Climate Change in the Southern Ocean during the Middle Eocene to Early Oligocene: A palynological perspective.

By

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ABSTRACT

The Antarctic and Southern Ocean is an area that was greatly affected by climatic changes during the Middle Eocene to Early Oligocene (E/O). This study aims to document climate-induced changes of the marine palynomorphs (mostly dinoflagellate cysts) by developing a Circum-Antarctic biozonation, and establishing the distribution and effects of cooling on the palynomorph assemblages and the palaeoenvironment.

Samples were obtained from four sites by the Ocean Drilling Program (ODP) and Deep Sea Drilling Project (DSDP) and the palynological content was analyzed. These sites were selected as they may record effects of circulation changes and cooling trends, reflecting climate changes. ODP site 696B, was inner neritic and located in the South Orkney microcontinent, Weddell Sea. The other three sites were pelagic with ODP 699A located on the Northeast Georgia Rise, Falklands, ODP 748B located in the Western part of the Raggart Basin, Kerguelen Plateau and DSDP 277 located in Cathedral Depression on the Southern Campbell Plateau. From this analysis a comprehensive record of the local climatic transitions was ascertained, utilising assemblages of fossil organic-walled dinoflagellate cysts (dinocysts), acritarchs, prasinophyte algae, microforaminiferal linings, scoledonts and terrestrial material.

The establishment of a standard nannofossil biostratigraphy provided a temporal framework of the marine palynomorphs in each site. Key dinocyst datums recognised as first or last occurrences that correlated reliably between sites, were compared with the nannofossil zones of each site. The purpose was to provide a Middle Eocene/Early Oligocene dinocyst biostratigraphy that temporally constrains the assemblages. Six primary datums and two secondary datums resulted, which lead to the recognition of four biozones and established a new biozonation in the Southern Ocean. The zones identified various dinocyst events, giving an indication of their probable palaeoenvironments.

The Circum-Antarctic distribution pattern of palynomorph assemblages was documented in each site as a total abundance of grains per gram. The ranges and

composition of palynomorph assemblages of each site were displayed as a percentage of total abundance. To document any cooling effects the dinocysts were separated into Gonyaulacoid or Peridinioid assemblages to best illustrate their preferred palaeoenvironment.

Key findings showed that the pelagic and inner neritic sites differed greatly. Site 696B was the most climatically stable site and dominated by Peridinioid dinocysts which are predominantly heterotrophic. They are most common in an inner neritic palaeoenvironment, but are also present in nutrient upwellings and eutrophic surface waters with lower sea surface temperatures. Terrestrial material dominates all marine palynomorphs in this site which was shallow and warm with few changes up to the E/O boundary ~33.7 Ma, but became more variable in the Early Oligocene. In comparison, the pelagic sites (699, 748B, 277) were unstable, with missing or condensed sediments and no palynomorphs present at differing times. They were mostly dominated by Gonyaulacoid dinocysts, which are autotrophs and generally located in outer neritic to open ocean palaeoenvironments. The non dinocysts of Prasinophyte algae and *Leiosphaeridia* palynomorphs appeared in higher abundances in the pelagic sites than in the inner neritic sites.

Specific dinocyst markers identified temperature changes within the pelagic sites, subsequently highlighting the climatic changes that occurred during the Middle Eocene/Early Oligocene. From ~46 Ma the pelagic sites recorded conditions that were oceanic and cooler. Between ~44 - ~41.5 Ma, a warming in site 748B indicated enhanced stratification and elevated nutrient availability. This was not the case in site 696B and may be due to warm temperatures already present. From ~41.4 Ma the pelagic sites showed that the palaeoenvironment continued to cool, indicated by the presence of *Leiosphaeridia* and Prasinophyte algae. The palaeoenvironment was oceanic with upwelling and offshore sea surface productivity, illustrated by the Gonyaulacoid and Peridinioid dinocysts present. During the Late Eocene from ~37 Ma a transitional and changeable palaeoenvironment was shown by the high numbers of *Operculodinium* spp present in sites 696B and 277. From ~33.7 Ma (E/O boundary) in the pelagic sites, most Peridinioid dinocysts had disappeared and very few

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Gonyaulacoid dinocysts were present. In contrast the inner neritic site (696B) Peridinioid dinocysts were still dominant, and a more gradual disappearance of all the marine palynomorphs was evident.

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Introduction

CHAPTER ONE

1.0 Introduction

During the Cretaceous and early Cenozoic the Earth's climate was significantly warmer than the present day. Warmer conditions reached a peak in a transitory spike in temperature during the Late Palaeocene/Early Eocene (the PETM) (Kennett and Stott, 1991; Zachos *et al.*, 2001) and was followed by a series of cooling events. At the Eocene/Oligocene (E/O) boundary (~33.7 Ma) an abrupt cooling is designated as the Oi-1 event (Coxall *et al.*, 2005; Miller *et al.*, 1987; Shackleton and Kennett, 1975; Zachos *et al.*, 2001). This is characterized by a positive shift in oxygen isotopic (δ^{18} O) values of benthic foraminifera. The Oi-1 event resulted in a permanent drop in bottom water temperatures and the formation of the first continent wide Antarctic ice sheet and later, the first permanent ice-sheet developed (Barrett, 2003; DeConto and Pollard, 2003; Eldrett *et al.*, 2004; Kump, 2009; Miller *et al.*, 1987; Shackleton and Kennett, 1975; Zachos *et al.*, 2001).

1.1 Aims

The broad aim of this project is to document the climate induced changes in marine palynomorph assemblages from the Middle Eocene through to the Early Oligocene i.e. over the Oi-1 event. In particular the study aims to document changes in the high latitude Eocene fossil dinocyst assemblages that have been recovered from southern high latitudes.

More specifically, this study aims to:

- Develop a Circum-Antarctic biozonation for this climate transition in the Southern Ocean.
- 2. Establish the Circum-Antarctic distribution of palynomorph assemblages in the Eocene.
- Document the effect of cooling on palynomorph distribution and palaeoecology.



Figure 1.1: Antarctic and the Southern Ocean. Latitude and longitude positions for ODP sites 696B, 699A, 748B and DSDP site 277 that have been processed are marked by yellow circles. Sites 690B and 738B were processed but not included (see text). DP = Drake Passage, SOM = South Orkney Microcontinent, NEGR = Northeast Georgia Rise. MR = Maud Rise. KP = Kerguelen Plateau. STR = South Tasman Rise. CP = Campbell Plateau.

Four sites were selected for this study (Figure 1.1):

- ODP site 696B, South Orkney microcontinent, Weddell Sea.
- ODP site 699A, Northeast Georgia Rise, Falklands area.
- ODP site 748B, Western part of the Raggart Basin, Kerguelen Plateau.
- DSDP site 277, Cathedral Depression on the southern Campbell Plateau.

The sites chosen are in areas that should record the effects of any cooling trends and circulation changes in the Paleogene that may reflect climate changes. The Antarctic circumpolar region covers a wide area and some sectors may have responded differently to Antarctic cooling and changes in oceanic circulation.

1.2 Background

Earth's geologic past has recorded many instances where global temperatures have risen dramatically then rapidly dropped e.g. the extreme warming event of the PETM was followed by a significant warming during the Middle Eocene (MECO) and both were followed by a rapid cooling (Figure 1.2, 1.3). Ocean temperatures can be estimated by using oxygen isotopes included in the calcareous tests of foraminifera (Figure 1.2; Zachos *et al.*, 2001). Shifts in the ratio of ¹⁶O/¹⁸O are assumed to be a result of changes in both sea temperatures and ice volume. Variations in continental ice volume occur when freezing of the oceans is preferential for higher concentration of ¹⁶O in ice sheets and more ¹⁸O in the oceans during glacial periods. Higher ¹⁶O ratios in the ocean reflect changes in ice volume and warmer temperatures (Lear *et al.*, 2008; Liu *et al.*, 2009; Boulton, 1993). The Cenozoic O₂ isotope record of Zachos *et al.* (2001) is based on data from 40 DSDP and ODP sites combined to create a global deep-sea isotope record.

1.3 Paleogene Temperature Changes

The PETM has been recorded from a variety of areas including Clarence River Valley and Tawanui in the Southwestern Pacific, Wilson Lake and Bass River on The New Jersey Shelf and Lomonosov Ridge, Arctic Ocean (Crouch *et al.*, 2003; Crouch and Brinkhuis, 2005; Hollis *et al.*, 2005; Sluijs *et al.*, 2008; Zachos *et al.*, 2005, Zachos *et* *al.*, 2008). The high global temperatures achieved during the PETM lasted for ~170 kyr (Handley *et al.*, 2011). The PETM is superimposed on a gradually rising temperature (Figure 1.2). Deep Ocean and high latitude surface temperatures rose by 6°-8°C in less than 10,000 years and about that time more than 2,000 Gt CO₂ entered the atmosphere and oceans (Zachos *et al.*, 2008). With the PETM intense warming and excess carbon, came changes in the marine and terrestrial biota. Included were changes in planktonic organisms, a benthic foraminiferal extinction event (Kennett and Stott, 1991) and a global occurrence of an acme for the dinocyst genus *Apectodinium* (Crouch *et al.*, 2003).



Figure 1.2: Climate from 65 Ma up to Recent from deep-sea benthic foraminiferal oxygen-isotope curve from DSDP and ODP sites. The figure clearly shows the PETM (Eocene thermal max. 1) followed by a second ETM2 and the 2 Ma Early Eocene Climatic Optimum warming. The MECO event is also shown at 52 Ma and the Oi-1 at the E/O boundary ~33.7 Ma. The approximate positions of Antarctic ice sheets and Northern Hemisphere ice sheets are also displayed (Zachos *et al.*, 2008).

A further brief peak in warm conditions is recorded as the Eocene Thermal Maximum 2 (ETM2), followed closely by a longer period of warming at the Early Eocene Climatic Optimum (EECO). The EECO temperature curve (Figure 1.2) is represented by a broader peak consistent with a longer period lasting ~2 Ma (51-53 Ma) and is followed by a gradual decline in temperature. The MECO (~42 Ma) is the next significant warming event with a steep rise in temperature followed by a rapid decrease (Figure 1.2, 1.3). Following the MECO a further Late Eocene warming (~36 Ma) was followed by a brief cooling (~35 Ma; Vanhof *et al.*, 2000), before the most significant cooling event of the Oi-1 (~33.7 Ma; Figure 1.3).



Figure 1.3: Compilation of Southern Ocean stable isotope data taken from ODP sites 689, 690, 738, 744 and 748. The early Eocene climatic optimum (EECO) is featured at the base of the chart. A prominent minimum event in the δ^{18} O at ~41.5 Ma, is interpreted as significant warming during MECO. This was followed by gradual increase in δ^{18} O events of cooling, a late Eocene warming with a further Vonhof *et al.* (2000) cooling. A most prominent event of glacial cooling at ~33.5 Ma is the Oi-1 event which represents significant cooling of both surface and deep waters (Palike *et al.*, 2006). Figure adapted from Bohaty and Zachos (2003).

During most of the Eocene in the Northern Hemisphere winters were above freezing in the mid to high latitude continental interiors and both poles were free of significant permanent ice (Huber and Nof, 2005). After the MECO the climate cooled sufficiently to allow small ice sheets to form on the Antarctic continent. A decrease of partial pressure of atmospheric carbon dioxide (pCO_2), ensured the cooling continued (Figure 1.2, 1.3) from the middle to Late Eocene through to the Early Oligocene near the (E/O) boundary (~33.7 Ma; DeConto and Pollard, 2003; Francis *et al.*, 2009; Pagani *et al.*, 2005). Surface water temperatures decreased rapidly over the E/O boundary and this is reflected in a positive shift in δ^{18} O excursion with the resulting cooling lasting ~200,000 years (Billups and Schrag, 2003; Bohaty and Zachos, 2003; Bohaty *et al.*, 2009; Shackleton and Kennett, 1975; Zachos and Kump, 2005).

1.4 Causes of the Oi-1

The onset of the Antarctic Circumpolar Current (ACC) and the tectonic changes that deepened the Tasman Gateway between Australia and Antarctica and opened Drake Passage between South America and Antarctica, have been suggested as the triggers for Antarctic cryosphere initiation and growth (Kennett *et al.*, 1975; Shackleton and Kennett, 1975; Zachos *et al.*, 1996). However, DeConto and Pollard (2003) using a general circulation model (GCM), suggested that the opening of the Southern Ocean gateways and beginning of the ACC played only a secondary role in the sudden cooling and formation of the ice sheet. DeConto and Pollard (2003) proposed that a decline in atmospheric CO₂ and a position in orbital cycles resulting in low insolation were the primary causes for the event. In support Huber *et al.* (2004) concludes there was no direct dynamic effect of a termination of warm currents resulting in Antarctic glaciation. Warm ocean currents did not penetrate to high latitudes during the climatic transition of the Eocene/Early Oligocene. Further to this Stickely *et al.* (2004) supported a deepening of the Tasman Gateway as preceding significant Antarctic glaciation by ~2 Ma.

Figure 1.4 displays a proposed Middle Eocene ocean circulation inferred from the GCM results before full opening of gateways and commencement of the ACC (Francis *et al.*, 2009). Previous work in the Southern Ocean and Antarctica has recognised the presence of dinocysts that were endemic to the southern high latitudes during the Eocene/Early Oligocene (Kemp, 1975; Haskell and Wilson, 1975; Goodman and Ford, 1983; Wrenn and Hart, 1988; Wilson, 1989; Hannah, 1997; Levy and Harwood, 2000). Endemics are species of flora and fauna that are restricted to and exclusively native to a region and not found elsewhere.



Figure 1.4: A Middle Eocene prediction for ocean circulation inferred from GCM results before full opening of gateways. Endemic dinocysts show as per legend. Lighter shading shows submerged continental blocks. Red arrows are warmer currents, black arrows are cooler currents which dominate the Southern Ocean round Antarctica as clockwise gyres. The map is derived from the Ocean Drilling Stratigraphic Network (ODSN). TA-SW, Trans-Antarctic Seaway (hypothetical; see Wrenn and Beckmann, 1982); TSA-SW, Trans-South American Seaway (hypothetical; see Kohn *et al.*, 2004); EAC, East Australian Current; p-LC, proto-Leeuwin Current; p-RG, proto-Ross Gyre; TC, Tasman Current (Francis *et al.*, 2009).

Figure 1.4 utilizes the endemic southern high latitude fossil dinocysts to predict the Eocene palaeo-ocean circulation patterns before the opening of the ACC. Higher numbers of endemic dinocysts occupy the cooler equator ward flowing Tasman Current, the proto-Ross Gyre in the Pacific and the Counter Antarctic Current on the western side of the Antarctic. These currents were not warmed by sub tropical southward flowing currents. The warmer proto-Leeuwin Current circulating on the Western side of the Tasman Gateway between the Australian continent and Antarctica, contained cosmopolitan assemblages typical of low latitude taxa. Endemic high latitude southern dinocysts were rare in ODP sites in this region (Brinkhuis *et al.*, 2003; Francis *et al.*, 2009; Huber *et al.*, 2004). The opening of the Tasman Gateway would have allowed the warmer proto-Leeuwin Current to flow into the Southern Pacific Ocean creating a mild warming for the region, rather than a predicted cooling effect. Changes to dinocyst assemblages would favour cosmopolitan species and fewer endemic dinocysts would exist (Huber *et al.*, 2004; Stickely *et al.*, 2004).

In addition, the timing of the opening of both the Tasman Gateway and Drake Passage are currently debated and Barker *et al.* (2007) point out that the timing of this event is not certain for Drake Passage (Table 1.1). Barker *et al.* (2007) have listed alternatives to the timing and onset of the ACC for the Drake Passage opening.

Author/date	Sites	Type of Research	Onset
Diester-Haass and Zahn (1996, 2001)	689, 763, 592	Benthic biomass increase	37 Ma
Scher and Martin (2004, 2006)	689, 1090	Nd isotopes	41 Ma
Florindo and Roberts (2005) Roberts <i>et al</i> . (2003)	690, 744, 748	Magnetobiochronology	31-30 Ma
Gamboa <i>et al</i> . (1983)	515	Increased sedimentation	Early Miocene
Persico and Villa (2004)	689, 690, 744, 748	Nannofossils	33.5 Ma
Diekmann <i>et al</i> . (2004)	1090	Opal pulse, reduced sedimentation	33-30 Ma
Pfuhl and McCave (2003, 2005)	1170	Grain size	23.9 Ma
Wei and Wise (1992)	737, 744, 748, 751	Planktonic biofacies	Latest Miocene

Table 1.1: Various estimates for the onset of the opening of Drake Passage (Barker et al., 2007)

Livermore *et al.* (2005) suggest that a deep water connection at 34 – 30 Ma developed due to seafloor extension of the West Scotia Ridge. Francis *et al.* (2009) suggests the Drake Passage from the Middle Eocene may have been open to upper bathyal water depths, as noted by Eagles *et al.* (2006).

ODP leg 189 was drilled to document the changes in the Australian sector of the Southern Ocean and the results from Stickley *et al.* (2004) for the Tasman Gateway suggest:

- > ~35.5 Ma, a minor deepening in the Tasman Gateway
- ~35.5-33.5 Ma, the onset of glauconitic deposition, increased deepening of the Tasman Gateway and commencement of energetic bottom-water currents.
- ~33.5-30.2 Ma further deepening to bathyal depths with episodic erosion and a further increase in energetic bottom water currents.
- <30.2 Ma oligotrophic warm temperate open ocean settings with siliceous carbonate ooze deposition (Stickley *et al.*, 2004).

1.5 Previous Work in Antarctica and Southern Ocean

There has been a variety of studies on fossil dinocysts from Antarctica and the Southern Ocean and a particular focus has been on the Eocene/Oligocene boundary. Some of the earliest investigations of Antarctic and the Southern Ocean were completed during the 1960's. These include Cranwell *et al.* (1960) with one of the first records of *Hystrichosphaerid* species from Paleogene sediments in the McMurdo Erratics. Wilson (1967a) followed with an investigation into the palynomorph contact of the Erratics from Black Island and Minna Bluff. He named seven new species attributable to the dinocyst genera for *Deflandrea* and *Spinidinium* as well as *Cordosphaeridium filosum*. Further afield, Cookson (1965a,b) described the content of the Upper Eocene Browns Creek Clays, SW Victoria. The dinocysts described included *Deflandrea phosphoritica, Impagidinium victorianum,* Impagidinium elegans, Impagidinium dispertitum, Samlandia reticulifera, and Hystrichosphaeridium spp.

During the 1970's, Kemp (1975) examined sediments from beneath the Ross Sea reporting on results from DSDP sites drilled during leg 28 partly in the Ross Sea, and between Wilkes Land Antarctica and South of Australia in the Southern Indian Ocean. Sediments of possible Late Eocene age from site 274 yielded rich dinocyst assemblages that included *Areosphaeridium diktyoplokus*, *Deflandrea* spp, *Selenopemphix nephroides*, *Spinidinium macmurdoense*, *Thalassaphora pelagica*, and *Turbiosphaera filosa*. These assemblages can be considered to be typical of high latitude endemic Eocene environments. All other sites contained only sparse dinocyst assemblages

Haskell and Wilson (1975) reported on the dinocyst assemblages from DSDP sites 280-284 on leg 29, situated off the South Tasman Rise and to the west of New Zealand in the Tasman Sea. Most cores recovered Eocene/Oligocene sediments except site 284 which was restricted to the late Miocene to Pleistocene. Some typical Eocene dinocysts recorded included *Areosphaeridium diktyoplokus*, *Deflandrea antarctica*, *Deflandrea cygniformis*, *Deflandrea phosphoritica*, *Thalassaphora pelagica* and *Impagidinium victorianum*.

Analysis of gravity cores recovered from beneath the southern Ross Ice Shelf by Wrenn and Beckman (1982) recorded the presence of dinocysts, acritarchs and sporomorphs throughout the cored sequence. The dinocysts that were becoming accepted as Eocene endemics included *Deflandrea antarctica, Spinidinium macmurdoense,* and *Vozzhennikovia apertura*. Goodman and Ford (1983) examined DSDP sites 511, 512 and 513A from Leg 71 in the South Western Atlantic Ocean. Site 511 dinocysts were common to abundant and Goodman and Ford (1983) considered the flora recovered to be similar to those from the Browns Creek Clays (Cookson, 1965). Haskell and Wilson (1975) also concluded a similarity to the Browns Creek Clays and sites examined by them (DSDP sites 280, 283). Site 511 includes *Phthanoperidinium* SpA, *Eurydinium* sp, *Deflandrea antarctica, Deflandrea*

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phosphoritica, Samlandia reticulata, Spinidinium macmurdoense, and Vozzhennikovia apertura. Similar dinocysts were also recovered from site 512. Site 513A was restricted from the Lower Oligocene to Lower Miocene and contained few dinocyst assemblages including Corrudinium incompositum, Deflandrea antarctica, Phthanoperidinium SpA, and Impagidinium victorianum.

Wrenn and Hart (1988) documented the Paleogene dinocysts of Seymour Island, Antarctica from two lithologic formations, the Cross Valley and La Meseta. The Cross Valley Formation sediments are considered Late Paleocene in age and included cosmopolitan taxa with none of the endemic dinocysts. The La Meseta Formation did contain Eocene dinocysts including *Arachnodinium antarcticum*, *Areosphaeridium diktyoplokus, Deflandrea antarctica, Deflandrea cygniformis, Impagidinium victorianum, Lejeunecysta fallax, Selenopemphix nephroides, Spinidinium essoi, Spinidinium macmurdoense,* and *Vozzhennikovia apertura*.

CIROS-1 was drilled offshore of the Ferrar Glacier in McMurdo Sound and has been the focus for many marine palynomorph studies. Wilson (1989) originally described the flora and suggested that the late Eocene endemic flora found between 473-696 mbsf toward the base of the hole were a result of reworking. Based on diatoms an Early Oligocene age was suggested by Harwood (1989). The dinocyst assemblage included *Deflandrea antarctica, Alterbidinium distinctum, Vozzhennikovia apertura, Spinidinium macmurdoense, Alterbidinium asymmetricum, Hystrichosphaeridium tubiferum* and *Turbiosphaera filosa*. Following this Hannah (1997) re-sampled the base of CIROS-1 (455-696 mbsf), and suggested that the endemic dinocysts were *in situ* and of Eocene age with some last occurrences extending into the Early Oligocene. The dinocysts included Alterbidinium distinctum, Deflandrea antarctica, *Enneadocysta partridgei, Hystrichosphaeridium tubiferum, Spinidinium macmurdoense, Turbiosphaera filosa*, and *Vozzhennikovia apertura*.

ODP site 696B leg 113 from middle Eocene to Oligocene in the Weddell Sea yielded dinoflagellate cysts and sporomorphs with a stratigraphic range of late middle Eocene to late Eocene/earliest Oligocene (Mohr, 1990). Many of the species

recovered were indicative of a shallow marine environment and contained endemic dinocysts including *Areosphaeridium diktyoplokus, Deflandrea antarctica, Spinidinium essoi, Spinidinium luciae, Spinidinium macmurdoense, Turbiosphaera filosa,* and *Vozzhennikovia apertura*. Site 696B was included in this study with results shown in the following chapters.

Crouch and Hollis (1996) revised the Paleogene palynomorph and radiolarian biostratigraphy from the Middle Eocene to Late Eocene for DSDP sites 280 and 281, leg 29 off the South Tasman Rise. The dinocyst distribution reflected the depositional differences between sites. Site 281, deposited in shallower marine conditions, yielded a restricted dinocyst assemblage, whereas site 280 contained an abundant and diverse dinocyst assemblage reflecting its deep water environmental deposition. Endemic dinocysts were present in both sites and many dinocysts were long ranging and extended through the Eocene into the Oligocene including *Deflandrea antarctica, Spinidinium macmurdoense* and *Vozzhennikovia apertura*. Other dinocysts recorded in the Middle and Late Eocene and part of the Early Oligocene are Eocene endemics. Hollis *et al.* (1997) described marine palynomorphs from the Paleocene to Middle Eocene in an integrated biostratigraphic study for site 277 leg 29 on the Campbell Plateau. Of the fifteen samples examined from this site, only five samples contained palynomorphs with no age significant taxa being reported.

Sites off Western Tasmania and the western edge of the South Tasman Rise were the focus of Truswells 1997 study. Samples from off Western Tasmania contained very low numbers of endemic dinocysts whereas South Tasman Rise sites contained higher frequencies for endemics including high numbers of *Deflandrea antarctica*. Levy and Harwood (2000) studied the McMurdo Erratics and most of the sediments examined appeared to be of Middle Eocene to Early Oligocene age based on taxon ranges. The most common dinocysts recovered were *Vozzhennikovia apertura* and *Enneadocysta partridgei* and other common dinocysts included *Octodinium askinae*, *Alterbidinium asymmetricum*, *Deflandrea antarctica*, *Spinidinium colemanii*,

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Spinidinium essoi, Spinidinium macmurdoense, Impagidinium victorianum and *Thalassaphora pelagica*.

ODP leg 189 drilled five sites in the Tasmanian Gateway (1168,1169,1170,1171, 1172). The purpose of the drilling was to assess whether the opening of the Gateway near the Eocene/Oligocene led to the formation of the ACC, causing climatic cooling and development of Antarctic glaciation.

Site 1168 (Brinkhuis *et al.*, 2003a) off Western Tasmania contained sediments of Mid Eocene/Early Oligocene age and showed that the dinocysts present were largely cosmopolitan and virtually lacked typical endemic Antarctic dinocysts. Brinkhuis *et al.* (2003b) also looked at site 1172 off East Tasman Plateau from Late Cretaceous-Late Oligocene, samples investigated between the Middle Eocene to Early Oligocene contained endemic species which included *Alterbidinium distinctum*, *Deflandrea antarctica*, *Octodinium askinae*, *Enneadocysta partridgei* and *Spinidinium macmurdoense*.

Sluijs *et al.* (2003) examined sediments from Middle Eocene/Early Oligocene recovered from sites 1170-1172 off the South Tasman Rise. Sites 1170 and 1171 were sampled at a low resolution and showed similar results to site 1172. Site 1172 was more thoroughly investigated with low resolution sampling up to the Late Eocene and a much higher resolution through to the Early Oligocene. The results showed changes occurred in the dinocyst assemblages from the Late Eocene. Site 1172 dinocyst analysis has been integrated with this study for comparison.

Guerstein *et al.* (2008) examined palynological data from northern Tierra del Fuego, Southern Argentina, in the Middle to Late Eocene La Despedida Formation and the Late Eocene/Early Oligocene Cabo Peña Formation. The most common dinocysts included *Deflandrea* spp, *Spinidinium* spp and *Vozzhennikovia* spp from the Middle Eocene with an increase of cosmopolitan dinocysts near the E/O boundary of *Spiniferites* spp, *Operculodinium* spp and *Impagidinium* spp. Bijl *et al.* (2011) examined Paleogene assemblages from a number of sites drilled from the DSDP and ODP (269,277,511,512,696.739,748,1090). They conclude that the spatial distribution of the endemic, bipolar, middle to low latitude and cosmopolitan groups match the GCM experiments of Huber *et al*. (2004) for ocean current patterns during the middle and late Eocene.

1.6 Site Locations, Lithology and Palaeoenvironments

1.6.1 Introduction

Sites used in this study were selected on the basis that they contained the thickest sections of Eocene/Oligocene sediments with the best core recovery over the interval. The need for wide geographical/circum-Antarctic coverage was required to improve understanding of Southern Ocean climatic development.

Southern Ocean DSDP and ODP Sites Investigated					
Legs	Sites	Legs Sites		Legs	Sites
DSDP 28	264-274	DSDP 29	275-284	DSDP 35	322-325
DSDP 36	326-331	DSDP 71	511-514	DSDP 90	587-594
ODP 113	689-697	ODP 114	698-702	ODP 119	736-746
ODP 120	747-751	ODP 141	859-863	ODP 177	1088-1094
ODP 178	1095-1103	ODP 181	1119-1125	ODP 183	1135-1142
ODP 187	1152-1164	ODP 188	1165-1167	ODP 189	1168-1172

Table 1.2: Sites chosen for investigation into core recovery of sediments deposited during the Eocene through to early Oligocene.

Table 1.2 shows the DSDP and ODP sites that were initially investigated (Appendix 2.1). ODP cores having been drilled more recently than the DSDP cores are generally of better quality. Nevertheless DSDP site 277 was included because it completes the circum Antarctic coverage. Drilling was sparse in some areas of the oceans surrounding the Antarctic continent but sites 696B, 699A, 748B and 277 are reasonably spread and in positions that should reflect any paleoenvironmental changes that were occurring at that time (Table 1.2).

ODP Leg 113, site 690B and ODP leg 119, site 738B were investigated without success (Table 1.3). Site 690B proved to be barren of palynomorphs and was therefore replaced by site 696B, also within leg 113, which proved to be rich in

palynomorphs. Similarly site 738B from leg 119 was found to be sparsely populated with palynomorphs, making any count or comparison with other sites very problematic. However, due to the sites close proximity to site 748B on the Kergulen Plateau, which did have a good count in palynomorphs, preference was given to site 748B and site 738B was eliminated from this study.

Site	Leg	<u>E/O</u> <u>Depth</u> (mbsf)	Total Samples	Lat-Long	Predominant Lithology	Southern Ocean
696B	ODP 113	578.71 - 642.98	28	61° S - 42° W	Sandy mudstone	South Orkney Microcontinent
699A	ODP 114	249.73 – 465.65	30	51° S - 30° W	Siliceous nannofossil ooze Nannofossil ooze	Northeast Georgia Rise
690B	ODP 113	70.12 – 134.36	17	65°S- 1°E	Nannofossil ooze diatom rich, foram nannofossil ooze	Maud Rise
748B	ODP 120	76.83 – 200.47	22	58° S - 78° E	Nannofossil ooze, nannofossil chalk, chert, porcellanite	Kerguelen Plateau: (Western part Raggatt Basin)
738B	ODP 119	20.09 – 108.18	30	62° S - 82° E	Nannofossil ooze, chalk some chert	Southern Kerguelen Plateau
277	DSDP 29	122.17– 435.01	28	52° S - 166° E	Nannofossil ooze, chert nodules, some clay.	Southern Campbell Plateau: (Cathedral Depression)

Table 1.3: Eocene/Oligocene DSDP and ODP cores that were initially investigated for this study with leg, site and Southern Ocean position in a west/east transect. Latitude and longitude, depth in meters below the sea floor (mbsf), total number of samples and lithology of sediment received are also shown. Only sites 696B, 699A, 748B and 277 were chosen as suitable for this study.

The Shipboard Scientific Party (1975, 1988, 1989) and except where noted is the source for the detailed information reported here.

1.6.2 Site 696B

Site 696B is located on the southeast margin of the South Orkney microcontinent (SOM), South Scotia Ridge at 61° S, 42° W (Figure 1.5). Drilling took place in March 1987 at a water depth of 650 m. Site 696B was one of a series of nine sites, six in the Weddell Sea area (689-694) and three on the margin of the SOM (695-7). Site 696B is the shallowest site and was drilled to recover continuously cored, shallow water sedimentary records from the middle Paleogene through to the Neogene. It was suggested (ref p16) that during the Eocene, sediments were deposited in less than 100 m water depth. The dominantly terrigenous deposition indicated that the SOM was still contiguous with the West Antarctic continental margin.

1.6.2.1 Lithology and Palaeoenvironment

There are 28 samples from this study ranging from 642.9-578.7 mbsf with samples spaced every 1-2 m except for the three youngest samples which were spaced every 10 m. The sampled section is described as mainly terrigenous with minor pelagic content consisting of sandy mudstone from the base of the hole to 598.30 mbsf, where it changes to glauconite silty mudstone which continues up to 578.71 mbsf (Appendix 2.3a). Barker *et al.* (1988) have suggested that between 645.6 mbsf and 616.6 mbsf the presence of benthic foraminifera and the abnormally high chlorinity of interstitial waters, created hypoxic and slightly hyposaline conditions. The shallow hypersaline waters largely excluded planktonic assemblages in favour of abundant assemblages of invertebrates (Mollusca and Cnidaria).



Figure 1.5: Red arrow depicts the position of site 696B in the SOM part of the Weddell Sea. Other sites within Leg 113 are also shown, six in the Weddell Sea area (689-694) and three in the SOM. Map was obtained from the initial results by the ODP Shipboard Scientific Party (1988).

Estimates of the Paleogene age for samples in this site are from a biostratigraphic age assessment provided by calcareous nannofossil and foraminifera between ~607-631.6 mbsf. *Isthmolithus recurvus, Reticulofenestra oamaruensis, Chisamolithus altus* and *Reticulofenestra reticulata* are common and well preserved age assigned nannofossils with a known range from the Middle Eocene to Early Oligocene. The foraminifera include *Praeglobobulimina ovata, Gyroidinoides* spp, and *Cibicidoides* spp contained in similar assemblages to Eocene/Oligocene deposits in England. The transition at the E/O boundary is not well established due to a ~77 m condensed glauconitic terrigenous sequence of poorly dated sediments that are barren of stratigraphically useful microfossils. Glauconite contained in sediments usually implies a slow deposition rate and a non-oxidizing, shallow marine environment.

1.6.3 Site 699A

Site 699A was part of a series of seven sites drilled along a west-east transect in the South Atlantic Basin, and is located on the north eastern slope of the Northeast Georgia Rise on crust that is considered to be part of the rise itself at 51° S to 30° W (Figure 1.6). Five sites (698-702) were drilled in March 1987 in the east Georgia Basin on the west south side of the Mid Atlantic Ridge and two (703-704) on the east south side of the Mid Atlantic Ridge at Meteor Rise at a water depth of 3705.5 m.



Figure 1.6: Red arrow depicts the position of site 699A. Five other sites are to the West of the Mid Atlantic Ridge (698-702) and two (703-704) are to the East of the Ridge. Site 328 is part of ODP Leg 36 and sites 511-514 are part of Leg 71. Map was obtained from the initial results by the ODP Shipboard Scientific Party, (1988).

1.6.3.1 Lithology and Palaeoenvironment

Site 699A sediments are described as predominantly pelagic in origin. There are 30 samples used in this study ranging from 249-465.6 mbsf with sample spacing varying between 4-14 m. A dominance of nannofossil chalk occurs between 465.6-335.4 mbsf the lithology changes to nannofossil ooze up to 249.7 mbsf (Appendix

2.3b). An hiatus occurred at approximately the end of the middle Eocene which may have caused truncation of sediments down to the lower middle Eocene. This hiatus may also be seen at site 511, leg 71 (Figure 1.6) and sites 327 and 330, leg 36 where an unconformity occurred below the middle/late Eocene boundary and is believed to be a major erosional surface caused by bottom-current scouring (Ludwig *et al.* Leg 71 1983, Barker *et al.* Leg 36 1977; Robert and Maillot, 1983).

1.6.4 Site 748B



Figure 1.7: Red arrow depicts the position of site 748B. It is situated in the western part of the Raggatt Basin within the Kerguelen Plateau. The five sites above are part of Leg 120 (747-751). Map was obtained from the initial results by the ODP Shipboard Scientific Party (1989).

Site 748B is located on the Southern Kerguelen Plateau in the western part of the Raggatt Basin, east of Banzare Bank at 58° S, 78° E (Figure 1.7). Site 748B was part of a series of five sites (747-751) drilled at a water depth of 1290 m on the Kerguelen Plateau in March 1988. The site was drilled for the purpose of recovering Cretaceous and Paleogene sediments to provide information on the geologic and tectonic history in the area. By the late Paleocene extensional tectonics caused rapid subsidence down to ~1000 m in the Raggatt Basin, and pelagic sedimentation was nearly continuous during the rest of the Paleogene (18 m/ m.y.).

1.6.4.1 Lithology and Palaeoenvironment

Site 748B lithology is mainly pelagic in origin. There are 22 samples from this core ranging from 76.83-200.47 mbsf, with sample spacing varying between 4-9 m. Nannofossil ooze is dominant through all sediments in this site with four samples between 120.6-106.6 mbsf containing foraminiferal nannofossil ooze and siliceous foraminiferal nannofossil ooze (Appendix 2.3c). Ice rafted debris is present at intervals 115.45-115.77 mbsf in the early Oligocene. The mineral assemblage in the IRD did not come from a volcanic source on the Kerguelen Plateau. Coeval glacial activity along the Antarctic margin (CIROS-1; ODP leg 113 and 119) supports the presence of ice bergs large enough to travel to the Kerguelen Plateau (Breza and Wise Jr., 1992).

1.6.5 Site 277

Site 277 was part of a series of 10 sites drilled during leg 29 from the western part of the south Tasman Rise through to the eastern part of the Campbell Plateau. Site 277 is located on the Southern Campbell Plateau at 52° S, 166° E and is situated in the Cathedral Depression, between Auckland and Campbell Islands (Figure 1.8). Drilling took place from site 277 at a water depth of 1214 m in 1973 with a total of forty six cores recovered down to 472.5 mbsf. Five sites (275-9) were drilled on the Campbell Plateau area, four sites (280-3) on the South Tasman Rise area and one site (284) on Lord Howe Rise. Drilling at site 277 was for the purpose of establishing a biostratigraphic sequence for the subantarctic Southern Ocean.



Figure 1.8: Red arrow depicts the position of site 277 on the Campbell Plateau. It is part of a series of 10 sites from DSDP Leg 29, five on the Campbell Plateau (275-9), four sites (280-3) on the South Tasman Rise area and on site (284) on Lord Howe Rise. Inset shows the proximity of site 277 to Antarctica today in the Southern Ocean. Map was obtained from the Initial results by the Shipboard Scientific Party, (1975).

1.6.5.1 Lithology and Palaeoenvironment

Site 277 contains 28 samples from 435-122.1 mbsf with sample spacing varying between 4-25 m. Nannofossil ooze is present in all samples. The dominant lithology is nanno chalk for the lower seven samples (435.01 – 265.3 mbsf). Nannofossil ooze is the dominant lithology for the upper 21 samples (240.8– 122.17 mbsf) which also contain foraminifera, diatoms, radiolarian, micarb and spicules (Appendix 2.3d). Within the Paleogene the sedimentation rates were typical for nannofossil oozes, with little influence from terrigenous sources and sediments were deposited under uniform, fully oceanic conditions over a period of 35 Ma. Depths of sediment deposition were much the same throughout and well above the lysocline. Palaeotemperature proxies indicate three major stages of cooling from the Late Eocene to earliest Oligocene. These indicators were positive shifts of δ^{18} 0, an observed increase in abundance and diversity for radiolarians, a decline in the warm water *Discoaster* species abundance and an increase in the cold water *Chiasmolithus* species abundance (Hollis *et al.*, 1997).

Of the five sites from 275-279 within the Campbell Plateau area, site 277 was the only site that produced a complete 462 m Paleogene sequence from the middle Paleocene to the late Oligocene (10-472.5 mbsf). The Paleogene sequence recovered at site 277 is thought to have extended over most of the Campbell Plateau; however, during the Neogene it was eroded off southern and eastern parts of the Plateau by strong bottom water currents (Andrews *et al.*, 1975). The lack of active bottom currents affecting site 277 during the Paleogene can be seen by continued deposition of calcareous biogenic ooze which underlies a major hiatus that spans from late Oligocene to the Pleistocene. It is concluded that large areas of Paleogene sediment, as seen in seismic profile, are layered parallel to the sea floor exhibiting no obvious erosion (Kennett *et al.*, 1975).

1.7 Palaeopalynology

1.7.1 Why use Dinoflagellate Cysts?

The term palynomorph refers to acid-resistant, organic-walled microfossils and includes spores, pollen, dinoflagellates, green algae and acritarchs (Batten, 1996). Dinoflagellates are a diverse group of unicellular algae that are included alongside diatoms as being the most prominent primary producers in the oceans today and are an important part of the global carbon cycle. Originally classified as protozoans by Zoologists and protophyta by Botanists they are now commonly referred to as protists (Pross *et al.*, 2005; Sluijs *et al.*, 2005; Williams *et al.*, 2009). Today there are estimated to be ~1,772 marine and 230 freshwater species of living dinoflagellates, many of which have yet to be adequately described.



Figure 1.9a: Generalised section through a typical thecate motile dinoflagellate



Figure 1.9c: An illustration depicting differences between (A) thecate cell, (B) intermediate, and (C) chorate cyst.

Figure 1.9b: General morphology of a thecate motile cell



Figure 1.9d: A positive correlation between sea level and species diversity in shelfal environments. Dinocyst studies are a useful tool in sequence stratigraphy.



Figure 1.9e: Generalised life-cycle involving general reproduction and cyst formation. (A) Depicts motile and haploid cells. (B) Depicts motile and diploid cells. (C) Depicts non motile and diploid except for excysted cells on the left (Fensome *et al.*, 1996; Urbino dinoflagellate cyst course, 2009)

Dinoflagellates thrive in a variety of settings from relatively shallow marine environments along continental shelves, including fresh and brackish water, to continental rise settings from tropical to Polar Regions and some even inhabit ice, snow and the interstices of wet sand (Dale, 1996; Pross and Brinkhuis, 2005; Stover et al., 1996). Approximately 50% of living dinoflagellates are autotrophic and utilise light and dissolved nutrients. The remaining dinoflagellates are either heterotrophic, capturing their prey (often diatoms), or mixotrophic, capable of using both living strategies (Dale, 1996). Some dinoflagellate species are photosynthetic endosymbionts of coral reefs or other protists, and play a major role in the marine ecosystem (Dale, 1996; Stover et al., 1996). Motile forms are sensitive to very slight changes in surface water masses and have an extreme sensitivity to changes in temperature and nutrient availability (Reichart et al., 2004; Sluijs et al., 2005). The distribution of living dinoflagellate motile cells can be used as a proxy for paleoenvironmental reconstructions with regard to sea-surface productivity, upwellings, temperature, salinity, and transport. There is a positive correlation between sea level rise and fall and the degree of ecological variance of dinocysts in shelfal environments (Figure 1.9d) and has led to dinocyst studies being a useful tool in sequence stratigraphy (Sluijs, et al., 2005; Williams et al., 2009).

1.7.2 General Morphology

Dinoflagellates are eukaryotic and most species include asexual and sexual reproduction as part of their life cycle (Evitt, 1985; Dale, 1996). At some stage of their life cycle (Figure 1.9e) all dinoflagellates have a motile cell with two flagella used to propel them through the water in a rotating or corkscrew fashion (Williams *et al.*, 2009). One encircles the cell in a transverse furrow called the cingulum, and is ribbon like, and one trails posteriorly in a longitudinal furrow (the sulcus) (Figure 1.9b). They all possess dinokaryon (Figure 1.9a) which is an unusual type of cell nucleus lacking histones and containing chromosomes that remain condensed during cellular interphase (Fensome *et al.*, 1996; Williams *et al.*, 2009). Most motile dinoflagellates have a cellulistic test called a theca or an ephemeral membrane, neither of which are preservable as fossils. The complex outer membrane of the
living cell (amphiesma) may include cellulosic thecal plates; others have no plates and are referred to as athecate (Fensome *et al.*, 1996).

Some dinoflagellates produce a resting cyst (dinocyst), as part of their life cycle, i.e. a non motile cell possessing a cell wall and an opening (the archeopyle) for excystment (Dale, 1996; Fensome *et al.*, 1996; Head, 1996; Wrenn *et al.*, 1998). Cysts are formed inside the motile dinoflagellate theca and may mimic the motile cell, they have walls made of dinosporin, a complex organic compound that is very resistant to dissolution (Dale, 1996; Stover *et al.*, 1996). Cysts may form processes that rise from ridges at plate edges or rise from central parts of the plate, which can vary in length as a percentage of the central body (Figure 1.9c) either: proximate <10%; proximochorate 10-30%; chorate >30% (Evitt, 1985; Fensome *et al.*, 1996). Cysts are often preservable and can be abundant in the fossil record. Ease of preservation ensures a more continuous fossil record and for this reason they have fewer restrictions than other micropaleontological groups as they are not as prone to dissolution (Stover *et al.*, 1996).

1.8 Method and Results

1.8.1 Palynological Processing

A total of 155 sediment samples were requested from the ODP East Coast Repository at Lamont-Doherty Earth Observatory, Palisades, NY. On receipt of the sediments, tables were made up showing the core, section, top and bottom (cm), depth (mbsf) and content of the sediment along with the approximate age as per shipboard scientific party (Appendix 2.3a-d).

Samples were placed in beakers and put in an oven overnight to dry. The dry weight was recorded (Appendix 2.4) and approximately half (usually up to 10 grams per sample if enough sediment was provided) was used in the palynological processing. To safely process the sediment, 2 beaker holders, each containing 8 beakers were processed at one time. Sixteen samples representing differing depths and taken from different sites were chosen to process within each set of 16 beakers. Processing procedures followed standard palynological techniques with hydrochloric acid (HCl) added to each beaker to dissolve carbonates and gas evolution was monitored. The process was repeated until all reaction had ceased. In samples consisting of nannofossil ooze this process took at least 5-7 days for complete dissolution. The slurry was diluted with filtered water, stirred thoroughly and left for an hour to settle, then decanted.

In order to dissolve silicates, hydrofluoric acid (HF) was added into each beaker. The samples were then stirred intermittently. A reaction time of ~36 hours proved insufficient to remove all the silicates and in most cases it took up to seven days.

Each sample was then diluted with filtered water, left to settle and then slowly decanted into a solution of sodium bicarbonate to neutralize the HF. Each beaker was filled with filtered water, stirred, and left to settle for about an hour then decanted again. Some of the samples contained very fine sediment that required as much as 24 hours to settle. The process was repeated until all reaction in the neutralising tank had ceased, in most cases this meant about 3 to 4 washes.

The samples were then transferred into test tubes, agitated and topped up with filtered water, then centrifuged at 2,600 rpm for 5 minutes. This process was repeated, and then a small amount of HCl was added to the samples to help with disaggregation and remove soluble fluorides. The samples were finally washed with filtered water a further 3 times.

1.8.2 Fungal Contamination

From analysis of preliminary slides, it became evident that in most samples fungal hyphae forming mycelia were present. The fungi are believed to have grown at the storage facilities but were not visible until after most of the processing was completed and preliminary slides made. The mycelia were present in all sites except 696B, and within each site the amount varied at different depths, with some



Figure 1.10: A-B an example of the fungal hyphae clumping and entangling the process of the dinocysts. C-D an example of a lesser contamination with dinocysts more easily seen and E is an example of a dinocyst virtually free from fungal contamination.



Figure 1.11: A and B are an example of background that required up to seven days of HF to remove C -D are an example of the very fine background that required sieving with a 5 micron sieve unit to remove it. F - H are an example of the clarity of the slides after all the processing was completed.

samples being either quite contaminated by it, only mildly affected or completely free of mycelium (Figure 1.10). Efforts were made to try and destroy the mycelium while still retaining the palynomorphs by slow centrifuging, swirling, oxidation and ultrasonic cleaning. The only process that was able to successfully remove the mycelia was chlorine which had the unwanted side effect of destroying most of the palynomorphs.

The processes on many of the chordate dinocysts became entangled in the thicker clumps of mycelium that occurred in some samples, creating difficulties with counting and identification. The normal procedure of floating with sodium polytungstate at specific gravity 2.0 used to separate any palynomorphs present from heavy material, was not viable as the mycelium prevented many of the palynomorphs from floating. As a result of the contamination the processing of all of site 277 samples, 8 from site 699A and 2 from site 748B had to be repeated, although the mycelium could not be eliminated.

Site 696B was found to be free from mycelium and therefore could be floated in sodium polytungstate then sieved to remove finer background material (Figure 1.11). The samples were then centrifuged at 1,800 rpm for 15 minutes, and left to settle for a few hours. A pipette was used to extract the floating residue (float A) which was put into a test tube with a little HCl to stop the organic matter from clumping. The sample was then diluted, agitated, and centrifuged at 3,000 rpm for 3 minutes. This washing process was repeated 6 times.

Preparation of slides involved preheating and adding a small drop of glycerine jelly, followed by a small drop of residue mixed in from each sample. A cover slip was placed on top of the slide, before being left overnight to dry. A second set of slides were made by reagitation and centrifuging the sodium polytungstate to produce a second float.

1.8.3 Microscope and Camera Technique

Image acquisition was achieved using a light microscope Leica DML, mounted with a Leica DFC camera with still frames taken at several different focus levels for each palynomorph recorded. Slides were analysed at x20, x40, x63 and/or x100 magnification. Images were captured and slide references recorded with the name of the palynomorphs if possible and their size. The images were viewed in an image viewing programme (Picasa) where the use of the auto contrast and auto colour was used only to enhance each photo for clearer palynomorph detail. Picasa was also used to make up albums grouping the same species that were present in different sites within this study and for grouping of those species that could not immediately be identified. Over the course of this study ~17,500 photos were taken creating a comprehensive record of species encountered in all sites.

1.8.4 Counting Method

All slides were scanned for content before counting, although due to time constraints only one slide from each sample had a quantitative record of species made. All slides were scanned from left to right and any extra palynomorphs not noted in the initial slide were recorded and the image added to that sample. Individual palynomorphs were only counted if more than half of the cyst was present or it was positively recognisable even though not complete.

All data were entered on a separate excel worksheet for each sample with a record of the sample leg, site, core, section, sampling interval (cm) top and bottom, depth (mbsf), lithology, era if known, dry weight processed and number of slides made up. Initially all dinocysts were recorded followed by separate totals each for acritarchs, prasinophytes, tasmanites, foraminiferal linings, insect casings and terrestrial material. Data from excel worksheets was transferred on to the master spreadsheet (Appendix 2.5) for each sample.

Charts have been compiled from the raw data to display the grains per gram (g/g) total abundance and charts to display the percentages total abundance for each

site. The results of these charts will be discussed in detail in later chapters in this thesis.

1.9 General Results

The general results show that counts for dinocysts were higher than for other marine palynomorphs. The counts are taken from one slide in each site. In three sites in Table 1.4 (site 699A, 748B and 277) marine palynomorphs outnumbered terrestrial palynomorphs. Only site 696B contained more terrestrial than marine palynomorphs. Graphs of the percentages for marine palynomorphs are displayed in Figure 1.12.

Site 696B	3	Site 699A		Site 748B		Site 277	
Dinocysts	10733	Dinocysts	452	Dinocysts	1373	Dinocysts	3430
Acritarchs	145	Acritarchs	7	Acritarchs	554	Acritarchs	301
Cymatiosphaera	111	Cymatiosphaera	74	Cymatiosphaera	560	Cymatiosphaera	290
Leiosphaerida	1	Leiosphaerida	19	Leiosphaerida	3573	Leiosphaerida	192
Tasmanites	3	Tasmanites	0	Tasmanites	514	Tasmanites	142
Foraminiferal		Foraminiferal		Foraminiferal		Foraminiferal	
linings	302	linings	0	linings	17	linings	101
Insect parts	82	Insect parts	70	Insect parts	5	Insect parts	11
Terrestrial	25106	Terrestrial	64	Terrestrial	61	Terrestrial	277

Table 1.4: A total count from one slide on each site for dinocysts, acritarchs, prasinophytes, tasmanites, foraminiferal linings, insect parts and terrestrial palynomorphs.



Fig 1.12: Percentage of all marine palynomorphs counted in each site. Terrestrial percentages were not included due to the dominance shown in site 696B which significantly distorted the marine percentages. Colours display the percentage total for each palynomorph.

Table 1.5 has been organised to show alphabetically a total of 54 genera that occurred in each site. This result varied considerably:

- 12 Genera were found in all 4 sites
- 10 Genera were found in 3 out of 4 sites
- 12 Genera were found in 2 out of 4 sites
- 20 Genera were found in 1 out of 4 sites

Photos showing most genera discussed in this thesis along with their nomenclature are placed in Appendix 1.0

Site 696B Leg 113	Site 699A Leg 114	Site 748B Leg 120	Site 277 Leg 29
Alterbidinium sp	Alterbidinium sp	Alterbidinium sp	Alterbidinium sp
Batiacasphaera sp	Batiacasphaera sp	Batiacasphaera sp	Batiacasphaera sp
Cerebrocysta sp	Cerebrocysta sp	Cerebrocysta sp	Cerebrocysta sp
Chlamydophorella sp	Chlamydophorella sp	Chlamydophorella sp	Chlamydophorella sp
Corrudinium sp	Corrudinium sp	Corrudinium sp	Corrudinium sp
Impagidinium sp	Impagidinium sp	Impagidinium sp	Impagidinium sp
Minisphaeridium sp	Minisphaeridium sp	Minisphaeridium sp	Minisphaeridium sp
group	group	group	group
Nematosphaeropsis sp	Nematosphaeropsis sp	Nematosphaeropsis sp	Nematosphaeropsis sp
Operculodinium sp	Operculodinium sp	Operculodinium sp	Operculodinium sp
Phthanoperidinium sp	Phthanoperidinium sp	Phthanoperidinium sp	Phthanoperidinium sp
Spinidinium sp	Spinidinium sp	Spinidinium sp	Spinidinium sp
Spiniferites sp	Spiniferites sp	Spiniferites sp	Spiniferites sp
	Achomosphaera sp	Achomosphaera sp	Achomosphaera sp
Alisocysta sp		Alisocysta sp	Alisocysta sp
Deflandrea sp		Deflandrea sp	Deflandrea sp
Graptodinium sp		Graptodinium sp	Graptodinium sp
Hystrichosphaeridium sp		Hystrichosphaeridium sp	Hystrichosphaeridium sp
Impletosphaeridium sp		Impletosphaeridium sp	Impletosphaeridium sp
Lejeunecysta sp		Lejeunecysta sp	Lejeunecysta sp
	Lyphocysta sp	Lyphocysta sp	Lyphocysta sp
Samlandia sp		Samlandia sp	Samlandia sp
	Tectatodinium sp	Tectatodinium sp	Tectatodinium sp
Areosphaeridium sp		Areosphaeridium sp	
		Dapsilidinium sp	Dapsilidinium sp
Diconodinium sp			Diconodinium sp
		Hapsocysta sp	Hapsocysta sp
Octodinium sp			Octodinium sp
Paucisphaeridium sp			Paucisphaeridium sp
		Pterospermella	Pterospermella
Satyrodinium sp		·	Satyrodinium sp
Selenopemphix sp			Selenopemphix sp
		Thalassaphora sp	Thalassaphora sp
Turbiosphaera sp		Turbiosphaera sp	
Vozzennikovia sp		Vozzennikovia sp	
			Airiana sp
Brigantedinium sp			
			Cerodinium sp
Cordosphaeridium sp		<u></u>	·
		<u></u>	Dino sp
Eurvdinium sp		<u></u>	
		Forma b	<u></u>
Glaphrocysta sp			
		Heteraulacacvsta sp	<u></u>
Hvstrichokolpoma sp			<u></u>
			Linaulodinium
			Manumiella sp
Moria cf Zachosii			
	Odontochiting sp		
Oliaosphaeridium sp			
		Rhombodinium sp	
Schematophora sp			
			Stovercysta so
Systematophora sp			Stovercysta sp

Table 1.5: 54 dinocyst genera occur within all 4 sites. 12 genera were found in all 4 sites 10 genera in 3 out of 4 sites 12 genera in 2 out of 4 sites and 20 were found in 1 out of 4 sites.

2 Nannofossil Biostratigraphic Revision

CHAPTER TWO

2.0 Nannofossil Biostratigraphic Revision

2.1 Introduction

The sites in this study were drilled over an extended period of time and have had various biostratigraphic schemes applied (Aubrey, 1992; Edwards and Perch-Nielsen, 1975; Hollis, 1997; Nocchi et al., 1991; Roberts et al., 2003; Strong, 1996; Villa *et al.*, 2008; Waghorn, 1997; Wei and Wise, 1990, Wei *et al.*, 1992). In order to provide a consistent biostratigraphy for this study a reassessment of the original nannofossil data from the holes has been undertaken. The zonations used are those of Okado and Bukry (1980) and Martini (1971), calibrated using Berggren *et al.* (1995). A new nannofossil biostratigraphic zonation for the Middle Eocene to Early Oligocene resulted and allows a detailed correlation between each site studied. This re-evaluation utilised nannofossil data taken from original studies carried out in each of the four sites.

2.2 Nannofossil Biostratigraphic Zonation

Figure 2.1 shows the nannofossil zonations of Okado and Bukry (1980) (CP denotes Palaeogene coccolith zone) and Martini (1971) (NP denotes Palaeogene nannoplankton zone) being the two most common nannofossil zonations used in Cenozoic sequences. Both zones are very similar apart from a slight shift at some zonal boundaries. Time (27-46 Ma), age, CP/NP numbers and first and last occurrences for nannofossils are shown. Boundaries in the age and nannofossil zones occurring from the Middle Eocene to Oligocene are marked by first and last occurrences and with other biostratigraphically useful nannofossils are as follows.

The last occurrence of *Chiasmolithus gigas* ~44.5 Ma is below the CP13c/NP15c boundary in the Middle Eocene. Above is the first occurrence of *Reticulofenestra umbilicus* at ~43.7 Ma towards the top of the CP13c/NP15c boundary. The first occurrence of *Reticulofenestra reticulata* at ~42 Ma, is in CP14a/NP16. The boundary between CP14a/NP16 and CP14b/NP17 is placed at the last occurrence of *Chiasmolithus solitus* ~40.4 Ma. Berggren *et al.* (1995) established the last occurrence of *Ericsonia formosa*, at ~39.7 Ma, CP14b/NP17, in the High Southern



NANNOFOSSIL BIOSTRATIGRAPHIC ZONATION

Figure 2.1: The nannofossil timescale adapted from the zonations of Okado and Bukry (1980) and Martini (1971) has been correlated into the revised magnetobiochronologic Cenozoic timescale of Berggren *et al.* (1995). The time scale 27 - 46 Ma and age from Middle Eocene to Early Oligocene is from Berggren *et al.* (1995).

latitudes and noted it is ~7 Ma earlier than recorded at low latitudes. Above is the first occurrence of *Reticulofenestra bisecta* at 38 Ma, CP14b/NP17. The last occurrence of *Chiasmolithus grandis* at 37.1 Ma occurs close to the first occurrence of *Chiasmolithus oamaruensis* at 37 Ma, the latter marks the boundary at the top of CP14b/NP17 and the Middle/Late Eocene boundary.

The boundary at CP15a/NP18 and CP15b/NP19-20 is placed between the last occurrence of Reticulofenestra reticulata at 36.1 Ma and the first occurrence of Isthmolithus recurvus at 36 Ma. Close above is the first occurrence of Reticulofenestra oamaruensis, at ~35.4 Ma, CP15b/NP19-20 which Berggren et al. (1995) noted as restricted to the Southern High Latitudes. The last occurrence of Reticulofenestra oamaruensis at 33.7 Ma, is the only species in CP16a/NP21, and marks the Eocene/Oligocene boundary occurring approximately in the middle of that zone. The nearest species above the Eocene/Oligocene boundary are the first occurrence of Sphenolithus distentus and a last occurrence of Isthmolithus recurvus which are also very close to the E/O boundary. However, Berggren et al. (1995) allowed for some temporal uncertainty due to inconsistencies associated for both species which could be included in either CP15b/NP21 or CP17-18/NP22-23. The last occurrence of *Reticulofenestra umbilicus* CP17-18/NP22-23 is placed by Berggren et al. (1995) at ~31.3 Ma in the Southern High Latitudes which is younger than the low-mid latitude. The first occurrence of Sphenolithus ciperoensis at 29.9 Ma occurs at the top of CP17-18/NP22-23 in the Early Oligocene. The last occurrence of Sphenolithus predistentus at 27.5 Ma marks the top of the CP19a/NP24 zone which occurs in the Late Eocene (Berggren et al., 1995).

2.2.1 Site 696B, South Orkney microcontinent, Weddell Sea

The original nannofossil data from site 696B was from Wei and Wise (1990). Data was very poor and there are key nannofossil species missing. Last occurrences for some species are older than expected and many species are grouped at the same depths with no nannofossils recorded between. Figure 2.2 is the completed reassessment and the nannofossil zones show one boundary between

(mbsf) positions)	ge	Study	norossii ones	Depth plot of key events ODP Site 696B South Orkney microcontinent Weddell Sea	l (mbsf)			
)epth ample	Ă	This Na⊓ Z		Wei and Wise (1990)				
_ (∳Sa				Nannofossils				
575- 580-	Late Oligocene	CP 19	NP 24-25		575 580			
585-	ene	8	3		585			
590	rly Oligoce	CP 17-1	NP22-2		590			
595-	Ea	CP 16	NP 21	T R oamaruensis	595			
600				R bisecta R daviesii	600			
605- • •	ate Eocene	CP 15b	NP 19-20		605 610			
615				⊥ R oamaruensis └ C altus ⊥ I recurvus	615			
620-		CP 15a	NP 18	C pelagicus	620 -			
625-		CP 14b	NP 17		625			
630 - 635 -	dle Eocene	CP 14a	NP 16		630 ⁻ 635 ⁻			
640 4	Mid	CP13c	NP15c	⊥ R daviesii ⁺ R umbilica C altus, R bisecta	640-			
645		• • • •		R reticulata	645 -			

Figure 2.2: Depth plot of key events for nannofossils in site 696B, South Orkney microcontinent, Weddell Sea. Shown are the depth (mbsf), age, and nannofossil zones of Okado & Bukry (1980) and Martini (1971). The nannofossil zones are taken from the data of Wei and Wise (1990). Dashed lines indicate uncertain boundary positions. T Indicates a first appearance datum. ⊥ indicates a last appearance datum.

CP15a/NP18 and CP15b/NP21 with all other possible boundaries not defined. The age boundary for the Eocene/Oligocene is defined.

Site 696B has some defining species in similar positions as the nannofossil biostratigraphic zonation (Figure 2.2) including the first occurrence of *Reticulofenestra umbilica* at ~645 mbsf. The last occurrence of *Reticulofenestra reticulata*, ~645 mbsf, the first occurrence of *Reticulofenestra bisecta* ~645 mbsf and the last occurrence of *Reticulofenestra umbilica* ~637.7 mbsf, are earlier than expected from the standard nannofossil scheme. The boundary between CP15a/NP18 and CP15b/NP19-20 is placed at the first occurrence of *Isthmolithus recurvus* at ~616 mbsf. Above, the first occurrence of *Reticulofenestra oamaruensis* at ~614 mbsf, CP15b/NP19-20 and the last occurrence of *Isthmolithus recurvus* at ~612 mbsf, CP15b/NP19-20 are recorded younger in the nannofossil scheme (Figure 2.1). The last occurrence of *Reticulofenestra oamaruensis* ~598 mbsf, marks the Eocene/Oligocene boundary. There are no nannofossils recorded in the Early Oligocene above 598.4 mbsf and there are no foraminiferan or radiolarian results for this site.

2.2.2 Site 699A, Northeast Georgia Rise

The initial studies in site 699A of Ciesielski *et al.* (1988), Crux (1991) and Madile and Monechi, (1991) were followed by Wei, (1991) who utilized the first three results and obtained a better consistency for first and last occurrences (Figure 2.3). The foraminifera first and last occurrences are also calibrated to Berggren *et al.* (1995) in this site, though the radiolarian first and last occurrences of Takemura and Ling (1997) are not calibrated. The age boundaries are the Middle/Late Eocene and the Late Eocene/Early Oligocene and there are three nannofossil boundaries. Biostratigraphically useful nannofossils, radiolarians and foraminiferan are as follows.

The first occurrence of the foraminiferan *Morozovella crater* at ~460 mbsf and the last occurrence of *Morozovella crater* ~440 mbsf (below P10) are towards the base

sf)		dy	sil		era	Depth plot of k	(ey events ODP Sit h East Georgia Rise	e 699A	bsf)
oth (mb: ♦ Sample)	Age	nis Stu	annofos Zones	diolarié	raminife	Wei, W. (1991)	Takemura & Ling (1996)	Nocchi <i>et al.</i> (1991)	pth (m
Der		È	2 Z	Ra	Бo	Nannofossils	Radiolarian	Foraminifera	De
250-	ocene	CP17-18	NP22- 23	Upper RP 15	20 P 21	⊤ Reticulofenestra umbilica	L Ax irregularis	⊤ Subbotina ⊤ angiporoides ⊤ Subbotina utilisindex	250- 260-
270	Early Oliç	16	21		19 - P	⊤ Isthmolithus recurvus	T Eu spinosum ┬ Amphistylus? spp	G suteri Chiloguemblina spp	270-
280 -		СР	NP	RP 15	P 18-	Reticulofenestra ⊤_oamaruensis	1 ::		280
290 - -					P17		Litnomelissa challengerae		290-
300-	e	P 15b	P19-20		Pio		⊥ Eu antiquum		300-
310 -	Eocer	U U	Ĩ			Reticulofenestra	D microcephala Th diabloensis		320-
330-	Late			RP 1,	15	⊥ oamaruensis ⊥I recurvus	T Zy butschli ⊥Eu spinosum		330-
- 340-		CP 15a	NP 18		μ. Γ.	Reticulofenestra reticulata .	Calocyclas sp B	⊤ Glob index ⊤ Paragloborotella	340
W	www		W	ww	ww.	C oamaruensis		opima nana	350
300 -		CP 1	NP		P14 P13	Coolitus		– opima nana	300
360 -		ā	9					→ A primitiva Acarinina	360-
370 -		CP 14	NP 1		P 12	R reticulata R bisecta		rotundimarginata Globigerapsis index FAD	370-
380 -	sene			.en				→ Acarinina rugosoaculeata Piecenvey	380
390	e Eoc			Barr	7			morozovellids	390-
400	Middl	P 13	IP 15		₽.			utilisindex Pseudohastigerina micra P donvillensis	400
410		O	Z					∏ Planorotalites spp	410-
420					·			Guembelitria spp <u> </u> Globorotaloides	420 -
430 -		P 12	P 14		P 10			suteri	430-
440		O	ĬŻ					M crater └─ C amekiensis	440-
450 -								"A" aquiensis M crater acme & Pseu danvillensis	450-
460-		CP 11	NP 13		Ь 9			Acarinina triplex	460-
470		CP 10	NP 12					Acarinina └ interposita	470 -

Figure 2.3: Depth plot of key events for nannofossils, radiolarian and foraminiferal linings, in site 699A, North East Georgia Rise. Shown are the depth (mbsf), age, and the nannofossil zones of Okado and Bukry (1980) and Martini (1971). The nannofossil zones are from Wei (1991), the radiolarian zones are from Takamura and Ling (1996) and the foraminifera zones are from Nocchi *et al.*, (1991). Dashed lines indicate uncertain boundary positions. \bot indicates a first appearance datum \top indicates a last appearance datum. The hiatus is indicated by

of Figure 2.3 in the Middle Eocene, and also occur in site 277 near the base of Figure 2.5. Above is the first occurrence of the foraminifera *Globigerapsis index* ~373 mbsf near P12 and CP14a/NP16. Occurring together are the first occurrences of the nannofossils *Reticulofenestra bisecta* and *Reticulofenestra reticulata* at ~370.3 mbsf, CP14a/NP16 and no nannofossils were recovered below this depth. The boundary between CP14a/NP16 and CP14b/NP17 is placed at the last occurrence of the nannofossil *Chiasmolithus solitus* ~356.30 mbsf. Very close is the last occurrence of the foraminifera *Acarinina primitiva* ~358 mbsf, P15, CP14a/NP16, though is placed slightly older in Berggren *et al.*, (1995) at CP14b/NP17 (39.0 Ma, P14). The Middle/Late Eocene boundary and the boundary between CP14b/NP17 and CP15a/NP18 is marked by the first occurrence of the nannofossil *Chiasmolithus oamaruensis* at ~342 mbsf.

The last occurrence of the nannofossils *Reticulofenestra reticulata* at ~332.23 mbsf CP15a/NP18 and the first occurrence of *Isthmolithus recurvus* ~329 mbsf CP15b/NP19-20 mark the boundary between them. The last occurrence of the foraminifera *Globigerapsis index* at ~335 mbsf, P15, CP15a/NP18 is also close to this boundary, though in Berggren *et al.*, (1995) it is at the base of CP16a/NP21, 34.3 Ma, P16-17. No foraminifera were recovered between depths of 335 mbsf and ~270 mbsf. The last occurrence of the radiolarian *Calocyclas* spB and the first occurrence of *Eucyrtidium spinosum* occur together at 330.98 mbsf, RP14, CP15a/NP18 and no radiolarians were recovered below this depth.

The first occurrence of the nannofossil *Reticulofenestra oamaruensis* is at 322.84 mbsf, CP15b/NP19-20, where it is also placed in the nannofossil scheme (Figure 2.1). The last occurrence of the nannofossil *Reticulofenestra oamaruensis* 284.90 mbsf, CP16/NP21, marks the Eocene/Oligocene boundary. Nannofossils above the E/O boundary are the last occurrences of *Isthmolithus recurvus* ~261.35 mbsf and *Reticulofenestra umbilica* at ~249.80 in the Early Oligocene where they also occur in the nannofossil biostratigraphic scheme. The radiolarians last occurrence of *Axoprunum irregularis* and the first occurrence of *Eucyrtidium spinosum* are both at 260.71 mbsf and though their boundaries cannot be defined at this site they occur

in the Early Oligocene. The last occurrence of the foraminifera *Subbotina angiporoides* ~250 mbsf is in the Early Oligocene in this site and placed there in Berggren *et al.*, (1995) CP18/NP23 (30 Ma, P20).

2.2.3 Site 748B, Raggatt Basin, South Kerguelen Plateau

The original nannofossil data in site 748B were discussed by Aubrey (1992), Wei *et al.* (1992) and later Villa *et al.* (2008) revisited this site (Figure 2.4). There is one age boundary marked between the Eocene/Oligocene and two nannofossil boundaries. The foraminifera are calibrated to Berggren *et al.* (1995) first and last occurrences. The biostratigraphically useful nannofossils and foraminifera are as follows.

The first occurrence of the nannofossil Reticulofenestra reticulata, 171.8 mbsf in the Middle Eocene cannot be defined in this site but is placed by Berggren et al., (1995) in CP14a/NP16. Below 171.8 mbsf there are no nannofossils recorded. The last occurrence of the nannofossil Ericsonia formosa 157.11 mbsf, CP14a/NP16 is placed younger at ~39.7 Ma, CP14b/NP17 in the nannofossil scheme (Figure 2.1). The first occurrence of Chiasmolithus oamaruensis 155.01 mbsf is earlier than expected and below the last occurrence of Chiasmolithus solitus 150.2 mbsf at the top of CP14a/NP16 which marks the nannofossil boundary (CP14b/NP17) above. The nannofossil biostratigraphic zonation (Figure 2.1) has the first occurrence of Chiasmolithus oamaruensis at 37 Ma, in CP14b/NP17 which marks the Middle/Late Eocene boundary and places it above *Chiasmolithus solitus* 40.4 Ma, CP14a/NP16. Subsequently the Middle/Late Eocene boundary and the boundary between these nannofossil zones cannot be defined in this site. The last occurrence of the foraminiferan Acarinina primitiva at 153.45 mbsf (CP14a/NP16) in this site is placed earlier in CP14b/NP17 by Berggren et al., (1995) (39.0 Ma, P14). Below 153.45 mbsf no foraminifera are recorded.

The nannofossil first occurrence of *Reticulofenestra bisecta*, 143.90 mbsf in CP14b/NP17 is also placed in that zone in the nannofossil scheme. The last occurrences of the foraminifera *Subbotina linaperta* 144.14 mbsf, P15, and

42

osf) sitions)		dy	ssil	era	Depth plot of key even Raggatt Basin, Ker	nts ODP Site 748B guelen Plateau	bsf)
epth (mt	Age	is Stu	nnofo: Zones	raminif	Aubrey (1992) Wei et al., (1992)	Roberts <i>et al.</i> (2003)	oth (m
De (†Sar		Thi	Na	Fo	G. Villa <i>et al.</i> (2008) Nannofossils	Foraminfera	Dep
75 -	cene	19	-25	21b			75 -
80	Oligo	G	P 24	1a P		T G labiacrassata	80 -
85	Late		Z	Ρ2		\top C cubensis	85 -
◆ 90							90 -
+ 95	ne	ø	e S	20			95 -
400	goce	17-1	22-2	6		┬─ S angiporoides	400
100 -	y Oli	СР	Ч				100 -
105 -	Earl				┬ C oamaruensis		105 -
110 -		<u>ہ</u>	 Σ	18-19	T ^T recurvus		110 -
115			CP 1	NP 2	ш. 	— Reticulofenestra	
120					Gamai densis	- G index	120 -
125	cene	CP 1	IP 19.		⊥ R oamaruensis		125 -
130 -	te Ec	Ба	18		⊥ I recurvus ⊤ R reticulata		130 -
+	La	CP 1	Ч	5	TC cf altus		405
135 -			1	Ρ1			135 -
140 -		슝	17	14	R bisecta	⊤A collactea	140 -
145		CP 12	NP 1	٩		⊤ Subbotina linaperta	145 -
150		0		P13	⊤C solitus		150 -
155 -		14a	16	12	LC oamaruensis	┬─ A primitiva	155 -
160 -	ē	СР	RP	٩	⊤ E formosa		160 -
165 -	ocen						165 -
+	dle E				T Discoaster spp		470
170-	Mid				R reticulata		170-
175 -							175 -
180							180 -
185							185 -
190							190 -
195							195 -
200-							200-

Figure 2.4: Depth plot of key events for nannofossils and foraminiferal linings, in site 748B, Raggatt Basin, Kerguelen Plateau. Shown are the depth (mbsf), age, and the nannofossil zones of Okado and Bukry (1980) and Martini (1971). The nannofossil zones are from Villa *et al.* (2008), and the foraminifera zones are from Roberts *et al.* (2003). Dashed lines indicate uncertain boundary positions. \Box indicates a first appearance datum \bot indicates a last appearance datum.

Acarinina collactea 141.39 mbsf, P15, placed at different depths in this site, are both placed together by Berggren *et al.*, (1995) at 37.7 Ma, P15, CP14b/NP17. The last occurrence of the nannofossils *Reticulofenestra reticulata* 128.35 mbsf, CP15a/NP18 and the first occurrence of *Isthmolithus recurvus* 127.48 mbsf at the base of CP15b/NP19-20 mark the nannofossil boundary between them. However, in contrast to the findings of Aubrey (1992) and Wei *et al.*, (1992) who placed the first occurrence of *Isthmolithus recurvus* at 127.48 mbsf where it is also placed in this study (Figure 2.4), Villa *et al.* (2008) placed this species at 148.25 mbsf due to a rare occurrence at this depth.

The nannofossil above is the first occurrence of *Reticulofenestra oamaruensis* 125.20 mbsf, CP15b/NP19-20 also recorded in the same nannofossil zone by Berggren *et al.*, (1995). The last occurrence just above is the foraminiferan *Globigerapsis index* 121.45 mbsf, and although neither the nannofossil zone nor the foraminifera zone can be defined in this site, it does occur in Berggren *et al.*, (1995) at 34.3 Ma, in CP16a/NP21. The last occurrence of the nannofossil *Reticulofenestra oamaruensis* 115.86 mbsf marks the Eocene/Oligocene boundary. Above that boundary the last occurrence of *Isthmolithus recurvus* 109.01 mbsf cannot be defined though is in the Early Oligocene. Above is the last occurrence of the nannofossils were recorded above this depth. The last occurrence of the foraminiferan *Subbotina angiporoides* 97.95 mbsf is in the Early Oligocene and cannot be defined though Berggren *et al.*, (1995) has placed it at 30Ma, in CP18/NP23.

2.2.4 Site 277, Southern Campbell Plateau

The original nannofossil data from site 277 (Edwards and Perch-Nielsen, 1975) was reassessed by Hollis *et al.* (1997). Age boundaries in this site occur at the Middle/Late Eocene and the Eocene/Oligocene (Figure 2.5) and there are two nannofossil boundaries defined, one radiolarian and one foraminiferal boundary. The biostratigraphically useful nannofossils and foraminifera are as follows.

sf)		≥	sil	۳	inifera 997)	i a	Depth p	olot of key events Southern Campbell	DSDP Site 27 Plateau	7	(jsi
qш) լ	ge	Stuc	nofos: ones	iolaria	s foram e <i>t al.</i> (1	iminife	Hollis CJ, Waghor	rn DB, Strong CP & C	rouch EM (1997)	Liu <i>et al</i> (2009)	h (mb
Depth	À	This	Nan Z	Rad	NZ Stage Hollis ∈	Fora	Nannofossils	Radiolarian	Foraminfera	Isotope and nannosfossil Age control points	Dept
120 140 160 200 220	Late Eocene Early Oligocene Late Eocene Early Oligocene 15a CP 15b CP 16 CP 17-18 18 NP 19-20 NP 21 NP 22-23 18 NP 19-20 NP 21 NP 22-23 Ak P Lower RP 15 Upper RP 14 P P P P	P 15 P16-17 P 18-19 0	⊤ R umbilica ⊤ I recurvus ⊤ R oamaruensis ⊤ D saipanensis ⊥R oamaruensis ⊤ R reticulata ⊥ I recurvus ⊥ R scissura	⊥ Ax ? Irregularis ⊥ E antiquum ⊤ CaI sp B	⊤G linaperta ∏G index	$- \delta^{18}O$ $- \delta^{18}O$ $R oamaruensis$	120 140 160 200 220				
260		с С	Ч.				⊥ C oamaruensis	⊥ Eu spinosum Sethocyrtis sp.A	collactea		260
280	ane	CP 14b	NP 17	RP 12-13	Ab	P 13 P 14	┬ C grandis ┴ R reticulata ┬ C solitus	- Calocyclas sp B	⊤ P primitiva		280 300
320 –	Eoce						'				320 -
340	Middle	CP 14a	NP 16			P 12	I R hampdanansis		Globigerapsis index		340
360		P 13c	P15c	5	Dp		$\perp R$ cf bisecta		Globigerina		360 -
380		0		RP 10-			⊥ R umbilica ⊤ D kuepperi		⊤ boweri Morozovella ⊤ crater		380
400 -					à	Ē		LCycladophora? auriculaleporis			400
420					Dm	P 10	⊥ D sublodensis C grandis ⊥D lodensis		⊥ Morozovella ⊥ crater		420

Figure 2.5: Depth plot of key events for nannofossils, radiolarian and foraminiferal linings, in site 277, Southern Campbell Plateau. Shown are the depth (mbsf), age, and the nannofossil zones of Okado and Bukry (1980) and Martini (1971). The nannofossil zones are from Waghorn, (1997), the radiolarian zones are from Hollis, (1997) and the foraminifera zones are from Strong, (1997). Dashed lines indicate uncertain boundary positions. The isotope and nannofossil age control points are adapted from Liu *et al.* (2009). \perp indicates a first appearance datum \top indicates a last appearance datum The hiatus is indicated by The first and last occurrence of the foraminifera Morozovella crater at 416 mbsf and 386 mbsf is shown near the base of Figure 2.5, though the foraminiferal zone cannot be defined. The first and last occurrence for Morozovella crater also occurred near the base of Figure 2.3, site 699A. The first occurrence of the nannofossil Reticulofenestra umbilica at 380.2 mbsf cannot be defined in this site though it occurs at ~43.7 Ma, CP13c/NP15c, in the nannofossil scheme. Above, is the last occurrence of Chiasmolithus solitus, 311 mbsf however, a reassessment of this species was necessary (see below). The first occurrence of the nannofossil Reticulofenestra reticulata, 280 mbsf, CP14b/NP17, occurs younger in this site than the nannofossil scheme where it occurs in CP14a/NP16. The last occurrence of Chiasmolithus grandis, 273 mbsf occurs in CP14b/NP17 close to Chiasmolithus oamaruensis (~260 mbsf) above. The boundary between CP14b/NP17 and CP15a/NP18 is placed by the first occurrence of Chiasmolithus oamaruensis, ~260 mbsf and also marks the boundary between the Middle/Late Eocene. In the nannofossil scheme both Chiasmolithus grandis and Chiasmolithus oamaruensis also occur very close together towards the top of CP14b/NP17.

The first occurrence of the radiolarian *Eucyrtidium spinosum* 247 mbsf, RP14, CP15a/NP18 occurs younger at CP15b/NP19-20 in site 699A. The first occurrence of the nannofossil *Isthmolithus recurvus* 235.1 mbsf at the base of CP15b/NP19-20 (Late Eocene) indicates the boundary with CP15a/NP18. Above, the last occurrence of *Reticulofenestra reticulata*, 210 mbsf, CP15b/NP19-20, occurs younger than the nannofossil scheme where this species is placed below *Isthmolithus recurvus* at the top of CP15a/NP18. The first occurrence of *Reticulofenestra oamaruensis*, 206 mbsf, CP15b/NP19-20, is in the same zone as the nannofossil scheme (Figure 2.1). The last occurrence of the radiolarian *Calocyclas* spB, 200 mbsf, CP15b/NP19-20, occurs younger than at site 699A where it is placed in CP15a/NP18.

The last occurrences of the foraminifera *Globigerapsis linaperta*, and *Globigerapsis index* both at 190 mbsf, cannot be defined in this site. In Berggren *et al.*, (1995), the last occurrence of *Globigerapsis index*, 34.3 Ma, occurs at the top of CP15b/NP19-20, while *Globigerapsis linaperta* is not recorded. The last occurrence of the nannofossil *Reticulofenestra oamaruensis*, 184 mbsf, CP16/NP21 and marks the Eocene/Oligocene boundary. Notably the two δ^{18} O of Liu *et al.* (2009) were very near the Eocene/Oligocene boundary with ages of 33.7 Ma (190.4 mbsf) and 33.5 Ma (171.4 mbsf) however, *Reticulofenestra oamaruensis* was lower than the last occurrence given above. Above, is the last occurrence of the nannofossil *Isthmolithus recurvus*, 150.2 mbsf and the last occurrence of *Reticulofenestra umbilica*, 137.6 mbsf though they cannot be defined both occur in the Early Oligocene. The nannofossil scheme places both species in CP17-18/NP22-23 in the Early Oligocene.

2.2.4.1 Reassessing *Chiasmolithus solitus*

Site 277 nannofossil zone NP17, has been reassessed in this study from the initial report by Edwards and Perch-Nielsen (1975). This reassessment also affects the results of NP17 in Figure 5, of Hollis *et al.*, (1997). The NP17 nannofossil zone is defined by the first occurrence of *Chiasmolithus oamaruensis* at the top of the zone and the last occurrence of *Chiasmolithus solitus* at the top of NP16 below (Villa *et al.* 2008). In table 4C (p478, Edwards and Perch-Nielsen, 1975), *Chiasmolithus solitus* plus an undescribed *Chiasmolithus* spp were placed as a first occurrence together in the initial count at 434.5 mbsf with the last occurrence together at 311.0 mbsf. From 301.5 mbsf *Chiasmolithus solitus* is no longer recorded with *Chiasmolithus* spp (Table 4B, p477-478, Edwards and Perch-Nielsen, 1975). The undescribed *Chiasmolithus* spp eventually becomes less frequent with a last appearance at 149.5 mbsf. Accordingly including *Chiasmolithus solitus* and *Chiasmolithus* spp together makes it difficult to define the correct depth for the last appearance of *Chiasmolithus solitus* and subsequently to mark the boundary between NP16 and NP17.



CHAPTER THREE

3.0 Dinocyst Data

3.1 Dinocyst Biostratigraphy

Chapter three is presented primarily to document the dinocyst biostratigraphy and compare it with the nannofossil zones in each site as developed in chapter two. Secondly, to review the palynomorph total abundance data for each site (mainly dinocysts).

The purpose of establishing a new zonation is to provide a biostratigraphy that temporally constrains the assemblages occurring during the Middle Eocene through to the Early Oligocene in the Southern High Latitudes. Brinkhuis and Biffi (1993) concluded that accurate long-range correlation of dinoflagellate cysts at the E/O boundary in central Italy was hampered by the effects of provincialism and environmental settings. They found it necessary to define a new zonation rather than relate to any existing zonation scheme where the E/O boundary may be poorly calibrated, missing or condensed. A new zonation is important to this project as it will assist with assessing the timing of dinocyst assemblage changes and any possible changes to the palaeoenvironment in the southern high latitude environmental settings.

3.2 Dinocyst Datums

The biostratigraphy was developed in this study using key datums recognised as first or last occurrence which reliably correlate between the sites. The two levels of datums recognised are:

- A. Primary datums: of first or last occurrences from older to younger, always in the same temporal order and occur in at least two out of the four sites.
 - 1. First occurrence of Corrudinium regulare
 - Sites 696B, 699A, 748B, 277
 - 2. First occurrence of Phthanoperidinium echinatum
 - Sites 696B, 748B, 277

- 3. First occurrence of Phthanoperidinium geminatum
 - Sites 696B, 748B
- 4. Last Occurrence of Phthanoperidinium echinatum
 - Site 696B, Site 748B, Site 277
- 5. Last occurrence of Phthanoperidinium spA
 - Sites 696B, 699A 277
- 6. Last occurrence of *Corrudinium regulare*
 - Sites 696B, 699A, 748B, 277
- **B.** Secondary datums: first occur together in two of the four sites at the base or below the *Phthanoperidinium echinatum* zone.
 - 1. First occurrence of Impagidinium victorianum
 - Sites 748B, 277
 - 2. First occurrence of Impagidinium aculeatum
 - Sites 748B, 277

In addition acmes are documented in two of the cores and are an indication of dinocysts abundances that may have temporal or palaeoenvironmental significance.

Figure 3.1 displays the new dinocyst biostratigraphic zonation across the Middle and Late Eocene. From the left of the figure are time (Ma) from Berggren *et al.* (1995), age and the nannofossil zones of Okado and Bukry, (1980) and Martini (1971). The first and last occurrence of the five primary datums and first occurrence of secondary datums are depicted, along with the four newly named dinocyst zones on the right of the Figure.

Figure 3.2 displays from the left ODP sites 696B, 699A and 748B and DSDP site 277. The sample spacing for each site is shown by small arrows along with depth in mbsf, age, nannofossil zones from this study and if present foraminifera (P) and radiolarian (RP) zones. Each site is aligned to the E/O boundary position. The primary and secondary datums with acmes are depicted for each site and the zones are coloured as Figure 3.1 below.



Figure 3.1: A new dinocyst biostratigraphic zonation across the Middle and Late Eocene. Time (Ma) from Berggren *et al.* (1995). Nannofossil Zones of Okado and Bukry, (1980) and Martini (1971), depicts first and last occurrence of primary datums and first occurrence of secondary datums, along with the newly named dinocyst zones.

Analysis of the species distribution in Figure 3.1 in Ma and their placement in each site in Figure 3.2 is outlined below.

3.2.1 Phthanoperidinium echinatum Zone

Base: In Figure 3.1 the first occurrence of *Corrudinium regulare* and *Phthanoperidinium echinatum* at approximately 45 Ma within the

CP14a/NP16 nannofossil zone defines the base of the zone.

Top: The first occurrence of *Phthanoperidinium geminatum* at approximately 43 Ma in the CP14a/NP16 nannofossil zone defines the top of the zone.



DINOCYST BIOSTRATIGRAPHIC ZONES ODP SITES 696B, 699A, 748B DSDP SITE 277

Figure 3.2: Dinocyst biostratigraphic zones correlating primary datums across all four sites. Primary datums are coloured coded to match their position within the nannofossil zones from this study CP (Okado and Bukry, 1980) NP (Martini, 1971). \perp = First occurrence. Secondary datums and Acmes are labelled as such and their sample depth positions are shown by an arrow \longrightarrow or [The dashed green line --- shows the position of the E/O boundary. \longrightarrow signifies an hiatus.

Remarks (Figure 3.2): In site 696B, the base of this zone is identified by the first occurrence of *Corrudinium regulare* and *Phthanoperidinium echinatum* at 641.27 mbsf in the Middle Eocene and the top of the zone is marked by the first occurrence of *Phthanoperidinium geminatum* (636 mbsf).

A full discussion of site 699A is given later due to differences occurring between this site and the other three sites.

Below the base of this zone in site 748B, the first occurrence of the secondary datums *Impagidinium victorianum* and *Impagidinium aculeatum* along with an acme of *Spiniferites* spp, occur at 197.38 mbsf. At the base of this zone the first occurrence of *Corrudinium regulare*, *Phthanoperidinium echinatum* and an acme of *Impagidinium parvireticulatum* occur at 177.76 mbsf. The top of the zone is identified by the first occurrence of *Phthanoperidinium geminatum* (167.39 mbsf)

The base of the zone at site 277 is placed at the first occurrence of *Corrudinium regulare* and *Phthanoperidinium echinatum* along with the secondary datums of *Impagidinium victorianum* and *Impagidinium aculeatum* at 292.53 mbsf. The top of the zone cannot be identified due to an inconsistency in the first occurrence of *Phthanoperidinium geminatum*. This species occurs at the same depth as the last occurrence of *Phthanoperidinium echinatum* (280.15 mbsf) which defines the base of the *Phthanoperidinium* spA zone as mentioned below. Further occurrences of *Phthanoperidinium geminatum* at 162.56 and 122.17 mbsf are sparse and considered to be reworked.

3.2.2 Phthanoperidinium geminatum Zone

Base: In Figure 3.1 the first occurrence of *Phthanoperidinium geminatum* at approximately 43 Ma in the CP14a/NP16 nannofossil zone defines the base of the zone.

- Top: The last occurrence of *Phthanoperidinium echinatum* at approximately 40.5Ma in the CP14a/NP16 nannofossil zone defines the top of the zone.
- **Remarks (Figure 3.2):** The base of this zone is identified in site 696B with the first occurrence of Phthanoperidinium *geminatum* (636 mbsf) and the top of the zone is at the last occurrence of *Phthanoperidinium echinatum* (628.55 mbsf).

Site 748B shows the base of this zone is identified with the first occurrence of *Phthanoperidinium geminatum* (167.39 mbsf). Acmes of *Deflandrea antarctica* and *Thalassaphora* spp occur at 162.1 mbsf, and above acmes of *Spinidinium* spp and the prasinophycean algae *Leiosphaerida* occur at 156.9 mbsf. The top of this zone is identified by the last occurrence of *Phthanoperidinium echinatum* (152.11 mbsf).

In site 277 the base of this zone cannot be identified due to an inconsistency in the first occurrence of *Phthanoperidinium geminatum* as mentioned above. The last occurrence of *Phthanoperidinium echinatum* (280.15 mbsf) which marks the top of this zone is identified.

3.2.3 Phthanoperidinium SpA Zone

- **Base:** In Figure 3.1 the last occurrence of *Phthanoperidinium echinatum* at approximately 40.5 Ma in the CP14a/NP16 nannofossil zone defines the base of zone.
- **Top:** The last occurrence of *Phthanoperidinium* spA at approximately 36.4 Ma in the CP15bNP19-20 nannofossil zone defines the top of the zone.

Remarks (Figure 3.2): This zone is identified in site 696B by the last occurrence of *Phthanoperidinium echinatum* (628.55 mbsf) at the base and at the top of the zone the last occurrence of *Phthanoperidinium* spA (613.65 mbsf).

In site 748B the base of the zone is identified by the last occurrence of *Phthanoperidinium echinatum* (152.11 mbsf). Above, an acme is recorded for *Phthanoperidinium dentatum* (148.78 mbsf). The top of this zone cannot be identified due to the absence of *Phthanoperidinium* spA.

Site 277 shows the base of this zone is marked by the last occurrence of *Phthanoperidinium echinatum* (280.15 mbsf). Above, an acme is recorded for Operculodinium spp at 240.84 mbsf. The top of this zone is identified by the last occurrence of *Phthanoperidinium* spA (199.59 mbsf).

3.2.4 Corrudinium regulare Zone

- Base: In Figure 3.1 the last occurrence of *Phthanoperidinium* spA at approximately 36.4 Ma in the CP15b/NP19-20 nannofossil zone defines the base of the zone.
- **Top:** The last occurrence of *Corrudinium regulare* at approximately 34.2 Ma in the CP15b/NP19-20 nannofossil zone marks the top of the zone.
- **Remarks (Figure 3.2):** Site 696B shows the base of the *Corrudinium regulare* zone is identified by the last occurrence of *Phthanoperidinium* spA (613.65 mbsf) with the top of this zone marked by the last occurrence of *Corrudinium regulare* (607 mbsf.)

In site 748B the base of this zone cannot be identified due to the absence of the last occurrence of *Phthanoperidinium* spA however, the last occurrence of *Corrudinium regulare* (126.36 mbsf) marks the top of this zone.

The base of this zone in site 277 is identified by the last occurrence of *Phthanoperidinium* spA (199.59 mbsf) and the top of this zone is marked by the last occurrence of *Corrudinium regulare* (190.8 mbsf).

3.2.5 Discussion of Site 699A

Remarks (Figure 3.2): The first occurrence of *Corrudinium regulare* (339.07 mbsf) in CP15a/NP18 is placed younger than the other three sites where it occurs in

CP14a/NP16. This first occurrence marks the base of the *Phthanoperidinium echinatum* zone; however the other primary datums above are absent until the last occurrence of *Phthanoperidinium* spA (286.53 mbsf). The last occurrence of *Phthanoperidinium* spA is placed in the correct temporal position, although closer to the E/O boundary than the other three sites. Additionally, the last occurrence of *Corrudinium regulare* (272.24 mbsf) identifies the top of the *Corrudinium regulare* zone as occurring in the Early Oligocene which is much younger than at the other sites.

On reviewing the nannofossil occurrences in Figure 3.4 of this site, the position of the E/O boundary is placed at the last occurrence of *Reticulofenestra oamaruensis* (284.90 mbsf), consistent with the other sites. However, the dinocyst occurrences appear to be in the correct order although apparently in younger sediments as identified in Figures 3.2 and 3.4.

3.3 Dinocyst Datums and other Microfossils

Figures 3.3-3.6 represent the incorporation of dinocyst primary and secondary datums with the nannofossil, radiolarian and foraminifera data from Chapter Two (Figs 2.2-2.5). The dinocyst datums were established through a compilation of first and last occurrences of each datum. They were documented as occurring in the same temporal order and in the same nannofossil zone within each site, and resulted in six primary and two secondary dinocyst datums being defined. In Figures 3.3-3.6 they are compared with the other microfossil data from chapter two.

It is evident that the dinocyst primary datums do not consistently correlate with the positions of other microfossils datums within each of the sites. For example, within the dinocyst primary datums, the first occurrence of *Corrudinium regulare* and *Phthanoperidinium echinatum* in sites 748B (177.76 mbsf) and 277 (292.53 mbsf; Figures 3.3-3.4) occur below, although close to, the first occurrence of

Reticulofenestra reticulata (171 mbsf; CP14/NP16-17). However, in site 699A the first occurrence of *Corrudinium regulare* (339.07 mbsf; CP15a/NP18) occurs above the first occurrence of *Reticulofenestra reticulata* (370 mbsf; CP14/NP16-17) and in site 696B this species occurs in one sample only at 645 mbsf placing it below the first occurrence of *Corrudinium regulare*.

In addition the last occurrence of *Phthanoperidinium* spA (CP15b/NP19-20) in sites 696B (613.65 mbsf) and 277 (199.59 mbsf) occurs very close to the first occurrence of *Reticulofenestra oamaruensis* in sites 696B (613.5 mbsf) and 277 (199.59 mbsf). In site 699A *Phthanoperidinium* spA (286.53 mbsf) occurs near the E/O boundary and much younger than the first occurrence of *Reticulofenestra oamaruensis* (321.5 mbsf) near the base of CP15b/NP19-20. In site 748B *Phthanoperidinium* spA occurs in only one sample at 172.12 mbsf well below the first occurrence of *Reticulofenestra oamaruensis* (~125 mbsf).

The last occurrence of *Corrudinium regulare* (CP15b/NP19-20) in sites 696B (607mbsf) and 277 (190.8 mbsf) is placed above the first occurrence of *Reticulofenestra oamaruensis* in sites 696B (613.5 mbsf) and 277(261 mbsf). Site 748B shows the last occurrence of *Corrudinium regulare* (126 mbsf) is below the first occurrence of *Reticulofenestra oamaruensis* (125 mbsf) though still in CP15b/NP19-20. However, site 699A places the last occurrence of *Corrudinium regulare* (272.24 mbsf) as much younger occurring in the Early Oligocene and above the last occurrence of *Reticulofenestra oamaruensis* (286.5 mbsf).

Foraminifera show the last occurrence of *Globigerina index* (CP15b/NP19-20) in sites 748B (122 mbsf) and 277 (190.5 mbsf), occurs before the E/O boundary and after, although close to, the last occurrence of *Corrudinium regulare* within site 748B (126.36 mbsf), and is found in a similar location at site 277 (190.8 mbsf). In site 699A the last occurrence of *Globigerina index* (333 mbsf) occurs below in CP15a/NP18, while the last occurrence of *Corrudinium regulare* (272.24 mbsf) is Early Oligocene. Foraminifera are absent from site 696B.

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	Depth Plot of Key Events ODP Site 696B South Orkney Microcontinent, Weddell Sea											
f) ons)		>	=	(suc	Depth plot	of key events	f) ons)					
)epth (mbs1 ample positic	Age	This Stud Vannofoss Zones		epth (mbsf) ample positic	This Study	Wei and Wise (1990))epth (mbs f ample positic					
÷s	0	· ·	2	∎ä €	Dinocysts	Nannofossils	⊔ ŝ ŧ					
575- 	Late Oligocene	CP 19	NP 24-25	575- 			575- 580-					
585-	ligocene	CP 17-18	NP22-23	585 • 590			585 - 590					
595	Early C	CP 16	NP 21	595-		🖵 R oamaruensis	595-					
600 605 610	Late Eocene	CP 15b	NP 19-20	600- 605- 610-	⊤ C regulare	R bisecta R daviesii	600 - 605 - 610-					
+ + 615-				+ + 615-	<i>⊤ Ph</i> spA	R oamaruensis T C altus LAD ⊥ I recurvus	+ + 615-					
620_		CP 15a	NP 18	620		C peragicus	620_					
625			CP 14b	NP17	625	- Dh achinatum		625				
630 -	e Eocene	3P 14a	NP 16	630 -	⊥ Pri ecninatum		630 -					
635 + -	Middl	5		635 - + +	⊥ Ph geminatum	╪ R daviesii R umbilica	635 - -					
645		CP 13c	NP 15c	645 -	C regulare	C altus, R bisecta, C pelagicus, R umbilica R reticulata	645 -					

Figure 3.3: Dinocysts datums from this study are displayed against nannofossils from Wei and Wise (1990). The nannofossil zones are from Okado and Bukry (1980) CP and Martini (1971) NP. Also shown are age, depths (mbsf), arrows indicate sample positions. ⊥ Indicates First Occurrence and ⊤ Last Occurrence.

))		dy	ssil	ia	ra	Depth plot of key events ODP Site 699A North East Georgia Rise						
oth (mt Sample	Age	is Stu	nnofo: Zones	diolar	aminife	This Study	Wei, (1991)	Takemura & Ling (1996)	Nocchi <i>et al.</i> (1991)	th (m		
Der	`	Th	Nai	Ra	For	Dinocysts	Nannofossils	Radiolarian	Foraminfera	Dep		
250 260	Oligocene	CP 17-18	NP 22-23	Upper RP 15	P20 P21		⊤ Reticulofenestra umbilica ⊤ Isthmolithus rocunum	Ax irregularis Eu spinosum	T Subbotina angiporoides ⊤ Subbotina utilisindex	250 260		
270 - 280-	Early (CP 16	NP 21	RP 15	P 18-19	Corrudinium regulare	Reticulofenestra	┬ Amphistylus? spp	T <i>Chiloguemblina</i> spp	270 280		
290 -		[∞] .	P17	→ Phthanop. spA	⊤ oamaruensis	⊥ Lithomelissa challengerae		290-				
300 -	ene	15b	19-20		P16			⊥ Eu antiquum		300-		
310 -	ate Eoc	IJ	NF	o 14			Potioulofonootro	D microcephala		310-		
320 ~	Ľ			RF	15		⊥ camaruensis ⊥ I recurvus	Zy butschli		330-		
↔ 340 ÷		CP 15a	NP 18			L _{Corrudinium}	Reticulofenestra reticulata	Calocyclas sp B	⊤ Glob index ⊤ Paragloborotella	340-		
350 -	\rangle	CP 14b	NP 17		✓ P14				Paragloborotella ⊥ opima nana	350-		
360 -	sene	4a	16		P13 CL 0		⊤ C solitus ∣ R reticulata		⊤ A primitiva Acarinina ⊤ rotundimarginata	360-		
370 -	dle Eo(CP 1	NP		Ľ		⊥ R bisecta		L Globigerapsis index	370-		
380 -	Mid]	Irren					rugosoaculeata Biconvex	380-		
400 -		13	15	Ba	P 11				L Subbotina utilisindex	400-		
410 -		С	NP						P donvillensis	410-		
420 -									Globorotaloides	420-		
430 -		CP 12	IP 14		P 10				suteri	430-		
440		0							- M crater - C amekiensis	440-		
450 →		СР	NP						"A" aquiensis M crater acme & Pseu danvillensis	450-		
460 470 -		11 CP 10	13 NP 12		P S				∏Acarinina triplex M crater ⊤ Acarinina ⊤ interposita	460-		

Figure 3.4: Dinocysts datums from this study are displayed against the nannofossils from Wei (1991), radiolarian from Takemura and Ling (1996), and the foraminiferal linings are from Nocchi et al. (1991). The nannofossil zones are from Okado and Bukry (1980) CP and Martini (1971). Also shown are age, depths (mbsf) Small arrows indicate sample positions in mbsf. L Indicates First Occurrence and T Last Occurrence. The hiatus is indicated by the rippled line

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-				21a	-				00
90 +	е			 	90 +				90 -
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100	Oligo	;P 17	Np2	Р	100			T S angiporoides	100 -
105	ırly (0			105 -		T C oamaruensis		105 -
-	Еа			-19	-		· -⊤I recurvus		
110		16	21	P 18	110 -		⊥ C altus		110 -
115_		СР	NP		115		Reticulofenestra oamaruensis		115 -
120	эг	15b	9-20	P16-17	120			⊤ G index	120 -
125	Eocei	СР	NP 1		125		L R oamaruensis		125 -
130	Late	15a	o 18	15	130 -		T R reticulata T C cf altus		130 -
135 -		СР	Z	₽	135		⊤ N dubius		135 -
140					140 -				140 -
145		14b	17	0 14	145		⊥ R bisecta	T Subbotina	145 -
150		СР	ЧN	P13	150		T C solitus	шарена	150
-		ła	9		-	⊤ Ph echinatum	Coamaruensis	┬─ A primitiva	
155	e	:Р 1	NP 1		155		C cf altus		155 -
160 +	ocen	0			160 +		⊤ E formosa		160 -
165	le E(12	165 -	Dh.gominatum			165 -
170	Midd			₽	170 -	— Thigeninaum	<u>⊥</u> R clatrata		170 -
175					175 -	C. regulare	R reticulata		175 -
+					+	Ph echinatum			100
180					180				180-
185					185				185
190					190				190
195					195 -	(Secondary datums)			195 -
200-					200	I aculeatum I victorianum			200-

Figure 3.5: Dinocysts datums from this study are displayed against the nannofossils from Villa et al. (2008), foraminiferal linings from Roberts et al. (2003). The nannofossil zones are from Okado and Bukry (1980) and Martini (1971).Also shown are age, depths (mbsf). Small arrows indicate sample positions in mbsf. ⊥ Indicates First Occurrence and T Last Occurrence.
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120 141 140	y Oligocene	CP 17-18	NP 22-23	Upper RP 15	V Lwh	19 05	120 140		⊤ R umbilica ⊤ I recurvus	⊥ Ax ? Irregularis		120
160	Earl	16	21	wer RP 15	Ear	P 18	160			⊥ E antiguum		160
180		С.	IN :	Ľ	Ar	5-17,	180	┬ C regulare	⊤R oamaruensis ⊤D saipanensis		G linaperta G index	180
200	Eocene	CP 15b	NP 19-20	4	۲k	P 16	200	T Ph spA	⊥ R oamaruensis ⊤ R reticulata	⊤ <i>Cal</i> sp B		200
220	Late I	a	~	RP 1.	1		220		⊥l recurvus ⊥R scissura			220
240-	\sim	CP 15	VP 18	~	~	P 15	240-			⊥ Eu spinosum	⊤ Trun ⊤ collactea	240
280		4b	7	~			280-	T Ph echinatum	⊥ C grandis ┬ C grandis ⊥ R reticulata	┬ Sethocyrtis sp A <i>└└ Calocyclas</i> sp B	⊤ P primitiva	280 -
300	ene	CP.	NP :	RP 12-1:	Ab	13 P14	300	C regulare (Secondary datums) I aculeatum I victorianum	— C solitus			300
320	dle Eoce					-	320					320
340	Mig	CP 14a	NP 16		DD	P 12	340		<u>R</u> hampdenensis		Globigerapsis ─_index	340
380		CP 13c	NP15c	710-11	ЧD	P 11	380		⊥R cf bisecta ⊥R umbilica		Globigerina ⊤ boweri	380
400				RF	Dm	P 10	400		╈ → D kuepperi	LCycladophora?	Morozovella ⊤⊂crater	400 -
420							420		⊥ <i>D sublodensis</i> & C grandis	auriculaleporis	Morozovella ⊥ crater	420
440							440		⊥ D lodensis			440

Figure 3.6: Dinocyst datums from this study are displayed against the nannofossils, radiolarian andforaminiferal linings from Hollis, Waghorn, Strong and Crouch (1997). The nannofossil zones are from Okado and Bukry (1980) and Martini (1971). Also shown are age, depths (mbsf), small arrows indicate sample positions. \bot Indicates First Occurrence and Last Occurrence. Secondary datums are shown as first occurrence beneath the first occurrences of *Ph echinatum* and *C regulare*. The hiatus is indicated by the rippled line

3.4 Total Abundance

The palynomorph counts for each site (Appendix 3.5-3.8) are presented in terms of grains per gram (g/g) (Figure 3.7-3.10). To the left of each chart is the nannofossil biostratigraphic zonation as set out in chapter two, together with age, sample depths (mbsf) and if present foraminifera or radiolarian zones. Palynomorphs are numbered in alphabetical order at the top of each chart and listed in first occurrence order in the second row. Dinocysts marked as red are longer ranging and more consistent, occurring in nearly every sample while those marked as blue are more sporadic in occurrence. Primary dinocysts on the far right of each chart are marked by horizontal red lines showing their first or last occurrences. Dinocyst zones are shown in the same colours as Figure 3.1. Green intermittent lines mark age boundaries for the Middle/Late Eocene and Eocene/Oligocene. The positions of acmes are marked by blue arrows. Also listed on each chart are counts (purple) of acritarchs present with most species simply grouped as acritarchs while individual species if known are shown separately. The Prasinophycean algae of Cymatiosphaera spp and Tasmanites together with counts of microforaminiferal linings, insect parts and terrestrial material (spores and pollen coloured green) are shown on the far right.

3.4.1 Site 696B – Figure 3.7

Dinocysts abundances in this site range from 0.52 g/g (*Deflandrea cygniformis*) to 238.7 g/g (*Vozzhennikovia apertura*). All the dinocyst zones are present and acmes are absent in this site. Seventeen dinocyst species appear in the lowest sample depth and dinocysts occurring below the Oligocene include four that occur in every sample from 642.98 mbsf.

3.4.1.1 Dinocysts below the Oligocene

Those species consistently appearing below the Oligocene are *Lejeunecysta fallax* first occurring at 642.98 mbsf (11 g/g), with a highest abundance of 29.6 g/g, at 607 mbsf, the top of the *Corrudinium regulare* Zone. *Octodinium askinae* has a first occurrence of 9 g/g at 642.98 mbsf, and increases up section to peak at 47.7 g/g

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					Palynomorphs Alphabetical order	62. Acritarch	40. Alisocysta circumtabulata	18. Alterbidinium asymmetricum	 Alterbidinium distinctum A diktvonlokus NOW (F Partridaei) 	2. A diregoplaced rough to a characterit	61. Batiacasphaera spp	59. Brigantedinium spp	54. Cerebrocysta mundus	52. Cordosphaeridium inodes	20. Corrudinium regulare	63. Cyclopsiella spp	67. Cymatiosphaera	3. Derianorea antarcuca 21. Deflandrea cygniformus	22. Deflandrea phosphoritica	23. Deflandrea sp broken	24. Diconodinium cristatum	57. Eurydinium spp	04. renesuration claumodermani 69. Foraminiferal linings	50. Glaphyrocysta retiintexta	60. Graptodinium reticulatum	53. Hystrichokolpoma spp	29. Hystrichosphaeridium truswelliae	35. Impagidinium dispertitum	36. Impagidinium elegans	25. Impagidinium spp2	41. Impagidinium victorianum	4. Impletosphaeridium spp 26. Leiennerveta rowiei	zo. tejeunecysta towiei 5. Leieunecysta fallax	66. Leosphaerida	56. Minisphaeridium latirictum	37. Minisphaeridium minimum	6. Minisphaeridium spp group	49. Moria cf zachosii 47. Nemetosubaeronsis snn	7. Octodinium askiniae	30. Oligosphaeridium spp	31. Operculodinium janduchenei	8. Operculodinium spp	65. Palambages o Daucienhaerid inversiburcinum	 Pathanoperidinium crenulatum 	27. Phthanoperidinium dentatum	28. Phthanoperidinium echinatum	38. Phthanoperidinium geminatum	58. Phthanoperidinium granulatum	46. Phthanoperionium sp1 39. Phthanoperidinium spA	43. Samlandia spp	44. Satyrodinium bengalense	32. Schematophora spp	10. Selenopemphix nephroides	48. Spinidinium colemanı 11 Sainidinium escai	11. Spiniainium essoi 12. Sninidinium luciae	13. Spinidinium macmurdoense	14. Spiniferites spp	15. Systematophora placacantha
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Il palynomorphs are placed in alphabetical order ondary to the dinocysts. The new nannofossil nary dinocysts first occurrence and last (613.65 mbsf) at the base of the *Corrudinium regulare* Zone. The first occurrence of *Selenopemphix neophroides* at 642.98 mbsf yielded 7.7 g/g, increasing upsection to peak at 39.7 g/g, (628.55 mbsf). *Vozzhennikovia apertura* has a first occurrence at 642.98 mbsf (17.2 g/g), with higher abundances occurring up section including 106 g/g, at 624.64 mbsf, and peaks at 239 g/g (608.13 mbsf), in CP15b/NP19-20 the *Corrudinium regulare* Zone.

Other significant occurrences below the Oligocene are high abundances of Spinidinium luciae. Initially sparse, this species first occurs at 642.98 mbsf (2.4 g/g), before increasing significantly up section, peaking at 209 g/g (626.64 mbsf), within the Phthanoperidinium spA Zone, then decreasing at the top of the Corrudinium regulare Zone to 47.0 g/g (607 mbsf). Alterbidinium distinctum makes its first appearance at 642.98 mbsf (13.0 g/g), increases its numbers up section peaking at 71 g/g, 641.27 mbsf then is sporadic above before fading at 607 mbsf to 9.8 g/g. Spinidinium macmurdoense first occurred at 642.98 mbsf, (3.6 g/g), peaking above at 60.5 g/g (622.55 mbsf, CP15a/NP18), in the Phthanoperidinium spA Zone. The first occurrence of Operculodinium spp yielded low numbers of 7.7 g/g (642.98 mbsf). This species fluctuated up section with abundances peaking at 85.4 g/g, (621.5 mbsf, CP15a/NP18), in the *Phthanoperidinium* spA Zone and further upsection at 80 g/g (608.13 mbsf, CP15b/NP19-20) near the top of the *Corrudinium* regulare Zone. Impagidinium victorianum first occurs at 638.63 mbsf (1.1 g/g) and is sparse and sporadic upsection with an increase to 4 g/g at 619.06 mbsf then decreased higher in the section reaching 0.6 g/g at 608.13 mbsf. Vozzhennikovia netrona at 0.6 g/g (628.55 mbsf), is initially sparse then high abundances occur above at 148.65 g/g (611.75 mbsf, CP15b/NP19-20), within the Corrudinium regulare zone (Late Eocene) before decreasing upsection. It last occurs at 607 mbsf (14.8 g/g).

The remaining dinocyst occurrences are sparse in comparison. Abundances are significantly reduced with *Phthanoperidinium echinatum* at 1.0 g/g (641.27 mbsf) before its last occurrence at the top of the *Phthanoperidinium geminatum* Zone (8.3 g/g, 628.55 mbsf). *Corrudinium regulare* first occurs at 641.27 mbsf, (1.04 g/g) and

is sparse up to its last occurrence of 3.7 g/g, (607 mbsf) at the top of the *Corrudinium regulare* zone. *Impletosphaeridium* spp first occurs at 642.98 mbsf (6.5 g/g), is reduced in the Middle Eocene to 1.7 g/g, (619.06 mbsf). It then is present in every sample above. *Deflandrea antarctica* occurs at 642.98 mbsf (0.6 g/g); this species reaches its highest occurrence peaking with 18.7 g/g at 613.65 mbsf.

Among the other marine palynomorphs most acritarchs appear in the lowest sample (642.98 mbsf) but are sporadic above this level and few occur above the E/O boundary. Individuals assigned to the acritarch genus *Cyclopsiella* (1.7 g/g, 642.96 mbsf) were the most abundant acritarch species peaking at 13.2 g/g, 631.63 mbsf. The prasinophycean algae *Cymatiosphaera* spp occurs throughout the hole though they were not present in every sample. Their numbers were low at 1.8 g/g (642.98 mbsf), then peaked upsection with 8.6 g/g, at 607 mbsf (CP15b/NP19-20). *Tasmanites* only occurred in two samples at 613.65 mbsf (0.6 g/g) and 612.75 mbsf at 1.2 g/g (CP15b/NP19-20). Microforaminiferal linings were present in all samples in low abundances peaking with 17.7 g/g, at 608.13 mbsf (CP15b/NP19-20).

3.4.1.2 Dinocysts in the Early Oligocene

Most of the dinocysts that occurred consistently also continued into the Early Oligocene. They are *Alterbidinium distinctum* (607 mbsf, 10 g/g), which continued up to 598.3 mbsf (1.5 g/g), increasing upwards with a last occurrence at 588.16 mbsf of 13 g/g in the Early Oligocene. Samples yielded high numbers of *Vozzhennikovia apertura* (607 mbsf, 87.7 g/g) increasing upwards into the Early Oligocene peaking at 172.5 g/g (588.16 mbsf) then decreasing with a last occurrence at 578.71 mbsf of 14.1 g/g. *Spinidinium luciae* (607 mbsf, 47 g/g), recurs at 578.71 mbsf, decreasing to 13.2 g/g in the Early Oligocene. *Octodinium askinae* (607 mbsf, 11.1 g/g), continues into the Early Oligocene with 14 g/g at 598.3 mbsf before decreasing to 1.0 g/g (578.71 mbsf). *Impagidinium victorianum* though sporadic and poor below (0.6 g/g, 608.13 mbsf) increases with a last occurrence of 2.8 g/g, at 578.71 mbsf and is the only species among the more sporadic dinocysts that extended into the Early Oligocene. *Selenopemphix neophroides* continues into the Early Oligocene (28 g/g, 598.3 mbsf) increasing slightly with a last occurrence of 33 g/g, at 578.71 mbsf. *Lejeunecysta fallax* (8.5 g/g, 598.3 mbsf) decreases into the Early Oligocene before the last occurrence of 6.1 g/g (578.71 mbsf). *Spinidinium macmurdoense* (607 mbsf, 20 g/g) decreased to 14.7 g/g at 598.3 mbsf. *Operculodinium* spp (608.13 mbsf, 80 g/g) decreased significantly to 3 g/g at 598.3 mbsf with the last occurrence of 4.7 g/g, at 588.16 mbsf in the Early Oligocene. *Impletosphaeridium* spp (2.3 g/g, 598.3 mbsf) increases in the Early Oligocene with a last occurrence of 14 g/g, at 578.71 mbsf and *Deflandrea antarctica* (6.6 g/g, 608.13 mbsf) decreases with a last occurrence of 0.8 g/g at 598.3 mbsf.

Most of the less well represented dinocysts are not consistent in appearances and in most cases do not occur in the Early Oligocene. Dinocysts that do occur above the E/O boundary include *Eurydinium* spp which at the base of its range yields 4.9 g/g (607 mbsf), but increases in numbers upsection reaching 91.8 g/g at 598.3 mbsf. To a lesser extent the first occurrence of *Chlamydophorella neopilata* (609.65 mbsf, 1.2g/g) was sparse in the Late Eocene, and is most abundant in the Oligocene with 33.4 g/g, at 588.16 mbsf, before the last occurrence of 4.7 g/g (578.71 mbsf). The first occurrence of *Brigantedinium* spp at 588.16 mbsf (25 g/g) is in the Early Oligocene, this species increases to 56.4 g/g at 578.71 mbsf. Also recorded in the Early Oligocene in one sample only is *Batiacasphaera* spp (33.4 g/g, 578.71 mbsf). The prasinophycean algae *Cymatiosphaera* spp (8.6 g/g, 607 mbsf) continues into the Early Oligocene decreasing to 2.8 g/g, at 578.71 mbsf. Microforaminiferal linings (7.7 g/g, 598.3 mbsf), also continue into the Early Oligocene at 2.8 g/g (578.71 mbsf) along with insect parts.

Terrestrial material dominates all assemblages making up to 68.8% of the total palynomorph assemblage. Present in all samples the highest counts were recorded near the top of the CP15a/NP18 (1048.8 g/g, 620.05 mbsf) before increasing up to 1517.2 g/g at 607 mbsf in the Late Eocene (CP15b/NP19-20) before decreasing in the Early Oligocene from 442.2 g/g at 598.3 mbsf down to 116.5 g/g at 578.71 mbsf.

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						Palynomorphs Alphabetical order	20. Achomosphaera alcicornu	29. Acritarch spp	10. Alterbidinium asymmetricum	7. Batiacasphaera perforata	11. Batiacasphaera spp	26. Cerebrocysta delicata	8. Cerebrocysta mundus	27. Cerebrocysta waipawaense	12. Chlamydophorella neopilata	1. Corrudinium regulare	21. Corrudinium sp1	33. Cymatiosphaera	30. Cystidiopsis certa	31. Fenestridium clathrodermum	2. Impagidinium aculeatum	22. Impagidinium dispertitum	28. Impagidinium maculatum	13. Impagidinium spp1	3. Impagidinium victorianum	34. Insect casing	32. Leiosphaeridia spp	4. Lophocysta spp	14. Minisphaeridium sp group	15. Nematosphaeropsis spp	16. Odontochitina spp	5. Operculodinium janduchenei	9. Operculodinium spp	24. Phthanoperidinium dentatum	23. Phthanoperidinium geminatum	25. Phthanoperidinium sp1	6. Phthanoperidinium spA	17. Spinidinium luciae	18. Spiniferites spp	19. Tectatodinium cf sp	35. Terrestrial	LEGEND Sample sizes with their approximate count numbers in g/g site 699A 0 - 5.0 5.0 - 21.0 0.0
						Palynomorphs First up hole	- 1. Corrudinium regulare	2. Impagidinium aculeatum	- 3. Impagidinium victorianum	4. Lophocysta spp	5. Operculodinium janduchenei	6. Phthanoperidinium spA	7. Batiacasphaera perforata	8. Cerebrocysta mundus	9. Operculodinium spp	10. Alterbidinium asymmetricum	11. Batiacasphaera sp1	12. Chlamydophorella neopilata	13. Impagidinium spp1	- 14. Minisphaeridium sp group	15. Nematosphaeropsis spp	16. Odontochitina spp	17. Spinidinium luciae	18. Spiniferites spp	19. Tectatodinium cf sp	20. Achomosphaera alcicornu	21. Corrudinium sp1	- 22. Impagidinium dispertitum	- 23. Phthanoperidinium geminatum	24. Phthanoperidinium dentatum	25. Phthanoperidinium sp1	26. Cerebrocysta delicata	27. Cerebrocysta waipawaense	28. Impagidinium maculatum	29. Acritarch	30. Cystidiopsis certa	31. Fenestridium clathrodermum	- 32. Leiosphaerida spp	33. Cymatiosphaera spp	- 34. Insect casing	- 35. Terrestrial	125.4 0.0 0.0 Biostratigraphic zones Boundaries Acmes
Depth (mbsf)	/ Oligocene Age s do	CP17-18 This Study and	NP22-23 ZONES 6 NP22-23 ZONES 6 Takemura & Linu(1006) 7	P 20 P 21 Nocchi <i>et al.</i> (1991) 1	Depth (mbsf)	249.73 253.55 261.27																																				
270 280	Early	CP 16	NP 21	P 18-19	270	272.24 280.33				ļ							<u>.</u>		-		-					-						Ļ				-	ļ					ATE EOCENE/OLIGOCENE
290 300- 310 320- 330- 340-	Late Eocene	CP 15a CP 15b	NP 18 NP19-20	P 12	290 - 300- 310 - 320- 330- 340-	293.83 299.07 305.16 319.86 324.55 329.68 334.99 339.07																																				Phanoperidinium spA
350 360 370 380 390 400 410	Middle Eocene	CP 13 i CP 14a CP 14b	NP 15 NP 16 NP 17		350 - 360 - 370- 380 - 390- 400 - 410 -	356.17 364.5 369.08 373.81 386.71 390.89 396.95	V																																			
420 430 440 450 460 470		01 CP 12 CP 12	P 17 NP 13 NP 12	P9 - P10	420 - 430 - 440 - 450 - 460 - 470 -	413.1 417.77 432.37 436.6 443.66 449.92 454.86 460.81 465.65																																				

Figure 3.8: ODP site 748B shows total abundance for all palynomorphs within the samples depths from 642.98 to 578.71 mbsf. Bar charts have been produced using the Bugwin excel charting program from a grains per gram count. At the top of the chart all palynomorphs are placed in alphabetical order and numbered. The second row places each dinocyst in the order of first occurrence. Acritarchs, prasinophytes, foraminifera, insect castings (Purple) and terrestrial (Green) palynomorphs are displayed on the far right of the chart secondary to the dinocysts. The new nannofossil biostratigraphic zones CP and NP, nannofossil zones are presented for this study along with the age and sample depths inserted to match the sample depths of the Bugwin program. The green intermittant lines show the position of the boundaries. The red lines show the position of primary dinocysts first or last occurrence. The position of acmes are show by the blue arrows. Palynomorphs in red are longer ranging and appear in most depths and blue palynomorphs are sporadic in appearance. The hiatus is shown as a jagged line.

3.4.2 Site 699A – Figure 3.8

Samples from this site yielded only low diversity assemblages and dinocysts are not recorded between 465.65-356.17 mbsf. Dinocysts numbers range from 0.6 g/g (*Batiacasphaera* spp) to 125.4 g/g (*Phthanoperidinium dentatum*). The last occurrence of *Phthanoperidinium* spA is the only primary dinocyst in this site, and allows recognition of the top of the *Phthanoperidinium* spA zone and the base of the *Corrudinium regulare* zone. The presence of *Corrudinium regulare* first and last occurrences have been mentioned above in 3.2. No acmes have been recorded.

3.4.2.1 Dinocysts below the Oligocene

More consistent in appearances below the Oligocene is *Impagidinium victorianum* which first occurs at 339.07 mbsf with 8.4 g/g, (CP15a/NP18), and peaked upsection to 15.8 g/g at 299.07 mbsf. *Lyphocysta* spp occurs at 339.07 mbsf (1.05 g/g), and increased upsection to 7.2 g/g, at 293.83 mbsf in the Late Eocene.

Other dinocysts occurring in the Late Eocene were *Impagidinium aculeatum*, (1.0 g/g, 339.07 mbsf), with highest abundance upsection of 8.3 g/g (305.16 mbsf). The first common occurrence of a number of dinocyst species is recorded at 305.16 mbsf (mid-Late Eocene). The most abundant is *Batiacasphaera* spp (14.7 g/g) which increased upsection to 21.0 g/g, at 299.07 mbsf. *Corrudinium regulare* first occurs at 3.2 g/g (339.07 mbsf), with a slight increase above at 3.7 g/g (305.16 mbsf). *Operculodinium janducheni* (2.1 g/g, 339.07 mbsf), is sparse and sporadic in occurrence upsection near the Early Oligocene (1.1 g/g, 286.53). Dinocysts occurring in one sample only that have recorded high abundances, include *Phthanoperidinium dentatum* at 125.4 g/g, 293.83 mbsf and *Phthanoperidinium* sp1 at 84.6 g/g, 293.83 mbsf in the Late Eocene.

Of the other marine palynomorphs, Acritarch species were sparse throughout, although numbers of *Leiosphaerida* with 18.0 g/g, at 293.83 mbsf decreases to 3.4 g/g at 286.53 mbsf. *Cymatiosphaera* spp first occurs at 7.4 g/g (339.07 mbsf), and peaks above at 28 g/g, 305.16 mbsf, (CP15a/NP18) in the Late Eocene and again upsection at 27.5 g/g (293.83 mbsf), toward the end of the Late Eocene. Insect casings were recorded in three samples (465.65, 417.77 and 390.89 mbsf) well below the barren interval for palynomorphs. They reoccur in the Late Eocene in three samples with one further occurrence in the Early Oligocene. Terrestrial material is present in most samples in the Late Eocene, fluctuating in numbers with a peak of 15.5 g/g, at 305.16 mbsf,

3.4.2.2 Dinocysts in the Early Oligocene

Dinocysts that occur above the E/O boundary are *Impagidinium victorianum* occurring with a high abundance of 25.6 g/g at 280.33 mbsf in the Early Oligocene then to a lesser extent last occurred at 2.0 g/g at 249.73 mbsf. *Lyphocysta* spp (286.53 mbsf, 1.1 g/g) last occurrence decreased to 0.8 g/g (272.24 mbsf), in the Early Oligocene. *Impagidinium aculeatum* (293.83 mbsf, 2.4 g/g) last occurs in the Early Oligocene at 249.73 mbsf with 1.3 g/g and *Batiacasphaera* spp (299.07 mbsf, 21 g/g) was sparse above in the Early Oligocene with a last occurrence of 1.0 g/g at 280.33 mbsf. *Corrudinium regulare* (305.16 mbsf, 3.7 g/g), was sporadic below the boundary and reoccurs in the Oligocene with a last occurrence of 1.6 g/g at 272.24 mbsf. *Operculodinium janducheni* (1.1 g/g, 286.53 mbsf) has a last occurrence of 1.6 g/g, at 272.24 mbsf in the Early Oligocene. The Acritarch *Cymatiosphaera* spp (5.6 g/g, 286.53 mbsf) decreases with a last occurrence of 0.9 g/g, at 261.27 mbsf, in the Early Oligocene.

Terrestrial material (286.53 mbsf, 3.4 g/g) occurs in the Early Oligocene with a peak at 13.8 g/g at 280.33 mbsf, before decreasing with a last occurrence of 2 g/g at 253.55 mbsf.

3.4.3 Site 748B – Figure 3.9

In site 748B palynomorphs were absent above the E/O boundary, their last record is 126.36 mbsf towards the base of CP15b/NP19-20 in the Late Eocene. Dinocysts abundances in this site range from 0.26 g/g (*Spinidinium macmurdoense*) to 1712.8 g/g (*Thalassaphora* spp). The *Phthanoperidinium echinatum* and *geminatum* zones are present and the last occurrence of *Corrudinium regulare* at 126.36 mbsf marks

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				Palynomorphs Alphabetical order	21. Achomosphaera spp	22. Enneadocysta spp	1. Alisocysta spp	64. Alterbidinium asymmetricum	46. Alterbidinium distinctum	2. bauadospiraera periorata 5. Cerebrocysta cf delicata	4. Cerebrocysta delicata	6. Cerebrocysta mundus	3. Cerebroycysta bartonensis	24. Chlamydophorella neopilata	47. Corrudinium incompositum	 Corrudinium otagoense Corrudinium regulare 	69. Cymatiosphaera spp	37. Dapsilidin pseudocoligerum	8. Deflandrea antarctica	51. Deflandrea convexa 58. Deflandrea flounderensis	52. Deflandrea leptodermata	25. Deflandrea phosphoritica	9. Deflandrea spp dmged	53. Deflandrea truncata 59. Dino so1	10. Dino sp3	67. Fenestridium clathrodermum	71. Foraminiferal linings	38. Forma b 60. Grantodinium inconditum	48. Hapsocysta kysingensis	54. Heteraulacacysta pustulata	11. Hystrichosphaeridium spp	12. Imagidinium dispertitum	26. Impagidinium aculeatum 63. Impagidinium crassimuratum	49. Impagidinium elegans	13. Impagidinium maculatum	32. Impagidinium parvireticulatum	27. Impagioinium victorianum 14. Impletosphaeridium spp	72. Insect parts	68. Leiosphaerida spp	65. Lejeunecysta spp 15. Lophorysta spp	39. Minisphaeridium latirictum	16. Minisphaeridium spp group	17. Nematosphaeropsis spp	28. Operculoalnium janaucnenei 40. Operculodinium sop	61. Phthanoperidinium crenulatum	33. Phthanoperidinium dentatum	34. Phthanoperidinium echinatum	50. Phthanoperidinium geminatum	35. Phthanoperidinium spp dmgd	29. Pterospermella	55. Rhombodinium spp	36. Samlandia reticulifera 56. Samlandia spp	42. Spinidinium essoi	18. Spinidinium luciae	43. Spinidinium macmurdoense בי כיואואויוייש באיז	62. Spiniainium sp.1 19 Sniniferites snn	10. 00111111111111111111111111111111111
(su			(s	Palynomorphs First up hole	1. Alisocysta spp	2. Cerebroycysta bartonensis	4. Cerebrocysta delicata	5. Cerebrocysta cf delicata	5. Cerebrocysta mundus	 Corructinum otagoense B. Deflandrea antarctica 	9. Deflandrea spp dmged	10. Dino sp3 11 Hvstrichosnhaeridium son	12. Imagidinium dispertitum	13. Impagidinium maculatum	14. Impletosphaeridium spp	15. Lophocysta spp 16. Minisphaeridium spp group	17. Nematosphaeropsis spp	18. Spinidinium luciae	19. Spiniferites spp	20. Ihalassaphora spp 21. Achomosphaera spp	22.Enneadocysta spp	23. Cerebrocysta waipawaense	24. Chlamydophorella neopilata	25. Detlandrea phosphoritica 26. Impagidinium aculeatum	27. Impagidinium victorianum	28. Operculodinium janduchenei	29. Pterospermella	30. Tectatodinium spp 31. Corrudinium regulare	32. Impagidinium parvireticulatum	33. Phthanoperidinium dentatum	34. Phthanoperidinium echinatum	35. Phthanoperidinium spp dmgd	36. Samlandia reticulitera 37. Dapsilidin pseudocoligerum	38. Forma b	39. Minisphaeridium latirictum	40. Operculodinium spp	41. Pritnanoperiainium sp.A 42. Spinidinium essoi	43. Spinidinium macmurdoense	44. Tricodinium hirsutum	45. Vozzhennikovia apertura 46. Alterbidinium distinctum	47. Corrudinium incompositum	48. Hapsocysta kysingensis	49. Impagidinium elegans	ou. Pntnanoperioinum geminatum 51. Deflandrea convexa	52. Deflandrea leptodermata	53. Deflandrea truncata	54. Heteraulacacysta pustulata	55. Rhombodinium spp sk Samlandia snn	57. Turbiosphaera sp1	58. Deflandrea flounderensis	59. Dino sp1	ou. Graptodinium inconditum 51. Phthanoperidinium crenulatum	52. Spinidinium sp1	53. Impagidinium crassimuratum	54. Alterbidinium asymmetricum دد امنسمیردام دس	ob. Lejeunecysta spp არ Δcritarchs	
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Figure 3.9: ODP site 748B shows total abundance for all palynomorphs within the samples depths from 642.98 to 578.71 mbsf. Bar charts have been produced using the Bugwin excel charting program from a grains per gram count. At the top of the chart all palynomorphs are placed in alphabetical order and numbered, the second row places each dinocyst in the order of first occurrence. Acritarchs, prasinophytes, foraminifera, in63sect casings (Purple) and terrestrial (Green) palynomorphs are displayed on the far right of the chart secondary to the dinocysts. The new nannofossil biostratigraphic zones CP and NP, are presented for this study along with the age sample depths inserted to match the sample depths of the Bugwin program. The green intermittant lines show the position of the boundaries. The red lines show the postion of primary dinocysts first occurrence and last occurrence. The position of acmes are show by the blue arrows. Palynomorphs in red are longer ranging and appear in most depths and blue palynomorphs are sporadic in appearance.



the top of the *Corrudinium regulare* zone. No primary datums have been recognised between the top of the *Phthanoperidinium geminatum* zone and the top of the *Corrudinium regulare* zone.

Twenty dinocysts species which first appear at the base of the section (200.47 mbsf), of which six are more consistent in appearance upsection. These are *Cerebrocysta delicata* (7.7 g/g, 200.47), reaching 31.7 g/g at 177.76 mbsf, before decreasing to 0.4 g/g at 148.78 mbsf. *Cerebrocysta* cf *delicata* (2.6 g/g, 200.47 mbsf), increases to 6.3 g/g (167.39 mbsf), and decreases above to 0.2 g/g at 141.81 mbsf. *Impagidinium dispertitum* (16.3 g/g, 200.47 mbsf) is found only sporadically above with the highest abundance at end of its range of 24.2 g/g at 148.78 mbsf. *Lyphocysta* spp with a first occurrence of 1.7 g/g, at 200.45 mbsf, is consistent above though sparse throughout with a last occurrence reduced to 0.3 g/g at 141.81 mbsf. The highest abundance of *Nematosphaeropsis* spp occurs at 15.4 g/g, 200.47 mbsf). Numbers fluctuate upsection, fading at the last occurrence with 0.3 g/g, at 148.78 mbsf. *Spiniferites* spp (42.0 g/g, 200.47 mbsf), peaks at 282.719 g/g (197.38 mbsf) and is abundant above occurring in every sample upsection to its last occurrence at 141.81 mbsf where it has decreased to 0.6 g/g.

Other long ranging dinocysts in this site are the first occurrence of *Impagidinium victorianum* at 197.38 mbsf (6.6 g/g). This species occurs only sparsely up to the end of its range where it increases to 27.0 g/g at 126.36 mbsf. *Corrudinium regulare* first occurs at 177.76 mbsf (6 g/g) and increases up section reaching its highest abundance of 36 g/g, (148.78 mbsf), the last occurrence is at 126.36 mbsf where it records only 2.2 g/g.

Dinocysts not as long ranging and more sporadic in their presence include *Deflandrea antarctica* first occurring at 200.47 mbsf (42.9 g/g). This species is sporadic above with the highest abundance of 459.5 g/g (162.1 mbsf) and decreases to 45.1 g/g at 156.9 mbsf in its last occurrence. *Thalassaphora* spp (200.4 mbsf, 0.9 g/g) has its highest abundance and last occurrence of 1712.807 g/g at 162.1 mbsf. *Impagidinium aculeatum* first occurs at 197.38 mbsf (3.6 g/g) and is consistent up section with the highest abundance in its last occurrence at 13.4 g/g (148.78 mbsf). *Phthanoperidinium dentatum* at 177.76 mbsf (151.6 g/g) is sporadic above although its last occurrence of 552.3 g/g at 148.78 mbsf shows very high numbers. There are a number of dinocysts that occur in one sample only in the *Phthanoperidinium echinatum* or *Phthanoperidinium geminatum* Zones.

Among the other marine palynomorphs the longest ranging are of the Acritarch *Leiosphaerida* spp (17.2 g/g, 200.47 mbsf) with high abundances of 157.0 g/g, (152.11 mbsf) and 163.5 g/g (148.78 mbsf), then fading at their last occurrence at 2.4 g/g (141.81 mbsf). The Prasinophycean Algae has a first occurrence of *Cymatiosphaera* spp at 200.47 mbsf (18.8 g/g), and are consistent up section with a highest abundance of 49.7 g/g, at 148.78 mbsf and a last occurrence at 141.81 mbsf of 7.0 g/g. *Tasmanites* first occur at 200.47 mbsf (16.2 g/g) and appear sporadically above with the highest abundance of 72.4 g/g at 177.76 mbsf and the last occurrence reduced to 1.1 g/g, at 126.36 mbsf. Microforaminiferal linings are very sparse being recorded in only two samples. Terrestrial material occurs in most samples up to 126.36 mbsf but has low grains per gram counts.

Acmes occurring throughout this site are:

Below The Phthanoperidinium echinatum Zone

• Spiniferites spp at 283 g/g (197.38 mbsf).

The Phthanoperidinium echinatum Zone

- Imagidinium parvireticulatum at 211.1335 g/g (177.76 mbsf).
 The Phthanoperidinium geminatum Zone
- Deflandrea antarctica at 460.0 g/g (162.1 mbsf).
- Thalassaphora spp at 1712.8 g/g (162.1 mbsf).
- Spinidinium sp1 at 192.0 g/g (156.9 mbsf).
- Leiosphaerida spp at 957.1 g/g, (156.9 mbsf).
 Above the Phthanoperidinium geminatum Zone
- Phthanoperidinium dentatum at 552.3 g/g, (148.78 mbsf).

In site 748B palynomorph assemblages are dominated by Gonyaulacoid dinocysts recording the highest percentage of 95 % at 197.38 mbsf. Peridinioids highest percentage of 72 % occurs at 148.78 mbsf. Dinocyst percentages range from 0.05 % (*Deflandrea* spp) to 73 % (*Minisphaeridium* group).

3.4.4 Site 277 – Figure 3.10

Dinocysts occurring in this site range from 0.35 g/g (*Achomosphaera* spp) to 175.3 g/g (*Operculodinium* spp). The *Phthanoperidinium* spA and *Corrudinium regulare* zones are present and first occurrences of *Phthanoperidinium echinatum* and *Corrudinium regulare* at 292.53 mbsf, define the base of the *Phthanoperidinium echinatum* zone. Dinocysts first occur at 296.3 mbsf, although some rare acritarchs and terrestrial material are recorded below this level.

3.4.4.1 Dinocysts below the Oligocene

Dinocysts consistently appearing below the Oligocene show three species that stand out as being more consistent and longer ranging than the rest. *Spiniferites* spp first occurrence is at 296.3 mbsf (3.3 g/g) and is most abundant up section at 28.3 g/g, in 265.335 mbsf, in the *Phthanoperidinium* spA Zone. *Impagidinium victorianum* at 292.53 mbsf 0.5 g/g has a low grains per gram count throughout its occurrence which is consistent up to 185.55mbsf (0.55 g/g). The first occurrence of *Operculodinium* spp is at 292.53 mbsf (4.7 g/g), this species numbers fluctuate above to 175.3245 g/g (240.84 mbsf) before fading just before the Early Oligocene to 0.8 g/g, at 190.8 mbsf.

Dinocyst that are sporadic in appearance below the Oligocene are *Corrudinium regulare* (292.53 mbsf, 2.1 g/g). This species is sporadic above with a highest abundance at 15.2 g/g, 220.145 mbsf (CP15b/NP19-20) in the *Phthanoperidinium* spA Zone, and fading to a last occurrence of 0.4 g/g, at 190.8 mbsf. *Impagidinium aculeatum* from 292.53 mbsf (2.1 g/g) is sparse and peaks at 3.5 g/g (265.335 mbsf). *Nematosphaeropsis* spp at 292.53 mbsf (1.1 g/g,) is also sporadic above peaking at 8.3 g/g (220.145 mbsf).

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						Palynomorphs Alphabetical order	5. Achomosphaera spp	75. Acritarchs :um 58. Airiana velicosa	22. Alisocysta circumtabulata 46. Alterbidinium asymmetricum	47. Batiacasphaera perforata	73. Batiacasphaera spp 23. Cerebrocysta bartonensis	7. Cerebrocysta cf delicata	6. Cerebrocysta delicata 48. Cerebrocysta mundus	66. Cerebrocysta teuriensis atum 56. Cerodinium medcalfii	24. Chlamydophorella neopilata	n 68. Corrudinium eyrense 68. Corrudinium obscurum	69. Corrudinium otagoense 8. Corrudinium regulare	tum 81. Cymatiosphaera spp	/ɒ. cysuaiopsis spp 1. Dapsilid. pseudocoligerum	25. Deflandrea antarctica 26. Deflandrea cygniformis	ata 59. Deflandrea dartmoorium	60. Deflandrea medcalfii 27. Deflandrea phosphoritica	61. Deflandrea scabrata	28. Deflandrea spp dmged 9. Deflandrea truncata	1 62. Diconodinium multispinulum	n 29. Dino spp2 n 70. Dino spp3	um 77. Fenestridium clathrodermum	83. Foraminiferal linings 30. Graptodinium inconditium	31. Graptodinium reticulatum 10. Hapsocysta kysingensis	nei 32. Hystrichosph brevispinium	latum 2. Hystrichosphaer tubiferum iicum 11. Impagidinium aculeatum	atum 33. Impagidinium crassimuratum	nged 12. Impagidinium elegans	35. Impagidinium maculatum 56 13. Impagidinium parvireticulatum	tum 14. Impagidinium victorianum	36. Impletosphaeridium spp	80. Leiosphaeridia spp	um 49. Lejeunecysta fallax	e / z. Eniguiounium sp 15. Lophocysta spp	57. Manumiella druggii 16. Minischaeridium latirictum	63. Minisphaeridium spp group	17. Nematosphaeropsis spp	37. Octodinium askiniae 38. Operculodinium janduchenei	18. Operculodinium spp	78. Palambages spp 79. Paucilobimorpha inaequalis	um 50. Paucisphae inversibuccinium 10 Dhthanonardinium achinatum	tum 3. Phthanoperidinium aculeatum	39. Phthanoperidinium crenulatum 64. Phthanoperidinium dentatum	40. Phthanoperidinium eocenicum 41. Phthanoperidinium geminatum	65. Phthanoperidinium sp1	42. Phthanoperidinium spA 43. Phthanoperidinium spp dmged	20. Pterospermella	/1. Samlandia reticulitera 44. Satyrodinium bengalense	51. Satyrodinium haumuriense 45. Selenapemphix nephroides	ium 52. Spinidinium essoi	4. Spiniferites spp lis 53. Spnidinium luciae	54. Stovercysta spp 82. Tasmanites	55. Tectatodinium spp	85. Terrestrial 21. Thalassiphora spb	74. Unknown sp1	San app nun	LEGE nple siz roxima nbers in 0 - 2. 2.5 - 9.18 22.9	ND es with te could n g/g si 5 9.18 - 22.9 - 40.3	h their nt te 277 5
Sample positions)	Age	This Study Is Site Site Study Is Nannofossil	Zones Radiolaria	Stages foraminifera Č ollis et al. (1997) S	Depth (mbsf) Sample positions)	Palynomorphs First up hole	 – – 1. Dapsilid. pseudocoligerum 	 – – 2. Hystrichosphaer tubiferum – – 3. Phthanoperidinium aculeat 	 4. Spiniferites spp 5. Achomosphaera spp 	 6. Cerebrocysta delicata 	 7. Cerebrocysta cf delicata 8. Corrudinium regulare 	– – – 9. Deflandrea truncata	 – – 10. Hapsocysta kysingensis – – 11. Impagidinium aculeatum 	 – – 12. Impagidinium elegans – – 13. Impagidinium parvireticuli 	– – – 14. Impagidinium victorianum	 – – 15. Lopnocysta spp – – 16. Minisphaeridium latirictur 	 - 17. Nematosphaeropsis spp - 18. Operculodinium spp 	– – – 19. Phthanoperdinium echina	 – – 21. Thalassiphora spp 	 22. Alisocysta circumtabulata 23. Cerebrocysta bartonensis 	– – – 24. Chlamydophorella neopila	 25. Deflandrea antarctica 26. Deflandrea cygniformis 	 – – 27. Deflandrea phosphoritica 	 – – 28. Deflandrea spp dmged – – 29. Dino spp2 	 – – 30. Graptodinium inconditium 	 31. Graptodinium reticulatum 32. Hystrichosph brevispinium 	– – 33. Impagidinium crassimurat	 34. Impagiainium aispertitum 35. Impagidinium maculatum 	 36. Impletosphaeridium spp 37. Octodinium askiniae 	– – – 38. Operculodinium janduche	 39. Phthanoperidinium crenul 40. Phthanoperidinium eocen 	41. Phthanoperidinium gemin	42. Phthanoperialmum spA 43. Phthanoperidinium spp dr	– – – 44. Satyrodinium bengalense – – – 45. Selenanemnhix nenhroide	46. Alterbidinium asymmetric	 47. Batiacasphaera perforata 47. Grebroweta mundus 	 46. Cerebrocysta munuus 49. Lejeunecysta fallax 	 50. Paucisphae inversibuccini 51 Satvrodinium haumuriens 	52. Spinidinium essoi	53. Spnidinium luciae	55. Tectatodinium spp	56. Cerodinium medcalfii	 57. Manumiella druggii 58. Airiana velicosa 	59. Deflandrea dartmoorium	 – – 60. Deflandrea medcalfii – – 61. Deflandrea scabrata 	– – – 62. Diconodinium multispinul	64. Phthanoperidinium denta	 65. Phthanoperidinium sp1 66. Cerebrocysta teuriensis 	– – – 67. Corrudinium eyrense – – – 68. Corrudinium obscurum	69. Corrudinium otagoense	 70. Dino spp3 71. Samlandia reticulifera 	72. Lingulodinium sp	 /3. Batiacasphaera spp 74. Unknown sp1 	 75. Acritarchs 76. Cystidiopsis spp 	– – 77. Fenestridium clathroderm	 – – 78. Palambages spp – – 79. Paucilobimorpha inaequal 	 80.Leiosphaerida spp 81.Cvmatiosphaera spp 	82. Tasmanites	 – – 83. Foraminiferal linings – – 84. Insect parts 	– – 85. Terrestrial		40.3: 0.0 Bio 2 Bo Aci	stratig ones undario mes	u raphic es
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Figure 3.10: DSDP site 277 shows total abundance for all palynomorphs within the samples depths from 642.98 to 578.71 mbsf. Bar charts have been produced using the Bugwin excel charting program from a grains per gram count. At the top of the chart all palynomorphs are placed in alphabetical order and numbered. The second row places each dinocyst in the order for first occurrence. Acritarchs, prasinophytes, foraminiferal linings, insect castings (Purple) and terrestrial (Green) palynomorphs are displayed on the far right of the chart secondary to the dinocysts. The new nannofossil biostratigraphic zones CP and NP, are presented for this study. The age and sample depths, inserted to match the sample depths of the Bugwin program. Green intermittant lines show the position of the E/O boundary. The red lines show the position of primary dinocysts first occurrence and last occurrence. The position of acmes are marked by the blue arrows. Palynomorphs in red are longer ranging and appear in most depths and blue palynomorphs are sporadic in appearance.

One acme is recorded for *Operculodinium spp* of 175.3 g/g, at 240.84 mbsf (CP15a/NP18), in the *Phthanoperidinium* spA Zone.

The first occurrence of Acritarchs appears well below the dinocyst first appearances with 21.3 g/g, being at 369.63 mbsf and a maximum abundance of 47.3 g/g at 265.335 mbsf. *Leiosphaerida* spp first occurs at 292.53 mbsf (0.5 g/g), appearances above this level are sporadic to 185.75 mbsf, at 24.6 g/g. The longest ranging of the Prasinophycean Algae is *Cymatiosphaera* spp which first occurs at 296.3 mbsf (0.7 g/g), with the highest abundance above of 32.8 g/g, at 240.84 mbsf. *Tasmanites* first occurrence at 296.3 mbsf of 0.6 g/g, and has a highest abundance up section at 23.1 g/g (280.15 mbsf). The first occurrence of microforaminiferal linings are at 16.0 g/g, 280.15 mbsf though they are sporadic above this level and fade near the Oligocene (0.5 g/g, 185.75 mbsf). Insect casings are very sparse occurring between 280.15 mbsf to 180.825 mbsf.

The first occurrence of Terrestrial material had a small presence in samples below 296.3 mbsf. Above from 292.53 mbsf they occurred in nearly every sample peaking at 22.2 g/g, at 220.15mbsf.

3.4.4.2 Dinocysts in the Early Oligocene

Dinocysts that continue into the Early Oligocene are *Spiniferites* spp at 180.825 mbsf (5.8 g/g), and decreases with the last occurrence of 0.4 g/g, at 132.995 mbsf. *Impagidinium victorianum* (180.825 mbsf, 4.4 g/g) is sporadic above, fading with a last occurrence of 0.4 g/g, at 126.415 mbsf. *Operculodinium* spp (190.08 mbsf, 0.8 g/g) reoccurs at 157.515 mbsf (1.6 g/g) and is sporadic above, decreasing to 3.8 g/g, at 122.17 mbsf in the Early Oligocene. *Impagidinium aculeatum* is sparse and sporadic in the Early Oligocene occurring in only two samples at 162.56 mbsf (0.4 g/g) and 141.25 mbsf (0.9 g/g). *Nematosphaeropsis* spp (199.59 mbsf, 0.7 g/g,) reoccurs in the Early Oligocene at 157.515mbsf (0.53 g/g) is sparse and sporadic above with the last occurrence at 122.17 mbsf (1.6 g/g).

The other marine palynomorphs have low grains per gram and are sporadic in the Early Oligocene. The acritarchs have a last occurrence of 0.5 g/g is at 141.25 mbsf. *Leiosphaerida* spp last occurs at 1.3 g/g at 126.415 mbsf and *Cymatiosphaera* spp is sporadic up to the last occurrence fading at 0.5 g/g, at 122.17 mbsf. *Tasmanites* at 180.825 (2.2 g/g) decreases and last occurs at 126.415 mbsf (0.4 g/g) and microforaminiferal linings last occur at 141.25 mbsf (1.5 g/g). Terrestrial material (180.825 mbsf, 6.5 g/g) last occur with a small reduction to 10.9 g/g, at 122.17 mbsf.



CHAPTER FOUR

4.0 Assemblage Analysis

4.1 Introduction

Chapter four introduces the data from this study using percentages to document the proportion of various palynomorphs in the assemblages. Percentages from the initial data count were calculated separately for the dinocyst assemblages, the marine palynomorphs assemblages and the total palynomorphs count, including Terrestrial material. To avoid spurious abundance peaks samples containing less than twenty palynomorphs were omitted from calculations. The percentage results of the dinocyst assemblages are separated into two groups representing autotrophs and heterotrophs (Gonyaulacoid/Peridinioid) which are thought to reflect differing environments. Raw data (Appendices 2.5) contains the full counts of all samples, with total abundances in Appendices 2.7-2.14.

4.2 Gonyaulacoid and Peridinioid Dinocysts

Evitt (1985) recognized that on the basis of morphology most dinocyst genera could be assigned to either the Order Gonyaulacales or Order Peridiniales, here they will be referred to as Gonyaulacoid or Peridinioid dinocysts. The main differences between their morphology are the tabulation patterns. In Gonyaulacoid dinocysts six precingular and six postcingular plates are a typical number with one antapical plate, whereas the Peridinioid characteristically have seven precingular and five postcingular with two antapical plates. Gonyaulacalean tabulation is also missing the left sulcal plate and the cingulum is offset at the flagella pore. In the Peridinialean tabulation the cingulum is only slightly offset and both the left and right sulcal are present (Evitt, 1985; Fensome *et al.*, 1996; Williams *et al.*, 2000).

Gonyaulacoids are thought to largely represent autotrophs, reliant on sunlight for photosynthesis and dissolved nutrients as a food source and considered warmer water species. Peridinioids are mostly heterotrophs and capture their prey; they are common in high latitude sites where sea-ice can occur (Williams *et al.*, 2009). High Gonyaulacoid percentages principally represent oligotrophic conditions of outer neritic to open ocean, low Gonyaulacoid percentages represent eutrophic conditions of shallow inner neritic waters, or may represent upwellings or sea-ice cover (Pross and Brinkhuis, 2005; Sluijs *et al.*, 2005). Based on this assumption the differences in dinocyst feeding strategies are often used by researchers to indicate productivity variations during the Paleogene (Crouch and Brinkhuis, 2005; Dale, 1996; Pross and Brinkhuis., 2005; Röhl *et al.*, 2004; Sluijs *et al.*, 2005).

4.3 Dinocyst Groups

Brinkhuis and Biffi (1993) defined dinocysts groupings of morphologically related taxa and with a known similarity of environmental affinity. These groups are often dominated by one taxon after which the group is named. These are shown in Table 4.1.

Dinocyst genera	Dinocyst Groups
Spiniferites spp (dominant)	
Achomosphaera spp	Spiniferites group
Impagidinium spp (dominant)	_
Nematosphaeropsis spp	<i>Impagidinium</i> group
Operculodinium spp (dominant)	
Impletosphaeridium spp	<i>Operculodinium</i> group
Various genera	Minisphaeridium group

Table 4.1: Dinocysts that are morphologically related in this study have been placed in groups and named under their dominant genera. The Minisphaeridium group is considered to contain all very small spheroidal cysts and dominance of one genera cannot be ascertained (Brinkhuis and Biffi, 1993; Fensome *et al.*, 2009).

The percentage figures were calculated using the groupings as defined by Brinkhuis and Biffi (1993) and Fensome *et al.* (2009). Throughout each site (ODP 696B, 699A, 748B, DSDP 277) the dominant genus for each dinocyst group was recorded as shown in Table 4.1 and combined with other dinocyst genera for interpreting the palaeoenvironment. The grouping of morphologically related dinocysts has been used by researchers to assist with interpretation of the palaeoenvironment in other studies (Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Crouch and Brinkhuis, 2005; Eldrett and Harding, 2009; Firth, 1996; Pross and Schmiedl, 2002).

Among the *Minisphaeridium* group dominance of one genus cannot be ascertained. The group encompasses all very small spheroidal cysts (central body 20-25 μ m across), proximochorate to chorate as discussed by Fensome *et al.* (2009). The dinocysts are placed into the *Minisphaeridium* group due to the high yields found in assemblages and a lack of a generic name to assign them. In this study the groups are found in each site.

Each site is represented by two figures (4.1a,b to 4.4a,b). All the "a" figures show the dinocyst data as discussed above. The "b" figures show both the entire marine and non marine breakdown and the breakdown of the complete palynomorph assemblage. Appendix 2.6 displays Gonyaulacoid and Peridinioid dinocysts totals from each site. The dinocyst zones developed in chapter 3 are shown in all Figures. Charts of the total abundance and marine genera can be found in Appendices 2.7-2.14 respectively. A Gonyaulacoid and Peridinioid analysis of ODP site 1172 of Sluijs *et al.* (2003) has been included as Figure 4.5 for comparison to sites from this study.

4.3.1 Site 696B, South Orkney microcontinent, Weddell Sea Palynomorph assemblages (642.98-578.71 mbsf)

Figures 4.1a, b, illustrate the dominance of Peridinioid dinocysts assemblages among the marine palynomorphs, recording their highest percentage of 92 % (612.75 mbsf) in the *Corrudinium regulare* zone. Gonyaulacoid dinocysts recorded their highest percentage of 37 % (617.7 mbsf) in the *Phthanoperidinium* spA Zone. The dinocyst groups and species percentages range from the highest percentage of 76 % recorded by *Spinidinium* spp to a low of 0.12 % recorded by the *Spiniferites* group. The non dinocyst marine palynomorphs are sparse in this site and consist of Acritarchs, Prasinophyta algae, microforaminiferal linings and some insect parts. Terrestrial material are the most dominant palynomorphs present making up 68.8 % of all the assemblages.



Figure 4.1a: Gonyaulacoid and Peridinioid pecentages of morphologically closely related dinoflagellate cysts quantitavely grouped to show their distribution within each of the four samples (Total = 100%). *Impagidinium, Nematosphaeropsis = Impagidinium* group; *Operculodinium, Impletosphaeridium = Operculodinium* group; *Achomosphaera, Spiniferites = Spiniferites* group (Brinkhuis & Biffi, 1993); Minisphaeridium spp group (Fensome *et al.,* 2009) The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980)



Figure 4.1b: Gonyaulacoid and Peridinioid dinocysts are compared with other marine palynomorphs (Acritarchs, Cymatiosphaera, Leiosphaerida, Tasmanites, Foraminifera and Insect parts). All marine palynomorphs = 100%. Terrestrial palynomorphs percentage was taken from a total abundance and presented here for comparison. The green dashed lines represent the E/O and Middle/Late boundaries. The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980)

Assemblage Analysis

4.3.1.1 Palynomorph assemblages in the Eocene (642.98-607 mbsf)

Figure 4.1a

Peridinioid dinocysts assigned to the genera *Spinidinium* spp and *Vozzhennikovia* spp display a reciprocal relationship between 642.98 and 607 mbsf. Yields were highest in the Middle Eocene with *Spinidinium* spp recording 76 % (626.64 mbsf) in the *Phthanoperidinium* spA Zone. *Vozzhennikovia* spp yielded higher percentages in the Late Eocene peaking at 55 % (608.13 mbsf) in the *Corrudinium regulare* zone. In addition other well represented dinocysts include peaks of *Selenopemphix* spp (22 %, 638.43 mbsf) recorded in the *Phthanoperidinium* zone, *Octodinium* spp (18 %, 631.63 mbsf) recorded in the *Phthanoperidinium geminatum* Zone and, up section, *Lejeunecysta* spp peaks at the top of the *Corrudinium regulare* Zone (14 %, 607 mbsf).

Gonyaulacoids are sparse in comparison to Peridinioid dinocysts and are dominated by the Operculodinium group with the highest abundance of 34 % at 617.7 mbsf in the Phthanoperidinium spA Zone. Lower percentages of Areosphaeridium spp (638.43 mbsf), Spiniferites group (640.13 mbsf) and Impagidinium group (636.94 mbsf), peak in the Phthanoperidinium echinatum Zone at 8%, 14% and 10% respectively, while all other Gonyaulacoids dinocysts are sparse in the Eocene.

Figure 4.1b

This figure again demonstrates that Peridinioid dinocysts dominate all the marine palynomorphs over this interval. The Acritarchs are sparse although present in almost every sample with the highest percentage in the *Phthanoperidinium echinatum* Zone of 8 %, (631.63 mbsf). The Prasinophyta algae *Cymatiosphaera* are sparse with 4% at 610.75 mbsf. *Tasmanites* percentages were low and specimens were recorded in only a few samples. Microforaminiferal linings occurred in every sample with the highest percentage of 6 % occurring at 619.06 mbsf in the *Phthanoperidinium* spA Zone. Insect parts were sporadic in appearance. Terrestrial material dominate this interval with peaks of 86 % (642.98 mbsf), 85 % (620.05 mbsf) and 83 % (607 mbsf).

4.3.1.2 Palynomorph assemblages in the Early Oligocene (598.3-578.71 mbsf) Figure 4.1a

Above the *Corrudinium regulare* Zone the sampling is at a lower resolution (~ 10 m in comparison to the ~2 m sampling below). Peridinioid dinocysts dominate the Early Oligocene assemblages. Changes occurring at the E/O transition include an increase in the percentage of *Eurydinium* spp from 2 % at 607 mbsf to a high yield of 47 % at 598.3 mbsf, dominating the assemblages from this depth. *Selenopemphix* spp makes up 14 % of the assemblage at 598.3 mbsf while the percentage of all other dinocysts species has decreased.

At 588.16 mbsf *Vozzhennikovia* spp dominate the assemblage (63 %). Species attributable to the genus *Brigantedinium* make their first appearance at 588.16 mbsf where they represent 10% of the assemblage and increase to 30% at 578.71 mbsf. In the youngest sample at 578.71 mbsf *Selenopemphix* spp yields 17 % and *Vozzhennikovia* spp has decreased to 7 %. *Spinidinium* spp (7 %), *Octodinium* spp (4 %) and *Lejeunecysta* spp (7 %) were sparse from 598.3 mbsf although they maintain a presence up to the youngest sample.

The yield of the Gonyaulacoid genus *Chlamydophorella* spp (12 %, 588.16 mbsf) decreases to 2% at 578.71 mbsf and the *Operculodinium* group (3 %, 598.3 mbsf) increased slightly to 7 % (578.71 mbsf). *Batiacasphaera* spp first occurs in the youngest sample at 578.71 mbsf where it makes up 18 % of the assemblage.

Figure 4.1b

This figure illustrates the continuing dominance of Peridinioid dinocysts above the E/O transition yielding 83 % at 598.3 mbsf decreasing to 64 % in the youngest sample (578.71 mbsf). In contrast Gonyaulacoid dinocysts were 9 % at 598.3 mbsf and increase to 30 % in the youngest sample (578.71 mbsf). At 578.71 mbsf only low yields of *Cymatiosphaera* (1 %) and microforaminiferal linings (1 %) are present. Terrestrial material still dominate all marine palynomorphs at 598.3 mbsf yielding 68 %. However in the last two samples shows a decrease with 46 % at 588.16, near

equal with Peridinioid dinocysts, and is no longer dominant at 578.71 mbsf with 37 %.

4.3.2 Site 699A, Northeast Georgia rise, Palynomorph assemblages (465.65-249.73 mbsf)

Gonyaulacoid dinocysts assemblages are dominant throughout most of this site with the highest percentage at 72% (299.07 mbsf). Peridinioid percentages peak at 293.83 mbsf where they make up 77 % of the dinocyst assemblage. Dinocyst genera are fewer in numbers compared with other sites in this study. *Phthanoperidinium* spp has the highest percentage of 92 % among the dinocyst groups and species with a low percentage of 0.5 % from *Corrudinium* spp. Among the non-dinocysts, Acritarchs, Prasinophyta algae and Insect parts have been recorded. Terrestrial material is present in nearly every sample. Palynomorphs are present from the Late Eocene through to the Early Oligocene and are not present in the Middle Eocene.

4.3.2.1 Palynomorph assemblages in the Eocene (465.65-293.83 mbsf) Figure 4.2a

In the early Late Eocene CP15a/NP18 at 339.07 mbsf dinocysts are sparse and the only Peridinioid dinocyst present at this depth is *Phthanoperidinium* spp which makes up 42 % of the dinocyst assemblage. It is the most dominant dinocyst present. The Gonyaulacoid *Impagidinium* group is also present making up about 35 % of the assemblage while *Corrudinium* spp (10 %) and *Operculodinium* group (7 %) are minor occurrences. Dinocysts are not present between 334.99-319.86 mbsf and at 319.86 mbsf.

Peridinioid dinocysts are absent at 324.55 mbsf and *Cerebrocysta* spp makes up 75 % of the assemblage. At 305.16 mbsf Peridinioid occurrences are sparse while Gonyaulacoids yield the highest percentages of *Impagidinium* group (29 %) and *Batiacasphaera* spp (17 %). At 299.07 mbsf *Impagidinium* group remain at 29 % while *Batiacasphaera* spp has increased to 39 %. *Spinidinium* spp at 14 % is the highest percentage for the Peridinioids at this depth. Close to and below the



Figure 4.2a: Gonyaulacoid and Peridinioid pecentages of morphologically closely related dinoflagellate cysts quantitavely grouped to show their distribution within each of the four samples (Total = 100%). Impagidinium, Nematosphaeropsis = Impagidinium group; Operculodinium, Impletosphaeridium = Operculodinium group; Achomosphaera, Spiniferites = Spiniferites group (Brinkhuis & Biffi, 1993); Minisphaeridium spp group (Fensome *et al.*, 2009). The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The hiatus is represented by VVVV



Figure 4.2b: Gonyaulacoid and Peridinioid dinocysts are compared with other marine palynomorphs (Acritarchs, Cymatiosphaera, Leiosphaerida, Tasmanites, Foraminifera and Insect parts). All marine palynomorphs = 100%. Terrestrial palynomorphs percentage was taken from a total abundance and presented here for comparison. The green dashed lines represent the E/O and Middle/Late boundaries. The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The hiatus is represented by VVVV Insect casings at the base of the section are included due to a count of 43 whole and part specimens in one slide. They are a possible contamination

Eocene/Oligocene transition at 293.83 mbsf, the Peridinioid *Phthanoperidinium* spp at 92 % dominate the assemblages while all other dinocysts are sparse.

Figure 4.2b

At 339.07 mbsf Gonyaulacoids make up 43 % and Peridinioids 31 % of the marine palynomorph assemblage. The Prasinophyta algae *Cymatiosphaera* makes up 20% while Acritarchs are sparse at 5 %. From the middle Late Eocene at 324.55 mbsf only Gonyaulacoids (92 %) and the Prasinophyta algae *Cymatiosphaera* (8 %) are present. *Cymatiosphaera* increase to 22 % up section at 305.16 mbsf and Gonyaulacoids decreased to 63 %, 305.16 mbsf although still remain dominant (72 %) up to 299.07 mbsf. At 293.83 mbsf Gonyaulacoids faded significantly (6 %) as the Peridinioids (77 %) dominate the assemblages. The Prasinophyta algae *Cymatiosphaera* is present at 10 % and the Acritarch *Leiosphaeridia* spp occurs in only two samples, 7 % at 293.83 mbsf and 10 % at 286.53 mbsf.

Insect casings occurred in a single sample well below the Middle/Late Eocene boundary at 465.65 mbsf which yielded no other palynomorphs. Despite a raw data count of 43 it is still likely that they are present as a downhole contamination, as insect casings are also present in two samples near the Eocene/Oligocene transition at 5 % (299.07 mbsf) and 10 % (286.53 mbsf).

4.3.2.2 Palynomorph assemblages in the Early Oligocene (286.53-249.73 mbsf) Figure 4.2a

At the E/O transition (286.53 mbsf) assemblages of *Impagidinium* group at 28 % and *Phthanoperidinium* spp 27 % were nearly equal in dominance, while the *Operculodinium* and *Spiniferites* groups both yielded 17%. In the Early Oligocene at 280.33 mbsf, the *Impagidinium* group dominate the assemblages at 72%. *Cerebrocysta* spp yielded 18 % while *Batiacasphaera* spp, the *Operculodinium* group and the Other Gonyaulacoids all recorded 3 %. Palynomorphs are absent in samples above 280.33 mbsf.

Figure 4.2b

Samples from the Early Oligocene yield assemblages dominated by Gonyaulacoid dinocysts (89 % at 280.33 mbsf). Among the non dinocysts only the Prasinophyte *Cymatiosphaera* (8 %) and Acritarchs (3 %) were present. Terrestrial material is present in most samples with a highest percentage of 27 % at 324.55 mbsf and 26 % at 280.33 mbsf and to a lesser extent follows a similar distribution pattern to the Gonyaulacoid dinocysts.

4.3.3 Site 748B, Southern Kerguelen Plateau, Raggatt Basin Palynomorph assemblages (200.47-76.83 mbsf)

Figures 4.3a-b shows that Gonyaulacoid dinocysts dominate assemblages from the base of the site recording their highest percentage of 81 % at 197.38 mbsf. Peridinioid assemblages become dominant from the middle of the *Phthanoperidinium geminatum* Zone. They dominated the assemblages with 57 % at 148.78 mbsf above that zone. Dinocyst groups and species percentages range from a high of 73 % by the *Minisphaeridium* group with the lowest percentage of 0.05 % by *Deflandrea* spp. The non dinocyst marine palynomorphs consist of Acritarchs, Prasinophyta algae, microforaminiferal linings and insect casings, although the latter are too sparse to be included. Terrestrial material is sparse at this site and all palynomorphs are absent across the E/O transition and into the Early Oligocene.

4.3.3.1 Palynomorph assemblages in the Eocene (200.47- 126.36 mbsf) Figure 4.3a

Gonyaulacoid dinocyst assemblages dominate between 197.38-162.1 mbsf with their dominance changing in each sample from the base of the section into the *Phthanoperidinium echinatum* and *geminatum* Zones above. From the lower sample of 197.38 mbsf, *Spiniferites* group is most dominant at 56 %. At the base of the *Phthanoperidinium echinatum* Zone at 177.76 mbsf *Impagidinium* group is most dominant at 46 % while in the middle of that zone *Minisphaeridium* group at 73 % (172.12 mbsf) is dominant. At the top of the zone the *Spiniferites* group with 59 %



ODP Site 748B Southern Kerguelen Plateau, Raggatt Basin

Figure 4.3a: Gonyaulacoid and Peridinioid pecentages of morphologically closely related dinoflagellate cysts quantitavely grouped to show their distribution within each of the four samples (Total = 100%). Impagidinium, Nematosphaeropsis = Impagidinium group; Operculodinium, Impletosphaeridium = Operculodinium group; Achomosphaera, Spiniferites = Spiniferites group (Brinkhuis & Biffi, 1993); Minisphaeridium spp group (Fensome *et al.*, 2009). The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The positions of the dinocyst zones are shown.



Figure 4.3b: Gonyaulacoid and Peridinioid dinocysts are compared with other marine palynomorphs (Acritarchs, Cymatiosphaera,Leiosphaerida,Tasmanites, Foraminifera and Insect parts). All marine palynomorphs = 100%. Terrestrial palynomorphs percentage was taken from a total abundance and presented here for comparison. The green dashed lines represent the E/O and Middle/Late boundaries. The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The positions of the dinocyst zones are shown.

(167.39 mbsf) dominate the assemblages. In the *Phthanoperidinium geminatum* Zone, *Thalassaphora* spp with 74 % (162.1 mbsf) dominate as an acme.

Peridinioid assemblages increase in the *Phthanoperidinium geminatum* Zone from 162.1 mbsf as *Deflandrea* spp records 21 %. Gonyaulacoids become less abundant at 156.9 mbsf as *Spinidinium* spp yields 35 % and *Deflandrea* spp 15 % of the assemblages. At the top of the Zone and in the next sample above *Phthanoperidinium* spp now dominate the assemblages at 67 % (152.11 mbsf) and 63 % (148.78 mbsf) respectively, while further above at 141.81 mbsf, *Spinidinium* spp dominate at 68 %. Dinocysts are absent in samples 137.68 and 132 mbsf.

At the top of the *Corrudinium regulare* Zone 126.36 mbsf Peridinioid assemblages are absent and the *Impagidinium* group dominate, making up 75 % of the dinocyst assemblages present.

Figure 4.3b

From the base of the section to the middle of the *Phthanoperidinium geminatum* Zone, Gonyaulacoids dominate all palynomorph assemblages yielding 60 % at 200.47 mbsf with a highest yield of 80 % at 197.38 and 172.12 mbsf. In this interval Peridinioid assemblages yielded 28 % at 177.76 mbsf. At 156.9 mbsf the Acritarch *Leiosphaeridia* spp makes up 60 % of all palynomorph assemblages, while Gonyaulacoids (11 %) have decreased as Peridinioids increased to 23 %. At the top of the Zone at 152.11 mbsf the Acritarchs (39 %) and *Leiosphaeridia* spp (36 %) were most dominant. In samples 138.78 and 141.81 mbsf Peridinioids made up 57 % and 49 % of the marine assemblages respectively, dominating all other palynomorphs.

Minor occurrences of *Tasmanites* yielded 6 % at 200.47 mbsf and increased at the base of the *Phthanoperidinium echinatum* Zone yielding 12 % at 177.76 mbsf before fading above. The only occurrence of microforaminiferal linings was recorded at 141.81 mbsf where they make up 11 % of the marine palynomorph assemblage. Terrestrial material makes up less than 10 % of the assemblages.



DSDP Site 277 Southern Campbell Plateau Dinocyst Assemblages

Figure 4.4a: Gonyaulacoid and Peridinioid pecentages of morphologically closely related dinoflagellate cysts quantitavely grouped to show their distribution within each of the four samples (Total = 100%). Impagidinium, Nematosphaeropsis = Impagidinium group; Operculodinium, Impletosphaeridium = Operculodinium group; Achomosphaera, Spiniferites = Spiniferites group (Brinkhuis & Biffi, 1993); Minisphaeridium spp group (Fensome *et al.*, 2009) The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The hiatus =



Figure 4.4b: Gonyaulacoid and Peridinioid dinocysts are compared with other marine palynomorphs (Acritarchs, Cymatiosphaera, Leiosphaeridia Tasmanites, Foraminifera and Insect parts). All marine palynomorphs = 100%. Terrestrial palynomorphs percentage was taken from a total abundance and presented here for comparison. The green dashed lines represent the E/O and Middle/Late boundaries. The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980). The hiatus = VVVVVV

4.3.4 Site 277, Southern Campbell Plateau Palynomorph assemblages (435.01-122.17 mbsf)

Gonyaulacoid forms in Figures 4.4a-b dominate the dinocyst assemblages throughout most of this site, recording their highest percentage of 69 % at 220.145 mbsf in the *Phthanoperidinium* spA Zone. Assemblages of Peridinioid dinocysts do make up 54 % of the assemblages at 280.15 %, the base of the *Phthanoperidinium* spA Zone. Other dinocyst groups and species yield a high percentage of 79 % by the *Operculodinium* group with the lowest percentage of 0.3 % recorded by *Octodinium* spp. Non dinocysts that are present include Acritarchs, Prasinophyta algae, microforaminiferal linings and insect casings. Terrestrial material is present in every sample in this site.

4.3.4.1 Palynomorph assemblages in the Eocene (435.01- 190.8 mbsf) Figure 4.4a

At the base of the *Phthanoperidinium echinatum* Zone the Gonyaulacoid *Thalassaphora* spp and *Spiniferites* group together dominate the dinocysts. Assemblages peak at 28 % and 23 % respectively at 292.53 mbsf. At the base of the *Phthanoperidinium* spA Zone (280.15 mbsf), Peridinioid assemblages were most dominant yielding 36 % of *Phthanoperidinium* spp and 25 % of *Deflandrea* spp. *Operculodinium* group made up 79 % of all dinocyst assemblages at 240.84 mbsf. However, the Peridinioid dinocyst *Deflandrea* spp at 43 % (236.3 mbsf) yield a higher percentage than the *Operculodinium* group which decreases to 31 % (236.3 mbsf).

Upsection, at 220.145, 210.275 and 199.59 mbsf the *Operculodinium* group consistently makes up about 26 % of the dinocyst assemblages. Gonyaulacoids occurring with the *Operculodinium* group (26 %) dominated assemblages at 220.145 mbsf and 199.59 mbsf with *Corrudinium* spp yielding 29 %, and *Impagidinium* group 38 % respectively. The *Phthanoperidinium* spp, near the top of the *Phthanoperidinium* spA Zone yielded 25 % (210.275 mbsf) then decreased slightly to 16 % at the top of that zone (199.59 mbsf). Dinocysts are absent at 190.8 mbsf the top of the *Corrudinium regulare* Zone.

Figure 4.4b

Figure 4.4b clearly indicates that Gonyaulacoid dinocysts dominate the Peridinioid assemblage from most samples with a peak of 76 % at 292.53 mbsf then fluctuate up section; 77 % at 240.84 mbsf and 70 % at 220.145 mbsf. Notably, the Peridinioid dinocysts are dominant at 280.15 mbsf recording 54 %. Up section in the *Phthanoperidinium* spA Zone at 236.3 mbsf, Peridinioid dinocysts at 45 % are slightly above the percentage recorded for Gonyaulacoids of 44 % (236.3 mbsf).

Among the non dinocysts, Acritarchs are recorded at 369.63 mbsf (Middle Eocene) well below the first occurrences of all palynomorphs recorded above at 292.53 mbsf. From 292.53 mbsf the Acritarch assemblages fluctuate through the *Phthanoperidinium* spA Zone yielding 11 % at 265.335 mbsf and 16 % 220.145 mbsf. The Acritarch *Leiosphaeridia* spp were sparse, recording 7 % (240.84 mbsf) then fading up section. The Prasinophyta algae *Cymatiosphaera* from 292.53 mbsf at 8 % was present in all samples through the *Phthanoperidinium* spA Zone and yielded 12 % at 240.84 mbsf, increasing to 20 % at 210.275 mbsf. Species of the genus *Tasmanites* (5 %) from 292.53 mbsf was sporadic and sparse through the Zone averaging 5 % in most samples recorded. At 190.8 mbsf no dinocysts were present. The Acritarch *Leiosphaeridia* (56 %) dominate all palynomorph assemblages and *Cymatiosphaera* (33 %) is also an important component. Terrestrial material (5 %, 292.53 mbsf), is sparse initially and increases up section in the *Phthanoperidinium* spA Zone (10 %, 210.275 mbsf) and peaks (30 %, 190.8 mbsf) at the top of the *Corrudinium regulare* Zone.

4.3.4.2 Palynomorphs assemblages in the Early Oligocene (185.75-122.17 mbsf) Figure 4.4a

The lowest sample from this interval (185.75 mbsf) yielded dinocyst assemblages dominated by the *Minisphaeridium* group (32 %) and *Spiniferites* group (23 %). Species of the genus *Phthanoperidinium* were slightly less dominant yielding 21 % of the assemblages. Across the E/O transition at 180.825 mbsf, *Tectatodinium* spp yielded the highest percentage at 49 % while *Spiniferites* group (14 %), *Phthanoperidinium* spp (14 %) and *Impagidinium* group (10 %) were minor
contributions. Marine palynomorphs were not present between samples 162.56-141.25 mbsf although terrestrial material was present. Gonyaulacoid dinocysts were further recorded at 136.76 mbsf, with *Batiacasphaera* spp at 33 % being the most significant among the dinocyst assemblages. Present to a lesser extent were *Operculodinium* group and *Spiniferites* group yielding 20 % with *Impagidinium* group and the Other Gonyaulacoids yielding 14 %.

Figure 4.4b

The sample from 185.75 mbsf yielded assemblages dominated by Gonyaulacoids (55 %) increasing to 58 % at 180.825 mbsf across the E/O transition. Peridinioid dinocysts (16 %, 185.75) decrease slightly (12 %, 180.825 mbsf) across the E/O transition. Also at this depth (185.75 mbsf) the Acritarch *Leiosphaeridia* yielding 23 % decreases across the E/O transition to 4 % (180.825 mbsf). *Cymatiosphaera* (3 %, 185.75 mbsf) increases across the E/O transition yielding 19 % (180.825). Microforaminiferal linings occur in most samples averaging ~ 3 % up to the top of the *Phthanoperidinium* spA Zone.

Peridinioids were not present at 136.76 mbsf while Gonyaulacoids reoccur (49 %) along with the Prasinophyta algae *Cymatiosphaera* (42 %). Also occurring recording very low percentages are *Leiosphaeridia* spp (5 %), *Tasmanites* (2 %) and insect parts (2 %). Terrestrial material continues into the Early Oligocene and occurs in every sample between (180.825-122.17 mbsf).

4.3.5 ODP Site 1172, Leg 189 (Sluijs *et al.*, 2003)

Site 1172 (Figure 4.5) was part of a study from ODP leg 189 of the Tasmanian Gateway undertaken on dinocyst assemblages. The original dinocyst count from site 1172 (Sluijs *et al.*, 2003, Table 3) have been converted to percentages of Gonyaulacoid and Peridinioid dinocysts for comparison with this study Figure 4.5. The dinocysts assemblages are placed in the same genera or grouped percentages of Gonyaulacoid and Peridinioid assemblages that are used in this study. The sample spacing for site 1172 was at a high resolution of ~10 cm apart during the





late Middle Eocene to Early Oligocene (364.24-356.14 mbsf) and below in the Middle Eocene (380.5-364.14 mbsf) sample spacing was at ~1.5 m apart. This study utilizes the Sluijs *et al.* (2003) Late Eocene/Early Oligocene results sampled at the highest resolution. Dinocysts occurring from the Middle Eocene to Early Oligocene are displayed in Appendix 2.15 which gives an indication of dinocyst assemblage percentages that were present during the Middle Eocene.

4.3.5.1 Dinocysts assemblages in the Eocene (364.24-364.06 mbsf)

Site 1172 has an overall dominance of Peridinioid assemblages with *Deflandrea* spp yielding 63 % (364.24 mbsf) in CP14a,b/NP17, peaking up section at the Middle/Late Eocene boundary with a high yield of 87 %, (363.66 mbsf) in CP15a/NP18. *Spinidinium* spp 55 %, (363.92), also occurs up to the boundary and to a lesser extent minor percentages are attributable to *Vozzhennikovia* spp (9 %, 363.71 mbsf) and *Phthanoperidinium* spp (10 %, 363.71 mbsf). A significant occurrence was of the Gonyaulacoid *Areosphaeridium* spp yielding 40 % at 364.06 mbsf.

From the Middle/Late Eocene boundary the dominant dinocyst assemblage is attributable to *Deflandrea* spp yielding 87 % at 363.66 mbsf and 90 % at 360.41 mbsf. *Spinidinium* spp (50 %, 362.75 mbsf and 34 %, 361.66 mbsf) in the Late Eocene displays a reciprocal relationship with *Deflandrea* spp which yielded 28 % at 362.75 and 361.66 mbsf. From 361.05 mbsf *Spinidinium* spp yield less than 10 % while *Deflandrea* spp 80 % at 360.89, 360.71 and 360.66 mbsf respectively, dominate.

Vozzhennikovia spp during the Late Eocene yields 20 % of the dinocyst assemblages at 362.21 and 361.61 mbsf and fluctuates up section, peaking at 26 % at 360.83 mbsf then significantly reduces to 5 % at 360.45 mbsf. To a lesser extent *Phthanoperidinium* spp and *Octodinium* spp occur at less than 10 %, between 363.66-360.41 mbsf. *Alterbidinium* spp is sparse below the Middle/Late Eocene boundary and sporadic above peaking at 20 % at 363.33 and 361.66 mbsf. The Gonyaulacoid dinocyst *Areosphaeridium* spp is 40 % at 364.06 mbsf in the late Middle Eocene although from there into the Late Eocene all Gonyaulacoid dinocysts assemblages are very sparse with very low percentages.

4.3.5.2 Dinocyst Changes from the E/O transition (360.31-356.14 mbsf)

Dinocysts are not recorded in samples 360.31 and 360.15 mbsf at the top of CP15b/NP19-20, very close to the E/O transition. The Peridinioid dinocyst Deflandrea spp decreases significantly yielding 5 % at 360.01 mbsf. Brigantedinium spp increases from 8 % at 360.01 mbsf to dominate all dinocyst assemblages in the Early Oligocene yielding 80 % at 358.79 mbsf. Vozzhennikovia spp from 5 % at 360.01 mbsf fluctuates through the E/O transition peaking at 40% at 359.55 mbsf and 16 % at 359.09 mbsf before fading at 358.59 mbsf. Phthanoperidinium spp (16 %, 360.01 mbsf), increases to 19 % at 358.99 mbsf. Slight increases occur to Octodinium askinge and Lejeunecysta spp both yielding 0.1 %, at 359.41 mbsf. Across the Eocene Oligocene transition the Gonyaulacoid Spiniferites group has increased (24 %, 360.01 mbsf), yielding the highest percentage of 31 % at 359.21 mbsf. The Other Gonyaulacoid dinocysts spp yield 37 % (359.96 mbsf) and decrease to 32 % at 359.25 mbsf and 27 % at 359.09 mbsf. From 358.66 to 356.29 mbsf there are no dinocysts present. At 356.14 mbsf Gonyaulacoid dinocysts of Spiniferites group (48%), the Other Gonyaulacoids (36%), and to a lesser extent Operculodinium group (10%) also occur. Peridinioid dinocyst assemblages are not present from 358.66 mbsf.



CHAPTER FIVE

5.0 Discussion

5.1 Introduction

The distribution of dinocysts during the Paleogene is influenced by many factors such as sunlight, water temperature, salinity, nutrient levels, surface winds, upwelling systems, currents and the level of ocean water mixing (Chapter 1.7; Batten, 1996; Pross and Brinkhuis, 2005; Sluijs *et al.*, 2005). The dominant factors in the Late Eocene and Oligocene, surface water temperature and salinity, were arguably most important in the southern high latitudes, due to the development of the Antarctic ice sheets. δ^{18} O curves (Figures 1.2, 1.3) show cooling temperatures since the EECO, but brief peaks of warmer temperatures were included during the Middle Eocene (MECO) and a further warming in the Late Eocene was followed by the Vonhof *et al.* (2000) cooling event (DeConto and Pollard, 2003; Francis *et al.*, 2009; Pagani *et al.*, 2005). Over the same time interval it was expected that marine palynomorphs would shift from older assemblages reflecting warm conditions to assemblages indicative of cooler conditions.

5.2. Interpreted Dinoflagellate Palaeoenvironments

The transition from neritic to fully marine oceanic conditions is reflected in a change from restricted marine (inner neritic), to coastal (outer neritic) and offshore (oceanic). High salinity inner neritic environments are generally dominated by Peridinioid dinocysts which are predominately heterotrophs and the outer neritic to oceanic environments are generally dominated by Gonyaulacoid dinocysts, predominately autotrophs. In addition, some Peridinioids may also be abundant in coastal or oceanic upwelling palaeoenvironments where nutrient rich or eutrophic waters containing food for heterotrophs are present.

Table 5.1 documents the inferred palaeoenvironment of various dinocyst groups and genera. Crouch and Brinkhuis (2005) refer to Gonyaulacoid dinocysts as oligotrophic, with a preferred environment ranging from outer neritic to open ocean conditions. They suggested that Peridinioid dinocysts prefer eutrophic surface waters with lower sea surface temperatures and/or nutrient upwellings. The dinocysts listed in Table 5.1 are mostly related to those conditions.

Dinoflagellate Palaeoenvironment Interpretation							
Gonyaulacoid Dinoflagellates							
Genera	Possible Palaeoenvironment	References					
Gonyaulacoid	Oligotrophic outer neritic to open ocean conditions	Crouch and Brinkhuis (2005)					
<i>Cerebrocysta</i> spp <i>Corrudinium</i> spp	Oceanic, offshore taxa	Pross and Brinkuis (2005)					
Enneadocysta spp	Oligotrophic conditions, coastal taxa	Pross and Brinkuis (2005)					
Impagidinium group Tectatodinium spp	Outer most continental shelf, slope, rise and abyssal sediments representing Oceanic and transitional coastal – oceanic systems they require stable salinities of about 35%	Dale (1996) Brinkhuis and Biffi (1993) Sluijs <i>et al.</i> (2005) Pross and Brinkhuis (2005)					
Operculodinium group	Cool brackish stratified estuaries. Exploits transitional or changing conditions can tolerate the changes adapts to unstable environments	Wall <i>et al.</i> (1977) Dale (1996)					
Spiniferites group	Cosmopolitan and co occur with endemics to a certain extent	Sluijs <i>et al.</i> (2003)					
Thalassaphora spp (Mainly Thalassaphora pelagica)	Enhanced stratification, eutrophication and productivity in upper water column, and high salinity or oxygen depletion in lower water column.	Pross and Schmiedl, (2002) Sluijs <i>et al.</i> (2005) Vonhof <i>et al.</i> (2000) Pross and Brinkuis (2005)					
Peridinioid Dinoflagellates							
Peridinioid	Eutrophic surface waters with lower sea surface temperatures or nutrient upwellings	Crouch and Brinkhuis (2005)					
Brigantedinium spp	Coastal and oceanic upwelling regions as well as sea ice conditions. Heterotrophs typically feeding on diatoms.	Sluijs <i>et al.</i> (2003) Wall <i>et al.</i> (1977) Rochon <i>et al.</i> (1999)					
Deflandrea spp	Marginal marine heterotrophic, closely tied to ancient deltaic settings, organic rich facies, inshore eutrophic conditions associated with diatoms. Elevated nutrient availability. Offshore sea surface productivity	Sluijs et al. (2003; 2005)					
Phthanoperidinium spp Spinidinium spp Vozzhennikovia spp	Coastal and off shore sea surface productivity. Marginal marine, highly eutrophic, and high latitude setting	Pross and Brinkhuis (2005) Sluijs <i>et al.</i> (2003)					

 Table 5.1: Peridinioid and Gonyaulacoid dinocysts including groups are shown separately, with suggested palaeoenvironmental preference from previous works as referenced.

Among the Gonyaulacoid genera are several genera considered to be truly oceanic e.g. *Impagidinium*, *Corrudinium* and *Spiniferites*. However, they can also be found

with endemic species in more shallow conditions, although not usually in high numbers. The preferred marine conditions for the genus *Thalassaphora* are enhanced stratification and high salinity suggesting calm oceanic conditions. Wall *et al.* (1977) and Dale (1996) suggested that the *Operculodinium* group is capable of exploiting changeable conditions and can adapt to unstable and transitional environments, an exception to the general Gonyaulacoid inferred oceanic palaeoenvironment.

Peridinioid dinocysts in general can be linked to inner neritic eutrophic conditions (e.g. *Deflandrea* spp; Sluijs *et al.*, 2003, 2005) or elevated nutrient availability and offshore sea surface productivity (e.g. *Phthanoperidinium* spp, *Deflandrea* spp; Pross & Brinkhuis, 2005). *Brigantedinium* spp are referred to by Rochon *et al.* (1999), Sluijs *et al.* (2003) and Wall *et al.* (1977) as heterotrophs found in coastal and oceanic upwelling regions as well as conditions where sea ice is present.

Non Dinocyst Palynomorph Palaeoenvironmental Interpretation								
Taxon	Possible Palaeoenvironment	References						
Acritarch spp	Organic walled cysts that cannot be assigned	Strother (1996)						
	to known groups of organisms.							
Leiosphaeridia spp	Abundant in nutrient rich cold waters,							
	adjacent to sea ice margins, normal to low	Batten (1996)						
	salinity. Ice age indicator of lower salinity.	Wrenn <i>et al.</i> (1998)						
	Occur between margins of pack ice and sea	Mudie (1992)						
	ice in the Arctic							
Prasinophyte algae	Stratified water mass low salinity	Batten (1996)						
	In Arctic waters most abundant in upwelling	Mudie and Harland (1996)						
Cymatiosphaera spp	or nutrient rich waters in normal or low	De Vernal and Mudie						
	salinity	(1992)						
Tasmanites spp	Low temperature, reduced salinity	Guy-Ohlson (1996)						
	Nutrient rich upwelling, shallow water with							
Microforaminiferal	coarser sediment and high salinity.	Stancliffe (1996)						
linings	Occurrences decreasing with increase in							
	water depth.							
	Most abundant in shallow water marine							
Scoledonts	sediments associated with spores and	Szaniawski (1996)						
	acritarchs. Rare in deep water							
Terrestrial	High terriginous output, indicates eutrophic	Crouch and Brinkhuis						
Terrestriur	conditions, possible warmer climate	(2005)						

Table 5.2: Palaeoenvironments related to Quaternary and modern analogues and to other previous work for acritarchs, *Leiosphaeridia, Cymatiosphaera, Tasmanites*, microforaminifera and scoledonts.

Table 5.2 documents various non dinocyst palynomorphs and their suggested palaeoenvironments. The species assigned to the Acritarch genus *Leiosphaeridia*

are abundant near sea ice margins or upwellings. Guy-Ohlson (1996) suggests that Prasinophyte algae such as *Cymatiosphaera* spp and *Tasmanites* may be ice indicators or found in low temperatures situations with reduced salinity. Microforaminiferal linings and scholedonts are most abundant in nutrient rich shallow water, with high salinity and rare in deeper water (Stancliffe, 1996; Szaniawski, 1996). Crouch and Brinkhuis (2005) suggest terrestrial material is an indication of eutrophic conditions, and a possible warmer climate.

5.3 Palynomorph distribution and interpretation

Figure 5.1 shows the distribution of the most dominant or environmentally significant palynomorphs occurring throughout each site. This data is plotted against age in millions of years. The biostratigraphic zones of Chapter 3 are shown with dashed lines for uncertain boundaries. The E/O boundary (~33.7 Ma) and Middle/Late Eocene boundary (~37 Ma) markers are also shown as dashed lines. The vertical arrows indicate palynomorph distribution, dotted arrows indicate palynomorphs are present but fading or sparse, and bars at the tips of the arrows indicate where distribution ends.

The interpreted palaeoenvironment for the four sites (696B, 699A, 748B, 277) shown in Figure 5.2, has been compiled by the translation of the palynomorph distribution laid out in Figure 5.1, to a possible palaeoenvironmental interpretation using Tables 5.1 and 5.2.

5.4 Palaeoclimate Interpretation

5.4.1 Pre Phthanoperidinium echinatum Zone (~46 - ~44.8 Ma)

The Peridinioid dinocysts present together with fluctuations in the numbers of *Operculodinium* spp suggest the Middle Eocene palaeoenvironment (~46-~44.8 Ma) in site 696B to be inner neritic, marginal marine and highly eutrophic with changeable conditions. Its close proximity to the shore would imply that inner neritic waters should be warmer than an open ocean environment. The non dinocysts of *Leiosphaeridia* and Prasinophyte algae are most abundant in cooler **Figure 5.1**: This figure is converted to time in Ma through the nannofossil zones of Berggren *et al.*, (1995). Each site is separated into dinocysts, non dinocysts and terrestrial material. The biostratigraphic zones of Chapter 3 are shown with dashed lines for uncertain or missing positions of their boundaries. The E/O and Middle/Late boundary markers are shown as dashed lines. Verticle arrows show palynomorph distribution. Dotted arrows indicate palynomorphs are present but fading or sparse. Bars at the tips of arrows indicate where palynomorph distribution ends. Each site has been correlated to their positions at the E/O boundary and the nannofossils zones where possible. Condensed sediments and areas with no palynomorphs present are shown as grey. Distribution of palynomorphs that are dominant, significant or useful as palaeoenvironmental indicators are shown.

TIM (Ma	E a) AGE	Okad & Bukr (1980	Martini (1971)	Site 696I South Orkney micro	B continent	Site 69 Northeast Geor	9A rgia Rise	Site 748E Kerguelen Plateau, Rag) Jgatt Basin	South	err
28				DINOCYSTS - DINOCYSTS	· TERRESTRIAL		TERRESTRIAL	DINOCYSTS DINOCYSTS	TERRESTRIAL	DINOCYSTS	· · · ·
29-		CP 19a	NP 24	Brigantedinium	1						
30		\vdash	$\left \cdot \right $	dominate				: No			:
				↑ ± + −	:	: No					
31-					:			Palynomorp	: hs		
	Digocen	17-18	22-23	Sediment	S	Palynomorph	s		- - -	Gonyaulacoids dominate	c
32-	arly O	6	ď					Present	:		:
	ш		Ц	condense	d	- Tresent			•		
33		CP 16b	NP 21	Eurydinium		Impagidinium group Cymatiosphaer dominate present	a			Gonyaulacoids	
34 -		CP 16	ТΙ	spike	· · · ·				:	dominate	:
		\vdash	Η		:			<u>↓</u>	· · ·		:
35-			20	· · · ·		-		Impagidinium . group :	:		Leios
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Figure 5.2: This figure is converted to time in Ma through the nannofossil zones of Berggren *et al.*, (1995). Each site is separated into dinocysts, non dinocysts and terrestrial material. The biostratigraphic zones of Chapter 3 are shown with dashed lines for uncertain or missing positions of their boundaries. The E/O and Middle/Late boundary markers are shown as dashed lines. Verticle arrows indicate palynomorph distribution. Dotted arrows indicate palynomorphs are present but fading or sparse. Bars at the tips of arrows indicate where palynomorph distribution ends. Each site has been correlated to their positions at the E/O boundary and the nannofossils zones where possible. Condensed sediments and areas with no palynomorphs present are shown as grey. Palynomorph interpretation for the palaeoenvironment have been compiled by replacing their distribution laid out in Figure 5.1 with the translation of the possible palaeoenvironment of Tables 5.1 and 5.2.

conditions but are sparse in site 696B and combined with the dominance of terrestrial material the site is indicative of prevailing warmer conditions.

Peridinioid dinocyst are useful in determining cooler conditions, therefore their domination of marine palynomorph assemblages in this site may indicate conditions were cooler than predicted (Crouch and Brinkhuis, 2005). Alternatively their dominance in this site may serve to indicate that they are also tolerant of warmer inner neritic conditions if food is plentiful. Peridinioid dinocysts are also found in cooler oceanic conditions with elevated nutrients, upwellings (i.e. a vertical mixing from the ocean depths of nutrient rich cold waters with surface waters) and sea surface productivity which suggests that the hunt for food was their main objective rather than a specific cool environment in the Southern Ocean.

During this interval site 699A has no palynomorphs present; however, Wei (1991), Takemura and Ling (1996) and Nocchi *et al.* (1991) indicate that nannofossils, radiolarian and foraminifera were present, although microforaminiferal linings were not found in this study at this site. In addition, the absence of dinocysts at this site may be a result of oxidation due to a slow rate of sedimentation (3 m/m.y. averaging 14 m/m.y.). From ~37 Ma the sedimentation rate increased to 25 m/m.y. coinciding with the presence of dinocysts (Shipboard Scientific Party, 1988). However the sedimentation rate may not have been fast enough for some genera to be preserved, as not all the species that were common in the other sites were present in this site (e.g. *Thalassaphora* and *Deflandrea* spp), and many of the palynomorphs that were present were sparse. Therefore the sedimentation rate may still have been too slow to prevent oxidation of the dinocysts.

Site 748B at ~46 Ma is dominated by an acme of the cosmopolitan *Spiniferites* group indicating prevailing oceanic conditions. The non dinocysts (*Cymatiosphaera, Leiosphaeridia, Tasmanites*) present confirm that salinity was reduced and temperatures were low. In site 277 acritarchs are present; however, their exact environmental interpretation is undetermined. Notably there are no other palynomorphs present until ~44.8 Ma in this site (Figures 5.1, 5.2).

5.4.2 Phthanoperidinium echinatum Zone (~44.8 - ~43 Ma)

During the *Phthanoperidinium echinatum* Zone in site 696B, very little change in palynomorph assemblages is evident and an inner neritic palaeoenvironment is still indicated with non dinocysts remaining sparse and a dominance of terrestrial material. Also, there is no change in site 699A as it continues to be barren of palynomorphs.

At ~44.8 Ma the dominance of Gonyaulacoidia species suggests oceanic conditions were present at both sites 748B and 277. However, other dinocysts present (e.g. *Phthanoperidinium* in site 748B and *Thalassaphora* in site 277) point to an environment with nutrient upwelling, which is usually accompanied by cooler oceanic conditions and increased productivity in the upper water column. The presence of the Prasinophyte alga *Tasmanites* in both sites suggests salinity was reduced and that sea ice or cool waters may have been present or deeper oceanic conditions prevailed (Figures 5.1, 5.2).

Above ~44.8 Ma, site 277 does not contain palynomorphs. However, in site 748B up to ~43 Ma, the top of the *Phthanoperidinium echinatum* Zone, the palaeoenvironment was oceanic and warm. This interpretation is suggested by the reduction in numbers of the cooler species of Peridinioids such as *Deflandrea*, *Phthanoperidinium* and *Spinidinium* and may indicate less or no upwelling with calmer oceanic conditions. These changes are considered to be a response to the beginning of a warmer ocean environment which is further supported by the cooler non dinocysts species *Leiosphaeridia* and *Cymatiosphaera* becoming sparse during this interval.

5.4.3 *Phthanoperidinium geminatum* Zone (~43 - ~40.3 Ma)

In this zone sites 696B and 748B contain Middle Eocene strata of the right age for the MECO to be recorded (~41.5 Ma; Bohaty and Zachos, 2003). In site 696B strata, there are no significant changes from the strata below, and Peridinioid dinocysts still dominate during this warmer interval that is indicative of a MECO palaeoenvironment. This implies that the interval was warm and dinocysts present remained unchanged.

In site 748B the palaeoenvironment was oceanic and warm with less of the cooler species of Peridinioids present such as *Deflandrea*, *Phthanoperidinium* and *Spinidinium* or the non dinocysts *Leiosphaeridia* and *Cymatiosphaera*. At ~41.5 Ma acmes of *Thalassaphora* and *Deflandrea* spp indicated enhanced stratification, highly eutrophic, nutrient rich sea surface productivity in the upper water column and high salinity. At ~41 Ma in site 748B an acme of *Spinidinium* alongside the presence of *Deflandrea* signified highly eutrophic sea surface conditions. Also present is an acme of *Leiosphaeridia*, which points to cooler ice edge conditions in nutrient rich cold waters replacing the warmer MECO (Figures 5.1, 5.2).

Site 699A conditions have not changed from ~46 Ma and palynomorphs are not present. Site 277 also has no palynomorphs present.

5.4.4 Phthanoperidinium spA Zone (~40.3 - ~37 Ma)

The Palaeoenvironment remained unchanged in site 696B up to the Middle/Late Eocene boundary (~37 Ma). Site 699A still lacks any palynomorphs.

In site 748B the *Phthanoperidinium* spA Zone cannot be properly documented due to key indicator dinocysts not being present. An acme of *Phthanoperidinium* in this site, suggests the climate continued to be highly eutrophic with offshore sea surface productivity and lower temperatures. Non dinocysts (*Leiosphaeridia, Cymatiosphaera*) indicate the presence of nutrient rich cold waters with normal to low salinity. At ~38.7 Ma marine palynomorph conditions remain constant, while terrestrial material, although sparse, is still present. Additionally the interval between ~38.7 - ~37 Ma is void of all palynomorphs.

In site 277 assemblages of equivalent age (~38.7 Ma) are initially dominated by Peridinioid dinocysts (*Phthanoperidinium, Deflandrea*), equivalent to events in site 748B. The non dinocysts present (*Cymatiosphaera*) point to a possible upwelling of

nutrient rich waters bringing lower temperatures (Figures 5.1, 5.2) and although sparse, terrestrial material is also present. These identified conditions continue up to the Middle/Late Eocene boundary (~37 Ma).

5.4.5 Phthanoperidinium spA Zone (~37 - ~35.4 Ma)

At the Middle/Late Eocene boundary (~37 Ma) in site 696B, Peridinioid dinocysts dominate assemblages, still suggesting an inner neritic palaeoenvironment. In addition, increases of the *Operculodinium* group imply a changing, unstable palaeoenvironment, despite the consistency exhibited by both non dinocysts and terrestrial material during this interval.

Despite not being the dominant palynomorph in site 696B, appearance of the *Operculodinium* group is synchronous with an acme of the *Operculodinium* group occurring in site 277 (~36.8 Ma). Present in site 277, is an initial domination of Peridinioid dinocysts (*Deflandrea*) in combination with the *Operculodinium* group. Sequential intermittent occurrences of Gonyaulacoid (*Corrudinium*) and Peridinioid (*Phthanoperidinium*) dinocysts then continue to dominate until oceanic conditions, (*Impagidinium*) with some offshore sea surface productivity prevail by ~35.4 Ma (Figures 5.1, 5.2). These predictions of cooler conditions are reinforced by analysis of non dinocysts with *Leiosphaeridia* present, being dominant over the *Cymatiosphaera*. Terrestrial material increases through this interval.

The environment in sites 696B and 277 during the early Late Eocene (~37 - ~35.4 Ma) is different to that documented in site 699A, where assemblages of the *Impagidinium* group combined with *Phthanoperidinium* suggest an offshore setting with high surface productivity (~36.8 Ma). The appearance of *Cerebrocysta* at ~36 Ma suggests that the site was becoming oceanic. During this period at 36 Ma the presence of the non dinocyst (*Cymatiosphaera*) suggests possible upwelling or cold nutrient rich waters also evident with sparse terrestrial material. From ~36 Ma Gonyaulacoids dominate, indicating an offshore oceanic environment and cooler conditions associated with the presence of non dinocyst (*Cymatiosphaera, Leiosphaeridia*). Changes in dinocyst assemblages at ~35.3 Ma to one of a

domination of Peridinioid dinocysts, reflect additional coastal/offshore sea surface productivity. Cooler temperatures during this period are signified by the non dinocysts (*Cymatiosphaera, Leiosphaeridia*) and terrestrial material present (Figures 5.1, 5.2).

5.4.6 Corrudinium regulare Zone (~35.4 – 34.8 Ma)

In the middle Late Eocene (~34.8 Ma) site 696B marine palynomorph assemblages continued to be dominated by Peridinioid dinocysts, with the non dinocysts remaining sparse and terrestrial material the most dominant palynomorph present. In contrast the *Corrudinium regulare* Zone in site 699A is void of a key dinocyst indicator in the upper part of the Zone, with a notable lack of marine palynomorphs from ~35.4 Ma. Palynological assemblages from this Zone still yield terrestrial material.

The top of this zone is also recognised in site 748B, with Gonyaulacoid (*Impagidinium*) assemblages indicating an oceanic palaeoenvironment, with a notable lack of Peridinioid dinocysts, non dinocysts and terrestrial material. In contrast, site 277 yielded no dinocysts but non dinocysts are present, with *Leiosphaeridia* dominating, indicating sea ice edge or cold water conditions while the presence of *Cymatiosphaera* suggests cool, nutrient-rich waters. Terrestrial material is still present in this interval.

5.4.7 Post Corrudinium regulare Zone (34.8 - ~29 Ma)

From ~34.8 Ma, site 696B assemblages continue unchanged up to 33.7 Ma (E/O boundary), where the Peridinioid genus *Eurydinium* dominates the dinocysts. Its appearance at the E/O boundary in this site coincided with its appearance in the Late Eocene/Early Oligocene of site 511 (Goodman and Ford, 1983). This key finding suggests this species may be characteristic of the E/O transition in the Southern Ocean. During this period Peridinioid dinocysts continue to dominate the marine palynomorphs. At ~29 Ma *Brigantedinium* spp are most dominant which signifies coastal or oceanic upwelling and possible sea ice conditions. This change replaces the inner neritic palaeoenvironment that was present throughout the

Eocene. In addition, the first occurrences of the Gonyaulacoid genera *Chlamydophorella* and *Batiacasphaera* indicate conditions may have begun to change to a deeper coastal palaeoenvironment in the Early Oligocene. Non dinocysts are sparse remaining unchanged and terrestrial material is still the most dominant Palynomorph in this site.

In site 748B palynomorphs are no longer present however, in the earliest Oligocene at ~33.7 Ma (115 mbsf) ice rafted debris indicates a presence of sea ice with cold conditions (Shipboard Scientific Party, 1992).

At ~33.7 Ma in site 699A, oceanic conditions are indicated by the dominance of Gonyaulacoid dinocyst (*Impagidinium*) assemblages, as the non dinocysts (*Cymatiosphaera, Leiosphaeridia*) indicate nutrient rich waters with upwelling, low salinity and cooler conditions. Terrestrial material continues up to this time, however no palynomorphs are present above the E/O boundary. Those conditions are very similar in site 277 (~33.7 Ma) with Gonyaulacoid dinocysts dominant inferring oceanic conditions and non dinocysts (*Cymatiosphaera, Leiosphaeridia*) indicating upwelling or nutrient rich waters with cooler conditions. Terrestrial material is also present. However, further occurrences are indicated in this site at ~31 Ma with Gonyaulacoids still dominating and conditions being offshore/oceanic. The non dinocysts are dominated by *Cymatiosphaera* which implies upwelling, nutrient rich waters and cooler conditions. Terrestrial material is still present up to this time, with no palynomorphs present above this interval.

In the pelagic sites (699A, 748B, 277) it is considered that many of the marine palynomorphs are no longer present due to the climatic changes at the E/O boundary. The inner neritic site 696B differed in that it contained more palynomorphs and conditions were warmer than the pelagic sites, however this changed during the transition indicating the presence of colder and deeper waters during the Early Oligocene. These occurrences demonstrate that all the sites in this study were affected by the climatic changes during the transition from the Late Eocene culminating at the Oi-1 event of the Early Oligocene



Figure 5.3: A compilation of Southern Ocean stable isotope data taken from ODP sites 689, 690, 738, 744 and 748 adapted from Bohaty and Zachos (2003) as shown in Chapter one, page 6, Figure 1.3. The figure includes text boxes indicating the important events referred to on the isotope chart that can be related to the occurrences or dominance of Gonyaulacoid and Peridinioid dinocysts and non dinocysts. The sites from this study containing marine palynomorphs that are present for each event shown on the isotope chart include the approximate timing in Ma for their occurrences. Attached to each text box an arrow indicates the position of the event on the chart.

5.5 Dinoflagellate Events in a Global Context

The isotope curve of Bohaty and Zachos (2003) (Chapter one, page 6) is repeated in Figure 5.3, along with key marine palynomorphs from Figures 5.1 and 5.2. Significant changes in the presence or absence of marine palynomorphs in this study appear synchronous to the isotope events recorded in Figure 5.3. The figure is a compilation of Southern Ocean stable isotope data based on benthic foraminifera from ODP Sites 689, 690, 738, and 748 between 50 - 32 Ma (Bohaty and Zachos 2003), which complements the timeframe for this study (~46 – ~29 Ma). The EECO at the base of Figure 5.3 shows a steady decline in temperature from ~50 Ma to ~44 Ma. At 41.5 Ma, prominent minimum δ^{18} O values were interpreted as a significant warming and designated as the MECO. A gradual cooling between ~41 – 37 Ma is followed by a further Late Eocene warming at ~36 Ma, and at ~35 Ma the Vonhof *et al.* (2000) cooling occurs. In addition to these events an Oi-1 glacial is recorded at ~33.7 Ma.

5.5.1 EECO Trends

The palaeoclimate interpretations presented (5.4, page 105) also can be related to the warming and cooling events listed in Figure 5.3. Although the EECO is not recorded in this study the cooling trend that followed the event can be seen in sites 748B and 277. An acme for the cosmopolitan *Spiniferites* group at ~46 Ma changed to *Phthanoperidinium* spp and *Tasmanites* at ~44.8 Ma in site 748B indicative of colder waters. In site 277 at ~46 Ma, Acritarchs dominate and at ~44.8 Ma the presence of the non dinocysts *Cymatiosphaera* spp and *Tasmanites* indicate conditions were cooler.

5.5.2 MECO

The MECO warming (~42 – 41 Ma) begins in the *Phthanoperidinium echinatum* zone (~44 Ma), with a dominance of Gonyaulacoid spp in site 748B culminating in an acme for *Thalassaphora* spp between ~41-~42 Ma, the middle of the *Phthanoperidinium geminatum* zone. Also present in site 748B, was an acme for *Deflandrea* spp, possibly indicating elevated nutrient availability, rather than cooler

conditions (Sluijs *et al.*, 2003; 2005). Warmer oceanic conditions occur during this period, with productivity in the upper water column. In contrast in site 696B the MECO was not recorded, although *Operculodinium* spp at the upper part of the *Phthanoperidinium geminatum* zone (~41 Ma) increased significantly, indicating that changes or transitional events were being recorded in this neritic setting. A reduction in the Peridinioid numbers for *Spinidinium* and *Vozzhennikovia* spp were also recorded.

5.5.3 Post MECO

The cooling following the MECO (~41 – ~37 Ma) is reflected in the dinocyst record at the top of the *Phthanoperidinium geminatum* zone (~41.3 Ma), and is seen in sites 699A, 748B and 277. In site 699A (~37 Ma) *Cymatiosphaera* dominate Acritarchs. In site 748B (~41 – ~39 Ma) the Peridinioids of *Deflandrea* spp and an acme for *Spinidinium* spp were recorded. Above the *Phthanoperidinium geminatum* zone an acme for *Phthanoperidinium* spp is present while the non dinocysts have an acme for *Leiosphaeridia* and a presence of other Acritarchs and *Cymatiosphaera*. All are cooler temperature species. This cooling trend is also recorded in site 277 (~36.8 – 36.5 Ma) with a dominance of *Deflandrea* spp. *Cymatiosphaera* and other non dinocysts are present. Conditions are interpreted in all three pelagic sites as offshore/oceanic, upwelling, cold nutrient rich waters, low salinity and lower sea surface temperatures. In addition, site 277 recorded transitional or changing conditions with an acme of *Operculodinium* spp.

5.5.4 Late Eocene Warming

Throughout the Late Eocene in site 696B Peridinioids still dominate, however *Operculodinium* spp increase significantly at ~35.5 Ma suggesting transitional changes were occurring during this period. The Late Eocene warming (~36 Ma) is indicated by dominance of Gonyaulacoids in site 699A, and *Corrudinium* and *Operculodinium* spp in site 277. Conditions were oceanic with high productivity recorded.

5.5.5 Vonhof Cooling

The Vonhof *et al.* (2000) cooling event (~35.4 Ma) in site 699A is reflected in the dominance of *Phthanoperidinium* spp and the presence of non dinocysts (*Cymatiosphaera, Leiosphaeridia*). In site 277 the cosmopolitan *Impagidinium* spp dominate however, *Phthanoperidinium* spp, *Cymatiosphaera* and *Tasmanites* are also present. Again these two sites appear to reflect as cooler ice edge conditions, with nutrient upwelling. In site 696B however, there is little change with Peridinioids still dominating.

5.5.6 Oi-1

The Oi-1 glacial shows no change in site 696B as Peridinioid dinocysts are still dominant. At ~33.7 Ma *Eurydinium* spp is dominant and in the Early Oligocene, *Brigantedinium* and *Vozzhennikovia* spp dominate up to ~30 Ma. In site 699A *Impagidinium* group dominate and *Cymatiosphaera* spp are present at the E/O boundary. In site 277 Gonyaulacoids dominate and *Cymatiosphaera* spp are present between ~37 - 31 Ma. The abundance of these species indicates that oceanic cooler conditions occurred in the Early Oligocene as seen in Figure 5.3.



CHAPTER SIX

6.0 Conclusions

This study has documented climate-induced changes in marine palynomorph assemblages in the Southern Ocean from the Middle Eocene across the E/O transition at the Oi-1 event and into the Early Oligocene. A total of 107 samples from four ODP and DSDP sites were processed for their palynological content. The locations of the investigated sites are the South Orkney microcontinent, in the Weddell Sea (ODP site 696B), the Northeast Georgia Rise, Falkland's area (ODP site 699A), the Western part of the Raggart Basin on the Kerguelen Plateau (ODP site 748B), and in the Cathedral Depression on the southern Campbell Plateau (DSDP site 277). The locations provided an interesting comparison and analysis of areas in the Southern Ocean.

An additional 47 samples from two sites (690B, 738B) were also processed but later discarded due to a lack of palynomorphs. In most cases the sediments proved difficult to process due to fungal contamination, requiring longer processing of the nannofossil ooze. Best results were achieved with additional sieving of the finer material in each sample to give an accurate count of the palynomorphic contents. Total abundance of assemblages included dinocysts, non dinocysts, microforaminiferal linings, insect casings and terrestrial material.

A standard nannofossil biostratigraphy was established in chapter two for all sites, using a timescale (Ma) by Berggren *et al*. (1995). The data were investigated to provide a temporal framework for this study.

The broad aim of this study was to document changes in marine palynomorph assemblages in the Middle Eocene/Early Oligocene. More specifically the first aim was to develop a Circum-Antarctic biozonation for the climate transition in the Southern Ocean. Using the nannofossil biostratigraphy as a framework, a new biozonation was achieved by identifying datum (first and last occurrences) correlations at each site that occurred in the same temporal order and the same nannofossil zone. The results show the assignment of six primary and two secondary datums, leading to the recognition of four new biozones. These were the *Phthanoperidinium echinatum* (~45-~43 Ma), *Phthanoperidinium geminatum* (~43- ~40.5 Ma), *Phthanoperidinium* spA Zones (~40.5-36.4 Ma) and the *Corrudinium regulare* Zone (~36.4-~34.2 Ma). These zones were then used to identify various dinocyst events to indicate probable palaeoenvironments. This process was complicated by condensed or missing sediments in some sites affecting dinocyst occurrences (699A, 748B, 277). Site 696B proved to be the most stable palaeoenvironment, producing the best biostratigraphy for the Southern Ocean, and was complemented at differing timeframes, by the other three sites.

The second aim was to document the Circum-Antarctic distribution of palynomorph assemblages. This was accomplished by presenting the palynomorphs from each site as a total abundance of grains per gram. Analysis of the ranges and compositions of palynomorphs present was also displayed as a percentage of total abundance in each site, giving insight into palynomorphic distribution patterns.

To accomplish the third aim of documenting the effect of palaeoclimatic changes in the dinocysts assemblages, to the range of palaeoenvironmental signals, the dinocyst distribution was separated into Gonyaulacoid and Peridinioid assemblages. The Gonyaulacoid dinocysts are predominantly oceanic autotrophs while the Peridinioids are considered to be mostly heterotrophic and inner neritic, although they are also prevalent in oceanic palaeoenvironments that generate productivity and nutrient upwelling in the water column. A further grouping of the dinocysts was undertaken in order to place together morphologically related taxa associated to a known environmental affinity, to assist with interpretation of the palaeoenvironment in each site. Additionally, totals of Gonyaulacoid and Peridinioid dinocysts were combined with non dinocysts and terrestrial material for comparison and to provide further assistance with interpretation. Previous work in the Southern Ocean and Antarctica gave an indication of suggested palaeoenvironments for dinocysts and non dinocyst (including terrestrial) material, which additionally provided concise reference points for this study.

Comparison between each site showed that the Weddell Sea (site 696B) was the most climatically stable of the four sites. Here terrestrial material dominated all

palynomorph assemblages, with Peridinioid dinocysts in turn dominating the identified marine palynomorphs. The indications were for a warmer inner neritic palaeoenvironment indicated by an approximate water depth of less than 100 m, a high abundance of terrestrial material and few of the cooler species of Prasinophyte algae and Leiosphaeridia. Some possible transitional changes may have occurred due to Operculodinium present, although the site remained constant through to the middle of the Late Eocene (~36 Ma). The pelagic sites where palynomorphs were present demonstrated a different palaeoenvironment. On the Kerguelen (site 748B) and Campbell (site 277) Plateaus at ~46 Ma, oceanic conditions with low temperatures prevailed and by 45 Ma, additional nutrient upwelling and high productivity was recorded in the upper water column, while overall conditions remained cool. The only pelagic site that contained palynomorphs during most of the Middle Eocene was site 748B on the Kerguelen Plateau. This site illustrated an oceanic and warm period between ~44 - ~42 Ma, in addition, at ~41.5 Ma productivity was inferred in the upper water column. This period of warming and productivity was not, however, illustrated in the Weddell Sea (site 696) as the palaeoenvironment was already significantly warmer and did not register the changes that were shown in site 748B.

Between ~41-~38.7 Ma, site 748B underwent significant changes in palynomorph assemblages indicating that the palaeoenvironment was becoming cooler, with high productivity in the sea surface and highly eutrophic conditions prevailing. At ~39 Ma nutrient rich waters and upwelling is inferred, and the same conditions can be found on the Campbell Plateau (site 277) from ~38.7 Ma up to the Late Eocene (~37 Ma). During the Late Eocene conditions changed both in the Weddell Sea (site 696B) and on the Campbell plateau (site 277), with both sites indicating changeable conditions through the presence of *Operculodinium* spp. The conditions were more pronounced in site 277 with *Deflandrea* dominating at ~36.5 Ma, which changed to a domination of *Impagidinium* by ~35.3 Ma indicating deeper, oceanic and conditions were cooler, while site 696B remained as inner neritic with suggested warm conditions. In contrast the Falklands (site 699A) differed with cooler, oceanic (*Impagidinium*) sea surface high productivity suggested during this interval. By ~35.3 Ma Gonyaulacoid dinocysts were

dominated by Peridinioid dinocysts and coastal/offshore conditions with high sea surface productivity prevailing.

At the E/O transition (~33.7 Ma) the Weddell Sea (site 696B) is dominated by the Peridinioid dinocyst *Eurydinium* whose possible palaeoenvironment is unknown but may be considered as a transitional species. In the Falklands region (site 699A), the palaeoenvironment was oceanic and upwellings of nutrient rich cold waters continued, similar to the possible conditions on the Campbell Plateau (site 277). The Kerguelen Plateau (site 748B) was barren of palynomorphs; however, ice rafted debris was present suggesting cold sea surface conditions.

In the Early Oligocene indications of change in the Weddell Sea (site 696B) were identifiable with a slight increase in Gonyaulacoid dinocysts, indicating a possible outer neritic/coastal palaeoenvironment. These changes continued and by ~29 Ma coastal/oceanic upwelling (deepening) and possible sea ice conditions were present. The Falklands (site 699A) and Kerguelen Plateau (site 748B) were both barren of palynomorphs during this interval, while at the Campbell Plateau (site 277) ~30 Ma cooler conditions, offshore/oceanic upwelling or nutrient rich waters were predominant.

Key findings between all sites in this study illustrate that the pelagic and inner neritic sites differed greatly in the Southern Ocean. In the inner neritic site Peridinioid dinocysts dominated, conditions were warmer and changes occurred more slowly. In comparison the pelagic sites were unstable and showed condensed sequences or missing sediments, with palynomorphs not present during those times. However, known palynomorph markers (e.g. Peridinioid dinocysts, Prasinophyte algae, *Leiosphaeridia*) for temperature change were present throughout the pelagic sites, highlighting the climatic changes occurring throughout the Middle Eocene/Early Oligocene.

In addition, Peridinioid (heterotrophic) dinocysts were present in both warm, inner neritic conditions and colder, oceanic upwelling palaeoenvironments. Perhaps this illustrates Peridinioid dinocysts were tolerant to changes in ocean temperatures, and the productivity in the Southern Oceans was the main reason for their presence. The preference of non dinocysts (Prasinophyte algae and *Leiosphaeridia*) for colder conditions, are more indicative of cooler temperature changes in the Southern Ocean.

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Appendices

NOMENCLATURE

An alphabetical list of all marine palynomorphs is provided below with most illustrated on Plates 1-27. The synonymy lists are not intended to be complete. The taxonomic citations can be found in Lentin and Williams (2004), the electronic version also used is from DINOFLAJ2 (Fensome *et al.*, 2008). Included is a reference to the journal used in identifying each genus or species.

Domain Eukarya Woese *et al.* 1990 Kindom Alveolata Cavalier-Smith 1991 Phylum Dinoflagellata Bütschli 1885 Class Dinophyceae (Bütschli 1885) Pascher 1914 Subclass Peridiniphycidae Fensome *et al.* 1993b Order Gonyaulacales Taylor 1980 Suborder Gonyaulacineae Taylor 1980 Family Gonyaulacaceae Lindemann 1928

Genus: Achomosphaera Evitt, 1963; Lentin and Williams 1989.

Achomosphaera alcicornu Eisenack 1954b

Fensome et al. (2009)

Plate 1, Images 1-3

Occurrences: 699A Late Eocene present 748B Middle Eocene common 277 Middle Eocene present

Genus: Alisocysta Stover and Evitt 1978

Alisocysta circumtabulata (Drugg, 1967) Stover and Evitt, 1978

Brinkhuis et al., (2003b)

Plate 1, Images 4-6

Occurrences: 696B Middle Eocene present 748B Middle Eocene present 277 Middle-Late Eocene present

Genus: Batiacasphaera Drugg, 1970b

Goodman and Ford (1983)

Plate 2, Images 1-4

Occurrences: 696B Early Oligocene common 699A Late Eocene common 748B Middle-Late Eocene present 277 Middle Eocene-Early Oligocene present

Genus: Cerebrocysta Bujak et al., 1980

Cerebrocysts bartonense Bujak et al., 1980

Brinkhuis et al., (2003b)

Plate 2, Images 5-6

Occurrences: 748B Middle Eocene common 277 Middle Eocene present

Cerebrocysta delicata Wilson, 1988

Wilson, (1988)

Plate 3, Images 3-6; Plate 4, Images 1-2

Comment: Cerebrocysta has been the preferred name for species of the mainly

Cenozoic group. Pyxidiniopsis is preferred for Jurassic-Neocomian grouping by

Fensome et al. (2009).

Occurrences: 699A Early Oligocene present 748B Middle Eocene abundant 277 Middle Eocene present

Cerebrocysta cf delicata

Comment: *Cerebrocysta* cf *delicata* differs in size (~27 μm) from *Cerebrocysta delicata* (~40 μm).

Plate 4, Images 3-4

Occurrences: 748B Middle Eocene common 277 Middle Eocene common

Cerebrocysta mundus n sp Clowes, (2009)

Clowes, 2009, PI.74 figs 4-12

Occurrences: 696B Late Eocene present 699A Late Eocene present 748B Middle Eocene present 277 Middle Eocene-Early Oligocene present

Cerebrocysta teuriensis n sp Clowes, (2009)

Clowes, 2009, Pl.72 figs 7-12; Pl.73, figs 1-6

Occurrences: 277 Late Eocene present Cerebrocysta waipawaense Wilson, 1988

Fensome et al. (2009)

Plate 3, Images 1-2

Occurrences: 699A Early Oligocene present 748B Middle Eocene common

Genus: Chlamydophorella Cookson and Eisenack, 1958

Fensome et al. (2009)

Plate 4, Images 5-6

Occurrences: 696B Late Eocene-Early Oligocene common 699A Late Eocene present 748B Middle Eocene abundant 277 Middle-Late Eocene common

Genus: Cordosphaeridium Eisenack, 1963b emend Morgenroth, 1968.

Cordosphaeridium inodes Eisenack, 1963b emend Morgenroth, 1968.

Cookson and Eisenack (1967a)

Occurrences: 696B Late Eocene present

Genus: Corrudinium Stover and Evitt, 1978

Corrudinium eyrense n. sp

Clowes and Wilson (2006)

Plate 5, Images 1-2

Occurrences: 277 Late Eocene present

Corrudinium incompositum (Drugg, 1970) Stover and Evitt, 1978.

Clowes and Wilson (2006)

Plate 5, Images 3-4

Occurrences: 748B Middle Eocene present

Corrudinium obscurum Wilson, 1988

Clowes and Wilson (2006)

Occurrences: 277 Late Eocene present

Corrudinium otagoense n sp; (Wilson, 1982a)

Clowes and Wilson (2006)

Plate 5, Images 5-6

Occurrences: 748B Middle Eocene abundant 277 Late Eocene present

Corrudinium regulare n sp.

Clowes and Wilson (2006)

Plate 6, Images 1-4

Occurrences: 696B Middle-Late Eocene present 699A Late Eocene-Early Oligocene present 748B Middle-Late Eocene abundant 277 Middle-Late Eocene common

Genus: Dapsilidinium Bujak et al., 1980

Dapsilidinium pseudocolligerum Stover, 1977

Fensome et al. (2009)

Plate 6, Images 5-6

Occurrences: 748B Middle Eocene present 277 Middle Eocene present

Genus: Enneadocysta Stover and Williams, 1995

Enneadocysta partridgei Stover and Williams, 1995

Levy and Harwood (2000)

Plate 7, Images 1-2

Occurrences: 696B Middle Eocene-Early Oligocene common-abundant 748B Middle Eocene present

Genus: Forma B, n sp Goodman and Ford, 1983

Goodman and Ford (1983)

Plate 7, Image 3

Occurrences: 748B Middle Eocene present

Genus: Glaphyrocysta Stover and Evitt, 1978

Glaphyrocysta retiintexta Cookson, 1965a

Fensome et al. (2009)

Occurrences: 696B Late Eocene and Early Oligocene present Genus: Graptodinium n gen Clowes 2009

Graptodinium inconditum Meiourogonyaulax sp cf. 1976

Plate 7, Image 4

Occurrences: 748B Middle Eocene present 277 Middle-Late Eocene present

Graptodinium reticulatum Clowes, n sp 2009

Clowes n sp (2009)

Plate 8, Image 1

Occurrences: 696B Early Oligocene present 277 Middle Eocene present

Genus: Hapsocysta Davey, 1979b

Hapsocysta kysingensis sp nov

Heilmann-Clausen and van Simaeys (2005)

Plate 7, Images 5-6

Occurrences: 748B Middle Eocene present 277 Middle Eocene present

Genus: Heteraulacacysta Drugg and Loeblich Jr., 1967.

Heteraulacacysta pustulata Jan du Chêne and Adediran, 1985

In Fensome *et al*. (2009)

Occurrences: 748B Middle Eocene present

Genus: Hystrichokolpoma Klumpp, 1953,

Brinkhuis et al. (2003b)

Occurrences: 696B Late Eocene present

Genus: Hystrichosphaeridium Deflandre, 1937b.

Occurrences: 748B Middle Eocene common

Hystrichosphaeridium brevispinum Davey and Williams 1966b

Wilson (1988)

Occurrences: 277 Middle Eocene present

Hystrichosphaeridium truswelliae Wrenn and Hart, 1988

Brinkhuis et al. (2003b)

Occurrences: 696B Middle Eocene present

Hystrichosphaeridium tubiferum (Ehrenberg, 1838), Deflandre 1937b.

Brinkhuis et al. (2003b)

Occurrences: 277 Middle Eocene present

Genus: Impagidinium Stover and Evitt, 1978

Impagidinium aculeatum Wall, 1967

Schioler (2005) Pl.9, fig 15.

Plate 8, Image 2

Occurrences: 699A Late Eocene-Early Oligocene present 748B Middle Eocene common 277 Middle-Late Eocene present

Impagidinium crassimuratum, Wilson, 1988

Wilson (1988)

Plate 8, Images 3-4

Occurrences: 696B Middle Eocene present 748B Middle Eocene present 277 Middle Eocene common

Impagidinium dispertitum (Cookson and Eisenack, 1965a) Stover and Evitt, 1978.

Wilson (1988)

Plate 8, Image 5

Occurrences: 696B Middle Eocene present 699A Late Eocene present 748B Middle Eocene abundant 277 Middle Eocene-Early Oligocene present

Impagidinium elegans (Cookson and Eisenack, 1965a) Stover and Evitt, 1978.

Plate 8, Image 6; Plate 9, Image1

In Wilson (1982b)

Occurrences: 696B Middle Eocene present 748B Middle Eocene present 277 Middle Eocene present Impagidinium maculatum (Cookson and Eisenack, 1961b) Stover and Evitt, 1978

Brinkhuis et al. (2003b)

Plate 9, Images 2-3

Occurrences: 699A Early Oligocene present 748B Middle Eocene present 277 Late Eocene present

Impagidinium parvireticulatum Wilson, 1988

Wilson (1988)

Plate 9, Image 4

Occurrences: 748B Middle Eocene acme 277 Middle Eocene present

Impagidinium victorianum (Cookson and Eisenack, 1965a) Stover and Evitt, 1978

Brinkhuis et al. (2003b)

Plate 9, Image 5-6

Occurrences: 696B Middle Eocene-Early Oligocene present 699A Late Eocene-Early Oligocene common 748B Middle-Late Eocene abundant 277 Middle Eocene-Early Oligocene present

Genus: Impletosphaeridium Morgenroth, 1966a

Levy and Harwood (2000)

Plate 10, Image 1

Occurrences: 696B Middle Eocene-Early Oligocene abundant 748B Middle-Late Eocene common 277 Middle-Late Eocene abundant

Genus: Lophocysta Manum, 1979

Goodman and Ford (1983)

Plate 10, Image 2

Occurrences: 699A Late Eocene present 748B Middle Eocene common 277 Middle Eocene-Early Oligocene present

Genus: Minisphaeridium n gen Davey and Williams, 1969

Minisphaeridium group Fensome et al., 2009

Fensome et al (2009)

Plate 10, Images 4-5

Occurrences: 696B Middle Eocene-Early Oligocene abundant 699A Late Eocene present 748B Middle Eocene acme 277 Late Eocene common

Minisphaeridium latirictum Davey and Williams 1966b.

Fensome et al (2009) Pl.6 figs r-t

Plate 10, Image 3

Occurrences: 696B Middle-Late Eocene common 748B Middle Eocene present 277 Middle Eocene abundant

Genus: Moria gen nov. Sluijs et al., 2009

Moria zachosii sp nov Sluijs et al., 2009

Sluijs et al. (2009)

Plate 10, Image 6

Occurrences: 696B Middle-Late Eocene present

Genus: Nematosphaeropsis Deflandre and Cookson, 1955 emend. Wrenn, 1988.

Brinkhuis et al. (2003b)

Plate 11, Images 1-2

Occurrences: 696B Middle-Late Eocene present 699A Late Eocene present 748B Middle Eocene abundant 277 Middle Eocene-Early Oligocene common

Genus: Odontochitina Deflandre, 1937b emend Davey, 1970.

Fensome et al (2009)

Plate 11, Image 3

Occurrences: 699A Late Eocene present

Genus: Oligosphaeridium Davey and Williams, 1966b. emend. Davey 1982b

Fensome et al (2009)

Occurrences: 696B Middle Eocene-Early Oligocene present

Genus: Operculodinium Wall, 1967, Emend. Matsuoka et al., 1997

Levy and Harwood (2000)

Plate 11, Images 4 and 6

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 699A Late Eocene present 748B Middle Eocene abundant 277 Middle Eocene-Early Oligocene acme

Operculodinium janduchenei Head et al., 1989b

Brinkhuis et al. (2003a)

Plate 11, Image 5

Occurrences: 696B Middle Eocene present 699A Late Eocene present 748B Middle Eocene common 277 Late Eocene present

Genus: Paucisphaeridium Bujak et al., 1980

Paucishaeridium inversibuccinum (Davey and Williams, 1966b) Bujak et al., 1980

Levy and Harwood (2000)

Plate 12, Image 1

Occurrences: 696B Middle Eocene-Early Oligocene present 277 Late Eocene common

Genus: Samlandia Eisenack, 1954b

Samlandia reticulifera Cookson and Eisenack, 1965a

Goodman and Ford (1983)

Plate 12, Images 2-5

Occurrences: 748B Middle-Late Eocene present 277 Late Eocene present

Samlandia spp

Plate 12, Image 6; Plate 13, Images 1-6

Occurrences: 696B Middle-Late Eocene present 748B Middle Eocene present

Genus: Schematophora Deflandre and Cookson, 1955

Brinkhuis et al. (2003b)

Occurrences: 696B Late Eocene present

Genus: Spiniferites Mantell, 1850

Brinkhuis et al. (2003b)

Plate 14, Images 1-5

Occurrences: 696B Middle Eocene-Early Oligocene abundant 699A Late Eocene present 748B Middle Eocene acme 277 Middle Eocene-Early Oligocene high abundance

Genus: Systematophora Klement, 1960; emend. Brenner, 1988

Systematophora placacantha (Deflandre and Cookson, 1955) Davey et al., 1969

Goodman and Ford (1983)

Occurrences: 696B Middle Eocene-Early Oligocene present

Systematophora ?variabilis (Cookson and Eisenack, 1967a) Stover and Evitt, 1978

Cookson and Eisenack, 1967a as Cyclonephelium Pl 19 9-11

Occurrences: 696B Middle Eocene-Early Oligocene present

Genus: Tectatodinium Wall, 1967. Emend. Head, 1994a

Schiøler (2005)

Plate 15, Image 1

Occurrences: 699A Late Eocene present 748B Middle Eocene present 277 Late Eocene common

Genus: Thalassaphora Eisenack and Gocht, 1960. Emend. Gocht, 1968

Levy and Harwood (2000)

Plate 15, Image 2-4

Occurrences: 748B Middle Eocene acme 277 Late Eocene common Genus: Trichodinium Eisenack and Cookson, 1960, emend. Clarke and Verdier,

1967

Trichodinium hirsutum Cookson, 1965b

Williams et al. (2004)

Occurrences: 748B Middle Eocene present

Genus: Turbiosphaera Archangelsky, 1969a

Turbiosphaera filosa (Wilson, 1967a) Archangelsky, 1969a

Levy and Harwood (2000)

Plate 15, Image 5-6

Occurrences: 696B Middle-Late Eocene common 748B Middle Eocene present

> Domain Eukarya Woese *et al.* 1990 Kindom Alveolata Cavalier-Smith 1991 Phylum Dinoflagellata Bütschli 1885 Class Dinophyceae (Bütschli 1885) Pascher 1914 Subclass Peridiniphycidae Fensome *et al.* 1993b Order Peridiniales Haeckel 1894 Suborder Peridinlineae Haeckel 1894 Family Peridiniaceae Ehrenberg 1831

Genus: Alterbidinium Lentin and Williams, 1985; emend. Khowaja-Ateequzzaman

and Jain, 1991

Alterbidinium ?distinctum (Wilson, 1967a) Lentin and Williams 1985

Levy and Harwood (2000)

Plate 16, Images 1-6; Plate 17, Images 1-2

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene present

Alterbidinium ?asymmetricum Wilson, 1967

Wilson, (1989)

Occurrences: 696B Middle-Late Eocene present 699A Late Eocene present 748B Middle Eocene abundant 277 Middle Eocene present

Genus: Brigantedinium Reid, 1977, ex Lentin and Williams, 1993

Brinkhuis et al. (2003a)

Plate 17, Images 3-4

Occurrences: 696B Early Oligocene abundant

Genus: Cerodinium Vozzhennikovia, 1963 emend. Lentin and Williams, 1987.

Brinkhuis et al. (2003a)

Plate 17, Image 5

Occurrences: 277 Late Eocene present

Genus: Deflandrea Eisenack 1938b. emend Williams and Downie, 1966c; Stover,

1974.

Deflandrea antarctica Wilson, 1967a

Wilson (1988)

Plate 17, Image 6; Plate 18, Images 1-2

Occurrences: 696B Middle Eocene-Early Oligocene abundant 748B Middle Eocene acme 277 Middle-Late Eocene abundant

Deflandrea convexa Wilson 1988,

Wilson (1988)

Plate 18, Images 3-4

Occurrences: 748B Middle Eocene common

Deflandrea cygniformis Pöthe de Baldis, 1966

Wrenn and Hart (1988)

Plate 18, Images 5-6

Occurrences: 696B Middle Eocene present 277 Middle Eocene present Deflandrea dartmoorium Cookson and Eisenack, 1965b

Stover (1973)

Plate 19, Images 1-2

Occurrences: 277 Middle Eocene present

Deflandrea flounderensis Stover, 1974.

Stover (1973)

Plate 19, Images 3-4

Occurrences: 748B Middle Eocene present

Deflandrea leptodermata

Stover (1973)

Plate 19, Image 5

Occurrences: 748B Middle Eocene present

Deflandrea medcalfii Stover, 1974

Wilson (1988)

Occurrences: 277 Late Eocene present

Deflandrea phosphoritica Eisenack, 1938b

Stover (1973)

Plate 19, Image 6; Plate 20, Image 1

Occurrences: 696B Middle-Late Eocene present 748B Middle Eocene present

Deflandrea scabrata Wilson, 1988

Wilson (1988)

Occurrences: 277 Late Eocene present

Deflandrea truncata Stover, 1974

Wilson (1988)

Occurrences: 748B Middle Eocene present 277 Middle Eocene present

Genus: Diconodinium Eisenack and Cookson, 1960 emend. Morgan, 1977

Diconodinium cristatum Cookson and Eisenack, 1974

Wrenn and Hart (1988)

Plate 20, Image 2

Occurrences: 696B Middle- Late Eocene present

Genus: Eurydinium Stover and Evitt, 1978

Goodman and Ford (1983)

Plate 20, Images 3-4

Occurrences: 696B Late Eocene abundant

Genus: Lejeunecysta Artzner and Dörhöfer, 1978

Lejeunecysta cowiei Hannah et al., 1998

Hannah et al. (1998)

Plate 20, Image 5

Occurrences: 696B Middle-Late Eocene common

Lejeunecysta fallax (Morgenroth, 1966b) Artzner and Dörhöfer, 1978 emend. Biffi

and Grignani, 1983.

Wrenn and Hart (1988)

Plate 20, Image 6; Plate 21, Image 1

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene present 277 Late Eocene present

Genus: Manumiella Bujak and Davies, 1983

Manumiella druggii (Stover, 1974) Bujak and Davies, 1983

Brinkhuis et al. (2003a)

Occurrences: 277 Late Eocene present

Genus: Octodinium Wrenn and Hart, 1988

Octodinium askiniae Wrenn and Hart, 1988

Brinkhuis et al. (2003a)

Plate 21, Image 1

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene common

Genus: Phthanoperidinium Drugg and Loeblich Jr., 1967 emend. Islam, 1982

Phthanoperidinium aculeatum (Benedek, ?1972) n sp Clowes

Clowes (PhD thesis) 2009

Occurrences: 277 Middle Eocene present

Phthanoperidinium crenulatum (de Coninck, 1975) Lentin and Williams, 1977b

Clowes (PhD thesis) 2009

Plate 21, Image 2

Occurrences: 696B Middle Eocene present 748B Middle Eocene common 277 Middle Eocene abundant

Phthanoperidinium dentatum Wilson 1982b

Clowes (PhD thesis) 2009

Plate 21, Images 3-4

Occurrences: 696B Middle Eocene present 699A Late Eocene abundant 748B Middle Eocene acme 277 Late Eocene present

Phthanoperidinium echinatum Eaton, 1976

Brinkhuis et al. (2003a)

Plate 21, Image 5

Occurrences: 696B Middle Eocene present 748B Middle Eocene abundant 277 Middle Eocene common

Phthanoperidinium eocenicum (Cookson and Eisenack, 1965a) Lentin and Williams,

1973.

Cookson and Eisenack (1965) (as Peridinium eocenicum)

Occurrences: 277 Middle Eocene present

Phthanoperidinium geminatum Bujak et al., 1980

Schiøler (2005)

Plate 21, Image 6; Plate 22, Image 1

Occurrences: 696B Middle Eocene present 699A Late Eocene present 748B Middle Eocene common 277 Middle Eocene common

Phthanoperidinium granulatum Clowes and Wilson, 2009 n sp.

Clowes (PhD thesis) 2009

Occurrences: 696B Early Oligocene present

Phthanoperidinium spA Goodman and Ford, 1983

Goodman and Ford (1983)

Plate 22, Images 2-3

Occurrences: 696B Late Eocene present 699A Late Eocene present 748B Middle Eocene common 277 Middle-Late Eocene common

Phthanoperidinium sp1 n sp

Plate 22, Images 4-6

Occurrences: 696B Early Oligocene present 699A Late Eocene common 277 Late Eocene present

Genus: Rhombodinium Gocht, 1955 emend. Bujak, 1979

Head and Norris (1989)

Plate 23, Images 1-3

Occurrences: 748B Middle Eocene present

Genus: Satyrodinium Lentin and Manum, 1986

Satyrodinium bengalense Lentin and Manum, 1986

Roncaglia (1999)

Occurrences: 696B Middle Eocene present 277 Middle Eocene present

Satyrodinium haumuriense (Wilson, 1984c) Lentin and Manum, 1986

Roncaglia (1999)

Occurrences: 277 Middle Eocene present

Genus: Selenopemphix Benedek, 1972 emend. Head, 1993

Selenopemphix nephroides Benedek, 1972 emend. Head, 1993

Brinkhuis et al. (2003a)

Plate 23 Image 4

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 277 Middle Eocene present

Genus: Spinidinium Cookson and Eisenack, 1962b emend. Lentin and Williams,

1976

Spinidinium colemanii Wrenn and Hart, 1988

Levy and Harwood (2000)

Plate 23, Image 5-6

Occurrences: 696B Middle Eocene present

Spinidinium essoi Cookson and Eisenack, 1967a

Levy and Harwood (2000)

Plate 24, Images 1-3

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene present 277 Middle Eocene present

Spinidinium luciae Wrenn and Hart, 1988

Brinkhuis et al. (2003a)

Plate 24 Image 4; Plate 25 Images 1-3

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 699A Late Eocene present 748B Middle Eocene abundant 277 Middle Eocene common

Spinidinium macmurdoense (Wilson 1967a) Lentin and Williams, 1976

Brinkhuis et al. (2003a)

Plate 25 Images 4-6

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene present

Spinidinium sp1 n sp

Plate 23, Images 5-6

Occurrences: 699A Late Eocene common 748B Middle Eocene acme

Genus: Vozzhennikovia Lentin and Williams, 1976

Vozzhennikovia apertura (Wilson, 1967a) Lentin and Williams, 1976

Levy and Harwood (2000)

Plate 26 Images 1-3

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle Eocene abundance

Vozzhennikovia netrona Mohr, 1990

Levy and Harwood (2000)

Plate 26 Image 4-6

Occurrences: 696B Middle Eocene-Early Oligocene high abundance 748B Middle-Late Eocene high abundance

Informal group Acritarcha, Evitt 1963a

Acritarchs

Plate 27, Images 1-2

Occurrences: 696B Middle Eocene-Early Oligocene present 699A Late Eocene present 748B Middle Eocene high abundance 277 Middle Eocene abundant

Genus: Cyclopsiella Drugg and Loebilch, 1967

Levy and Harwood (2000)

Plate 27, Image 3

Occurrences: 696B Middle-Late Eocene abundant

Genus: Cystidiopsis Nagy, 1965

Wrenn and Hart (1988) P394 24 4-5

Occurrences: 699A Late Eocene present

277 Late Eocene present

Genus: Fenestridium clathrodermum (Clowes and Morgans, 1984) n sp Clowes

(PhD thesis) 2009

Clowes and Morgans (1984) as 'Valensiella' clathroderma p36

Plate 27, Image 4

Occurrences: 696B Middle Eocene present 699A Late Eocene present 748B Middle Eocene present 277 Late Eocene common

Genus: Paucilobimorpha De Coninck, 1986b

Paucilobimorpha inequalis De Coninck, 1986b, emend Prössl, 1994

Truswell (1997)

Occurrences: 277 Middle Eocene present

Genus: Leiosphaeridia Eisenack, 1958c

Hannah et al. (2000)

Plate 27 Image 5

Occurrences: 696B Middle Eocene present 699A Late Eocene present 748B Middle Eocene high abundance plus an acme 277 Middle Eocene-Early Oligocene abundant

> Division Chlorophyta Pascher, 1914 Class Chlorophyceae Kützing, 1843 Order Chlorococcales Marchand, 1895 orth. Mut. Pascher, 1915 Family chlorococcaceae Blackman and Tansley, 1902 Genus: Palamages Wetzel, 1961

> > Levy and Harwood (2000)

Plate 27 Image 6

Occurrences: 696B Middle Eocene present 277 Middle Eocene present

Division Prasinophyta, Round, 1971 Class Pterospermatales Family Cymatiosphaeraceae

Genus: Cymatiosphaera Wetzel, 1961

Hannah et al. (2000)

Plate 28 Images 1-2

Occurrences: 696B Middle Eocene-Early Oligocene abundant 699A Late Eocene common 748B Middle Eocene high abundance 277 Middle Eocene-Early Oligocene abundant

Family Pterospermellaceae

Genus: Pterospermella

Hannah et al. (2000)

Occurrences: 748B Middle Eocene present 277 Middle- Late Eocene common

Family Tasmanitaceae

Genus: Tasmanites Newton, 1875

Prebble et al. (2005)

Plate 28, Image 3

Occurrences: 696B Late Eocene present 748B Middle Eocene high abundance 277 Middle Eocene-Early Oligocene abundant

Kingdom Rhizaria,

Superphylum, retaria

Microforaminifera Góczán, 1962

Microforaminiferal linings Stancliffe, 1996

Plate 28, Images 4-5

Occurrences: 696B Middle Eocene-Early Oligocene abundant 748B Middle Eocene present 277 Middle Eocene-Early Oligocene abundant

Insect Casing

Plate 28, Image 6

Occurrences: 696B Middle Eocene-Early Oligocene common 699A Middle-Late Eocene common 748B Middle Eocene present 277 Late Eocene present

Terrestrial Material

Occurrences: 696B Middle Eocene-Early Oligocene very high abundances 699A Late Eocene-Early Oligocene common 748B Middle Eocene common 277 Middle Eocene-Early Oligocene abundant

Plate 1



Illustrations of taxa, (cyst number, sample, slide coordinates and scale of length, includes processes unless otherwise stated). Scale taken from X100.

^{1-3.} *Achomosphaera* spp (120-19H-1A, X53.5Y111, 100 μm). 4-6. *Alisocysta* spp (120-23X-3A, X46Y99.5, 45 μm; 120-23-3B, X53.5Y105, 45 μm).

Plate 2



1-2. Batiacasphaera perforata (29-29-2Boa, X54.5Y111, 60 $\mu m;$ 113-59R-2, X56Y106, 100 $\mu m).$

3-4. *Batiacasphaera* spp (3. 114-33X-2A, X49.8Y97, 45 μm; 4. 113-56R-1A, X36.5Y99, 55 μm).

5-6. *Cerebrocysta bartonense* (120-23X-1A, X32Y94, 25 μm).

Plate 3



1-2. Cerebrocysta waipawaense (120-18H-4A, X50Y100, 50 μm). 3-6. Cerebrocysta delicata (120-20H-5A, X36.5Y108, 43 μm; 120-20H-1A, X33Y101, 40 μm).

Plate 4









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1-2. Cerebrocysta delicata (120-20H-1A, X33Y101, 40 μm). 3-4. Cerebrocysta cf delicata (120-19H-1A, X49.8Y94.5, 27 μm; 29-32-1A, X50Y101.5, 25 μm).

5-6. *Chlamydophorella neopilata* (120-17H-4B, X40Y94, 34 µm).

Plate 5









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- 1-2. Corrudinium eyrense (29-22-2B, X59Y96, 55 $\mu m).$
- 3-4. *Corrudinium incompositum* (29-26-1A, X31Y98.5, 50 μm).
- 5-6. Corrudinium otagoense (29-24-3B, X30Y101.5, 55 μm).










1-4. *Corrudinium regulare* (29-22-2B, X49.5Y1-2, 55 μm; 120-16H7A, X37.5Y103, 55 μm; 113-60R-6A X57Y113.5, 55 μm). 5-6. *Dapsilidinium* sp (29-30-5A, X34.3Y94, 40 μm not including processes).

Plate 7













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1-2. Enneadocysta partridgei (113-60R-1b, X51Y104.5, 40 µm not including processes).

3. Forma b (120-20H-1A, X38.5Y98, 20 μm not including processes).

4. Graptodinium inconditum (29-26-1A X56Y97.5, 40 $\mu m).$

5-6. Hapsocysta kiysingensis (120-19H-4A X57.3Y109, 53 μm).





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1. Graptodinium reticulatum (29.23.3B X53Y102, 30 $\mu\text{m}).$

- 2. Impagidinium aculatum (29-32-1Α, X30Y106, 53 μm).
- 3-4. Impagidinium crassimuratum (29-29-2, X41Y91, 85 μm).
- 5. Impagidinium dispertitum (114-32X-5A, X38.5Y104, 40 μm). 6. Impagidinium elegans (29-30-5A, X34.5Y99.5, 115 μm).





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1. Impagidinium elegans (29-30-5B, X42Y94, 102 μm).

2-3. *Impagidinium maculatum* (120-23X-1A, X42Y93.5, 50 μm).

4. Impagidinium parvireticulatum (120-19-1A, X29Y111, 100 $\mu m).$

5-6. Impagidinium victorianum (114-37X-3B, X58Y93.8, 75 $\mu m).$

Plate 10





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1. Impletosphaeridium spp (113-59R-4b, X43Y93, 35 μm).

2. *Lophocysta* spp (120-23X-1A X32.5Y108.2, 55 μm).

3. *Minisphaeridium latirictum* (120-20H-1A, X44Y100.6, 15 μm not including processes).

4-5. *Minisphaeridium* group (29-29-2B, X34Y100.5, 40 μm ; 114-33X-6B, X54Y94.5, 20 μm).

6. *Moria zachosii* (113-60R-5A X35Y100, 45 μm).

Plate 11



- 1-2. Nematosphaeropsis spp (120-23X-3A, X40.3Y91.5, 50 μ m;120-20H-1A, X55Y93, 30 μ m not including processes).
- 3. *Odontochitina* spp (114-33X-6B, X38.5Y93, 130 μm length).
- 5. *Operculodinium janduchenei* (29-22-2A, X54.5Y95, 73 μm).
- 4 & 6. Operculodinium spp (29-29-2A, X45.9Y94, 45 μm ;29-29-2A, X38.5Y95.5, 55 μm).

Plate 12



1. Paucisphaeridium inversibuccinium (113-58R-1A, X35.5Y100.8, 30 $\mu\text{m}).$

2-3. Samlandia reticulifera (120-20H-5A, X48.5Y94, 95 $\mu m).$

4-5. *Samlandia reticulifera* (29-30-5Α, X54Y101.5, 110 μm).

6. Samlandia spp (120-19H-1A, X40Y104, 130 $\mu m).$

Plate 13



1-6. Samlandia spp (1-2. 120-19H-1A, X40Y104, 130 $\mu m;~$ 3-4. 120-19H-1A, X48,Y100, 115 $\mu m;$ 5-6. 120-19H-1A, X30.2Y95, 125 $\mu m).$

Plate 14











1-5. *Spiniferites* spp (2-3. 113-59R-3A, X36Y102, 70 μm; 4.120-23X-1A X48Y93.5. 50 μm; 120-19H-1A, X58.5Y95.8, 60 μm not including processes).



1. *Tectatodinium* spp (120-23X-1A, X44Y92, 34 μm).

2-4. Thalassaphora spp (2. 120-19H-1A, X31Y91.2, 200 μm; 3-4. 120-19H-1).

5-6. *Turbiosphaera filosa* (113-62R-6A, X57Y93, 120 μm).



1-6. Alterbidinium distinctum (1-2. 120-17H-4B, X39.2Y95.2, 75 μ m; 3-4. 113-59R-1b, X52Y92.3, 110 μ m; 5-6. 113-60R-2, X36Y97.3, 102 μ m).

Plate 17



Alterbidinium distinctum (113-59R-2, X56Y106, 100 μm).
Brigantedinium spp (113-56R-1A, X34.3Y105, 60 μm; 113-56R-1A, X34.3Y105, 65 μm).
Cerodinium medcalfii (29-26-4A X36Y104.5, 120 μm).
Deflandrea antarctica (120-19H-1A, X47Y92.5, 80 μm).









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- 1-2. *Deflandrea antarctica* (29-30-5B X35Y101.5, 120 μm; 113-59R-5, X64Y103, 120 μm). 3-4. *Deflandrea convexa* (120-19H-1A X47Y97.5, 75 μm; 120-19H-1A, X51Y103, 90 μm).

5-6. *Deflandrea cygniformis* (120-16H-7A, X54.5104, 65 μm).

Plate 19



1-2. Deflandrea dartmooria (29-26-1A, X39.5Y93.4, 125 μm; 29-26-1A, X35.5Y92, 110 μm).1823-4. Deflandrea flounderensis (120-18H-4A, X58Y97, 100 μm).5. Deflandrea leptodermata (120-19H-1, X37.5Y97, 85 μm).6. Deflandrea phosphoritica (29-24-3A, X49Y104, 112 μm).

Plate 20



- 5. *Lejeunecysta cowiei* (113-59R-2A, X34Y93, 110 μm).
- 6. *Lejeunecysta fallax* (113-59R-3A, X51.5Y97, 95 μm).



- 1. Octodinium askiniae (29-30-5B, X44Y95, 84 µm).
- 2. Phthanoperidinium ?crenulatum (29-30-5B, X51Y94.5, 50 µm).
- 3-4. Phthanoperidinium dentatum (114-32X-5, X46Y97, 40 $\mu m;~120\text{-}20\text{H}\text{-}5\text{A},$ X50Y92, 40 $\mu m).$
- 5. *Phthanoperidinium echinatum* (29-30-5A, X33Y92, 60 μm).
- 6. Phthanoperidinium geminatum (29-24-3A, X50.2Y104, 45 $\mu m).$



1. Phthanoperidinium geminatum (29-24-3A, X50.2Y104, 45 $\mu m).$

2-3. *Phthanoperidinium* spA (114-31X-6Am X37Y99, 42 μm; 120-19H-4, X40.9Y104, 38 μm).

4-6. *Phthanoperidinium* sp1 (114-32X-5, X44Y110.4, 40 μm; 114-32X-5A, X48Y92, 45 μm; 114-32X-5A, X59Y91.5, 50 μm).

Plate 23



1-3. Rhombodinium spp (120-19H-1A, X48.3Y96, 125 μ m; 129-19H-1A, X39.5Y99.5, 105 μ m). 4. Selenopemphix nephroides (29-30-5A, X58.2Y97.5, 70 μ m).

5-6. *Spinidinium* sp1 (120-18H-4A, X47Y101.5, 75 μm; 120-18H-4A, X59Y100.5, 75 μm).

Plate 24



1-2. Spinidinium colemanii (113-59R-1b, X36.5Y95, 55 μm). 3-5. Spinidinium essoi (113-59R-2, X43.5Y94.5, 53 μm; 113-59-2, X39.5Y100, 60 μm). 6. Spinidinium luciae (120-16H-7A, X40Y92.5, 55 μm).

Plate 25









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1-3. *Spinidinium luciae* (113-61R-3, X38Y102, 105 μm; 113-62R-1A, X35.5Y105, 85 μm). 4-6. *Spinidinium Macmurdoense* (113-59R-4b, X62Y92.5, 90 μm; 113-59Ra-1, X44Y98.5, 100 μm; 113-60R4a-X61.8Y105.2, 98 μm).



1-3. *Vozzhennikovia apertura* (113-59Ra-1, X42Y104, 65 μm; 113-59R1a-1, X33.5Y96, 60 μm). 4-6. *Vozzhennikovia netrona* (113-59R-1a, X32.5Y98, 75 μm; 113-59R-2, X43.5Y94, 90 μm).

Plate 27



1-2. Acritarchs (29-30-5B X48.5Y94.5 , 30 μm processes not included; 29-36-2A, X45.5Y95, 20 μm).

- 3. Cyclopsiella (113-59R-3A, X34Y105, 95 μm).
- 4. Fenestridium clathrodermum (29-24-3B, X45.2Y108).
- 5. Leiosphaeridia (120-18H-4A). 6. Palambages (113-62R-1A, X45Y96, 95 μm).

Plate 28



1-2. *Cymatiosphaera* (120.19H.1A, X34.5Y110, 20 μm). 3. *Tasmanites* (114-31X-2D, X45.2Y96.1, 125 μm). 4-5. Microforaminifera linings (29-29-2; 29-26-1A). 6. Insect casing (114-50X-5B).



Leg	Site	Eocene – Oligocene	Comments
		Transition present	Sediments as Initial Reports showed
28	267	Early Oligocene/Late Eocene	Core 6 E/O boundary photo shows
			small rock pieces
	274	Early Oligocene/Late Eocene	See Report
29	277	Early Oligocene/Late Eocene	Sediments good see report
	280A	Early Oligocene/Late Eocene	Sediments good see report
	281	Early Oligocene/Late Eocene??	See Report
	282	Early Oligocene/Late Eocene	Sediments good see report
35		Sites 322-325 not Oligocene/Eocene	
36	328B	Early Oligocene/Late Eocene	Sediments good
	329	Oligocene/Early Eocene	Voids in Oligocene sediments not good
	330A	Eocene to recent	Sediments not good
71	511	Early Oligocene/Late Eocene	Plenty Oligocene sediments not much
			Eocene but sediments good
90	588C	Late Oligocene to Middle Eocene	situated at 20° S – 40° S and there is a
			gap also sediments not good
	592	Early Oligocene to Late Eocene	Situated at 20° S – 40° S is a gap in the
			Oligocene. good
	593	Early Oligocene/Late Eocene	Sediments good
113	689B	Early Oligocene/Late Eocene	Sediments good
	689D	Early Oligocene/Late Eocene	Sediments good
	690B	Early Oligocene/Late Eocene	Sediments good
	696B	Early Oligocene/Late Eocene	Sediments very dark hard to see
114	699A	Early Oligocene/Late Eocene	Sediments good
	701C	Early Oligocene/Late Eocene	Sediments good
	703A	Early Oligocene/Late Eocene	Sediments good
119	737B	Early Oligocene/Late Eocene	Some sediments good
	738B	Early Oligocene/Late Eocene	Sediments good
	744A	Early Oligocene/Late Eocene	Sediments good
120	747A	Late & Early Oligocene/Late Eocene	Sediments good but not much there
	747C	Early Oligocene/Upper and Lower Eocene	Sediments good but not much there
			especially for the Eocene
	748B	Early Oligocene/Late Eocene	Sediments good
	749B	Early Oligocene/Late Eocene	Sediments good but not much there
177	1090B	Early Oligocene/Late Eocene	No photo
178		Sites 1095-1103 not suitable	Miocene and earlier only
181	1123C	Early Oligocene/Late Eocene	Voids present not much Oligocene no
			photo
	1124C	Early Oligocene/Mid-Late Eocene	Void present not much sediment no
			photo
183	1138A	Late Maastrichtian to Late Oligocene	Does not show a boundary for
			Eocene/Oligocene No photo
187	No litho or biostrat column this site focused on bacteria. The site was drilled in		
		deep ocean mantel	
188	1166A	Early Oligocene/Late Eocene	No photo

Appendix 2.1 - Sites initially researched

189	1168A	Leg 189 and these sites have been completed for dinoflagellates at the	
		Eocene/Oligocene boundary by Brinkhuis H. et al.	
	1170A	Early Oligocene	
	1170D	Mid Eocene (From Early Oligocene)	
	1171C	Oligocene	
	1171D	Early Eocene	
	1172A	Middle Eocene	
	1172D	Late Cretaceous (from Mid Eocene)	

Leg	Site	Eocene – Oligocene		
C		oldest sediment age		
28	267	Lower Tertiary		
29	275	Upper Campanian Late Cretaceous		
	277	Middle Paleocene		
	278	Middle Oligocene		
	280A	Middle Eocene		
	281	Upper Eocene		
	282	Upper Eocene		
	283	Paleocene		
35		Sites 322-325 not suitable		
36	328B	Upper Cretaceous		
	329	Upper Paleocene		
	330A	Eocene		
71	511	Jurrasic		
	512	Middle Eocene		
	512A	Middle Eocene		
	513A	Lower Oligocene		
90	588C	Middle Eocene to Late Oligocene		
	592	Late Eocene to Early Oligocene		
	593	Upper Eocene		
113	689B	Late Cretaceous (Campanian)		
	689D	Late Eocene		
	690B	Late Paleocene		
	690C	Late Cretaceous (gap from Late Paleocene to Oligocene)		
	696B	Late Eocene to Oligocene		
114	699A	Paleocene		
	700B	Late Cretaceous (Coniacian)		
	703A	Early/Middle Eocene		
119	737B	Middle Eocene		
	738B	Middle Eocene		
	744A	Late Eocene		
120	747A	Late Cretaceous (Campanian)		
	747C	Late Cretaceous (early Santonian)		
120	748B	Middle Eocene		
	749B	Middle Eocene		
177	1090B	Middle Eocene		
	1090D	Oligocene		
	1090E	Oligocene		
178		Sites 1095-1103 not suitable		
181	1123C	Late Eocene Late Eocene/Early Oligocene not very thick		

	1124C	Eocene Mid late Eocene/ Early Oligocene not very thick	
183	1135A	Late Cretaceous fig. 4 Early Middle Eocene but gap to Late Pliocene	
	1136A	Late Cretaceous Fig.6 Early Middle Eocene then gap	
	1138A	Late Cretaceous Fig.2.& 5. Late Maastrichtian to Late Oligocene but does not	
		show a boundary for Eocene/Oligocene	
187		No litho or biostrat column this site focused on bacteria. The site was drilled in	
		deep ocean mantel	
188	1166A	Late Cretaceous (Turonian) Upper Eocene to Lower Oligocene	
189	1168A	Late Eocene Leg 189 and these sites have been completed for dinoflagellates at	
		the Eocene/Oligocene boundary	
	1170A	Early Oligocene	
	1170D	Mid Eocene (From Early Oligocene)	
	1171C	Oligocene	
	1171D	Early Eocene	
	1172A	Middle Eocene	
	1172D	Late Cretaceous (from Mid Eocene)	

<u>Appendix 2.2</u> <u>Report on DSDP and ODP Legs in the Southern Ocean</u>

DSDP Leg 28 sites 264-274

Situated between 35° S and 70° S with 270-274 in the Ross Sea and 264-269 between Australia and the Antarctic.

Papers found in initial reports of DSDP that were related to palynomorphs were:

Kemp, E.M. 1975. Palynology of Leg 28 drill sites, Deep Sea Drilling Project (attached). In Barker and Dalziel initial reports DSDP 28. - Kemp reported that apart from sites 270 and 274 very little palynological material apart from abundant *Leiospheres* was recovered from sites 264,266, 268 and 269.

Site 264 unconformities' separate Miocene and younger strata from and Eocene sequence

Site 266 does not go beyond Early Miocene

Site 268 does not go beyond Oligocene

Site 269 no age given on this site.

Kemp comments that the lack of palynomorphs in some cores may be due to dilution factors.

Site 265 does not go beyond middle Miocene

Site 270 a nonconformity separates the Oligocene from earlier Palaeozoic

Site 272 does not go beyond Mid Miocene

Site 273 does not go beyond Lower Miocene

Site 274 Eocene Oligocene boundary in core 34 therefore core 35 to 45 must be Late Eocene

Core data shows only two holes have results for dinoflagellates, pollen and spores 270 and 274.

Other papers:

Fleming R.F., Barron J.A. 1996. Evidence of Pliocene Nothofagus in Antarctica from Pliocene marine sedimentary deposits (DSDP site 274). *Marine Micropaleontology* 27 277-236. - Fleming comments on previous work on page 228, with some criticism of ODP Leg 113 shipboard work in evaluating the presence of palynomorphs. Fleming also comments on Leg 114 p 229 on their evaluation on presence of pollen in their initial reports.

DSDP Leg 29 sites 275-284

Situated between 40° S and 60° S with 270-274 in the Tasman Gateway and South Pacific area. Papers found in initial reports of DSDP that were related to palynomorphs were:

Haskell T.R. and Wilson, G.J. 1975. Palynology of sites 280-284, DSDP Leg 29, off south-eastern Australia and Western New Zealand

Site 281 core 13-3 is Late Oligocene (130 cm) followed by a discontinuity which separates Upper greensand and Lower greensand CC13. Another discontinuity is followed by Core 14 which is the beginning of the Late Eocene.

Site 280A cores 1-9 were either devoid of palynomorphs or yielded extremely sparse palynofloras and are Oligocene. Cores 10 to 22 were richer in species and Eocene.

Site 282 cores 6-18 from Oligocene to Eocene found plenty.

Have listed what was found but not gone into depth with this paper.

Wilson G. Palynology of Deep Sea Cores from DSDP site 275, Southeast Campbell Plateau.

Wilson looked at 5 cores from this site:

Core 1 barren

Core 2 upper had sparse assemblages, middle was barren and lower contained an excellent assemblage

Core 3 no material was available

Core 4 relatively rich assemblages of dinoflagellates and miospores Core 5 " " " " " "

Short paper merely lists what is found

Other papers:

Crouch E.M and Hollis C.J. 1996 Palaeogene palynomorph and radiolarian biostratigraphy of DSDP Leg 29, Sites 280 and 281 South Tasman Rise. *Institute of Geological and Nuclear*

Sciences Science Report 96/19, 46pp.

This paper looks at Eocene sediments up to the Late Eocene

Hollis C.J., Waghorn, D.B. Strong, C.P. Crouch E.M. 1997. Integrated Palaeogene biostratigraphy of DSDP site 277 (Leg 19): foraminifera, calcareous nannofossils, Radiolaria and palynomorphs. *Institute of Geological and Nuclear Sciences Science Report* 97/07,

This report focuses on Radiolaria and not much is done on palynomorphs

Levy R.H. & Harwood D.M. 2000. Tertiary marine Palynomorphs from the McMurdo Sound Erratics, Antarctica. In (Eds Stilwell J.D. Feldmann R.M.) Paleobiology and Palaeoenvironment of Eocene Rocks. *Antarctic Research Series Vol 76*

DSDP Leg 35 sites 322-325

Situated between 60° S and 70° S near the Antarctic Peninsular. Papers found in initial reports of DSDP that were related to palynomorphs were:

No papers on palynology in this volume

Core data shows that only site 323 contained dinoflagellates with no mention of pollen or spores.

DSDP Leg 36 sites 326-331

Situated between 40° S and 60° S in the Subantarctic South Atlantic. Papers found in initial reports of DSDP that were related to palynomorphs were:

Harris W.K. 1977 Palynology of cores from DSDP sites 327, 328, 330, South Atlantic Ocean. In Barker P.F. and Dalziel et al Init. Repts. DSDP 36.

Site 327 does not go from Eocene gap then to Pleistocene

Site 328 goes from Late Eocene gap then to Middle Miocene

Site 329 does go from Early Eocene to Oligocene but has two very large voids in

- between
- Site 330 is Cretaceous in age

Site 330A has only 0.50 meters of sediment between Eocene and Recent.

This is a brief paper stating the ages and naming of species found and supplies photos with plates showing many of the species.

Hedlund, R.W. and Beju, D. 1977 Stratigraphic palynology of selected Mesozoic samples DSDP Hole 327A and site 330.

Mesozoic only N/A. This paper discusses the results from 13 selected samples from the two cores and supplies photos with plates showing many of the species.

DSDP Leg 71 sites 511-514

Situated between 40° S and 60° S in the Subantarctic South Atlantic (Falkland Plateau). Papers found in initial reports of DSDP that were related to palynomorphs were:

Goodman, David K. and Ford L.N. Preliminary dinoflagellate biostratigraphy for the middle Eocene to lower Oligocene from the southwest Atlantic Ocean. (sites were 511, 512, 513A). They consider these results as preliminary only.

Bason I.A., Cresielski P.F., Krasheninnikov V.A., Weaver, F.M. and Wise Jr. S.W. Biostratigraphic and Paleontologic synthesis: DSDP Leg 71 Falkland Plateau and Argentine Basin. In Initial Reports.

This paper gives a run down on all groups from the Jurassic to Holocene but does not give specific information.

DSDP Leg 90 587-594

Situated between 40° S and 60° S west and east of New Zealand are sites 593 and 594 these were the only sites I have gathered information on in Leg 90. Papers found in initial reports of DSDP that were related to palynomorphs were:

Huesser L.E. Palynology of selected Neogene samples Holes 594 and 594A **Is Neogene N/A**

Other papers:

Marret F., De Vernal A., Benderra F, and Harland Rex. 2001 Late Quaternary seasurface conditions of DSDP Hole 594 in the southwest Pacific Ocean based on dinoflagellate cyst assemblages. *Journal of Quaternary Science* 16 (7) 739-751 PDF on laptop

Late quaternary N/A

ODP Leg 113 sites 689-697

Situated between 60° S and 70° S in the Weddell Sea. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 113 that were related to palynomorphs were:

Futterer, Dieter Karl, The distribution of calcareous dinoflagellates at the Cretaceous-Tertiary boundary of Queen Maud Rise, Eastern Weddell Sea, Antarctica. Holes 689B and 690C.

Specifically targets the K/T boundary N/A

Mohr, Barbara A.R. Early cretaceous palynomorphs from ODP sites 692 and 693, the Weddell Sea, Antarctica.

Early Cretaceous palynomorphs N/A

Mohr, B.A.R. Eocene and Oligocene sporomorphs and dinoflagellate cysts from Leg 113 drill sites, Weddell Sea, Antarctica.

Shipboard smear slides were used. Lists findings and gives some environmental interpretation. Provides some plates with photos

Fleming comments (see leg 28 DSDP paper) on previous work, with some criticism of ODP Leg 113 shipboard work in evaluating the presence of palynomorphs. Fleming also comments on Leg 114 p 229 on their evaluation on presence of pollen in their initial reports.

Other papers:

Hildebrand-Habel, Tania and Strent Michael. 2003. Calcareous dinoflagellate associations and Maastrichtian-Tertiary climatic change in a high-latitude core (ODP Hole 689B, Maud Rise, Weddell Sea). *Palaeogeography, Palaeoclimatology, Palaeoecology* 197 : 293-321

Examines one ODP site only good paper, quite thorough

Rex Harland, Meriel E.J. FitzPatrick and Carol J. Pudsey 1999: Latest Quaternary dinoflagellate cyst climatostratigraphy for three cores from the Falkland Trough, Scotia and Weddell seas, Southern Ocean

Review of Palaeobotany and Palynology, Volume 107, Issues 3-4, , Pages 265-281 **Comment:** the three cores are shallow from Holocene and Late Pleistocene not ODP

Late Quaternary N/A

ODP Leg 114 sites 698-702

Situated between 40° S and 60° S in the Subantarctic South Atlantic (Falkland Plateau). Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 114 that were related to palynomorphs were:

Fenner, Julian. Rare and unknown nonclacareous microfossils recovered from Leg 114 sites.

Not dinoflagellates, pollen or spores.

Searches carried out on the internet or library journal finder have not been productive.

ODP Leg 119 sites 736-746

Situated between 40° S and 70° S with 5 sites drilled in Prydz Bay (738-743) and 6 sites were drilled on the Kerguelen Plateau (North KP 736, 737, and South KP 744-

746). Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 119 that were related to palynomorphs were:

Stockwell, Dean A. Distribution of *Chaetoceros* resting spores in the Quaternary sediments from Leg 119. **Quaternary N/A**

Tocher, Bruce A. Late Cretaceous dinoflagellate cysts from the Southern Kerguelen Plateau, site 738.

Late Cretaceous N/A

Data report: palynology of sediments from Leg 119 drill sites in Prydz Bay, East Antarctica 1991 Truswell E.M. *Proc. scientific results, ODP, Leg 119, Kerguelen Plateau-Prydz Bay*, pp. 941-945 (scopus results) Truswell looked at sites 739-743 see paper attached **Gives brief descriptions of ages and some names of palynomorphs**

ODP Leg 120 sites 747-751

Situated between 50° S and 60° S with 5 sites drilled in the central Kerguelen Plateau (747-751). Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 120 that were related to palynomorphs were:

Mohr, Barbara A.R. and Gee C.T. An early Albian palynoflora from the Kerguelen Plateau Southern Indian Ocean (Leg 120, site 750B).

Mohr B.A.R. and Gee C.T. Late Cretaceous palynofloras (sporomorphs and dinocysts) from the Kerguelen Plateau, Southern Indian Ocean (sites 748 and 750)

Mao, Shozhi and Mohr, B.A.R. Late Cretaceous dinoflagellate cysts (?Santonian-Maastrichtian) from the Southern Indian Ocean (Hole 748C).

Watkins, D.K. Quilty, P.G. Mohr, B.A.R. Mao, S., Francis J.E. Gee, C.T., and Coffin M.F., 1992. Palaeontology of the Cretaceous of the Central Kerguelen Plateau. In Proceedings of Leg 120 951-960

All 4 papers above are Cretaceous only

ODP Leg 141 sites 859-863

Situated between 40° S and 60° S in the Chile triple junction. There were no papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 141 that were related to palynomorphs. In summary this is a spreading ridge subducting area in addition hot fluids cause hydrothermal alteration, anomalous diagenesis and mineralization.

ODP Leg 177 sites 1088-1094

Situated between 40° S and 60° S in the Subantarctic South Atlantic. The Scientific Results citations are attached but do not have any palynomorphs included in this write up.

Shipboard scientific party report on the biostratigraphy for each site was based on calcareous nannofossils, planktic foraminifers, benthic foraminifers and *Bolboforma*, diatoms and radiolarians.

ODP Leg 178 sites 1095-1103

Situated between 60° S and 70° S at the Antarctic Peninsular. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 178 that were related to palynomorphs were:

Pudsey Carol, J. and Harland Rex. Data Report: Dinoflagellate cyst analysis of Neogene sediments from sites 1095 and 1096, Antarctic Peninsular Continental Rise.

Iwai, M. Kameo, K. and Miyake, N. Calcareous Nannofossils, Pollen and Spores from Leg 178 sites 1095, 1097, 1100 and 1103, Western Antarctic Peninsula: Age constraints and environmental implications.

Both papers above are Miocene or earlier. N/A

Shipboard scientific party report on biostratigraphy for each site was based on calcareous nannofossils, planktic foraminifers, benthic foraminifers, diatoms, radiolarians.

Other papers:

Harland Rex and Pudsey Carol J. 2002. Protoperidiniacean dinoflagellate cyst taxa from the Upper Miocene of ODP Leg 178, Antarctic Peninsula. *Review of Palaeobotany and Palynology* 120 : 263-284.

Sites 1095 and 1096 in the Bellingshausen Sea were looked at see attached paper. Upper Miocene only N/A

ODP Leg 181 sites 1119-1125

Situated between 40° S and 60° S in the Southwest Pacific (approx. North of Weddell Sea). Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 181 that were related to palynomorphs were not present in the results.

Shipboard scientific party report on biostratigraphy for each site was based on calcareous nannofossils, planktic foraminifers, benthic foraminifers and *Bolboforma*, diatoms, radiolarians.

Other sources are

Mildenhall D.C. Hollis C.J and Naish T.R. 2004 Orbitally influenced vegetation record of the Mid-Pleistocene climate transition, offshore eastern New Zealand (ODP) Leg 181, site 1123). *Marine Geology* 205 87-111.

This paper is mainly on spores and pollen but does mention that dinoflagellate cysts are present in all samples as well as tasmanitids and fresh water Botryococcus and Pediastrum.

ODP Leg 183 sites 1135-1142

Situated between 40° S and 60° S in the Kerguelen Plateau-Broken Ridge with 1141-1142 within the 20° S and 40° S. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 181 that were related to palynomorphs are: Mohr, B.A.R. Wahnert, V. and Lazarus D. 2002 Mid-Cretaceous Paleobotany and Palynology of the Central Kerguelen Plateau, Southern Indian Ocean (ODP Leg 183, Site 1138).

Exert from vol 183 shipboard scientific party:

"Plant fossils at site 1138: With proper specimen preparation onshore, the material should also be useful for palynomorphological biostratigraphy. The core-catcher material of Core 183-1138A-69R-CC seems to contain a rich flora of spores; we also observed some in the core catcher of Core 183-1138A-71R." **These are all Cretaceous results. Smear slides used.**

ODP Leg 187 sites 1152-1164

Situated between 40° S and 60° S in the Australian Antarctic Discordance. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 181 that were related to palynomorphs were not recorded in this leg. Results were focused on microbial (i.e. Bacteria) found in basalt and their DNA sequences.

Other papers:

ODP Leg 188 sites 1165-1167

Situated between 60° S and 70° S at Prydz Bay, Cooperation Sea. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 188 that were related to palynomorphs were:

McPhail M.K. and Truswell E.M. Palynology of Neogene slope and rise deposits from ODP sites 1165 and 1167, East Antarctica

McPhail M.K. and Truswell E.M. Palynology of site 1166, Prydz Bay, East Antarctica

Thorn Vanessa C. Phytoliths in drill core sediments from sites 1165 and 1166, Leg 188, Prydz Bay, East Antarctica.

Shipboard scientific party report on biostratigraphy for each site was based on calcareous nannofossils, planktic foraminifers, benthic foraminifers, diatoms, radiolarians.

Other papers:

Hannah, M.J. 2006 The palynology of ODP site 1165, Prydz Bay, East Antarctica: A record of Miocene glacial advance and retreat *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology*, 231, (1-2): Pages 120-133

ODP Leg 189 sites 1168-1172

Situated between 40° S and 50° S at the Tasmanian Gateway. Papers found in Proceedings of the Ocean Drilling Program, Scientific Results volume 189 that were related to palynomorphs were:

Brinkhuis, H., Munsterman, D.K., Sengers, S., Sluijs, A., Warnaar, J., and Williams, G.L., 2003. Late Eocene–Quaternary dinoflagellate cysts from ODP Site 1168, off western Tasmania. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results*, 189

Brinkhuis, H., Sengers, S., Sluijs, A., Warnaar, J., and Williams, G.L., 2003. Latest Cretaceous–earliest Oligocene and Quaternary dinoflagellate cysts, ODP Site 1172, East Tasman Plateau. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results*

Huber, M., Brinkhuis, H., Stickley, C.E., Doos, K. Sluijs, A., Warnaar, J., Schellenberg, S.A., Williams, G.L. 2004. Eocene circulation of the Southern Ocean: Was Antarctica kept warm by subtropical waters?

Sluijs, A., Brinkhuis, H., Stickley, C.E., Warnaar, J., Williams, G.L., and Fuller, M., 2003. Dinoflagellate cysts from the Eocene–Oligocene transition in the Southern Ocean: results from ODP Leg 189. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results*, 189

Stickley, C.E., Brinkhuis, H., McGonigal, K.L., Chaproniere, G.C.H., Fuller, M., Kelly, D.C., Nurnberg, D., Pfuhl, H.A., Schellenberg, S.A., Schoenfeld, J., Suzuki, N., Touchard, Y., Wei, W., Williams, G.L., Lara, J., and Stant, S.A., 2004. Late Cretaceous-Quaternary Biomagnetostratigraphy of ODP sites 1168, 1170, 1171, and 1172, Tasmanian Gateway.

Williams, G.L., Brinkhuis, H., Pearce, M.A., Fensome, R.A., and Weegink, J.W., 2004. Southern Ocean and global dinoflagellate cyst events compared: index events for the Late Cretaceous–Neogene. *In* Exon, N.F., Kennett, J.P., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results*, 189

Shipboard scientific party report on all sites includes calcareous nannofossils, planktic foraminifers, benthic foraminifers and *Bolboforma*, diatoms, radiolarians and pollen and spores and dinoflagellate cysts.

SUMMARY OF POSSIBLE SITES TO WORK WITH

Kerguelen Plateau and Prydz Bay area:

Leg 119 sites 736-746 Sites 737B, 738B, 744A Leg 120 sites 747-751 Sites 747A, 747C, 748B, 749B Leg 183 sites 1135-1140 Sites 1138A Leg 188 sites 1165-1167 Sites 1166A

Ross Sea Area

Leg 28 sites 264-274 Sites 267, 274

Australian Antarctic Discordance

Leg 187 sites 1152-1164 No papers for palynology results focused on bacteria.

Tasmanian Gateway

Leg 29 sites 275-284 Sites 277, 280A, 281, 282 Leg 189 sites 1168-1172 Brinkhuis et al

Southwest Pacific (New Zealand waters)

Leg 90 sites 593-594 Sites 588C, 592, 593 Leg 181 sites1119-1125 Sites 1123C, 1124C,

Antarctic Peninsular area

Leg 35 sites 322-325 Not Eocene/Oligocene Leg 178 sites 1095-1103 Miocene or earlier

Chile Triple Junction

Leg 141 sites 859-863 No papers on palynology for this site see leg summary.

Sub Antarctic South Atlantic (Falkland Plateau)

Leg 36 sites 326-331 Sites 328B, 329, 330A Leg 71 sites 511-514 Sites 511 Leg 114 sites 698-702 Sites 699A, 701C, 703A Leg 177 sites 1088-1094 Sites 1090B.

Weddell Sea

Leg 113 sites 689-697 Sites 689B, 689D, 690B, 696B
Appendix 2.3 – Sediments received - Predominant Lithology

LEG 113, Site 696B (Appendix 2.3a), Volume (cc) = 10.0. Total number of samples: 27 Total volume of samples: 540. Average volume of samples: 20.00

	Core	Section	Top (cm)	Bottom	Depth (mbsf)	Predominant lithology
1	51R	1	97	99	530.77	Sandy mudstone not included
2	53R	1	108	112	549.98	Mud/mudstone not included
3	53R	3	66	70	552.56	Clay/claystone not included
4	54R	1	122	126	559.72	Mud/mudstone not included
5	54R	2	81	85	560.81	Silty/mudstone not included
6	54R	3	124	128	562.24	Silty/mudstone not included
7	55R	1	78	82	568.98	Silty/mudstone not included
8	55R	3	66	70	571.86	Sandy/mudstone not included
9	55R	5	140	144	575.64	Silty/mudstone not included
10	56R	1	81	85	578.71	Silty/mudstone
11	57R	1	56	60	588.16	Silty/mudstone
1	58R	1	110	112	598.30	Sandy mudstone/silty mud Oligocene
2	59R	1a	10	12	607.00	Sandy mudstone L Oligocene/U Eocene
3	59R	1b	123	125	608.13	Sandy mudstone L Oligocene/U Eocene
4	59R	2	125	127	609.65	Sandy mudstone L Oligocene/U Eocene
5	59R	3	85	87	610.75	Sandy mudstone L Oligocene/U Eocene
6	59R	4a	35	37	611.75	Sandy mud mudstone L Oligocene/U
						Eocene
7	59R	4b	135	137	612.75	Sandy mud mudstone L Oligocene/U
						Eocene
8	59R	5	75	77	613.65	Sandy mud mudstone L Oligocene/U
						Eocene
9	60R	1a	30	32	616.90	Sandy mudstone L Oligocene/U Eocene
10	60R	1b	110	112	617.70	Sandy mudstone L Oligocene/U Eocene
11	60R	2	96	98	619.06	Sandy mudstone L Oligocene/U Eocene
12	60R	3	45	47	620.05	Sandy mudstone L Oligocene/U Eocene
13	60R	4a	45	47	621.55	Sandy mudstone L Oligocene/U Eocene
14	60R	4b	145	147	622.55	Sandy mudstone L Oligocene/U Eocene
15	60R	5	90	92	623.50	Sandy mudstone L Oligocene/U Eocene
16	60R	6	54	56	624.64	Sandy mudstone L Oligocene/U Eocene
17	61R	1	44	46	626.64	Sandy mudstone U Eocene
18	61R	2	85	87	628.55	Sandy mudstone U Eocene
19	61R	3	53	55	629.73	Sandy mudstone U Eocene
20	61R	4	93	95	631.63	Sandy mudstone U Eocene
21	62R	1	10	12	636.00	Sandy mudstone M/U Eocene
22	62R	2	63	65	636.94	Sandy mudstone M/U Eocene
23	62R	3	62	64	638.43	Sandy mudstone M/U Eocene
24	62R	4	82	84	640.13	Sandy mudstone M/U Eocene
25	62R	5	46	48	641.27	Sandy mudstone M/U Eocene
26	62R	6	67	69	642.98	Sandy mudstone M/U Eocene
27	62R	7	88	90	644.69	Sandy mudstone M/U Eocene
						This one not processed left out

LEG 114, Site 699A (Appendix 2.3b), Volume (cc) = 10.0. Total number of samples: 30 Total volume of samples: 690. Average volume of samples: 10.00

	Core	Section	Top (cm)	Bottom (cm)	Depth (mbsf)	Predominant lithology	
1	27X	5	63.0	65.0	249.730	Siliceous nanno and nannofossil ooze	
2	28X	1	95.0	97.0	253.550	Nannofossil ooze	
3	29X	2	67.0	69.0	261.270	Siliceous-bearing and siliceous nanno	
						ooze	
4	30X	3	64.0	66.0	272.240	Siliceous-bearing and siliceous nanno	
						ooze	
5	31X	2	73.0	75.0	280.330	Siliceous-bearing nanno ooze	
6	31X	6	93.0	95.0	286.530	Siliceous-bearing nanno ooze	
7	32X	5	23.0	25.0	293.830	Siliceous-bearing and chalk and nanno	
						ooze	
8	33X	2	47.0	49.0	299.070	Nanno ooze	
9	33X	6	56.0	58.0	305.160	Nanno ooze	
10	35X	3	76.0	78.0	319.860	Nanno ooze and siliceous bearing nanno	
						ooze	
11	35X	6	95.0	97.0	324.550	Nanno ooze and siliceous bearing nanno	
						ooze	
12	36X	3	108.0	110.0	329.680	Clayey nanno chalk ooze and clayey	
						nanno ooze	
13	36X	7	39.0	41.0	334.990	Clayey nanno chalk ooze and clayey	
						nanno ooze	
14	37X	3	97.0	99.0	339.070	Nanno chalk to clay-bearing nanno chalk	
15	39X	2	57.0	59.0	356.170	Nanno chalk to clay-bearing nanno chalk	
16	40X	1	90.0	92.0	364.500	Nannofossil chalk	
17	40X	4	98.0	100.0	369.080	Nannofossil chalk	
18	41X	1	71.0	73.0	373.810	Clay-bearing nanno chalk and clayey	
						nanno chalk	
19	42X	3	111.0	113.0	386.710	Nanno micritic chalk	
20	42X	6	79.0	81.0	390.890	Nanno micritic chalk	
21	43X	4	35.0	38.0	396.950	Nanno micritic chalk	
22	45X	2	50.0	52.0	413.100	Clay-bearing nanno micritic chalk	
23	45X	5	67.0	69.0	417.770	Clay-bearing nanno micritic chalk	
24	47X	2	77.0	79.0	432.370	Micrite-bearing nanno chalk	
25	47X	5	50.0	52.0	436.600	Micrite-bearing nanno chalk	
26	48X	3	106.0	108.0	443.660	Nannofossil chalk	
27	49X	1	82.0	85.0	449.920	Nannofossil chalk	
28	49X	4	126.0	129.0	454.860	Nannofossil chalk	
29	50X	2	71.0	73.0	460.810	Micrite-bearing nanno chalk	
30	50X	5	105.0	107.0	465.650	Micrite-bearing nanno chalk	

<u>LEG 120, Site 748B, (Appendix 2.3c),</u>
Volume (cc) = 10.0. Total number of samples: 22
Total volume of samples: 690. Average volume of samples: 10.00

	Core	Section	Top (cm)	Bottom (cm)	Depth (mbsf)	Predominant lithology
1	10H	1	73.0	75.0	76.830	Nannofossil ooze
2	11H	2	52.0	54.0	87.620	Nannofossil ooze
3	11H	5	54.0	56.0	92.140	Nannofossil ooze
4	12H	1	65.0	67.0	95.750	Nannofossil ooze
5	12H	5	92.0	94.0	102.020	Nannofossil ooze
6	13H	2	55.0	57.0	106.650	Nannofossil ooze nanno ooze with sil. debris
7	13H	5	107.0	109.0	111.670	Nannofossil ooze nanno ooze with
						sil. debris IRD present between
						115.45 and 115.77 mbst
8	14H	2	30.0	32.0	115.900	Nannofossil ooze with forams and
		_				with sil.debris
9	14H	5	55.0	57.0	120.650	Nannofossil ooze with forams and
						with sil.debris
10	15H	2	126.0	128.0	126.360	Nannofossil ooze
11	15H	6	90.0	92.0	132.000	Nannofossil ooze
12	16H	4	25.0	27.0	137.680	Nannofossil ooze
13	16H	7	66.0	68.0	141.810	Nannofossil ooze
14	17H	4	68.0	70.0	147.780	Nannofossil ooze
15	17H	7	51.0	53.0	152.110	Nannofossil ooze
16	18H	4	30.0	32.0	156.900	Nannofossil ooze
17	19H	1	50.0	52.0	162.100	Nannofossil ooze
18	19H	4	129.0	131.0	167.390	Nannofossil ooze
19	20H	1	102.0	104.0	172.120	Nannofossil ooze
20	20H	5	66.0	68.0	177.760	Nannofossil ooze
21	23X	1	78.0	80.0	197.380	Nannofossil ooze
22	23X	3	87.0	89.0	200.470	Nannofossil ooze

<u>LEG 29, Site 277 (Appendix 2.3d),</u> <u>Volume (cc) = 20.0 Total number of samples: 28</u> <u>Total volume of samples: 560.00. Average volume of samples: 20.00</u>

	Core	Section	Top	Bottom	Depth (mbsf)	Predominant lithology	
				(CM)	(mbst)		
1	14	1	117.0	122.0	122.170	Rad/spicule Foram bearing nanno ooze	
2	14	4	91.5	96.5	126.415	Rad/spicule Foram bearing nanno ooze	
3	15	2	99.5	102.5	132.995	Rad. Foram bearing nanno ooze	
4	15	5	26.0	29.5	136.760	Rad. Foram bearing nanno ooze	
5	16	1	125.0	129.0	141.250	Diatom/Glauconite Foram rich nanno ooze	
6	16	4	106.5	110.0	145.565	Foram rich nanno ooze	
7	17	3	122.5	126.0	153.725	Diatom/spicule Foram rich nanno ooze	
8	17	6	51.5	56.0	157.515	Diatom/spicule Foram rich nanno ooze	
9	18	3	56.0	59.0	162.560	Diatom/spicule Foram rich nanno ooze	
10	20	2	132.5	134.5	180.825	foram bearing micarb nanno ooze	
11	20	6	25.0	28.0	185.750	foram bearing micarb nanno ooze	
12	21	3	30.0	33.0	190.800	foram bearing nanno ooze	
13	22	2	109.0	112.0	199.590	foram rich nanno ooze	
14	23	3	77.5	81.0	210.275	spicule bearing foram rich nanno ooze	
15	24	3	114.5	119.0	220.145	spicule bearing foram rich nanno ooze	
16	26	1	130.0	135.0	236.300	foram bearing nanno ooze: chert nodules	
17	26	4	134.0	137.0	240.840	foram bearing nanno ooze: chert nodules	
18	29	2	33.5	37.5	265.335	nanno ooze: chert nodules	
19	30	5	115.0	120.0	280.150	nanno ooze chalk: chert nodules	
20	32	1	53.0	57.5	292.530	nanno ooze chalk	
21	32	3	130.0	133.0	296.300	nanno ooze chalks: chert nodules	
22	35	1	101.0	104.0	350.010	nanno chalk	
23	36	2	13.0	16.0	369.630	nanno chalk	
24	37	3	9.0	11.0	380.590	nanno chalk: chert nodules	
25	38	2	7.0	9.5	388.570	nanno chalk	
26	40	2	103.5	106.5	408.535	nanno chalk	
27	42	2	103.5	106.5	427.535	nanno chalk	
28	43	1	51.0	53.0	435.010	nanno chalk	

Sites below were initially processed and found to be either barren or

too sparse to work with

LEG 113, Site 690 B, Volume (cc) = 10.0. Total number of samples: 17 Total volume of samples: 690. Average volume of samples: 10.00

	Core	Section	Top (cm)	Bottom (cm)	Depth (mbsf)	Predominant lithology
1	9H	1	32.0	68.0	70.120	nanno ooze Lower Oligocene
2	9H	3	105.0	107.0	73.850	nanno ooze Lower Oligocene
3	9H	6	107.0	109.0	78.370	nanno ooze Lower Oligocene
4	10H	2	127.0	129.0	82.170	nanno ooze Lower Oligocene
5	10H	4	82.0	84.0	84.720	nanno siliceous ooze Lower Oligocene
6	11H	1	25.0	27.0	89.350	foram rad nanno ooze Lower Oligocene
7	11H	3	82.0	84.0	92.920	nanno ooze Lower Oligocene
8	11H	6	47.0	49.0	97.070	nanno ooze Upper Eocene
9	12H	2	46.0	48.0	100.760	foram bearing nanno ooze Upper/Mid Eocene
10	12H	5	14.0	16.0	104.940	foram bearing nanno ooze Middle Eocene
11	13H	1	105.0	107.0	109.550	foram bearing nanno ooze Middle Eocene
12	13H	4	52.0	54.0	113.520	foram bearing nanno ooze Middle Eocene
13	13H	6	128.0	130.0	117.280	foram bearing nanno ooze Middle Eocene
14	14H	3	52.0	54.0	122.020	nanno ooze Lower/Middle Eocene
15	14H	6	34.0	36.0	126.340	foram nanno ooze Lower/Middle Eocene
16	15H	2	44.0	46.0	130.040	foram nanno ooze Lower Eocene
17	15H	5	26.0	28.0	134.360	nanno ooze Upper Paleocene

	Core	Section	Тор	Bottom	Depth	Predominant lithology
			(cm)	(cm)	(mbsf)	
1	3 H	5	59.5	62.0	20.095	nanno ooze L Oligocene
2	4 H	2	63.5	66.0	25.135	nanno ooze L Oligocene
3	4 H	5	65.5	67.5	29.655	nanno ooze L Oligocene
4	5 H	1	124.0	126.0	33.740	nanno ooze L Oligocene
5	5 H	5	124.5	127.0	39.745	nanno ooze Upper Eocene
6	6 H	2	63.5	66.0	44.165	nanno ooze U Eocene
7	6 H	6	93.0	96.0	49.980	nanno ooze U Eocene
8	7 H	3	58.0	61.0	55.080	nanno ooze U Eocene
9	7 H	6	123.5	125.5	60.235	nanno ooze U Eocene
10	8 H	4	50.0	53.0	66.000	nanno ooze U Eocene
11	8 H	7	41.0	44.0	70.410	nanno ooze U Eocene
12	9 H	4	39.0	42.0	75.390	nanno ooze M Eocene
13	10 H	3	81.0	84.0	83.810	nanno ooze M Eocene
14	11 H	3	102.5	105.0	89.025	nanno ooze M Eocene
15	11 H	6	129.0	132.0	93.790	nanno ooze M Eocene
16	12 H	4	98.0	101.0	99.980	nanno ooze M Eocene
17	13 H	1	106.0	109.0	105.060	nanno ooze M Eocene
18	14 X	2	64.0	67.0	110.340	nanno ooze M Eocene
19	15 X	2	110.0	113.0	120.400	nanno ooze M Eocene
20	15 X	5	105.0	108.0	124.850	foram nanno ooze M Eocene
21	17 X	2	103.0	106.0	139.730	nanno ooze M Eocene
22	17 X	5	14.0	17.0	143.340	nanno ooze M Eocene
23	18 X	4	26.0	29.0	151.560	nanno ooze M Eocene
24	19 X	3	79.0	82.0	160.290	nanno ooze M Eocene
25	19 X	6	84.0	87.0	164.840	nanno ooze M Eocene
26	20 X	3	62.0	65.0	169.820	nanno ooze M Eocene
27	21 X	3	32.0	35.0	178.580	nanno ooze M Eocene
28	22 X	2	127.0	130.0	188.170	nanno ooze M Eocene
29	24 X	1	55.0	57.0	205.150	nanno ooze chalk M Eocene
30	24 X	3	58.0	61.0	208.180	nanno ooze chalk M Eocene

LEG 119, Site 738 B, Volume (cc) = 10.0. Total number of samples: 30 Total volume of samples: 300. Average volume of samples: 10.00

Samples,	Weight of	Cup with dry	Dry weight
Leg, Core,	cup without	sample.	processed
section	sample	Dry weight	(gr. taken out)
<u>Leg 113</u>	<u>Leg 113</u>	<u>Leg 113</u>	<u>Leg 113 696B</u>
<u>696B</u>	<u>696B</u>	<u>696B</u>	
1	26.08	65.03	
51R-1		38.95	
2	26.08	70.46	NOT
53R-1	20.20	44.38	DRY
5	28.28	64.73	
JSR-5	20.20	10.45 56.10	15 12
4 5/1R_1	20.20	27.82	(12.69)
5	28.29	63.40	22.57
54R-2	20.25	35.11	(12.57)
6	28.29	63.78	22.67
54R-3		35.49	(12.82)
7	28.29	59.05	18.09
55R-1		30.76	(12.67)
8	28.6	58.03	16.90
55R-3		29.77	(12.87)
9	28.6	62.00	20.43
55R-5		32.74	(12.31)
10	28.6	61.16	20.13
56R-1		32.90	(12.77)
11	28.6	68.14	27.94
57R-1		40.88	(12.94)
1	26.05	46.96	9.03
58R-1	26.06	20.91	(11.87)
<u>2nd</u>	26.06	37.93	9.07
2	28.26	11.87	(2.80)
	28.20	42.21	9.90
Jand	28.26	22 21	(4.07)
<u>2na</u>	20.20	4.05	(0.00)
	20.25	50.00	0.00
5 FORh 1	28.25	50.99	9.96
S9KD-1	76 72	22.74	(12.77)
<u>2na</u>	20.27	12 77	(3.72)
	26.06	12.77	(3.72)
	26.06	43.95	9.99
59K-2	20.25	17.89 E1 70	(7.91)
5	28.25	⊃⊥./ŏ フ₂ ⊑ว	9.58 (15.42)
-75C	26.06	23.33 /0.67	(13.42)
59R-/12	20.00	22 61	(14 2/1)
7	26.06	50.42	10.08
, 59R-4b	20.00	24.36	(14.30)

8	28.24	48.13	9.95
59R-5		19.89	(9.94)
9	26.08	38.65	6.56
60R-1a		12.57	(6.01)
<u>2nd</u>	26.06	31.97	5.91
		5.91	
10	26.07	54.61	9.80
60R-1b		28.54	(18.74)
11	26.06	47.18	9.73
60R-2		21.12	(11.39)
<u>2nd</u>	26.05	37.41	8.68
		11.36	(2.68
12	26.07	56.65	9.96
60R-3		30.58	(20.62)
13	26.07	47.69	11.97
60R-4a		21.62	(9.65)
<u>2nd</u>	28.24	37.80	9.56
		9.56	
14	28.28	62.03	18.67
60R-4b		33.75	(15.08)
<u>2nd</u>	26.05	40.06	9.33
		14.01	(6.12)
24	26.08	50.10	12.89
62R-4		24.02	(11.13)
<u>2nd</u>	28.27	39.36	8.62
		11.09	(2.47)
25	26.08	46.56	10.86
62R-5		20.48	(9.62)
2nd	26.08	35.66	9.58
		9.58	(0.00)
26	26.09	50.09	12.75
62R-6		24.00	(11.25)
2nd	26.06	37.13	8.41
		11.07	(2.66)
27	26.08	46.15	10.37
62R-7		20.07	(9.70)
2nd	28.25	37.94	9.69
		9.69	(0.00)
1			

Samples, Leg, Core, section	Weight of cup without sample	Cup with dry sample. Dry weight	Dry weight processed (gr. taken out)
Leg 114	Leg 114	Leg 114	Leg 114
1	26.08	42.45	9.07
27X-5		16.37	(7.30)
2	28.24	40.04	6.32
28X-1		11.80	(5.48)
3	26.06	35.93	5.54
29X-2		9.87	(4.33)
4	26.08	39.25	7.44
30X-3		13.17	(5.73)
5	26.09	43.75	10.09
31X-2		16.66	(6.57)
2 nd 31X-2			6.57
6	26.08	36.36	5.33
31X-6		10.28	(4.95)
7	28.25	41.22	7.27
32X-5		12.97	(5.70)
2 nd 32X-5	26.07	29.42	3.35??
8	26.05	37.13	5.71
33X-2		11.08	(5.37)
9	28.26	42.95	8.15
33X-6		14.69	(6.54)
2 nd 33X-6			6.54
10	26.07	39.59	8.34
35X-3		13.07	(5.18)
11	26.08	42.35	9.09
35X-6		16.27	(7.18)
12	28.27	44.22	9.71
36X-3		15.95	(6.24)
13	26.08	39.15	7.16
36-7		13.07	(5.91)
14	26.07	45.69	12.04
3/X-3		19.62	(7.58)
2 3/X-3		=	7.58
15	26.08	76.89	22.43
39X-2	26.07	50.81	(28.38)
16	26.07	42.83	10.76
40X-1	20.20	16.76	(6.00)
	28.26	45./3	9.39
40X-4	20.26	1/.4/	(ð.Uð) 6 07
<u>2nd</u>	20.20	6 07	0.07
		0.07	(0.00)
18	26.08	41.32	9.10
41X-1		15.24	(6.14)
19	26.06	42.02	9.95
42X-3	20.07	15.96	(6.01)
20	26.05	56.85	10.55

42X-6		30.80	(14.35)
2 nd 42X-6			14.35
21	26.10	58.02	16.71
43X-4		31.92	(15.21)
22	26.07	73.54	28.58
45X-2		47.47	(18.89)
2 nd 45X-2			18.89
23	26.07	40.08	7.83
45X-5		14.01	(6.18)
24	26.08	66.68	20.96
47X-2		40.60	(19.64)
25	26.08	54.99	15.95
47X-5		28.91	(12.96)
26	26.08	71.61	23.77
48X-3		45.53	(21.76)
27	26.08	70.94	24.04
49X-1		44.68	(20.82)
28	26.09	53.72	15.80
49X-4		27.63	(11.83)
29	28.26	62.02	19.71
50X-2		33.76	(13.95)
2 nd 50X-2			2nd
30	26.07	54.87	15.76
50X-5		28.80	(13.04)

Samples, Leg, Core, section	Weight of cup without sample	Cup with dry sample. Dry weight	Dry weight processed (gr. taken out)
<u>Leg 120</u>	<u>Leg 120</u>	<u>Leg 120</u>	<u>Leg 120</u>
1	26.08	44.64	10.04
10H-1		18.56	(8.52)
2	28.26	58.78	14.66
11H-2		30.52	(15.86)
3	28.26	48.92	10.99
11H-5		20.66	(9.67)
4	28.26	46.09	10.26
12H-1		17.83	(7.57)
5	26.08	39.40	6.88
12H-5		13.32	(6.44)
6	26.09	40.18	7.87
13H-2		14.09	(6.22)
7	26.28	44.08	9.71
13H-5		17.80	(8.09)
8	26.07	47.46	12.13
14H-2		21.39	(9.26)
9	28.27	47.31	10.80
14H-5		19.04	(8.24)
10	28.26	46.37	10.91

15H-2		18.11	(7.20)
11	28.27	51.26	13.52
15H-6		22.99	(9.47)
12	26.08	50.05	13.91
16H-4		23.97	(10.06)
13	26.07	43.51	10.03
16H-7		17.44	(7.41)
14	26.08	41.69	8.93
17H-4		15.61	(6.68)
15	26.06	52.81	15.16
17H-7		26.75	(11.59)
16	26.09	72.56	26.12
18H-4		46.47	(20.35)
17	26.06	41.05	7.73
19H-1		14.99	(7.26)
18	26.07	53.24	15.17
19H-4		27.17	(12.00)
19	28.27	55.06	16.14
20H-1		26.79	(10.65)
20	26.09	52.20	14.91
20H-5		26.11	(11.20)
21	26.09	43.14	9.78
23X-1		17.05	(7.27)
22	26.08	45.56	11.32
23X-3		19.48	(8.16)
2 nd 23X-3			8.16

Samples, Leg, Core, section	Weight of cup without sample	Cup with dry sample. Dry weight	Dry weight processed (gr. taken out)
<u>Leg 29</u>	<u>Leg 29</u>	<u>Leg 29</u>	<u>Leg 29</u>
1	28.27	47.75	10.23
14-1		19.48	(9.25)
2 nd 14-1	26.08	35.28	9.20
2	26.09	50.13	12.09
14-4		24.04	(11.95)
2 nd 14-4	26.06	37.28	11.22
3	26.07	52.41	(12.95)
15-2		26.34	13.39
2 nd 15-2	26.07	38.66	12.59
4	26.08	46.38	(9.60)
15-5		20.30	10.70
2 nd 15-5	28.26	37.82	9.56
5	28.27	54.10	15.61
16-1		25.83	(10.22)
2 nd 16-1	28.27	38.43	10.16
6	26.07	53.24	(11.77)

16-4		27.17	15.40
2 nd 16-4	26.08	38.99	12.91
7	28.27	52.55	(11.36)
17-3		24.28	12.92
2 nd 17-3	28.27	39.02	10.75
8	28.27	53.53	13.29
17-6		25.26	(10.22)
2 nd 17-6	26.05	37.35	11.30
9	28.27	47.58	10.09
18-3		19.31	(9.22)
2 nd 18-3	26.06	35.25	9.19
10	28.26	46.00	(8.27)
20-2		17.74	9.47
2 nd 20-2	28.27	36.54	8.27
11	28.27	53.85	(11.97)
20-6		25.58	13.61
2 nd 20-6	26.09	37.07	10.98
12	26.09	42.37	8.79
21-3		16.28	(7.49)
2 nd 21-3	26.09	33.41	7.32
13	28.27	45.24	8.64
22-2		16.97	(8.33)
2 nd 22-2	26.07	34.36	8.29
14	26.08	54.90	(13.34)
23-3		28.82	15.48
2 nd 23-3	26.07	38.41	12.34
15	28.26	47.93	8.18
24-3		19.67	(11.49)
2 nd 24-3	26.08	36.90	10.82
16	28.26	59.17	(14.50)
26-1		30.91	16.41
2 nd 26-1	26.08	39.84	13.76
17	28.27	43.43	7.83
26-4		15.16	(7.33)
2 nd 26-4	26.09	33.39	7.30
18	26.07	49.96	15.19
29-2		23.89	(8.70)
2 nd 29-2	26.09	39.65	13.56
19	28.26	51.73	(11.45)
30-5		23.47	12.02
2 nd 30-5	28.26	39.67	11.41
20	28.32	48.43	10.05
32-1		20.11	(10.06)
2 nd 21-1	26.08	35.60	9.52
21	28.26	47.70	(9.06)
32-3		19.44	10.38
2 nd 32-3	26.05	35.09	9.04
22	28.26	51.71	(11.17)
35-1		23.45	12.28
2 nd 35-1	28.26	39.42	11.16

23	28.26	44.55	(7.53)
36-2		16.29	8.76
2 nd 36-2	28.26	35.76	7.50
24	28.32	48.18	9.93
37-3		19.86	(9.93)
2 nd 37-3	26.08	35.90	9.82
25	28.26	47.51	10.86
38-2		19.25	(8.39)
2 nd 38-2	28.27	39.10	10.83
26	28.26	53.75	(11.90)
40-2		25.49	13.59
2 nd 40-2	40.13	28.25	11.88
27	28.27	54.69	(12.90)
42-2		26.42	13.52
2 nd 42-2	28.27	41.14	12.87
28	28.25	51.72	13.13
43-1		23.47	(10.34)
2 nd 43-1	26.08	36.39	10.31

Sites below were initially processed and found to be either barren or

too sparse to work with

Samples, Leg, Core, section	Weight of cup without	Cup with dry sample.	Dry weight processed (gr. taken
	sample	weight	out)
Leg 113	Leg 113	Leg 113	<u>Leg 113</u>
<u>690B</u>	<u>690B</u>	<u>690B</u>	<u>690B</u>
1	26.08	40.93	8.56
9H-1		14.85	(6.29)
2	28.27	48.19	11.04
9H-3		19.92	(8.88)
3	28.27	41.94	8.11
9H-6		13.67	(5.56)
4	26.06	46.02	11.69
10H-2		19.96	(8.27)
5	28.27	45.03	9.92
10-4		16.76	(6.84)
6	28.26	40.22	6.97
11H-1		11.96	(4.99)
7	28.28	48.53	10.92
11H-3		20.25	(9.33)
8	28.26	42.14	8.03
11H-6		13.88	(5.85)
9	28.27	45.37	9.67
12H-2		17.10	(7.43)

10	28.27	49.05	12.21
12H-5		21.78	9.57
11	26.09	48.26	12.16
13H-1		22.17	(10.01)
12	26.08	44.76	11.10
13H-4		18.68	(7.58)
13	26.06	47.53	12.49
13H-6		21.45	(8.96)
14	26.12	44.32	9.82
14H-3		18.20	(8.38)
15	28.28	45.74	9.93
14H-6		17.46	(7.53)
16	26.08	52.64	14.75
15-2		26.56	(11.81)
17	26.09	42.40	9.34
15H-5		16.31	(6.97)

Samples,	Weight of	Cup with	Dry weight
Leg, Core,	cup	dry	processed
section	without	sample.	(gr. taken
	sample	Dry	out)
		weight	
Leg 119	Leg 119	Leg 119	<u>Leg 119</u>
1	28.27	39.08	6.18
3H-5		10.81	(4.63)
2 nd 3H-5			4.63
5	28.27	40.43	7.04
5H – 5		12.16	(5.12)
2 nd 5H-5			5.12
9	28.27	39.38	6.11
7H – 6		11.11	(5.00)
2 nd 7H-6			5.00
13	28.27	39.50	6.16
10H – 3		11.23	(5.07)
2 nd 10H-3			5.07
17	28.27	40.79	7.29
13H – 1		12.52	(5.23)
2 nd 13H-1			5.23
21	28.27	39.84	6.53
17X – 2		11.57	(5.04)
2 nd 17X-2			5.04
25	28.27	38.32	5.15
19X – 6		10.05	(4.90)
2 nd 19X-6			4.90
29	28.32	40.15	6.93
24X - 1		11.83	(4.90)
4	28.27	37.64	(4.12)
5H-1		9.37	5.25
8	28.26	39.37	(5.05)
7H-3		11.11	6.06

12	26.07	40.20	(6.64)
9H-4		14.13	7.49
2 nd 9H-4			7.49
14	28.27	39.39	(4.94)
11H-3		11.12	6.18
16	26.06	37.52	(5.02)
12H-4		11.46	6.44
20	28.26	41.91	(5.90)
15X-5		13.65	7.75
24	26.07	37.66	(4.94)
19X-3		11.59	6.65
30	28.27	41.59	(5.85)
24X-3		13.32	7.47
2	26.09	39.76	(6.09)
4H-2		13.67	7.58
6	26.07	39.37	(6.70)
6H-2		13.30	6.60
7	26.08	44.10	(8.51)
6H-6		18.02	9.51
10	26.08	37.98	(5.35)
8H-4		11.90	6.55
15	26.07	39.28	(5.97)
11H-6		13.21	7.24
18	26.08	38.24	(5.91)
14X-2		12.16	5.25
22	26.06	36.57	(4.98)
17X-5		10.51	5.53
26	26.07	38.72	(5.96)
20X-3		12.65	6.69
3	28.28	37.56	(3.80)
4H-5		9.28	5.48
11	26.08	41.75	(6.28)
8H-7		15.67	9.39
19	26.08	39.88	(6.13)
15X-2		13.80	7.67
23	26.08	35.74	(4.08)
18X-4		9.66	5.58
27	28.26	40.76	(5.92)
21X-3		12.50	6.58
28	26.11	38.39	(5.70)
22X-2		12.28	6.58

SITE 696B LEG 113 TOTAL ABUNDANCE

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Dry Weight processed	Number of slides made up	Sample Depth mbsf	Core	Alisocysta circumtabulata	Alterbidinium asymmetricum	Alterbidinium distinctum	Areosphaeridium diktyoplokus	Areosphaeridium pectiniforme	Batiacasphaera spp	Brigantedin ium spp	Cerebrocysta mundus	Chlamydophorella neopilata	Cordosphaeridium inodes	Corrudinium regulare	Deflandrea antarctica	Deflandrea cygniformus	Deflandrea phosphoritica	Deflandrea spp dmged	Diconodinium cristatum	Eurydinium spp	Glaphyrocysta retiintexta	Graptodinium reticulatum	Hystrichokolpoma spp	Hystrichosphaeridium truswelliae	Impagidinium crassimuratum	Impagidinium dispertitum	Impagidinium elegans	Impagidinium victorianum	Impagidinium sp2	Impletosphaeridium spp	Lejeunecysta cowiei	Lejeunecysta fallax	Minisphaeridium latirictum	Minisphaeridium minimum	Minisphaeridium spp group	Moria cf zachosii	Nematosphaeropsis spp	Octodinium askiniae	Oligosphaeridium spp	Operculodinium janduchenei	Operculodinium spp
12.77	6	578.71	56R-1	0	0	0	2	0	71	120	0	10	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	6	0	30	0	13	0	0	5	0	0	2	0	0	0
12.94	6	588.16	57R-1	0	0	28	2	0	0	54	0	72	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	4	0	12	0	0	2	0	0	22	1	0	10
9.07	7	598.3	58R-1	0	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	119	0	0	0	0	0	0	0	3	0	3	0	11	0	0	1	0	0	18	0	0	4
4.05	5	607	59R-1a	0	0	8	0	0	0	0	0	0	0	3	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	3	10	24	0	0	0	0	0	9	0	0	8
9.05	5	608.13	59R-1b	0	0	49	0	0	0	0	0	0	0	0	12	0	0	0	2	0	0	0	0	0	0	0	0	1	0	7	3	27	0	0	3	0	2	19	0	0	145
9.99	6	609.65	59R-2	0	9	70	0	0	0	0	3	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	14	4	24	15	0	5	0	4	43	0	0	74
9.58	6	610.75	59R-3	0	0	17	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6	3	5	0	0	5	0	0	5	0	0	8
9.37	6	611.75	59R-4a	0	0	24	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	2	16	0	0	3	0	0	12	0	0	54
10.08	6	612.75	59R-4b	0	0	10	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	3	16	0	2	0	0	1	1	0	0	3
9.95	6	613.65	59R-5	0	1	15	1	0	0	0	1	0	0	3	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	13	0	0	7	0	0	79	0	0	83
5.91	6	616.9	60R-1a	0	0	11	0	0	0	0	0	0	0	0	10	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	2	0	3	0	0	0	11	0	0	36
9.8	6	617.7	60R-1b	0	1	4	2	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	6	0	0	4	0	0	9	0	0	49
8.68	5	619.06	60R-2	0	0	9	2	0	0	0	0	0	1	0	25	0	0	0	0	0	0	0	1	0	0	0	0	7	0	3	5	50	0	1	0	0	0	13	0	0	49
9.96	6	620.05	60R-3	0	0	14	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	14	0	1	11	0	1	6	1	0	11
9.56	6	621.55	60R-4a	0	0	12	2	0	0	0	0	0	0	1	25	0	13	8	0	0	0	0	0	0	0	0	0	0	0	4	4	24	0	15	7	0	0	14	0	0	136
9.33	6	622.55	60R-4b	0	1	2	6	0	0	0	0	0	0	0	10	0	0	5	0	0	1	0	0	0	0	0	0	0	0	4	2	23	0	0	3	0	0	12	0	0	99
10.52	6	623.5	60R-5	0	0	4	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	13	0	0	3	2	1	24	0	0	12
9.91	6	624.64	60R-6	0	0	12	7	0	0	0	0	0	0	1	12	0	7	0	2	0	0	0	0	0	6	0	1	4	0	4	3	36	0	0	0	35	0	26	0	0	61
8.18	5	626.64	61R-1	0	0	0	2	1	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	10	0	31	0	0	0	0	0	6	0	0	3
8.45	5	628.55	61R-2	0	0	2	0	5	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	32	0	0	3	0	0	18	0	0	12
8.49	6	629.73	61R-3	0	0	3	3	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	3	0	0	14	0	0	41
9.08	5	631.63	61R-4	1	0	4	14	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	1	0	3	0	2	0	30	0	0	8	0	1	47	0	0	6
8.51	5	636	62R-1	0	0	1	8	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	13	0	0	0	0	3	2	20	0	6	5	0	0	49	0	0	21
8.7	5	636.94	62R-2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	7	1	1	0	0	0	0	5	0	1	3	0	0	13	0	0	12
8.52	5	638.43	62R-3	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0	6	0	0	2	0	0	25	0	0	3
8.62	5	640.13	62R-4	0	0	9	5	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	1	0	0	1	0	0	5	1	1	23
9.58	5	641.27	62R-5	0	1	136	4	1	0	0	0	0	0	2	4	1	5	9	1	0	0	0	0	0	0	0	0	0	8	9	4	29	0	0	8	0	0	26	0	0	24
8.41	5	642.98	62R-6	0	0	22	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	18	0	0	7	0	0	15	0	0	13
Tot	al Pa	lynomoi	rphs	1	13	468	92	8	71	174	4	84	1	14	148	1	26	32	13	123	2	2	1	1	30	2	2	29	14	144	57	512	15	29	99	37	10	543	3	1	1000

	Continued																																
	.Con	tinu	ed																														
Paucisphaeridium inversibuccinum	Phthanoperidinium crenulatum	Phthanoperidinium dentatum	Phthanoperidinium echinatum	Phthanoperidinium geminatum	Phthanoperidinium granulatum	Phthanoperidinium spA	Phthanoperidinium sp1	Samlandia spp	Satyrodinium bengalense	Schematophora spp	Selenopemphix nephroides	Spinidinium colemanii	Spinidinium essoi	Spinidinium luciae	Spinidinium macmurdoense	Spiniferites spp	Systematophora placacantha	Systematophora variabilis	Turbiosphaera filosa	Vozzhennikovia apertura	Vozzhennikovia netrona	Vozzhennikovia spp dmged	Acritarchs	Cyclopsiella spp	Fenestridium clathrodermum	Palambages spp	Cymatiosphaera spp	Leosphaerida spp	Tasmanites	Foraminifera	Insect parts	Terrestrial	Totals per sample
0	0	0	0	0	0	0	9	0	0	0	70	0	0	28	0	3	1	0	0	30	0	0	3	0	0	0	6	0	0	6	7	248	675
2	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	1	0	0	0	372	0	2	0	0	0	0	7	0	0	2	12	522	1140
4	0	0	0	0	1	0	0	0	0	0	36	0	1	0	19	7	1	0	1	19	0	0	1	0	0	0	5	0	0	10	5	573	847
0	0	0	0	0	0	0	0	0	0	0	8	0	24	38	16	0	0	0	0	71	12	0	0	0	0	0	7	0	0	9	0	1229	1483
0	0	0	0	0	0	0	0	0	0	0	16	1	30	44	17	1	0	0	2	432	30	0	0	13	0	0	10	0	0	32	1	1346	2245
0	0	0	0	0	0	0	0	1	0	0	15	0	81	49	15	1	0	0	0	54	214	0	3	0	0	0	9	0	0	12	2	1045	1772
0	0	0	0	0	0	0	0	0	0	0	8	0	30	67	22	3	0	0	0	12	37	4	1	2	0	0	10	0	0	7	1	563	818
0	0	0	0	0	0	0	0	0	0	0	20	0	58	68	31	0	0	0	0	53	232	0	0	3	0	0	1	0	0	29	0	775	1390
0	0	0	0	0	0	0	0	0	0	0	14	0	39	108	16	0	0	0	0	128	31	0	0	2	0	0	1	0	2	7	6	1190	1587
0	0	0	0	0	0	4	0	0	0	4	31	0	7	33	52	1	0	0	0	88	39	0	0	3	0	0	1	0	1	8	2	937	1453
0	0	0	0	0	0	3	0	0	0	0	7	0	7	48	12	0	0	0	2	100	39	0	0	0	0	0	5	0	0	2	0	395	700
0	0	0	0	0	0	0	0	0	0	0	6	0	2	35	4	0	0	0	0	33	1	0	0	1	0	0	0	0	0	4	0	630	805
2	0	0	0	0	0	0	0	0	0	29	35	0	5	90	16	0	1	0	2	60	28	0	2	9	0	0	3	0	0	27	3	1706	2184
0	0	0	0	2	0	0	0	0	0	0	28	0	6	153	1	0	1	0	1	21	0	1	2	0	0	0	1	0	0	14	3	1741	2046
0	0	0	0	0	0	0	0	0	0	0	46	0	21	118	17	31	0	0	1	78	0	0	1	0	0	0	0	0	0	18	6	1303	1905
0	0	0	0	0	0	0	0	0	0	0	34	0	22	126	94	15	0	0	0	86	16	0	0	4	0	0	10	0	0	12	6	1615	2208
0	0	0	0	0	0	0	0	0	0	0	37	0	5	85	15	1	0	0	0	54	3	0	1	4	0	0	6	0	0	6	4	994	1278
0	0	0	0	2	0	0	0	0	0	0	30	0	10	172	39	4	0	0	4	175	9	0	0	3	0	0	5	0	0	6	6	1545	2227
0	0	0	0	0	0	0	0	0	0	0	10	2	9	342	1	5	5	0	0	31	0	0	1	1	0	0	6	0	0	10	1	906	1387
0	0	0	14	0	0	0	1	0	0	0	67	0	1	253	4	0	0	1	0	90	1	0	0	7	0	0	3	1	0	11	6	854	1391
0	6	0	0	0	0	0	0	0	0	0	14	0	3	24	46	2	0	0	0	11	0	0	1	1	0	0	0	0	0	4	0	671	860
2	0	0	0	0	0	0	0	2	1	0	33	0	5	1	61	5	0	1	2	28	0	0	2	24	0	0	0	0	0	17	0	694	999
0	0	0	0	5	0	1	0	0	0	0	27	0	4	1	41	1	0	0	0	23	0	0	1	7	0	11	5	0	0	10	0	473	741
0	0	0	0	0	0	0	0	0	0	0	9	0	1	0	17	2	5	0	0	9	0	0	0	0	0	0	0	0	0	2	0	356	448
4	0	0	0	0	0	0	0	0	0	1	41	0	4	1	63	1	0	1	4	6	0	0	0	4	0	0	4	0	0	11	6	368	575
0	0	0	4	0	0	0	0	0	0	0	4	0	4	0	6	24	0	0	1	73	0	0	0	2	0	1	1	0	0	2	0	175	351
1	0	7	2	0	0	0	0	0	0	0	31	0	14	0	3	36	0	0	20	55	0	0	2	6	3	0	2	0	0	16	2	660	1132
7	0	0	0	0	0	0	0	0	0	0	13	0	16	4	6	11	3	0	38	29	0	0	1	3	0	9	3	0	0	8	3	1592	1836
22	6	7	20	9	1	8	10	3	1	34	699	3	409	1888	634	155	17	3	78	2221	692	7	22	99	3	21	111	1	3	302	82	25106	36483

SITE 696B LEG 113 TOTAL ABUNDANCE

												SIT	E 6	99	ΑL	.EG	11	4	т	ЭТA		ABL	JN	DAI	NCE														
Dry weight processed	humber of slides	Sample Depth mbsf	Core	Achomosphaera alcicornu	Alterbidinium asymmetricum	Batiacasphaera perforata	b Batiacasphaera spp	Cerebrocysta delicata	 Cerebrocysta mundus 	Cerebrocysta waipawaense	Chlamydohorella neopilata	Corrudinium regulare	Corrudinium spp	Impagidinium aculeatum	Impagidinium dispertitum	Impagidinium maculatum	Impagidinium victorianum	Impagidinium spp	b Lyphocysta spp	Minisphaeridium sp group	 Nematosphaeropsis spp 	odontochitina spp	Operculodinium janduchenei	o Operculodinium spp	Phthanoperidinium geminatum	 Phthanoperidinium dentatum 	Phthanoperidinium sp1	Phthanoperidinium spA	Spinidinium luciae	Spiniferites spp	 Tectatodinium cf spp 	Acritarchs	Fenestridium clathrodermum	Cystidiopsis certa	 Cymatiosphaera spp 	b Leiosphaeridia spp	Insect casing	Derrestrial	Totals per sample
9.07	6	249.73	2/X-5 28X-1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
5.54	5	255.55	207-1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	3
7.44	6	272.24	30X-3	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	12
6.57	7	280.33	31X-2	0	0	0	1	5	0	1	0	0	0	0	0	0	24	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	3	0	0	13	50
5.33	6	286.53	31X-6	0	0	0	0	1	0	0	0	0	0	0	2	0	3	0	1	0	0	0	1	2	0	0	0	5	0	3	0	0	0	0	5	3	3	3	32
3.35	4	293.83	32X-5	1	0	0	0	0	0	0	0	0	1	2	1	0	2	0	6	1	0	0	0	0	3	105	70	0	2	0	0	0	0	2	23	15	0	11	245
5.71	6	299.07	33X-2	0	2	0	20	0	0	0	0	0	0	0	0	0	15	0	2	1	0	0	0	0	0	0	0	0	7	4	0	0	0	0	4	0	3	3	61
6.54	6	305.16	33X-6	0	2	1	16	0	0	0	2	4	0	9	0	0	15	5	4	5	2	13	1	0	0	0	0	7	8	4	2	0	0	2	30	0	0	18	150
8.34	6	319.86	35X-3	0	0	1	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	9
9.09	6	324.55	35X-6	0	0	1	0	0	9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	5	18
9.71	8	329.68	36X-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.16	6	334.99	36X-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.58	8	339.07	37X-3	0	0	0	0	0	0	0	0	3	0	1	0	0	8	0	1	0	0	0	2	0	0	0	0	11	0	0	0	2	0	0	7	0	0	1	36
22.43	6	356.17	39X-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.76	5	364.5	40X-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.87	6	369.08	40X-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.1	7	373.81	41X-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.95	5	386.71	42X-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.35	5	390.89	428-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	11
10.71	6	412 1	457-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 92	6	415.1	457-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	5
20.96	6	417.77	437-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 95	5	436.6	47X-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
23.77	7	443.66	48X-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.04	5	449.92	49X-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.8	5	454.86	49X-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.95	4	460.81	50X-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.76	5	465.65	50X-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	43
Tot	al Pa	lynomo	rphs	1	4	3	37	6	9	1	2	10	1	14	3	2	74	5	15	7	2	14	8	3	3	105	70	23	17	11	2	2	1	4	74	19	70	64	686

SITE 748B LEG 120 TOTAL ABUNDANCE

																																				(Cont	inue	:b
Dry Weight processed	Number of slides made up	Sample Depth mbsf	Cores	Achomosphaera spp	Aerosphaeridium spp	Alisocysta spp	Alterbidinium asymmetricum	Alterbidinium distinctum	Batiacasphaera perforata	Cerebroycysta bartonensis	Cerebrocysta delicata	Cerebrocysta cf delicata	Cerebrocysta mundus	Cerebrocysta waipawaense	Chlamydophorella neopilata	Corrudinium incompositum	Corrudinium otagoense	Corrudinium regulare	Dapsilidinium pseudocoligerum	Deflandrea antarctica	Deflandrea convexa	Deflandrea flounderensis	Deflandrea leptodermata	Deflandrea phosphoritica	Deflandrea truncata	Deflandrea spp dmged	Dino sp1	Dino sp3	Forma b	Graptodinium inconditum	Hapsocysta kysingensis	Heteraulacacysta pustulata	Hystrichosphaeridium spp	Impagidinium aculeatum	Impagidinium crassimuratum	Imagidinium dispertitum	Impagidinium elegans	Impagidinium maculatum	Impagidinium parvireticulatum
10.4	4	76.83	10H-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.66	4	87.62	11H-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.99	3	92.14	11H-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.26	3	95.75	12H-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.88	3	102.02	12H-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.87	3	106.65	13H-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.71	3	111.67	13H-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.13	5	115.9	14H-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.8	6	120.65	14H-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.91	6	126.36	15H-2	0	0	0	0	0	3	0	0	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.52	4	132	15H-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.91	2	137.68	16H-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.03	3	141.81	16H-7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	11	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0
8.93	4	148.78	17H-4	0	0	0	160	1	0	0	1	2	0	0	195	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	54	0	0	0
15.16	5	152.11	17H-7	0	0	0	0	0	0	0	3	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	16	0	0	0
26.12	10	156.9	18H-4	64	0	0	0	1	0	0	0	9	0	4	20	0	0	35	0	118	0	25	0	0	0	71	129	0	0	30	0	0	6	6	0	5	1	1	0
7.73	4	162.1	19H-1	1	0	0	0	0	20	0	10	2	0	2	0	0	0	4	0	888	43	0	24	6	1	0	0	0	0	0	0	1	30	0	0	1	1	0	18
15.17	4	167.39	19H-4	0	0	2	0	6	0	0	22	24	2	1	0	5	0	8	0	3	0	0	0	0	0	0	0	0	0	0	4	0	0	13	0	10	1	0	0
16.14	6	1/2.12	20H-1	0	1	0	0	0	0	0	23	10	0	6	0	0	0	6	10	3	0	0	0	0	0	0	0	0	36	0	0	0	13	9	0	0	0	0	0
14.91	4	1/7.76	20H-5	25	0	0	0	0	0	30	118	16	0	0	0	0	0	23	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	26	0	14	0	0	/8/
9.78	5	197.38	23X-1	6	3	0	0	0	1	40	46	2	0	51	3/	0	153	0	0	18	0	0	0	1	0	13	0	3	0	0	0	0	2	/	0	14	0	4	0
8.16	/	200.47	23X-3	0	0	3	0	0	2	8	9	3	10	0	0	0	2	0	0	29	0	0	0	0	0	4	0	2	0	0	0	0	1	0	0	19	0	1	0
Pal	ynom	orph To	tais	96	4	5	160	8	26	/8	232	69	13	64	252	5	155	185	10	1060	43	25	24	/	1	89	129	5	36	30	4	1	55	93	5	133	3	6	805

												SITE	748	3B	LEG	i 12	0	Т	OTA	AL A	ABL	JNC	DAN	CE													
C	ontir	nued	1																																		
Impagidinium victorianum	Impletosphaeridium spp	Lejeunecysta spp	Lyphocysta spp	Minisphaeridium latirictum	Minisphaeridium spp group	Nematosphaeropsis spp	Operculodinium janduchenei	Operculodinium spp	Phthanoperidinium crenulatum	Phthanoperidinium dentatum	Phthanoperidinium echinatum	Phthanoperidinium geminatum	Phthanoperidinium spA	Phthanoperidinium spp dmged	Pterospermella	Rhombodinium spp	Samlandia reticulifera	Samlandia spp	Spinidinium essoi	Spinidinium luciae	Spinidinium macmurdoense	Spinidinium sp1	Spiniferites spp	Tectatodinium spp	Thalassaphora spp	Tricodinium hirsutum	Turbiosphaera sp1	Vozzhennikovia apertura	Acritarchs	Fenestridium clathrodermum	Cymatiosphaera spp	Leiosphaerida spp	Tasmanites	Foraminifera	Insect parts	Terrestrial	Totals per sample
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	68
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8
3	0	0	1	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	2	0	0	0	0	3	0	0	22	8	0	15	0	8	146
16	0	3	12	0	0	8	32	108	0	1233	0	0	3	0	0	0	0	0	0	16	0	0	8	0	0	0	0	0	0	0	131	365	18	0	0	4	2480
2	0	0	3	0	6	10	6	8	0	0	65	98	0	42	0	0	0	0	0	28	0	2	2	0	0	0	0	0	518	0	19	475	0	0	0	2	1320
3	0	0	5	0	44	19	5	0	49	0	50	0	0	0	0	0	0	0	0	0	0	501	111	0	0	0	0	140	0	1	130	2500	77	0	4	4	4168
1	0	0	0	0	4	0	0	5	0	0	2	0	0	0	0	5	4	25	0	0	0	0	46	0	3310	0	27	1	0	0	2	12	2	0	0	0	4498
2	0	0	6	0	1	13	0	1	0	0	38	7	0	0	8	0	0	0	0	14	1	0	281	0	0	0	0	0	1	0	27	52	0	0	0	2	555
8	6	0	15	28	1271	29	0	3	0	0	0	0	58	0	12	0	0	0	6	6	1	0	126	0	16	5	0	63	0	0	112	98	59	1	0	5	2045
3	0	0	20	0	2	31	0	0	0	565	52	0	0	3	0	0	1	0	0	1	0	0	168	0	0	0	0	0	0	0	39	28	270	0	0	20	2246
14	0	0	3	0	2	4	4	0	0	0	0	0	0	0	1	0	0	0	0	20	0	0	553	2	0	0	0	0	33	1	56	15	67	0	1	7	1184
0	38	0	2	0	9	18	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	49	0	1	0	0	0	0	0	22	20	19	1	0	7	302
103	44	3	67	28	1339	133	54	126	49	1798	207	105	61	45	21	5	11	25	6	171	2	503	1346	2	3327	5	27	207	552	2	560	3573	514	17	5	61	19020

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								SIT	ΓE 2	277	LEC	5 29)	TOT	AL	AB	UN	DA	NCI	E														^ -			
								1																										6	ntin	luea	
Batiacasphaera perforata	Batiacasphaera spp	Cerebrocysta bartonensis	Cerebrocysta delicata	Cerebrocysta cf delicata	Cerebrocysta mundus	Cerebrocysta teuriensis	Cerodinium medcalfii	Chlamydophorella neopilata	Corrudinium eyrense	Corrudinium obscurum	Corrudinium otagoense	Corrudinium regulare	Dapsilidinium pseudocoligerum	Deflandrea antarctica	Deflandrea cygniformis	Deflandrea dartmoorium	Deflandrea medcalfii	Deflandrea phosphoritica	Deflandrea scabrata	Deflandrea truncata	Deflandrea spp dmged	Diconodinium multispinulum	Dino sp2	Dino sp3	Graptodinium inconditium	Graptodinium reticulatum	Hapsocysta kysingensis	Hystrichosphaeridium tubiferum	Hystrichosphaeridium brevispinium	Impagidinium aculeatum	Impagidinium crassimuratum	Impagidinium dispertitum	Impagidinium elegans	Impagidinium maculatum	Impagidinium parvireticulatum	Impagidinium victorianum	Impletosphaeridium spp
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
0	0	0	0	0	9	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	1	0
4	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	20	6	0	12	26	16	17	33	0	5	0	0	0	8	0	0	3	0	0	7	1	0	0	0	0	5	0	0	0	0	0	5	2
0	0	0	0	0	1	0	0	2	0	0	0	13	0	47	0	2	2	5	2	0	52	1	0	0	3	0	0	0	0	0	0	2	0	2	0	3	1
0	0	0	0	0	2	0	1	7	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	6
4	0	15	3	16	3	0	0	10	0	0	0	12	2	1	0	0	0	0	0	0	0	0	40	0	8	5	0	0	0	8	39	7	9	0	0	5	97
0	0	8	0	6	0	0	0	51	0	0	0	5	26	154	4	0	0	9	0	1	107	0	6	0	7	17	0	4	3	10	2	2	14	1	3	1	1
οl	0	0	12	10	0	0	0	0	0	0	0	1	0	0	0	Ο	0	0	0	9	Ο	0	0	0	0	0	1	0	0	1	Ο	0	1	0	5	1	r

0 0 0 0 0 0 0 0

4 2 2

0 0 0 0

0 0 0 0

24 2 10 166

0 0 0 0

3 33 41

0 0 0

0 0

27 13 8

0 0 0 0 0 0

0 0 0 0 0 0

0 0

0 0 0 0 0

0 0 0 0 0 0 0 0

0 0 0

0 0 0 0 0 0

22 1 6

0 0 0 0

Number of slides made up

Depth mbsf

Sample

122.17

132.995

136.76

141.25

162.56

185.75

190.8

199.59

236.3

240.84

265.335

280.15

292.53

296.3

350.01

369.63

380.59

388.57

408.535

435.01

Palynomorph Totals

427.535 42-2

126.415 14-4

145.565 16-4

153.725 17-3

157.515 17-6

180.825 20-2

210.275 23-3

220.145 24-3

Dry Weight Processed

9.2

11.22 5

12.59 6

9.56

10.16 5

12.91 5

10.75

11.3 6

9.19 4

8.27 6

10.98 6

7.32 6

8.29 6

12.34

10.82

13.76 8

7.3 5

13.56 6

11.41 4

9.52 5

9.04 6

11.16 5

7.5 4

9.82

10.83

11.88 4

12.87 5

10.31 5

Alterbidinium asymmetricum

0 1

0 0

0 0

0 0 0 0 0 0 0 0

0 26

2 0

0 0

0 0 0

0 0 0

23 16 43 37 6

0 0

0 0

8 7

0 0 0 0

0 0 0

90 26

0 0

0 1 0 0 0

0 0 0

0 0 0

29 207

16 17 76

Alisocysta circumtabulata

Airiana velicosa

Achomosphaera spp

0 0 0

0 0 0 0

0 0 0 0

0 0

0 0 0 0

0 0

24 0

0 0

0 0 0

0 0 0

0 0

2 9

Core

14-1 0 0 0 0

15-2 0 0 0 0

15-5 0 0 0 0

16-1 0 0 0 0

18-3 0 0 0 0

20-6

21-3

22-2 0 0 0 0

26-1 0 2

26-4

29-2

30-5 1 0 6 0

32-1 3 0 0 0

32-3

35-1

36-2

37-3

38-2 0 0 0 0

40-2 0 0

43-1 34 107

0 0

0 0

0 0

0 0

Co	ntin	ued.									-				-									_			_		_	_													
Lejeunecysta fallax	Lingulodinium sp	Lyphocysta spp	Manumiella druggii	Minisphaeridium latirictum	Minisphaeridium spp group	Nematosphaeropsis spp	Octodinium askiniae	Operculodinium janduchenei	Operculodinium spp	Paucisphaeridium inversibuccinium	Phthanoperidinium aculatum	Phthanoperidinium crenulatum	Phthanoperidinium dentatum	Phthanoperdinium echinatum	Phthanoperidinium eocenicum	Phthanoperidinium geminatum	Phthanoperidinium sp1	Phthanoperidinium spA	Phthanoperidinium spp damaged	Pterospermella spp	Samlandia reticulifera	Satyrodinium haumuriense	Satyrodinium bengalense	Selenap em phix nephroides	Spinidinium essoi	Spnidinium luciae	Spiniferites spp	Stovercysta spp	Thalassiphora spp	Tectatodinium spp	Unknown spp1	Acritarchs	Cystidiopsis spp	Fenestridium dathrodermum	Palambages spp	Paucilo bimorpha inaequalis	Cymatiosphaera spp	Leiosphaeridia spp	Tasmanites	Foraminifera	Insect parts	Terrestrial	Totals per sample
0	0	0	0	0	0	3	0	0	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	20	34
0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	1	0	0	9	18
0	0	0	0	0	0	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	4	2	0	0	0	1	16
0	0	3	0	0	0	3	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	18	2	1	0	1	18	61
0	0	1	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	3	0	2	19
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	9
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	49
0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	18
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	5	14
1	0	0	0	0	3	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	28	0	0	0	4	0	0	15	3	0	1	1	9	90
0	1	1	0	0	46	0	0	0	0	0	0	0	11	0	0	0	19	0	0	2	0	0	0	0	0	0	32	3	0	6	0	7	1	0	0	0	6	45	0	1	0	14	214
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	6	10	1	0	0	13	41
0	0	0	0	0	0	1	0	0	8	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	2	2	0	4	42
0	0	0	0	0	6	1	0	0	14	0	0	0	0	0	0	0	0	14	0	0	1	0	0	0	0	0	5	0	0	0	0	6	0	0	0	0	16	0	4	0	0	10	91
0	0	0	0	0	4	18	1	13	65	34	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	68	0	1	30	0	6	7	1	48	474
1	0	0	0	0	5	3	0	4	75	5	0	0	8	0	0	0	8	2	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	1	0	0	22	2	0	5	0	11	298
1	0	0	1	0	0	1	0	0	256	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	41	0	0	5	7	0	0	1	1	0	48	30	0	6	0	2	425
1	0	4	0	136	0	7	3	18	124	13	0	0	0	0	0	0	0	2	0	1	0	1	0	13	1	78	64	1	0	20	0	107	0	12	0	0	47	50	47	36	5	18	1143
0	0	7	0	115	0	0	37	1	11	0	0	166	0	58	2	62	0	12	96	20	0	0	2	4	0	0	49	0	0	0	0	33	1	0	0	1	49	43	66	40	3	17	1344
0	0	1	0	19	0	2	0	0	9	0	0	0	0	18	0	0	0	0	0	3	0	0	0	0	0	0	50	0	63	0	0	0	0	1	0	0	22	1	13	0	0	14	278
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	12
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	40
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	3
4	1	17	1	270	64	42	41	36	591	52	1	166	27	76	2	66	27	35	96	39	1	1	2	17	1	78	283	4	63	60	7	199	3	89	1	2	290	192	142	101	11	277	4744

SITE 277 LEG 29 TOTAL ABUNDANCE

Gonyaulacoid and Peridiniod Total Percentages



Appendix 2.6: Totals for Gonyaulacoid and Peridinioid dinocysts for the four sites in this study. Included are the Age, Depth for each site and Nannofossil zones (Martini, (1971) and Okado and Bukry, (1980). Also shown are Dinocyst Zones where present and the E/O boundary and Middle/Late Eocene boundary. Also included are the Gonlyaulacoid, Peridinioid results of ODP site 1172 of Sluijs *et al.*, (2003).

ODP Site 696B Total Abundance



Appendix 2.7 Total abundance for site 696B for marine palynomorphs taken to one hundred percent. Terrestrial calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980)

ODP Site 699A Total Abundance



Appendix 2.8: Total abundance for site 699A for marine palynomorphs taken to one hundred percent. Terrestrial calculated for a total abundance 100 percent. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980).



Appendix 2.9: Total abundance for site 748B for marine palynomorphs taken to one hundred percent. Terrestrial calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980)



Appendix. 2.10: Total abundance site 277 for marine palynomorphs taken to one hundred percent. Terrestrial calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980)

102 103 <th>D</th> <th>SDP S</th> <th>Site</th> <th>27</th> <th>7 L (</th> <th>g</th> <th>29</th> <th></th>	D	SDP S	Site	27	7 L (g	29	
Michael Control Control <t< td=""><td>Depth (mbsf) (#Sample positions)</td><td>Age</td><td>This Study</td><td>Nannofossil zones</td><td>Radiolaria</td><td>NZ Stages for aminifera</td><td>Hollis et al. (1997)</td><td>Depth (mbsf) (Sample positions)</td></t<>	Depth (mbsf) (#Sample positions)	Age	This Study	Nannofossil zones	Radiolaria	NZ Stages for aminifera	Hollis et al. (1997)	Depth (mbsf) (Sample positions)
	120 120	ocene	17-18	2-23	Upper RP15		P 20	120 - 120
	140 8	ly Olige	CP 1	NP2	5	rlv Lwh	3-19	140
	160	Ear	CP 16	VP 21	wer RP 1	Ea	P 18	160
2000 200 2000 2	490.4	-			Lo	Ar	Р 17	180
2240 100 <td>200</td> <td>ene</td> <td>CP 15b</td> <td>P 19-20</td> <td>H</td> <td></td> <td></td> <td>200</td>	200	ene	CP 15b	P 19-20	H			200
	220	ate Eoc	Ĭ	N	RP 14	Ak	15-16	220
280 280 280 280 280 280 280 280	240	-	P 15a	VP 18			4	240
	260		~			μ		260
100 100 100 100 100 100	280		4	~			ŀ	280
	300		CP 14	NP 1	2-13	46	-14	300
340 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	320	le Eocen			RP 1	Ì	P 13	320
	340	Middi	o 14a	P 16				340 -
	360		Ū	z			12	360
	380		CP 13c	Np15c	RP 10-11	Ê	4	380 ↓
						ЧD	P 11	400 -
	400							

D	SDP S	Site	27	7 Le	g	29	
Depth (mbsf) (#Sample positions)	Age	This Study	Nannofossil zones	Radiolaria	NZ Stages foraminifera	Hollis et al. (1997)	Depth (mbsf) (#Sample positions)
120 U U U U U U U U U U U U U U U U U U U	Oligocene	CP 17-18	NP22-23	Upper RP 15	Lwh	P 20	120
160	Early	CP 16	NP 21	Lower RP 15	Early	P 18-15	160
200		5b	-20		Ar	Р 17	200
220	Late Eocem	CP1	NP 19	RP 14	Ak	P 15-16	220
240		CP 15a	NP 18				240
260 -		-	m		~	m	260
280		CP 14b	NP 17				280
320	Eocene			RP 12-13	Ab	P 13-14	320 -
340	Middle	CP 14a	NP 16				340 -
360		CP 13c C	Np15c	0-11	Dp	P 12	360 -
380				RP 1	Dh	P 11	380 • •
420					Dm	P 10	420 -



Ph spA zone

Ph gen zone Ph echi zone

620

Appendix 2.11 Total abundance for site 696B for marine genera is taken to one hundred percent. Terrestrial is calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980)

ODP Site 699A Marine Genera



Appendix 2.12: Total abundance for site 699A for marine genera palynomorphs taken to one hundred percent. Terrestrial calculated for a total abundance 100 percent. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980).

ODP Site748B Marine Genera

90 -95 -

30 -35 -

150 -155 -160 -165 -170 -75 -



Appendix 2.13: Total abundance for site 748B for marine general taken to one hundred percent. Terrestrial calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980).

		ODP S	ite 74	8B L	eg 12	20
	Depth (mbs()	Age Age	This Study	Zones	Roberts et al. (2003)	Depth (mbsf) (¶Sample positions)
	75 80 85	Late Oligocene	CP 19	NP 24-25	la P21b	75 80 85
	90	arly Oligocene	CP 17-18	NP22-23	P 20 P 21	90 95 100 105
_	110		CP 16	NP 21	P 18-19	110 115
	120	Eocene	CP 15b	NP 19-20	P17	120 125
re	130	Late	CP 15a	NP 18	6	130 135
>	145	T.V. T. T. T.	CP 14b	NP 17	P 15-1	145 - 150 -
atum	155	die Eocene	CP 14a	NP 16	•	155 - 160 -
tum	165	Mide			P 12	165 170
	1/5	تسلسلسسان				1/5 180 185
	190	Lummun				190 195 -
	- I _206	4				200

DSDP Site 277 Marine Genera



Appendix 2.14: Site 277 marine genera taken to one hundred percent. Terrestrial is calculated from a total abundance of 100 percent and displayed above. The E/O and Middle/Late Eocene boundaries are marked with green dashed lines. Nannofossil zones are from Martini (1971) and Okado and Bukry (1980)



Appendix 2.15: Gonyaulacoid and Peridinioid pecentages of morphologically closely related dinoflagellate cysts quantitavely grouped to show their distribution within each of the four samples (Total = 100%). Impagidinium, Nematosphaeropsis = Impagidinium group; Operculodinium, Impletosphaeridium = Operculodinium group; Achomosphaera, Spiniferites = Spiniferites group (Brinkhuis & Biffi, 1993); Minisphaeridium spp group (Fensome *et al.*, 2009). The nannofossil zones are taken from Martini (1971) and Okado and Bukry (1980)