow (5Y 8/2) or grey green (10YR 8/1) carbonate ooze and chalk.

Individual samples of *c.* 20 g were collected at *c.* 1.5 m intervals from cores 762C-16X-4 to -37X-4 (307.5 to 503.5 m below sea floor (mbsf)). Portions of each sample were processed for microfossils at the Australian Geological Survey Organization (AGSO) palaeontological laboratory. These samples were treated with hydrogen peroxide to remove organic matter, sieved to remove the <63 µm fraction, and stored in glass vials. The residues were picked for planktic foraminifera, either to completion or to obtain a complete record of taxonomic content. At least 200 and upwards of 500 specimens from each sample were separated and examined as representative of the faunal record.

### Biostratigraphy

The identity, relative abundance of individual foraminiferal species, and distribution across the sample set from Site 762 were determined by optical microscopy and scanning electron microscope. Relative abundances of species were classified as dominant (D, >30%), common (C, 10 to 30%), rare (R, 2 to 10%) and extremely rare (X, <2%). Most specimens belong to the genus *Acarinina* (A), *Subbotina* (S), *Morozovella* (M), *Globanomalina* (G), *Chiloguembelina* (C) or *Parasubbotina* (P). The preservation state of the tests also was noted as 'poor', 'moderate' or 'good'. Tests with good preservation show minor secondary calcite growth or dissolution. Tests with moderate preservation are often infilled with calcite or fragmented, but can be classified to species. Tests with poor preservation are moderately to heavily encrusted with secondary calcite, and species identification is less certain.

The current planktic foraminiferal zonal scheme by Berggren *et al.* (1995) is used in this study. Although Site 762 was at southern mid-latitudes (*c.* 40°) during the Palaeogene (Veevers *et al.*, 1991; Clarke & Jenkyns, 1999), the low latitude biozonation scheme by Berggren *et al.* (1995) best describes the observed faunal assemblages. Palaeocene foraminiferal classification, including ranges and zonal boundaries, has been summarized recently by Olsson *et al.* (1999). Boundaries between biozones were placed halfway between the sample containing a defining marker species and the sample above or below it that lacks it.

### Stable isotopes

Specimens of *Subbotina* were separated and analysed for their carbon isotope composition. Although *Subbotina* probably inhabited deep surface waters in the thermocline (Berggren & Norris, 1997) this genus is considered especially appropriate for

such work because carbon isotope composition shows little inter-species variation (Berggren & Norris, 1997) and size-related variation (D'Hondt *et al.*, 1994; Norris, 1996). However, as an added precaution to minimize the effect of ontogenetic changes in depth ecology, we restricted the size range of tests (210 to 260 µm diameter) and collected 20–30 specimens for each analysis. Although no single *Subbotina* species spanned the entire early Palaeogene, species with suspected phylogenetic affinities (Olsson *et al.*, 1999) and similar morphologies within the genus were collected. The species collected for isotope analyses were *S. triloculinoides* (Zone P1c to the middle of Subzone P4a–b), *S. triangularis* (Subzone P4a/b to Subzone P6a) and *S. patagonica* (Subzone P6a to Zone P10).

Stable isotopes were analysed at the isotope laboratory in the Earth Science Board at the University of California, Santa Cruz (see Billups *et al.*, 1998). Samples were subjected to ultrasound whilst bathed in methanol for 3–5 s to remove adhering particles. Samples then were reacted at 90°C in H<sub>3</sub>PO<sub>4</sub> on an autocarb common acid bath with the CO<sub>2</sub> generated then analysed in a Prism gas source mass spectrometer. Carbon isotope values were calibrated to the Peedee belemnite (PDB) standard, and converted to conventional delta notation ( $\delta^{13}\text{C}$ ).

## RESULTS AND DISCUSSION

### Foraminiferal biostratigraphy

Planktic foraminifera contribute between 10% and 20% of bulk sample volume. The planktic to benthic foraminiferal ratio for the early Palaeogene is approximately 15:1 and the benthic foraminiferal component rarely exceeds 2%. Microfossils are generally complete and unabraded. Secondary recrystallization or dissolution hampers the identification of species in only a few intervals (Fig. 3), notably within the foraminiferal biozones P4 and P7 (discussed below).

Some 74 species belonging to 17 genera were identified at Site 762, and established biozones can be recognized from the pattern of faunal succession (Figs. 3, 4). All zones from P1c to P10, with the exception of Subzone P4b, are found at Site 762, spanning the interval from the early Palaeocene (Danian) to the early Middle Eocene (early Lutetian). Absolute age assignments are from Berggren *et al.* (1995). Boundaries between different zones are well defined unless noted otherwise. The zonal scheme adopted here generally follows that of Berggren *et al.* (1995) but some modification is required.

**P1c.** FAD of *Globanomalina compressa* and/or *Praemurica inconstans* to FAD of *Praemurica uncinata* (500.72 mbsf). Age: 63.0–61.2 Ma, early Palaeocene (Danian). Subzone P1c extends below our sampled interval as only two samples are representative of it. The upper boundary of Subzone P1c is difficult to locate in some sequences because of the short stratigraphic range of its marker species, *Pr. uncinata* (Pl. 1, figs 1–3). However, this species has been found at Site 762, and is a useful correlation tool. Common species found in uppermost Subzone P1c include *Pr. pseudoinconstans*, *Parasubbotina varianta*, *Subbotina trivialis*, *S. triloculinoides*, *Globanomalina compressa*, *Chiloguembelina midwayensis* and *C. subtriangularis*. Faunal assemblages within this subzone are consistent with the global scheme (Olsson *et al.*, 1999).

**P2.** FAD of *Praemurica uncinata* (500.72 mbsf) to FAD of *Morozovella angulata* (493.33 mbsf). Age: 61.2–61.0 Ma, late Early Palaeocene (late Danian). Site 762 contains the transition from *Praemurica inconstans/trinidadensis* to *Pr. uncinata*, which marks the lower zonal boundary. However, an 8 m core gap between cores -37X-1 and -36X-1 below the FAD of *Morozovella angulata* (Pl. 1, figs 4–6) precludes high resolution sampling and accurate placement for the upper boundary. Common species in this zone at Site 762 include *Parasubbotina varianta*, *P. pseudobulloides*, *Subbotina triloculinoides*, *S. cancellata*, *Praemurica pseudoinconstans* and *Chiloguembelina midwayensis*. This overall assemblage is typical of Zone P2 elsewhere (Olsson *et al.*, 1999).

**P3.** FAD of *Morozovella angulata* (493.33 mbsf) to FAD of *Globanomalina pseudomenardii* (470.75 mbsf). Age: 61.0–59.2 Ma, late Palaeocene (Selandian).

**P3a.** FAD of *Morozovella angulata* (493.33 mbsf) to FAD of *Igorina albeari* (484.55 mbsf). Age: 61.0–60.0 Ma, early late Palaeocene (Selandian). The boundaries for this subzone cannot be placed with a high degree of confidence because there is an 8 m core gap below the FAD of *Morozovella angulata*, and an 8 m core gap below the FAD of *Igorina albeari* (Pl. 1, figs 7–9). Common species in Subzone P3a at Site 762 include *Globanomalina compressa*, *Parasubbotina varianta*, *P. pseudobulloides* and *Subbotina triloculinoides*. The overall assemblage of Subzone P3a at Site 762 is similar to that described elsewhere (Olsson *et al.*, 1999), and includes the first appearances of the *Morozovella angulatalconicotruncata* complex, which marks the beginning of the late Palaeocene *Morozovella* radiation.

**P3b.** FAD of *Igorina albeari* (484.55 mbsf) to FAD of *Globanomalina pseudomenardii* (470.75 mbsf). Age: 60.0–59.2 Ma, late Palaeocene (Selandian). The upper boundary for Subzone P3b is well defined because *Acarinina subsphaerica*, *A. nitida* and *A. mckannai* have near-simultaneous FADs with *Globanomalina pseudomenardii* (Pl. 1, figs 10–12) at Site 762 and elsewhere (Olsson *et al.*, 1999). Common species in Subzone P3b at Site 762 include *Morozovella angulata*, *M. conicotruncata*, *Parasubbotina variospira*, *Subbotina triloculinoides*, *Globanomalina chapmani*, *G. ehrenbergi* and the first appearance of *Acarinina* with *A. strabocella*. This assemblage is typical of Subzone P3b faunal assemblages (Olsson *et al.*, 1999), except that *Morozovella velascoensis* does not make its first appearance here but at the base of Zone P4c.

**P4.** Total range of *Globanomalina pseudomenardii* (470.75 to 423.03 mbsf). Age: 59.2–55.9 Ma, middle Late Palaeocene (late Selandian–Thanetian). The lower boundary of Zone P4 is placed with moderate confidence because *Globanomalina pseudomenardii* has a patchy occurrence at Site 762 and has a similar morphology to both *G. ehrenbergi* and *G. chapmani* (Pl. 1, figs 10–12). Indeed, preliminary work on the foraminifera at Site 762 (Shipboard Scientific Party, 1990) described *Globanomalina pseudomenardii* as the inflated ‘*chapmani* type’. However, there is morphological variability within this species with some of the smaller specimens displaying a distinct keel and a





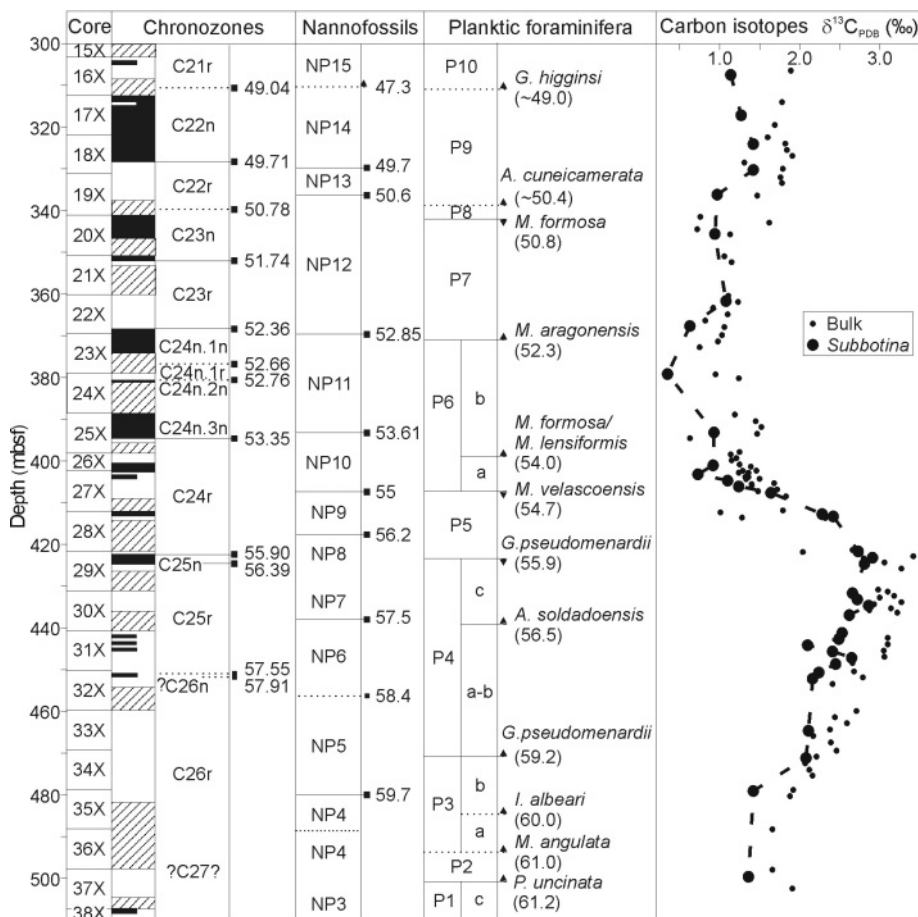
Early Palaeocene planktic foraminifera

Species	21	20	19	18	17	16	15	14	13	12	11	10	Diversity (No. species)	Dominant Genus	Comments	Foraminiferal Preservation
<i>Morozovella subbotinae</i>													21	A		Good
<i>Acarinina soldadoensis</i>													21	M		Good
<i>Acarinina pseudotopilensis</i>													22	S,A		Good
<i>Acarinina primitiva</i>													14	S		Good
<i>Chiliguembelina trinitatisensis</i>													19	S		Good
<i>Igorina brodermanni</i>													18	A,S		Good
<i>Subbotina patagonica</i>													22	M,A	Benthics common	Good
<i>Morozovella marginodentata</i>													25	A	Large <i>Acarinina</i> , calcite crystals	Good
<i>Acarinina queira</i>													21	A	Calcite crystals	Good
<i>Planorotalites pseudoscutula</i>													19	A,S		Good
<i>Subbotina socaena</i>													21	A,S		Good
<i>Acarinina wilcoxensis</i>													23	M	Calcite crystals	Good
<i>Morozovella dolabrata</i>													22	S	Calcite crystals	Mod
<i>Morozovella formosa</i>													22	A	Iron-stained pyrite, calcite crystals	Mod
<i>Morozovella lensiformis</i>													18	A	Calcite crystals	Poor
<i>Pseudohastigerina wilcoxensis</i>													21	A	<i>Morozovella</i> rare, calcite crystals	Mod
<i>Subbotina hagni</i>													19	A	Calcite crystals	Mod
<i>Pseudohastigerina micra</i>													18	S	Calcite crystals	Mod
<i>Morozovella aragonensis</i>													16	A	Large <i>Acarinina</i>	Mod
<i>Morozovella densa</i>													12	A,S	Iron-stained pyrite calcite crystals	Poor
<i>Acarinina collecta</i>													6?		Heavy recrystallisation	Poor
<i>Muricoglobigerina senni</i>													23	S		Poor
<i>Catapsydrax univavus</i>													20	A	Iron-stained pyrite	Poor
<i>Subbotina inaequilipira</i>													21	A	<i>Subbotina</i> rare	Good
<i>Morozovella caucasica</i>													13	A,S	<i>Morozovella</i> rare	Mod
<i>Acarinina cunicamerata</i>													17	A,S	Benthics common	Good
<i>Subbotina frontosa</i>													16	A,S	Benthics common	Poor
<i>Acarinina matthewsae</i>													15	A,S	Benthics common	Poor
<i>Acarinina bullbrookii</i>													14	A	Benthics common	Poor
<i>Morozovella spinulosa</i>													12	M,A	<i>Morozovella</i> common	Mod
<i>Acarinina decapta</i>													18	A,S		Poor
<i>Subbotina cryptomphala</i>													15	S,A	Pyrite	Poor
<i>Guembeltrioides lozanoi</i>													16	A,M	Pyrite	Good
<i>Guembeltrioides higginsii</i>													17	A		Good
Diversity (No. species)													16	M		Good
Dominant Genus													17	S		Good
Comments													17	M,S	Benthics common	Good
Foraminiferal Preservation													18	S,A		Good
													15	S		Mod
													14	S		Good
													14	S		Good
													14	S	Pyrite, Calcite crystals	Good
													14	A	Benthics rare	Mod
													16	A	Benthics rare	Good
													20	A	<i>Morozovella radiata</i> , benthics rare	Good
													18	A	Pyrite, benthics common	Mod
													21	S	Pyrite, benthics common	Poor
													14	S	Pyrite, benthics common	Mod
													16	S	<i>Chiliguembelina</i> rare	Mod
													17	A,S	<i>Chiliguembelina</i> rare	Mod
													14	S,A	<i>Morozovella</i> rare	Poor
													15	A,S	<i>Morozovella</i> rare	Poor
													13	A,S	<i>Morozovella</i> rare	Poor
													14	S	<i>Morozovella</i> rare	Mod
													20	S		Poor
													25	S		Poor
													29	A,S	Benthics common	Mod
													21	S	Benthics common	Mod
													20	S	Benthics common	Mod
													22	A	Benthics common	Mod
													19	M,G		Poor
													22	S		Mod
													16	S	Benthics common	Good
													16	P		Poor
													11	S	Benthics common	Poor
													23	S	Benthics common	Good
													18	S		Mod
													17	A,S	Benthics common	Poor
													21	S		Poor
													16	S		Mod
													15	P	Pyrite	Good
													12	S	Pyrite	Mod
													13	S	Pyrite, calcite crystals	Good
													15	P	Pyrite	Good
													14	G	Pyrite, calcite crystals	Good
													14	S	Benthics common	Good
													14	P	Benthics common	Good
													14	P,C	Benthics common	Good
													10	G,C	Benthics common	Mod

*Subbotina trilocolinoides*, *S. triangularis*, *S. velascoensis* and *Chiliguembelina midwayensis*. Such an assemblage is characteristic of Subzones P4a and P4b in the global scheme (Olsson *et al.*, 1999).

**P4c.** FAD of *Acarinina soldadoensis* (439.38 mbsf) to LAD of *Globanomalina pseudomenardii* (423.03 mbsf). Age: 56.5–55.9 Ma, late Palaeocene (late Thanetian). At the base of Subzone P4c at Site 762 the FAD of *Acarinina soldadoensis* (Pl. 1, figs 13–15) coincides with the FADs of *A. primitiva*, *A.*

*pseudotopilensis*, *Morozovella velascoensis*, *M. acuta* and *M. aequa* as found elsewhere (Olsson *et al.*, 1999). The interval assigned to this zone at Site 762 is relatively large compared to that of the global scheme (Berggren *et al.*, 1995) and its base in particular does not correlate well with the nannofossil zones for the site (Siesser & Bralower, 1992). However, we regard the lower boundary of Subzone P4c as being well defined at Site 762 because so many species make their first appearances at its base, representing a pattern consistent with that of the global scheme.



**Fig. 4.** Comparison of planktic foraminiferal biozones (this study), nannofossil biozones (Siesser & Bralower, 1992), recalibrated magnetostratigraphy (this study) and carbon isotope data for *Subbotina* (this study) and the bulk sediment (Thomas *et al.*, 1992) for the early Palaeocene interval at ODP Site 762. Ages follow Berggren *et al.* (1995). Larger circles with dashed lines are  $\delta^{13}\text{C}$ , *Subbotina* specimens; small filled circles are  $\delta^{13}\text{C}$ , bulk sediment.

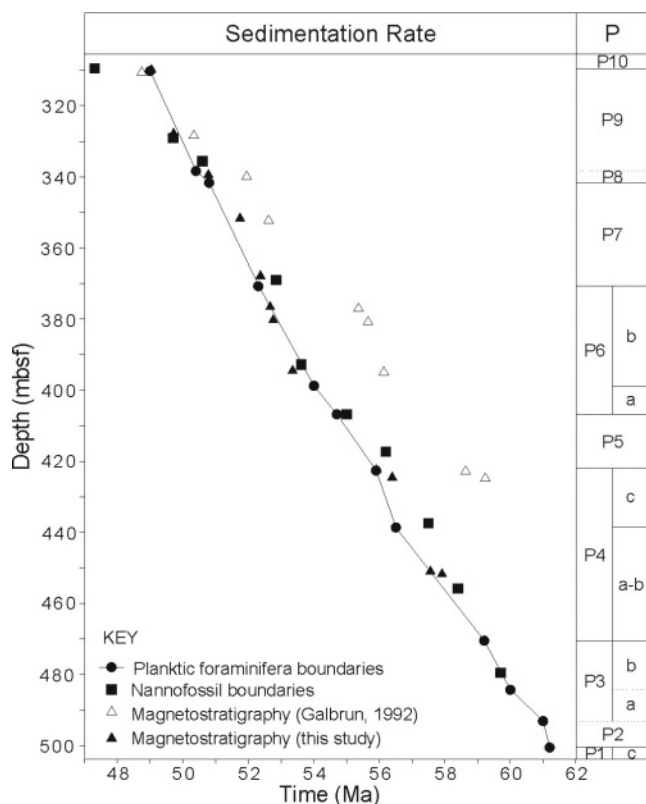
**P5.** LAD of *Globanomalina pseudomenardii* (423.03 mbsf) to LAD of *Morozovella velascoensis* (407.23 mbsf). Age: 55.9–54.7 Ma, latest Palaeocene–early Eocene (latest Thanetian–earliest Ypresian). The distribution of *Morozovella velascoensis* (Pl. 1, figs 16–18) is somewhat patchy at Site 762 (Fig. 3) and may not represent its true range. Such a pattern may relate to the higher latitudes and cooler temperatures for the Exmouth Plateau during the time of deposition (due to its location at that time, well to the south), as the species is typical of more tropical areas (Olsson *et al.*, 1999). Faunal assemblages in Zone P5 at Site 762 commonly include *Subbotina velascoensis*, *S. triangularis*, *S. patagonica*, *Igorina broedermanni*, *Morozovella aequa*, *M. subbotinae*, *Acarinina soldadoensis* and *A. primitiva*, all typical of other global locations (Berggren *et al.*, 1995). The FADs of *Morozovella dolobrata* and *Acarinina wilcoxensis* occur simultaneously in upper Zone P5, which correlates well with their FADs in New Zealand near the base of the Waipawan (Hornibrook *et al.*, 1989). The LADs of *Morozovella acuta* and *M. oclusa* occur in upper Zone P5, consistent with the global scheme (Olsson *et al.*, 1999). However, the distinct morphotypes *Morozovella allisonensis*, *M. africana* and *Acarinina sibaiyaensis* that developed and diversified during a brief interval of P5 (e.g. Kelly *et al.*, 1998; Pardo *et al.*, 1999) were not found at Site 762. As discussed later, these species may not have been recovered because of a 5 m core gap in uppermost P5 between 762C-28X-1 and -27X-4.

**P6.** LAD of *Morozovella velascoensis* (407.23 mbsf) to FAD of *Morozovella aragonensis* (370.74 mbsf). Age: 54.7–52.3 Ma, early Eocene (early Ypresian).

**P6a.** LAD of *Morozovella velascoensis* (407.23 mbsf) to FAD of *Morozovella formosa* or *Morozovella lensiformis* (399.25 mbsf). Age: 54.7–54.0 Ma, earliest Eocene (earliest Ypresian). At Site 762 and elsewhere (Berggren *et al.*, 1995) the FADs of *Morozovella formosa* (Pl. 1, figs 19–20; Pl. 2, fig. 1) and *M. lensiformis* (Pl. 2, figs 2–4) coincide. Common species found in this zone at Site 762 include *Subbotina patagonica*, *S. triangularis*, *Acarinina soldadoensis*, *A. primitiva*, *Morozovella subbotinae*, *M. marginodentata*, *Chiloguembelina wilcoxensis* and *C. crinita*. This overall assemblage is typical for Subzone P6a (Blow, 1979, as Subzone Zone P7; Berggren *et al.*, 1995).

There is a problem within the interval containing Subzone P6a at Site 762 with the labelling of core -26X. According to the drilling log, the depth of this core is 398.0 to 402.5 mbsf (4.5 m thick). However, there is *c.* 8 m of core photographed and illustrated in the lithological log for core -26X. As the next coring interval, -27X, starts at 402.5 mbsf, there is *c.* 3.5 m of core that has not been accounted for.

**P6b.** FADs of *Morozovella formosa* or *Morozovella lensiformis* (399.25 mbsf) to FAD of *Morozovella aragonensis* (370.74 mbsf) (Pl. 2, figs 5–7). Age: 54.0–52.3 Ma, early Eocene (early Ypresian). At Site 762 and elsewhere, the FADs of *Morozovella*



**Fig. 5.** Sedimentation rates calculated from planktic foraminifera (this study) and nannofossils (Siesser & Bralower, 1992) compared with published magnetostratigraphy (Galbrun, 1992) and recalibrated magnetostratigraphy (this study). The original magnetostratigraphy deviates from the other curves, showing where the major adjustment was made for Chron 22n at 49 Ma. Sedimentation rates calculated from the planktic foraminiferal and nannofossil biozonation using the global scheme are  $1.5 \text{ cm ka}^{-1}$  and  $1.4 \text{ cm ka}^{-1}$  respectively. P, planktic foraminiferal biozones (this study).

*lensiformis* and *M. formosa* coincide, although at Site 762 the latter species is rare. The FAD of *Pseudohasterigina wilcoxensis* also occurs at the base of Subzone P6b at Site 762. In tropical assemblages this datum occurs at the P5/P6 boundary but has a delayed entry in mid-high latitude regions within the P6b–P7 interval (Blow, 1979, as Subzone Zone P7; Berggren *et al.*, 1995). Faunal assemblages in Subzone P6a at Site 762 dominantly consist of *Subbotina eocaena*, *S. patagonica*, *Acarinina quetra*, *Acarinina soldadoensis*, *A. primitiva*, *Morozovella lensiformis*, *M. subbotinae*, *M. gracilis*, *M. marginodentata*, *M. aequa* and *Planorotalites pseudoscitula*. These are typical assemblages found elsewhere (Blow, 1979, as Subzone Subzone P8a; Berggren *et al.*, 1995). However, at other locations, the LAD of *M. subbotinae* occurs within Subzone P6b (Berggren *et al.*, 1995), but at Site 762, this datum occurs later in Zone P7.

**P7.** FAD of *Morozovella aragonensis* (370.74 mbsf) to LAD of *Morozovella formosa* (342.25 mbsf). Age: 52.3–50.8 Ma, middle early Eocene (mid-Ypresian). The upper boundary of this zone is poorly constrained as the occurrence of *Morozovella formosa* is patchy. Faunal assemblages in Zone P7 at Site 762 are dominated by *Acarinina soldadoensis*, *A. primitiva*, *A. quetra*, *Muricoglobigerina senni*, *Subbotina eocaena*, *S. patagonica*, *S.*

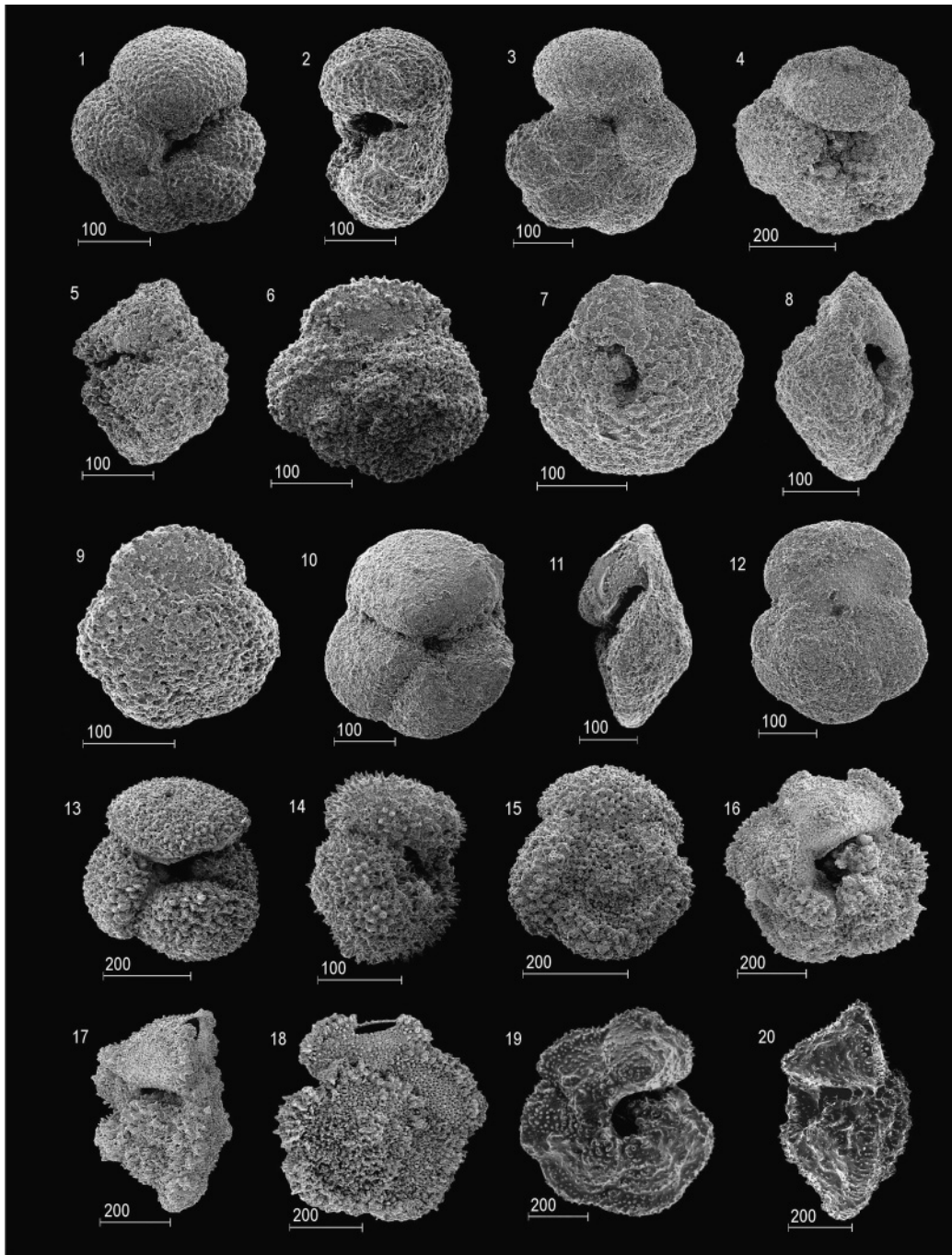
*hagni*, *Morozovella aequa*, *M. gracilis*, *M. dolobrata*, *M. lensiformis* and *Planorotalites pseudoscitula*. These assemblages are typical of Zone P7 assemblages found in other parts of the globe (Blow, 1979, as Subzone 8b; Berggren *et al.*, 1995). The LAD of *Morozovella aequa* occurs in Zone P7 in the global scheme (Olsson *et al.*, 1999), however, at Site 762, it occurs slightly later in our Zone P8.

**P8.** LAD of *Morozovella formosa* (342.25 mbsf) to FAD of secondary marker species *Acarinina cuneicamerata* (338.95 mbsf). Age: 50.8–50.4 Ma, late Early Eocene (late Ypresian). The top of Zone P8 is defined by the FAD of *Planorotalites palmerae* in the global scheme (Berggren *et al.*, 1995). This primary marker species is absent at Site 762. Other authors have noted that *Planorotalites palmerae* has a very patchy geographical distribution (Toumarkine & Luterbacher, 1985). In the absence of *Planorotalites palmerae*, the top of this zone is defined by the FAD of *Acarinina cuneicamerata* (Pl. 2, figs 8–10) and the common appearance of *A. bullbrookii* (W. A. Berggren, pers. comm., 1999). Common species found in this zone at Site 762 and elsewhere (Toumarkine & Luterbacher, 1985) include *Acarinina primitiva*, *A. pseudotopilensis*, *A. soldadoensis*, *A. collactea*, *A. decepta*, *Muricoglobigerina senni*, *Morozovella aragonensis*, *Subbotina inaequispira*, *S. eocaena* and *Pseudohasterigina wilcoxensis*.

**P9.** FAD of secondary marker species *Acarinina cuneicamerata* (338.95 mbsf) to FAD of secondary marker species *Guembeltrioides higginsii* (310.91 mbsf). Age: 50.4–49.0 Ma, late early Eocene (latest Ypresian). The FAD of *Hantkenina nuttalli* defines the top of Zone P9 in the global scheme (Toumarkine, 1981; Berggren *et al.*, 1995). However, this datum occurs higher in the sedimentary column at Site 762 (section 762C-15X-2) co-existing with taxa characteristic of Zone P11. The placement of this boundary has been problematic elsewhere because of the late arrival and/or rare early appearance of *Hantkenina nuttalli* (e.g. McGowran, 1974). The LAD of *Planorotalites palmerae* is another criterion for the P9/P10 boundary (W. A. Berggren, pers. comm., 1999). Unfortunately, this species was not found at Site 762. The FAD of *Guembeltrioides higginsii* (Pl. 2, figs 11–13) is close to the P9/P10 boundary at other locations (W. A. Berggren, pers. comm., 1999). We therefore use this datum to mark the top of Zone P9. Common species in Zone P9 at Site 762 and elsewhere (Toumarkine & Luterbacher, 1985; Berggren *et al.*, 1995) include *Acarinina primitiva*, *A. soldadoensis*, *A. pseudotopilensis*, *A. collactea*, *A. cuneicamerata*, *A. matthewsae*, *A. bullbrookii*, *A. decepta*, *Morozovella lensiformis*, *M. densa*, *M. aragonensis*, *M. caucasica*, *Subbotina patagonica*, *S. eocaena*, *S. inaequispira*, *S. frontosa*, *S. hagni*, *Pseudohasterigina wilcoxensis*, *Ph. micra*, *Planorotalites pseudoscitula*, *Igorina broedermanni* and *Guembeltrioides lozanoi* (in upper P9).

**P10.** FAD of secondary marker species *Guembeltrioides higginsii* (310.91 mbsf) to FAD of *Globigerapsis kugleri*. Age: 49.0–45.8 Ma, early middle Eocene (early Lutetian). Only one sample within Zone P10 was examined. The top of this zone, therefore, lies above our sampling interval. The sample examined contains *Guembeltrioides higginsii* and *Truncorotaloides* spp., which are characteristic species of Zone P10 (Berggren *et al.*, 1995).

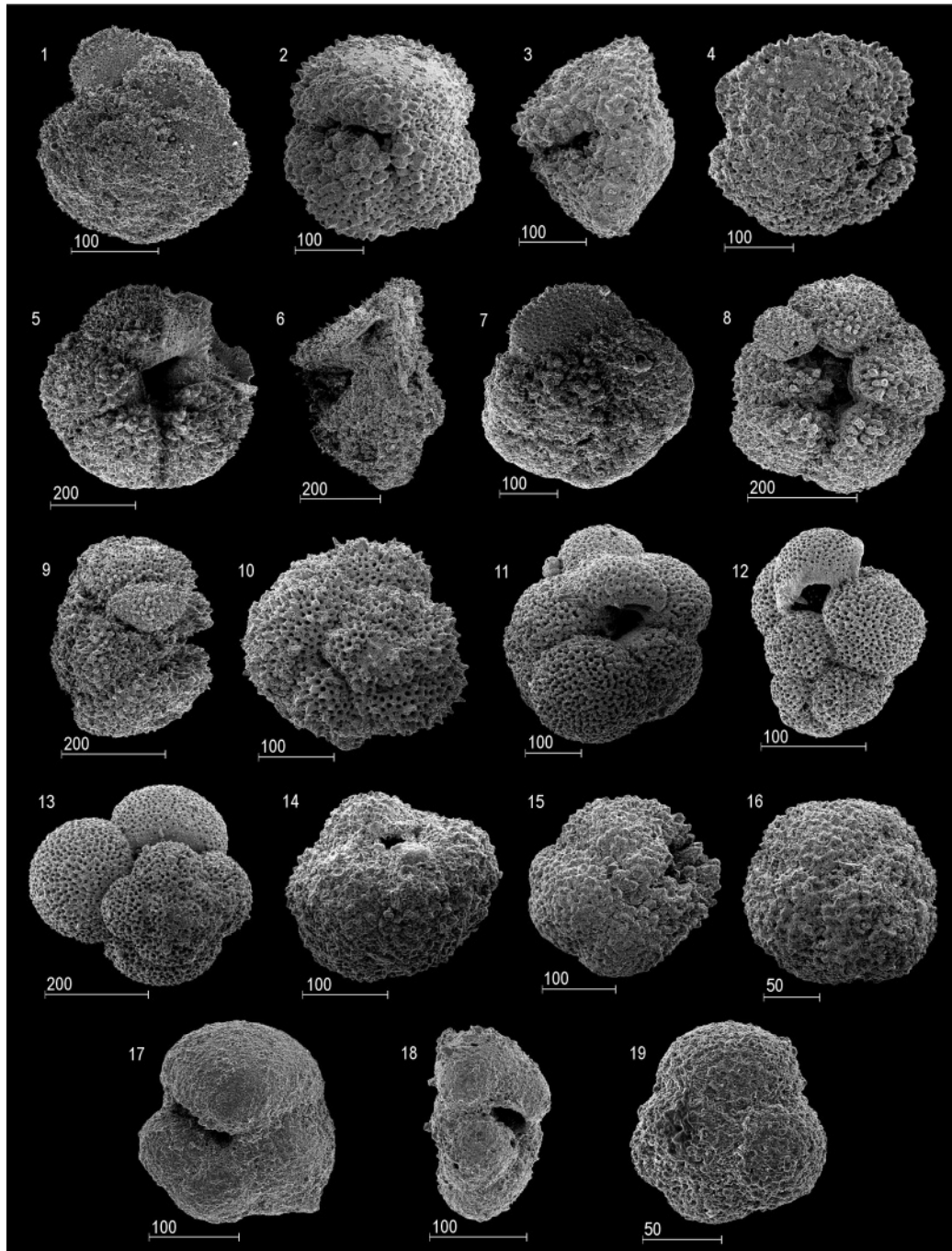




#### Explanation of Plate 1

Scale bars in  $\mu\text{m}$  for all figured specimens. **Figs 1–3.** *Praemurica uncinata* (Bolli, 1957*a,b*): **1**, umbilical view, CPC 35739, sample 762-37X-2, 97–100 cm; **2**, side view, CPC 25740, sample 762C-37X-2, 97–100 cm; **3**, dorsal view, CPC 35741, sample 762C-37X-2, 97–100 cm. **Figs 4–6.** *Morozovella angulata* (White, 1928*a,b*): **4**, umbilical view, CPC 35742, sample 762C-33X-1, 100–104 cm; **5**, side view, CPC 35743, sample 762C-33X-2, 100–104 cm; **6**, dorsal view, CPC 35744, sample 762C-34X-3, 95–99 cm. **Figs 7–9.** *Igorina albeari* (Cushman & Bermúdez, 1949): **7**, umbilical view, CPC 35745, sample 762C-31X-3, 97–101 cm; **8**, side view, CPC 35746, sample 762C-33X-4, 95–99 cm; **9**, dorsal view, CPC 35747, sample 762C-31X-2, 100–104 cm. **Figs 10–12.** *Globanomalina pseudomenardii* (Bolli, 1957*a*): **10**, umbilical view, CPC 35748, sample 762C-31X-2, 100–104 cm; **11**, side view, CPC 35749, sample 762C-31X-3, 97–101 cm; **12**, dorsal view, CPC 35750, sample 762C-29X-3, 46–50 cm. **Figs 13–15.** *Acarinina soldadoensis* (Brönnimann, 1952): **13**, umbilical view, CPC 35751, sample 762C-17X-4, 50–55 cm; **14**, side view, CPC 35752, sample 762C-18X-2, 90–95 cm; **15**, dorsal view, CPC 35753, sample 762C-17X-4, 50–55 cm. **Figs 16–18.** *Morozovella velascoensis* (Cushman, 1925): **16**, umbilical view, CPC 35754, sample 762C-31X-3, 97–101 cm; **17**, side view, CPC 35754, sample 762C-31X-3, 97–101 cm; **18**, dorsal view, CPC 35754, sample 762C-31X-3, 97–101 cm. **Figs 19–20.** *Morozovella formosa* (Bolli, 1957*a*): **19**, umbilical view, CPC 35755, sample 762C-22X-3, 49–54 cm; **20**, side view, CPC 35755, sample 762C-22X-3, 49–54 cm.





Explanation of Plate 2

Scale bars in  $\mu\text{m}$  for all figured specimens. **Fig. 1.** *Morozovella formosa* (Bolli 1957a). Dorsal view, CPC 35756, sample 762C-22X-3, 49–54 cm. **Figs 2–4.** *Morozovella lensiformis* (Subbotina, 1953): **2**, umbilical view, CPC 35757, sample 762C-23X-2, 50–54 cm; **3**, side view, CPC 35758, sample 762C-23X-2, 50–54 cm; **4**, dorsal view, CPC 35759, sample 762C-23X-2, 50–54 cm. **Figs 5–7.** *Morozovella aragonensis* (Nuttall, 1930): **5**, umbilical view, CPC 35760, sample 762C-17X-2, 50–55 cm; **6**, side view, CPC 35761, sample 762C-17X-5, 49–54 cm; **7**, dorsal view, CPC 35762, sample 762C-17X-5, 49–54 cm. **Figs 8–10.** *Acarinina cuneicamerata* (Blow, 1979): **8**, umbilical view, CPC 35763, sample 762C-19X-4, 50–55 cm; **9**, side view, CPC 35763, sample 762C-19X-4, 50–55 cm; **10**, dorsal view, CPC 35764, sample 762C-19X-3, 50–54 cm. **Figs 11–13.** *Guembeliurioides higginsi* (Bolli, 1957b): **11**, umbilical view, CPC 35765, sample 762C-16X-4, 30–35 cm; **12**, side view, CPC 35766, sample 762C-16X-4, 30–35 cm; **13**, dorsal view, CPC 35767, sample 762C-16X-4, 30–35 cm. **Figs 14–16.** *Acarinina subsphaerica* (Subbotina, 1947): **14**, umbilical view, CPC 35768, sample 762C-31X-3, 97–101 cm; **15**, side view, CPC 35769, 762C-31X-6, 97–101 cm; **16**, dorsal view, CPC 35770, sample 762C-32X-2, 100–104 cm. **Figs 17–19.** *Globanomalina australiformis* (Jenkins, 1965): **17**, umbilical view, CPC 35771, sample 762C-31X-3, 97–101 cm; **18**, side view, CPC 35772, sample 762C-31X-3, 97–101 cm; **19**, dorsal view, CPC 35773, sample 762C-30X-3, 96–100 cm.

Core section, interval (cm)	Depth (mbsf)	<i>Subbotina</i> spp. Analysed	$\delta^{13}\text{C}$ (‰)
15X-3, 80–85	297.30	<i>S. patagonica</i>	1.34
16X-4, 30–35	307.80	<i>S. patagonica</i>	1.15
17X-4, 50–55	317.50	<i>S. patagonica</i>	1.28
18X-2, 90–95	324.40	<i>S. patagonica</i>	1.43
18X-6, 106–111	330.56	<i>S. patagonica</i>	1.43
19X-4, 50–55	336.50	<i>S. patagonica</i>	0.98
20X-4, 40–45	345.90	<i>S. patagonica</i>	0.95
22X-2, 50–55	362.00	<i>S. patagonica</i>	1.09
22X-6, 47–51	367.97	<i>S. patagonica</i>	0.64
24X-1, 49–53	379.49	<i>S. patagonica</i>	0.36
25X-4, 49–53	393.49	<i>S. patagonica</i>	0.94
26X-3, 36–41	401.36	<i>S. patagonica</i>	0.93
27X-1, 100–104	403.50	<i>S. patagonica</i>	0.74
27X-2, 104–108	405.04	<i>S. patagonica</i>	1.11
27X-3, 95–99	406.45	<i>S. triangularis</i>	1.25
27X-4, 95–99	407.95	<i>S. triangularis</i>	1.65
28X-1, 104–107	413.04	<i>S. triangularis</i>	2.29
28X-2, 10–12	413.60	<i>S. triangularis</i>	2.43
29X-1, 48–52	421.98	<i>S. triangularis</i>	2.74
29X-2, 49–53	423.49	<i>S. triangularis</i>	2.92
29X-3, 46–50	424.96	<i>S. triangularis</i>	2.82
30X-1, 101–105	432.01	<i>S. triangularis</i>	2.67
30X-2, 100–104	433.50	<i>S. triangularis</i>	2.73
30X-3, 96–100	434.96	<i>S. triangularis</i>	2.87
30X-4, 66–70	437.26	<i>S. triangularis</i>	2.63
31X-1, 100–104	441.50	<i>S. triangularis</i>	2.54
31X-2, 100–104	443.00	<i>S. triangularis</i>	2.50
31X-3, 97–101	444.47	<i>S. triangularis</i>	2.11
31X-4, 97–101	445.97	<i>S. triangularis</i>	2.42
31X-5, 101–105	447.51	<i>S. triangularis</i>	2.66
31X-6, 97–101	448.97	<i>S. triangularis</i>	2.46
32X-1, 101–105	451.01	<i>S. triangularis</i>	2.25
32X-2, 100–104	452.50	<i>S. triloculinoides</i>	2.17
33X-4, 95–99	464.95	<i>S. triloculinoides</i>	2.12
34X-2, 100–103	471.50	<i>S. triloculinoides</i>	2.09
35X-1, 90–95	479.40	<i>S. triloculinoides</i>	1.43
37X-2, 97–101	499.97	<i>S. triloculinoides</i>	1.37

**Table 1.** Carbon isotope composition of *Subbotina* spp.

### Carbon isotopes

The  $\delta^{13}\text{C}$  of *Subbotina* tests averages 1.84‰ across our sampled interval but varies significantly between 0.36 and 2.92‰ (Table 1; Fig. 4). From the lowest sampled interval in P1 (502.96 mbsf) to the base of Zone P5 (423.49 mbsf)  $\delta^{13}\text{C}$  gradually increases by about 2.0‰. There is a marked decrease in  $\delta^{13}\text{C}$  through Zone P5 (423.49 to 407.95 mbsf) by about 2.5‰. From the top of Zone P5 (407.95 mbsf) to the top of the sampled interval in Zone P10 (307.80 mbsf)  $\delta^{13}\text{C}$  is relatively constant, except for a slight drop in upper Zone P6. The *Subbotina*  $\delta^{13}\text{C}$  curve mirrors the bulk carbonate  $\delta^{13}\text{C}$  curve at Site 762 (Thomas *et al.*, 1992), although *Subbotina*  $\delta^{13}\text{C}$  values are typically 0.5‰ lower at similar depth. This offset in  $\delta^{13}\text{C}$  is expected because surface waters are generally enriched in  $^{13}\text{C}$  relative to deeper waters of the thermocline.

The exogenic carbon cycle includes all carbon stored in the ocean, atmosphere and biomass reservoirs. Secular changes can occur in this exogenic carbon cycle with variations in carbon inputs or outputs to the ocean or atmosphere (e.g. Kump & Arthur, 1999; Dickens, 2001). Because carbon cycles through all reservoirs of the exogenic carbon cycle over relatively short time intervals, about 2000 years at present day, major perturbations

in the isotopic composition of the exogenic carbon cycle will be observed in all carbon reservoirs at nearly the same time (e.g. Dickens *et al.*, 1997). The early Palaeogene is especially amenable for correlating widespread locations by this “carbon isotope stratigraphy” because there are a series of prominent  $\delta^{13}\text{C}$  excursions in the exogenic carbon cycle of long and short duration (e.g. Zachos *et al.*, 1993; Corfield, 1994; Dickens *et al.*, 1997; Zachos *et al.*, 2001). Most key features of the global carbon isotope record for the Palaeogene (Fig. 1) can be recognized at Site 762 (Fig. 4). Importantly, when the  $\delta^{13}\text{C}$  variations at Site 762 are placed within the timescale defined by our foraminiferal biozones, they match within 0.5 Ma the age pattern suggested for the global  $\delta^{13}\text{C}$  record by Berggren *et al.* (1995). This cross-correlation supports the planktic foraminiferal zonation we have developed for Site 762.

### Integrated biostratigraphy

In the previously published nannofossil biostratigraphy for Site 762 (Siesser & Bralower, 1992), nannofossil datums and biozones were calibrated to the timescale of Haq *et al.* (1987). We have recalibrated the nannofossil biozones with the most current global timescale (Berggren *et al.*, 1995). The revised nannofossil biostratigraphy at Site 762 agrees reasonably well with both the planktic foraminiferal and carbon isotope stratigraphy. However, there are discrepancies, notably the placement of the NP6/NP7, NP8/NP9, boundaries, which appear to be too high in the column (Fig. 4). There are several possible reasons for such anomalies. First, key nannofossil markers are very rare at Site 762 (Shipboard Scientific Party, 1990) and may have been missed. Second, the high latitude of the Exmouth Plateau in the early Palaeogene may have put some species at the limits of their biogeographic range (Wonders, 1992) resulting in certain nannofossil and foraminiferal biomarkers at Site 762 being responsive to distribution patterns which applied to the north Australian margin rather than the temporal controls of evolution and extinction. Third, the mismatches could, at least in part, be artefacts of sampling resolution.

### Magnetostratigraphy problem

Galbrun (1992) determined the pattern of polarity reversals for Upper Cretaceous and Lower Tertiary core obtained from Site 762. As noted by Berggren *et al.* (1995, p. 184), the magnetostratigraphy raises a correlation problem. Starting with Chron C22n and continuing back through the Palaeocene, there are significant discrepancies between magnetostratigraphic and nannofossil datums at Site 762 (cf. Siesser & Bralower, 1992; Galbrun, 1992). In particular, Chron C22n has been placed within Zone NP12. However, according to global stratigraphic schemes, Chron C22n occurs within NP14 (Berggren *et al.*, 1995). Three plausible explanations could account for the mis-correlation. First, the nannofossil zones at Site 762 could be diachronous by some 1.5 Ma with the global timescale. Second, recognition of key nannofossil zones could be incorrect. Third, the polarity chrons could have been mislabelled or misinterpreted. It is noteworthy that the P7/P8 zonal boundary roughly coincides with the top of Chron C23n in global schemes (Berggren *et al.*, 1995), but at Site 762 it coincides with the chron labelled C22n (Galbrun, 1992). It is therefore likely that Chron C23n was mistaken for Chron C22n in previous work. Making

Datum	Age (Ma) <sup>a</sup>	Sample Core section, interval (cm)		Depth (mbsf)
		upper	lower	
FAD <i>N. fulgens</i> , NP14/NP15	47.3	16X-3, 99	16X, CC	306.99–313.49
FAD <i>G. higginsi</i> , P9/P10	49.0	16X-4, 30	17X-1, 56	307.80–314.01
C22n/C22r	49.037	16X-4, 16	17X-1, 26	307.67–312.76
FAD <i>D. subloensis</i> , NP13/NP14	49.7	18X-5, 100	18X-6, 100	329.00–330.51
C22r/C22n	49.714	18X-4, 110	18X-5, 51	327.60–328.51
FAD <i>A. cuneicamerata</i> , P8/P9	50.4	19X-4, 50	20X-1, 40	336.50–341.40
LAD <i>T. orthostylus</i> , NP12/NP13	50.6	19X-2, 101	19X-3, 101	335.51–337.01
C23n/C22r	50.778	19X-5, 30	20X-1, 53	337.77–341.52
LAD <i>M. formosa</i> , P7/P8	50.8	20X-1, 45	20X-2, 55	341.45–343.05
C23r/C23n	51.743	21X-1, 107	21X-2, 23	351.57–352.23
FAD <i>M. aragonensis</i> , P6b/P7	52.3	22X-3, 49	22X-4, 48	369.93–371.55
C24n.1n/C23r	52.364	22X-6, 27	22X-6, 27	367.77–368.32
C24n.1r/C24n.1n	52.663	23X, CC, 33	24X-1, 61	373.83–379.61
FAD <i>D. lodoensis</i> , NP11/NP12	52.85	22X-6, 100	23X-1, 100	368.50–370.50
C24n.2n/C24n.1r	52.757	24X-1, 124	24X, CC, 25	380.24–380.65
C24r/C24n.3n	53.347	25X-4, 139	25X-5, 27	394.40–394.76
LAD <i>T. contortus</i> , NP10/NP11	53.61	25X-3, 101	25X-4, 101	392.51–394.01
FAD <i>M. formosa</i> / <i>M. lensiformis</i> , P6a/P6b	54.0	26X-1, 50	26X-2, 50	398.50–400.00
LAD <i>M. velascoensis</i> , P5/P6a	54.7	27X-3, 99	27X-4, 99	406.46–407.99
FAD <i>T. bramlettei</i> , NP9/NP10	55.0	27X-3, 99	27X-4, 100	406.49–408.00
FAD <i>D. multiradiatus</i> , NP7–8/NP9	56.2	28X-1, 100	29X-1, 100	413.00–422.50
LAD <i>G. pseudomenardii</i> , P4c/P5	55.9	29X-1, 52	29X-2, 53	422.02–424.03
C25n/C24r	55.904	29X-1, 48	29X-1, 145	421.98–422.95
C25r/C25n	56.391	29X-2, 108	29X-3, 30	424.09–424.81
FAD <i>A. soldadoensis</i> , P4a–b/P4c	56.5	31X-3, 97	31X-4, 97	437.26–441.50
FAD <i>D. mohleri</i> , NP6/NP7–8	57.5	30X-3, 139	31X-1, 100	434.00–441.50
C26n/C25r	57.554	32X-1, 52	32X-1, 140	450.52–451.40
C26r/C26n	57.911	32X-1, 139	32X-2, 50	451.39–452.00
FAD <i>H. kleinpellii</i> , NP5/NP6	58.4	32X-2, 103	33X-1, 109	452.80–459.50
FAD <i>G. pseudomenardii</i> , P3b/P4a–b	59.2	34X-1, 100	34X-2, 100	470.00–471.50
FAD <i>F. tympaniformis</i> , NP4/NP5	59.7	35X-1, 99	35X-2, 12	479.40–480.12
FAD <i>I. albeardi</i> , P3a/P3b	60.0	35X-2, 92	36X-1, 17	480.92–488.17
FAD <i>M. angulata</i> , P2/P3a	61.0	36X-1, 17	37X-1, 99	488.17–498.49
FAD <i>P. uncinata</i> , P1c/P2	61.2	37X-2, 97	37X-3, 97	499.97–501.47

<sup>a</sup>Ages from Berggren *et al.* (1995).

**Table 2.** Planktic foraminifera, nannofossil and chron (this study) boundary ages at Site 762.

this correction, and relabelling the chron succession as a consequence, results in a magnetostratigraphy which correlates well with both the planktic foraminiferal zonation and the isotope stratigraphy (Figs 4, 5).

#### Palaeocene/Eocene transition

The transition between the Palaeocene and Eocene epochs is characterized by a brief warming event *c.* 55.5 Ma. Globally, this event is recognized in marine sediment sequences by a pronounced benthic foraminiferal extinction event, the appearance of distinct planktic foraminiferal morphotypes, and a remarkable  $-2.5$  to  $-3\%$  excursion in  $\delta^{13}\text{C}$  (e.g. Kennett & Stott, 1991; Bains *et al.*, 1999). The distinct morphotypes and abrupt  $\delta^{13}\text{C}$  anomaly were not observed at Site 762. The simplest explanation is that the warming event lies in a 5 m core gap in uppermost Zone P5 between 762C-28X-1 and -27X-4. One check on this interpretation is the occurrence of *Gavelinella beccariiiformis*. This species dominates benthic foraminiferal assemblages during the Palaeocene but disappears at the warming event. At Site 762 it last occurs in section -28X-1, immediately below the core gap. A  $-1.3\%$   $\delta^{13}\text{C}$  excursion is

represented in bulk carbonate from section -28X-2 to -28X-1 (Thomas *et al.*, 1992). The start of the warming event may thus be registered in section -28X-1.

#### Sedimentation rates

Collectively, all biostratigraphic and revised magnetostratigraphic datums show a near-linear age–depth relationship. Subzone P4c has a greater rate of sedimentation, which may relate to local processes such as uplift. However, the overall coherency permits the accurate calculation of sedimentation rates for the early Palaeogene sequence at Site 762. Sedimentation rates are remarkably constant at about  $1.5\text{ cm ka}^{-1}$ , which is typical for carbonate oozes on continental margins (Kennett, 1982) but relatively high compared to known Palaeogene sequences that have not been deeply buried. Continuous sedimentation rates also indicate that significant hiatuses are unlikely to exist at Site 762.

#### CONCLUSIONS

Site 762 on the Exmouth Plateau contains an expanded Palaeogene sequence with abundant and well-preserved calcareous



microfossils, including planktic foraminifera. We have constructed the first detailed early Palaeogene planktic foraminiferal biostratigraphy at this site, and for the region in general (Fig. 3, Table 2). Sediment deposited between 307.8 and 502.96 mbsf spans Zones P1c to P10 (Berggren *et al.*, 1995), although Subzone P4b cannot be recognized. Despite a relatively high latitude Palaeogene location for Site 762, planktic foraminiferal biozones are generally in phase and contain representative assemblages with those of the currently used global scheme for sub-tropical locations. However, rare, patchy or non-occurrences of the zonal marker species such as *Globanomalina pseudomenardii*, *Morozovella velascoensis*, *Morozovella formosa*, *Planorotalites palmerae* and *Hantkenina nuttalli*, make some correlations difficult.

The  $\delta^{13}\text{C}$  record constructed from tests of *Subbotina* spp. is similar to that constructed from bulk sediment. Both records show broad-scale excursions which match the global  $\delta^{13}\text{C}$  curve. However, the large and short-lived negative  $\delta^{13}\text{C}$  excursion that marks the Palaeocene/Eocene transition is at best partially represented at Site 762, probably because of a core gap. Nannofossil biozonation and magnetic polarity chron records (after adjustment) are consistent with the planktic foraminifera biozonation and the  $\delta^{13}\text{C}$  curve (Table 2). Despite core gaps, the integrated stratigraphy at Site 762 suggests that a complete and expanded Early Palaeogene sediment record exists on the Exmouth Plateau. The relatively shallow subsurface depth of this Palaeogene sequence makes the Exmouth Plateau an ideal location for future scientific drilling to understand Palaeogene oceanography.

#### ACKNOWLEDGEMENTS

We sincerely thank Christian Thun, Tony Watson, Andrew Kelman and Richard Brown at AGSO for sample preparation, and James Zachos at UC Santa Cruz for isotope analyses. Personal communications with William Berggren, Richard Norris and Brian Huber have helped us tremendously. This research was funded by AGSO for G. Chaproniere and an ARC small grant to G. Dickens; AGSO provided supplementary funding to H. Hancock. All figured specimens are registered and housed in the Commonwealth Palaeontological Collection (CPC), Australian Geological Survey Organisation, Canberra. The remaining assemblages and samples are stored in the general collections of that organization.

**Manuscript received 21 August 2000**

**Manuscript accepted 29 August 2001**

#### TAXONOMIC LIST

The early Palaeogene species represented at Site 762 are listed below alphabetically by genus. Planktic foraminiferal specific and generic concepts used here follow those of Olsson *et al.* (1999) for the Palaeocene, and generally follow those of Toumarkine & Luterbacher (1985) and Blow (1979) for the early Eocene.

*Acarinina bullbrooki* (Bolli, 1957b)  
*Acarinina collactea* (Finlay, 1939)  
*Acarinina cuneicamerata* (Blow, 1979)

*Acarinina decepta* (Martin, 1943)  
*Acarinina matthewsae* (Blow, 1979)  
*Acarinina mckannai* (White, 1928)  
*Acarinina nitida* (Martin, 1943)  
*Acarinina primitiva* (Finlay, 1947)  
*Acarinina pseudotopilensis* Subbotina, 1953  
*Acarinina quetra* (Bolli, 1957a)  
*Acarinina soldadoensis* (Brönnimann, 1952)  
*Acarinina strabocella* (Loeblich & Tappan, 1957)  
*Acarinina subsphaerica* (Subbotina, 1947)  
*Acarinina wilcoxensis* (Cushman & Ponton, 1932)  
*Catapsydrax unicavus* Bolli, Loeblich & Tappan, 1957  
*Chiloguembelina crinita* (Glaessner, 1937)  
*Chiloguembelina midwayensis* (Cushman, 1940)  
*Chiloguembelina subtriangularis* Beckmann, 1957  
*Chiloguembelina trinitatensis* (Cushman & Renz, 1942)  
*Chiloguembelina wilcoxensis* (Cushman & Ponton, 1932)  
*Eoglobigerina spiralis* (Bolli, 1957a)  
*Globanomalina australiformis* (Jenkins, 1965)  
*Globanomalina chapmani* (Parr, 1938)  
*Globanomalina compressa* (Plummer, 1926)  
*Globanomalina ehrenbergi* (Bolli, 1957a)  
*Globanomalina ovalis* Haque, 1956  
*Globanomalina pseudomenardii* (Bolli, 1957a)  
*Guembeltrioides higginsii* (Bolli, 1957b)  
*Guembeltrioides lozanoi* (Colom, 1954)  
*Igorina albeari* (Cushman & Bermúdez, 1949)  
*Igorina broedermanni* (Cushman & Bermúdez, 1949)  
*Igorina pusilla* (Bolli, 1957a)  
*Morozovella acuta* (Toulmin, 1941)  
*Morozovella acutispira* (Bolli & Cita, 1960)  
*Morozovella aequa* (Cushman & Renz, 1942)  
*Morozovella angulata* (White, 1928)  
*Morozovella apantesma* (Loeblich & Tappan, 1957)  
*Morozovella aragonensis* (Nuttall, 1930)  
*Morozovella caucasica* (Glaessner, 1937)  
*Morozovella conicotruncata* (Subbotina, 1947)  
*Morozovella densa* (Cushman, 1925)  
*Morozovella dolabrata* (Jenkins, 1971)  
*Morozovella formosa* (Bolli, 1957a)  
*Morozovella gracilis* (Bolli, 1957a)  
*Morozovella lensiformis* (Subbotina, 1953)  
*Morozovella marginodentata* (Subbotina, 1953)  
*Morozovella oclusa* Loeblich & Tappan, 1957)  
*Morozovella passionensis* (Bermúdez, 1961)  
*Morozovella spinulosa* (Cushman, 1927)  
*Morozovella subbotinae* (Morozova, 1939)  
*Morozovella velascoensis* (Cushman, 1925)  
*Muricoglobigerina senni* (Beckmann, 1953)  
*Parasubbotina pseudobulloides* (Plummer, 1926)  
*Parasubbotina varianta* (Subbotina, 1953)  
*Parasubbotina variospira* (Belford, 1984)  
*Planorotalites pseudoscitula* (Glaessner, 1937)  
*Praemurica inconstans* (Subbotina, 1953)  
*Praemurica pseudoinconstans* (Blow, 1979)  
*Praemurica uncinata* (Bolli, 1957a)  
*Pseudohasterigina micra* (Cole, 1927)  
*Pseudohasterigina wilcoxensis* (Cushman & Ponton, 1932)  
*Subbotina cancellata* Blow, 1979  
*Subbotina cryptomphala* (Glaessner, 1937)  
*Subbotina eocaena* (Gümbel, 1868) emended Hagn & Lindenberg, 1966  
*Subbotina frontosa* (Subbotina, 1953)  
*Subbotina hagni* (Gohrbandt, 1967)  
*Subbotina patagonica* (Todd & Kniker, 1952)  
*Subbotina triangularis* (White, 1928)  
*Subbotina trilocolinoides* (Plummer, 1926)  
*Subbotina trivialis* (Subbotina, 1953)  
*Subbotina velascoensis* (Cushman, 1925)  
*Rectoguembelina cretacea* Cushman, 1932  
*Zeauvigerina aegyptiaca* Said & Kenawy, 1956  
*Zeauvigerina waiparaensis* (Jenkins, 1965)

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