

2. **LATE EOCENE–QUATERNARY DINOFLAGELLATE CYSTS FROM ODP SITE 1168, OFF WESTERN TASMANIA**

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**ABSTRACT**

Palynomorphs were studied in samples from Ocean Drilling Program (ODP) Leg 189, Hole 1168A (slope of the western margin of Tasmania; 2463 m water depth). Besides organic-walled dinoflagellate cysts (dino-cysts), broad categories of other palynomorphs were quantified in terms of relative abundance. In this contribution, we provide an overview of the early late Eocene–Quaternary dinocyst distribution and illustrate main trends in palynomorph distribution.

Dinocyst species throughout Hole 1168A are largely cosmopolitan with important contributions of typical low-latitude taxa and virtual absence of endemic Antarctic taxa. Dinocyst stratigraphic distribution broadly matches that known from the Northern Hemisphere and equatorial regions, although significant differences are noted. Selected potentially biostratigraphically useful events are summarized. The distribution of dinocysts in the middle–upper Miocene interval is rather patchy, probably due to prolonged exposure to oxygen. An important general aspect in the dinocyst assemblages is the near absence of Antarctic endemic species and the apparent influence of relatively warm waters throughout the succession at Site 1168. General palynomorph distribution indicates continued deepening from an initial shallow, even restricted, marine setting from late Eocene–Quaternary times. A curious massive influx of small skolochorate acritarchs is recorded throughout the late early–early middle Miocene; the significance of this
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INTRODUCTION

Ocean Drilling Program (ODP) Site 1168 is located in middle bathyal water depths (2463 m) on the western margin of Tasmania (Fig. 1). Site 1168 is a5 on the Atlantic margin of the southern region of the Southwestern Pacific known as the Antarctic Basin, which forms the deep-water component of the Southern Ocean to the west.

The overall dinocyst distribution pattern corresponds to the long-term existence of a Leeuwin-like current influencing the region, which is also apparent across the late Pliocene–Quaternary interval and to illustrate main trends in palynological studies also indicated the presence and local abundance of dinocysts, broad groups of other palynomorphs were quantified. Here, we aim to provide an overview of the dinocyst distribution from the sedimentary succession at Site 1168. The combined shipboard results indicate that the upper Eocene–Quaternary succession is reasonably consistent occurrence of dinocysts throughout the Oligocene and Neogene deposits (Shipboard Scientific Party, 2001ab). Initially, in the late Eocene, the site was at the far eastern end of the restricted Australo–Antarctic Gulf and separated from the Pacific Ocean by the Tasmanian Promontory–South Tasman Rise. Plate movements and related margin tectonics to the west.

Besides dinocysts, broad categories of other palynomorphs were quantified. Here, we aim to provide an overview of the dinocyst distribution from the sedimentary succession at Site 1168. The combined shipboard results indicate that the upper Eocene–Quaternary succession is reasonably consistent occurrence of dinocysts throughout the Oligocene and Neogene deposits (Shipboard Scientific Party, 2001ab). Initially, in the late Eocene, the site was at the far eastern end of the restricted Australo–Antarctic Gulf and separated from the Pacific Ocean by the Tasmanian Promontory–South Tasman Rise. Plate movements and related margin tectonics during Site 1168, confirming results of earlier studies on other microfossil groups. The occasional influence of colder surface water conditions is, however, also apparent, notably during the late Pliocene–Quaternary, indicating the potential of high-resolution dinocyst analysis for future paleoceanographic studies.

Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant. Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant. Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant. Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant. Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant. Calcareous microfossils (foraminifers and nannofossils) are generally abundant down to the basal Oligocene. Benthic foraminifers are mostly complete. Of the siliceous groups, diatoms are generally rare and sporadic, whereas radiolarians are generally rare but occasionally abundant.
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Northern Hemisphere records and are herein only discussed for a few species, where appropriate.

**MATERIAL AND METHODS**

The combined cored sequence at Site 1168 (see Figs. F1, F2) (mainly Hole 1168A; total depth [TD] = 883.5 meters below seafloor [mbsf]) broadly consists of 260 m of nannofossil ooze of middle Miocene and younger age (lithostratigraphic Unit I); 400 m of clayey chalk, nannofossil siltstone, and sandstone of early Miocene and Oligocene age (Unit II); and 220 m of shallow-marine carbonaceous mudstone and sandstone (Units III–V) of late Eocene age (Shipboard Scientific Party, 2001b). Construction of a composite section of the triple-cored portion of the sedimentary sequence (~110 mbsf) indicates that there are no stratigraphic gaps to that depth. Beyond that, there are limited gaps, but overall core recovery averaged 93%. More details on lithology and sedimentology are available in the Leg 189 Initial Reports volume (Shipboard Scientific Party, 2001b).

Initial shipboard data and interpretation suggests that sedimentation rates were relatively low throughout the late Eocene–Quaternary for a setting close to land (6.9–1.5 cm/k.y.). The succession of sediment, climatic, and biotic changes recorded at Site 1168 was interpreted to reflect the three major steps in Cenozoic climate state, namely, “Greenhouse” in the late Eocene, “Doubthouse” of intermediate mode in the Oligocene–early Miocene, and “Icehouse” since the middle Miocene (Shipboard Scientific Party, 2001a). Relatively rapid changes mark the boundaries at the Eocene–Oligocene transition and during the middle Miocene at ~14 Ma. The most conspicuous change in the sediment and biotic sequence occurred during the transition from the latest Eocene to the early Oligocene, with an apparent reduction in sedimentation rates, deposition of glauconite sands, and a possible hiatus in the earliest Oligocene (Stickley et al., this volume). This transition is seen to reflect a transient event associated with temporarily increased bottom water activity in the basin (Shipboard Scientific Party, 2001a). The timing of this episode is apparently consistent with the hypothesis linking the critical deepening of the Tasmanian Gateway to major cooling of Antarctica and associated cryospheric development (see also Stickley et al., submitted). However, these links are as yet poorly understood (see discussion in Huber et al., submitted).

For further information on the general geologic and oceanographic setting of Site 1168, see reviews in Shipboard Scientific Party (2001a, 2001b).

**Palynological Processing and Counting**

Organic-walled microfossils were extracted for analysis using standard palynological processing techniques at the Laboratory of Palaeobotany and Palynology at Utrecht University. From the core samples, ~5 cm of wet sediment was oven-dried at 60°C and weighed (8–14 g). Processing involved an initial treatment in hydrochloric acid (10%) to dissolve carbonates, followed by a treatment of hydrofluoric acid (38%) to dissolve silicates. After each acid step, samples were washed two times by decanting after 24 hr settling and filling up with distilled water. The hydrofluoric step included 2 hr shaking at ~250 rpm and adding 30% hydrochloric acid to remove fluoride gels. Then, samples were repeatedly washed in distilled water and finally sieved through a 15-µm mesh. The fraction was then transferred to Nalgene bags and air-dried for 2–4 weeks. Sediment samples were then hand-picked for terrestrial palynomorphs and oceanic dinocysts. A 5 ml aliquot was removed for each sample, and the 5 ml aliquot of each sample was divided into two parts. One part was stored in 70% ethanol at 4°C and used for the taphonomic analysis. The other part was used for the palynological analysis. The palynological analysis was performed using a binocular microscope on a slide with a coverslip (5 × 24 × 0.15 cm) and a droplet of a 1:1000 solution of methyl blue stain. A minimum of 500 terrestrial palynomorphs and 500 oceanic dinocysts were counted for each sample. The samples were mounted in absolute n-butanol and briefly treated through a Crain.
nylon mesh sieve (10 µm nylon mesh sieve for Quaternary samples). To break up clumps of residue, the sample was placed in an ultrasonic bath for a maximum of 5 min after the first sieving. The residue remaining on the sieve was transferred to a glass tube. The tubes were centrifuged for 5 min at 2000 rpm and the excess amount of water was removed. For slide preparation, residues were transferred to vials and glycerin water was added. The residue was homogenized, no coloring was added, a droplet of each residue was mounted on a slide adding glycerin jelly, and the mixture was stirred and sealed with nail varnish. Two slides per sample were prepared.

Where possible, slides were initially counted to 200 palynomorphs, followed by the counting of 200 or more dinocysts. When dealing with low yields, counting was stopped after two slides at this stage (see Table T1). Dinocysts were counted at species level, whereas other palynomorphs were counted in broad categories, namely, bisaccate pollen, other pollen, spores, inner linings of foraminifers (if >3 chambers), remains of prasinophyte or chlorophyte algae such as *Cymatiosphaera* and *Tasmanites* spp., remains of Copepod eggs, and acritarchs. Here, of these other palynomorphs, only the calculated terrestrial percentage is presented to provide a general characterization (Table T1; Fig. F2). Aquatic palynomorphs are usually dominated by dinocysts. The lower Miocene interval is, however, characterized by massive influxes of small skolochorate acritarchs (palynomorphs of unknown affinity); this is an exceptional phenomenon. These microfossils occur in up to two orders of magnitude larger concentrations than dinocysts. Samples characterized by such huge influxes of acritarchs are marked in Table T1, but numbers were kept separate from the general palynomorph count as they obscure trends in relative terrestrial palynomorph abundance, for example.

The postcruise studies are here supplemented by the onboard studies performed on core catcher material. Essentially, shipboard processing followed the steps as described above, using a 20-µm stainless steel sieve (leading to the potential loss of small palynomorphs), and equipment was not as sophisticated as common modern laboratory setups. Results from these shipboard samples should be taken as rough estimations.

Cyst taxonomy follows that cited in Williams et al. (1998) and Rochon et al. (1999). A species list, including remarks on new taxa, is presented in the "Appendix," p. 15. For the purpose of the present study, which only provides a broad overview of the dinocyst distribution and general palynological contents, emphasis is placed on potential age-diagnostic taxa. Other species are placed in generic groups (see the "Appendix," p. 15). Future studies will consider dinocyst distribution of rare species, besides other aspects, in more detail. Slides are stored in the collection of the Laboratory of Palaeobotany and Palynology, Utrecht University.

Age Model

We adopt the postcruise age model as presented in Stickley et al. (this volume) for Hole 1168A. Ages (in mega-annum [Ma]) are indicated in Table T1 where relevant; for more detailed information see Stickley et al. (this volume). As an indication, the Pliocene/Pleistocene boundary occurs at ~16 mbsf, the early/late Pliocene boundary at ~46 mbsf, the Miocene/Pliocene boundary at ~92 mbsf, the middle/late Miocene boundary at ~190 mbsf, the early/middle Miocene boundary at ~265 mbsf, the Oligocene/Miocene boundary at ~420 mbsf, the early/late
Oligocene boundary at ~580 mbsf, the Eocene/Oligocene boundary (sensu Global Stratotype Section and Point [GSSP]) at ~745 mbsf, and the middle/late Eocene boundary close to the bottom of the hole (~880 mbsf). Using this age model, sedimentation rates varied from ~3.5 cm/k.y. in the Eocene to ~1.5 cm/k.y. during most of the Neogene (Stickley et al., this volume).

RESULTS

Dinocyst distribution, relative abundance of terrestrial palynomorphs, and samples with massive influxes of acritarchs, as well as percentages of non-neritic (oceanic) dinocysts (see explanation below) are depicted in Table T1. A summary of selected potentially stratigraphically useful or palaeoceanographically significant dinocyst events and derived ages is given in Table T2. Plots of percent terrestrial palynomorphs and percent oceanic dinocysts vs. depth and age are given in Figure F2.

Palynology: General

Recovery of palynomorphs is quite variable. Dinocysts are in most cases the most prominent palynomorph, as this argument is strongly biased in the Figures and Table. Sporomorphs dominate (up to 90% of the total palynomorph sum) in the Late Eocene, whereas the highest abundance of land plants occurs in the Late Miocene, the Late Pliocene, and the Late Pleistocene. Only in the Late Miocene and Pliocene are non-neritic (oceanic) dinocysts recorded in significant numbers. Massive influxes of small skolochorate acritarchs of unknown affinity (Pl. P1, figs. 140–151) occur between ~387 and 210 mbsf (upper lower–lower middle Miocene). Pulses of up to 1000 acritarchs vs. 1 dinocyst predominantly occur between 385 and 340 mbsf. The dinocyst (and palynological) record becomes patchy in the middle Miocene–basal Pleistocene interval. Possibly, the low sedimentation rates and related prolonged exposure to oxic conditions hampered significant accumulation of organic matter, including organic-walled dinocysts.

Dinoflagellate Cysts: General

Despite many attempts, only few studies of Oligocene–Neogene dinocysts are available from the circum-Antarctic domain; representatives of this fossil group have been found only sporadically (see overviews in Hannah et al., 1998; Wrenn et al., 1998; McMinn et al., 2001; Harland and Pudsey, 2002). This contrasts markedly the situation in the older Paleogene, where many studies have reported rich dinocyst associations from Antarctica (e.g., Goodman and Ford, 1983; Wilson, 1985, 1988; Wrenn and Hart, 1988; Mohr, 1990; Mao and Mohr, 1995; Crouch and Hollis, 1996; Truswell, 1997; Hannah, 1997a, 1997b; Hannah and Raine, 1997; Brinkhuis et al., this volume; Sluijs et al., this volume, for overviews). Only recently a first ever quasi-continuous Southern Ocean Oligocene–early Miocene dinocyst succession was documented from the Ross Sea continental shelf (Cape Roberts Project, see Hannah et al., 2000, and discussion in Brinkhuis et al., this volume). In other areas, the record of Oligocene–Neogene dinocysts remains fragmentary (e.g., Vinther et al., 2004), although attempts have been made to reconstruct palaeoceanographic conditions from the fossil Oligocene record (e.g., Brinkhuis et al., 2004).
et al. (1998), the organic wall of the dinocysts is not resistant to the oxygen-rich waters in the Antarctic domain and/or winnowing at depth and/or low sedimentation rates precludes preservation of these microfossils (e.g., Zonneveld et al., 1997, 2001; Versteegh and Zonneveld, 2002; Hopkins and McCarthy, 2002). Southern Ocean dinocyst assemblages should be present when preservation requirements are met. The studies by, for example, Hannah et al. (2000) on the Ross shelf or McMinn et al. (2001) analyzing Pliocene dinocysts and diatoms from Deep Sea Drilling Project (DSDP) Site 594, Chatham Rise, illustrate this aspect. Moreover, McMinn and Wells (1997) already demonstrated the potential of dinocyst analysis for paleoenvironmental reconstructions in the Quaternary in the region using piston-cored materials from locations close to Site 1168. The relative abundance of dinocysts in the Oligocene–Neogene of Site 1168 may therefore be taken to indicate that water mass, bottom conditions, and sedimentation rates were suitable for preservation of organic material.

Dinocyst species throughout Hole 1168A are largely cosmopolitan and widespread, and a varying degree of taxonomic overlap is observed (see below). Despite the occurrence of species from the Southern Hemisphere, the distribution of dinocysts in the middle to upper Miocene is rather patchy due to reasons discussed above. This hampers detailed cross-hemisphere comparisons. For example, the ranges of species stratigraphically important in Northern Hemisphere Neogene deposits such as Achomosphaera andalousiensis, Cerebrocysta poulsenii, Edwardsiella sexispinosum, and Labyrinthodinium truncatum, broadly match those recorded here, but not in detail, probably due to poor preservation/oxidation. The Eocene–Oligocene to perhaps lower Miocene interval has more potential for detailed comparisons (see below). Consistent with earlier studies based on other microfossil groups suggesting that a relatively warm current akin to the Leeuwin Current (or "proto-Leeuwin Current") dominated this region for the last ~40 m.y. (e.g., Li et al., 2003; Huber et al., submitted), the suite of events recorded in Hole 1168A has much in common with similar successful Southern Hemisphere successions (like those reported by, e.g., Biffi and Manum, 1988; Brinkhuis et al., 1992; Brinkhuis and Biffi, 1993; Wilpschaar et al., 1996). Conspicuously, species belonging to the "Transantarctic Flora" (cf. Wrenn and Beckmann, 1982) are virtually absent. Only very few specimens of species belonging to this endemic flora are recorded at Site 1168 (e.g., Deflandrea antarctica, Octodinium askiniae, and Enneadocysta partridgei). Several yet undescribed species were recorded (e.g., new species of Cerebrocysta, Hystrichokolpoma, Eocladopyxis, and Cannosphaeropsis). They will be treated in more detail elsewhere.

**Latest Middle–Late Eocene**

Although the latest middle–late Eocene record of Hole 1168A is somewhat patchy, probably due to the extremely shallow marine setting, the species composition broadly matches that described from the southeastern Australian surface section at the Browns Creek locality (Cookson and Eisenack, 1965; Stover, 1975). Ranges of, for example, Schematophora speciosa, Aireiana verrucosa, Hemiplacophora semilunifera, and Stoveracysta ornata appear useful for regional and even broad global correlation. Many of the Browns Creek late Eocene di
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...notably in central and northern Italy, including the Priabonian-type section (Brinkhuis and Biffi, 1993; Brinkhuis, 1994). It appears that these index species have slightly earlier range tops in this region than in the Tethys. This may be related to the progressive cooling during the late Eocene and/or the warm-temperate nature of the surface waters (see discussion below). The dinocyst distribution across the Eocene/Oligocene boundary, also from other Leg 189 sites, is discussed in more detail in Sluijs et al. (this volume).

It is likely that older Paleogene and Cretaceous deposits underlie the upper Eocene at Site 1168, not recovered during Leg 189 drilling. Studies of the nearby borehole at Cape Sorell indicate the presence of at least ~2400 m of Campanian/Maastrichtian–middle Eocene sediments in the immediate surroundings of Site 1168 (Boreham et al., 2002). Palynological studies (MacPhail in Boreham et al., 2002) indicate that the signature of these deposits is very similar to those recovered at Site 1168, with endemic species being relatively rare. This contrasts with results from dredge samples taken slightly farther to the south, along the South Tasman Rise (Truswell, 1997). Samples assigned to the middle Eocene there are characterized by the distinct presence of the Transantarctic Flora (Truswell, 1997). It is therefore apparent that completely different surface waters influenced sites more to the south from Site 1168 and Cape Sorell. Onboard results from Sites 1170 and 1171, also showing high abundances of the Transantarctic Flora in the Eocene, on the South Tasman Rise confirm this aspect (Shipboard Scientific Party, 2001c, 2001d; Brinkhuis et al.; Sluijs et al., both this volume).

The Oligocene relatively poorly diversified assemblages characterize the Oligocene succession at Site 1168 with long-ranging cosmopolitan representatives of Spiniferites, Operculodinium, Hystrichokolpoma, and Cleistosphaeridium being common to frequent. Thalassiphora pelagica and Apteodinium australense may be abundant in certain intervals. The near absence of Defflandrea spp. or of any (proto) peridinioid (probably heterotrophic) dinocysts is remarkable. Yet, other dinocysts are present in the background, albeit with a scattered distribution. The succession of events in this background pattern in the Oligocene interval shows remarkable resemblance to the succession of central Italy as summarized in Wilpshaar et al. (1996). Tethyan index species such as Areoligera? semicirculata, Wetzeliella gochtii, Hystrichokolpoma sp. cf. Homotryblium oceanicum, Hystrichokolpoma pusilla, Chiropteridium spp., Distatodinium biffii, and Ectosphaeropsis burdigalensis have virtually the same stratigraphic succession here as they display in Italy. They do, unfortunately, have a rather patchy distribution pattern at Site 1168, whereas they occur more consistently in Italy. For example, the FO of D. biffii matches its reported FO in Italy, following the current age model; its LO, however, occurs earlier at Site 1168. This may be due to the scarcity of this index fossil and the current rather large sample spacing. The scattered occurrences of H. sp. cf. H. oceanicum, H. pusilla, and Chiropteridium spp. basically fall within their ranges in Italy, but the pattern at Site 1168 is inconsistent so far. The FO of E. burdigalensis, an index event for recognition of the Oligocene/Miocene (O/M) boundary in Italy (Brinkhuis et al., 1992), apparently occurs much earlier at Site 1168, if the current age model is accepted. It should be noted that the upper Oligocene interval from Southern Hemisphere locations in the Southern Ocean...
A recent study of Chattian deposits in Belgium reports the FO of *E. burdigalensis* to occur well below the O/M boundary as well (van Simaeys et al., in press). Combined evidence therefore suggests this form to be a temperate to warm-temperate species. The FO of *E. burdigalensis* is followed upsequence by the successive FOs of *Membranilarnacia?* *picena* and a form morphologically similar to *Stoveracysta conerae* (*Stoveracysta* cf. *conerae*) at Site 1168. This pattern is identical to the Italian lower Miocene succession, but this suite of events appears (much) earlier at Site 1168. Remarkably, the FO of *D. biffii* practically coincides with a single influx of *Svalbardella* spp. This conjunction of events mimics the situation in central Italy (Wiltshire et al., 1996) and can even be traced to near the Rupelian/Chattian boundary in their type region (Van Simaeys et al., in press). In Italy, most recent information places these events at the base of Chron C9n (Prof. R. Coccioni, University of Urbino, pers. comm., 2003). The integrated magnetobiostratigraphic age model for Hole 1168A also indicates these events to be associated with the base of Chron C9n. Although international debate on the GSSP of the Rupelian/Chattian is ongoing, indications are that this episode will be selected to represent this important boundary in geological history. The aforementioned dinocyst events appear to have a widespread range and may well be associated with a pronounced episode of global cooling (possibly oxygen isotope [Oi] event Oi2b; e.g., Miller et al., 1998) that affected surface waters and circulation worldwide. The O/M transition around ~410 mbsf is characterized by a marked influx of *A. australiense* and a new species of *Eocladopyxis* (Table T1).

### Miocene

The distribution of dinocysts in the middle–upper Miocene is rather patchy due to reasons discussed above. The lower Miocene, however, has reasonable recovery and basically shows the same basic pattern as the Oligocene: relatively poorly diversified assemblages, with long-ranging cosmopolitan representatives of genera such as *Spiniferites* and *Operculodinium* being common to frequent. *Cerebrocysta* spp. and *Reticulatosphaera acticoronata* may be abundant in certain intervals. Typical oceanic (non-neritic) taxa such as *Nematosphaeropsis* and *Impagidinium* spp. markedly increase in abundance from the lower Miocene onward (Fig. F2). *Pentadinium laticinctum* has an acme near the top of the lower Miocene. Typical background taxa are *Invertocysta* spp. and *E. sexispinosum*. In the younger Miocene, where samples yield reasonably preserved dinocysts again, these trends continue, while potential index taxa, also relevant for cross-hemisphere comparison, such as *A. andalousiensis*, *C. poulsenii*, *Mendicodinium* sp. A of Wrenn and Kokinos, 1986, and *L. truncatum* are sporadically present. Several taxa have apparent range tops in the middle and upper Miocene interval but, again, the patchy record precludes any conclusions at this stage. As for the Oligocene, the near absence of (proto) peridinioid dinocysts is noteworthy. This group may reach high abundances in Neogene sequences around the world and is important for stratigraphic and environmental considerations (also discussed below). The virtual absence of cysts of *Protoperidinium* spp. may be related to poor preservation of organic materials in general or to the prevalence of oligotrophic water masses.

As noted above, notably the lower Miocene interval is marked by massive influxes of small skolochorate acritarchs. High magnification studies using scanning electron microscopy (SEM) (see Pl. P1, figs. 140–
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show that some of these appear to have angular openings similar to archaeopyles of dinoflagellate cysts. Although they probably represent a distinct stage of a specific species, the specific type of these cysts is unknown.

PlIOCENE–QUATERNARY

The Pliocene–Quaternary record is more consistent than the underlying Miocene interval, possibly due to changing oceanographic and depositional settings and/or sedimentation rates. Trends already apparent in the Miocene continued during the Pliocene to Quaternary (viz., ever-increasing abundances of typical oceanic species such as *Nematosphaeropsis* and *Impagidinium* spp.). The Pliocene interval is primarily marked by the influx of *Operculodinium echigoense* sensu McMinn (1992, 1993). This author recorded optima of this species at Sites 815 and 817 (Northeastern Australian margin) in the Pliocene and Pleistocene. This apparently tropical species has its optimum between 95 and 65 mbsf in Hole 1168A. Protoperidinioid species such as *Brigantedinium* spp. and *Algidasphaeridum* spp. begin to appear more consistently in the younger Pliocene. This and the overlying youngest interval of Hole 1168A are characterized by fluctuating abundances of the warm-water species *Impagidinium aculeatum*, *Impagidinium paradoxum*, *Impagidinium patula*, and cosmopolitan *Nematosphaeropsis* spp. (cf. Rochon et al., 1999). Occasionally, the cold-water species *Impagidinium pallidum* is present as well. Similar assemblages were recovered from nearby sites (McMinn and Wells, 1997), although these authors did not report the presence of, for example, *Algidasphaeridium* spp. or *Pentapharsodinium dalei*.

PALEOENVIRONMENTAL CONSIDERATIONS

In this paper, we are principally concerned with providing overall trends emerging from the initial data set. For this purpose, results in the form of species abundance curves are depicted in Figure F2, which are marked with (o) in Table T1. Species marked with (o) have been used to generate this curve, making use of previous studies focusing on global modern dinocyst distribution and empirical paleoenvironmental evidence from a wide variety of sources (e.g., Brinkhuis and Biffi, 1993; Brinkhuis, 1994; Stover et al., 1996). The succession at Site 1168 was interpreted to reflect an initial shallow-water, nearshore, restricted marine setting with poor ventilation and siliciclastic sedimentation, low oxygenation, and high organic carbon deposition during the late Eocene (Shipboard Scientific Party, 2001a, 2001b). Site 1168 Eocene sediments are similar in nature to those at Cape Sorell (Boreham et al., 2002) and to those reported from DSDP Site 282 to the northwest, suggesting widespread late Eocene suboxic to anoxic conditions in the eastern Australo-Antarctic Gulf. Following a transitional phase during the Oligocene, in the Neogene these conditions had been replaced by deposition of carbonate ooze in a well-oxygenated open ocean on a passive margin at middle bathyal depths (Shipboard Scientific Party, 2001ab; Boreham et al., 2002). The curves of Figure F2 both confirm the broad trend of initial shallow-marine, nearly continental conditions evolving into an open oceanic environment. A marked acceleration of this process apparently occurred near the end of the early Miocene as indicated by a sudden step in the relative abundance of marine dinocysts (Fig. F2). Variations in both curves...
During the late Eocene–early Oligocene, the ocean climate may be explained by the northward shift of the polar front and the resulting change in the Southern Hemispheric thermohaline circulation. The mid–late Eocene–early Oligocene may be explained by a high degree of stratification and the presence of a warm, saline water mass across the equatorial and subtropical region. This may have been due to an increase in the South Pacific Subtropical Gyre and the establishment of a warm-water current, possibly the historic Leeuwin Current (Brinkhuis et al., 1992; Brinkhuis and Biffi, 1993; Brinkhuis, 1994). The presence of large amounts of warm-water species, such as shallow-water and neritic species, indicates that the surface waters were not subject to significant temperature changes during this interval.

The late Eocene–early Oligocene is characterized by the presence of warm-water species, such as shallow-water and neritic species. The presence of large amounts of warm-water species, such as shallow-water and neritic species, indicates that the surface waters were not subject to significant temperature changes during this interval. The dinocyst assemblages in this interval are very similar to those recorded elsewhere from ancient Eocene–Oligocene delta-front deposits (Brinkhuis et al., 1992; Brinkhuis and Biffi, 1993; Brinkhuis, 1994). The Oligocene assemblages are characterized by a slight increase in diversity, with increasingly consistent occurrences of more open-marine neritic to offshore taxa such as T. pelagica, Cleistosphaeridium, and Hystrichokolpoma spp., besides ever-increasing numbers of typical oceanic taxa such as Nematosphaeropsis and Impagidinium spp. (Fig. F2). A general long-term post-Eocene oligotrophic nature of the surface waters influencing Site 1168 is suggested from the low abundance of (proto) peridinioid, presumably heterotrophic species.

An important general aspect in the dinocyst assemblages is the near absence of Antarctic endemic (Transantarctic) species and the apparent influence of relatively warm waters throughout the succession at Site 1168. As explained above, the dinocyst assemblages are to a high degree comparable with those reported from low latitudes, although some cosmopolitan taxa (e.g., Spiniferites spp., Operculodinium spp., and Nematosphaeropsis spp.) are also present. This suggests a long-term overall warm to warm-temperate nature of the surface waters influencing Site 1168. The Tethyan index taxa display a rather patchy distribution pattern, suggesting that these taxa may have a relatively limited distribution, possibly reflecting transportation. Conversely, already in Eocene and Oligocene times, occasional influence of cooler (cold temperate) water masses is apparent as well, judging from the distribution patterns of cool-temperate species such as Gelatia inflata and Impagidinium velorum, besides some of the Transantarctic Flora species discussed above. Overall, the assemblages may thus be described as being warm temperate in nature.

Specifically, the late Eocene assemblages are characterized by the concomitant presence of typical lower-latitude and cosmopolitan taxa, suggesting subtropical to warm-temperate conditions. This aspect matches reports on the nature of the Eocene and early Oligocene vegetation in the region, which suggests that air temperatures were subtropical to warm temperate and always above freezing (Greenwood and Wing, 1995). Indeed, the inference of warm-temperate surface water conditions also matches earlier reports based on other microfossil groups and stable isotope studies.

On the basis of stable isotope studies (e.g., Kamp et al., 1990; Buening et al., 1998), inferred surface water temperatures ranged from ~12° to 20°C for the region during the late Eocene. Calcareous microfossil studies in the region indicate similar temperatures, indicating a long-term influence of a proto-Leeuwin Current (e.g., McGowran et al., 1997; Li et al., 2000, 2003; Nelson and Cooke, 2001). Li et al. (2003), studying foraminifers from ODP Leg 182 drill sites, specifically state (p. 1) "...The southern temperate assemblage hosted several subtropical species in the middle–late Eocene and Oligocene as immigrants probably transported by a warm-water system similar to the present-day Leeuwin Current..."
This interpretation perfectly describes the dinocyst signal at Site 1168 as well. In the Neogene, assemblages are also marked by an abundance of warmer-water species (in this case many Impagidinium species, indicating relatively warm, oligotrophic oceanic surface water conditions throughout the Neogene). This effect is also observed throughout the whole Oligocene–Miocene interval, indicating relatively warm paleo-oceanic surface water conditions throughout the Neogene and early to mid-Miocene (cf. Rochon et al., 1999). In the Quaternary, a few specimens of the bipolar (cold) species Impagidinium pallidum are recorded as well. This aspect indicates the influence, albeit limited, of colder surface water masses in this interval or deep transport by possibly colder undercurrents, or its source from the North Atlantic or Bering Sea.

CONCLUDING REMARKS

Clearly, the present results confirm the potential for the application of quantitative palynological analysis for climatic and environmental reconstructions (except perhaps for the middle–upper Miocene interval), using materials from Site 1168. Further study involving higher-resolution analysis is under way, notably on the Eocene–Oligocene and Oligocene–Miocene transitions. Results of these more detailed studies will be presented in future contributions. Significantly, the overall dinocyst distribution pattern matches a long-term (>40 m.y.) existence of a proto-Leeuwin Current influencing the larger southern Australian region, including Site 1168, resulting in warm-temperate dinocyst assemblages during the Paleogene and distinct virtual absence of Antarctic endemic species. The influence of this current apparently quite abruptly diminished directly to the south of the studied area. Varying influence of colder (cold temperate) sea-surface conditions is, however, also apparent, notably during the late Pliocene (Late Miocene–Quaternary).

ACKNOWLEDGMENTS

This research used samples and data provided by the Ocean Drilling Program (ODP) 189, 189B, and 189C, sponsored by the U.S. National Science Foundation (NSF). We thank the crew of ODP Leg 189 (October 1997) for their support during our research. We thank the technical staff of the Department of Earth Sciences, Utrecht University, for all their help and assistance during the cruise. We also thank Susan Kerstholt for her assistance with palynological analysis and the crew of ODP Leg 189 for the opportunity to work on Site 1168 and to sample the sediments. We thank Professor M. A. Hogeveen and Dr. R. van der Schoor for their support during the research trip. We thank the reviewers for their comments and suggestions, particularly K. Peters, F. M. M. McCarthy, M. Malone, and J. Pross. We also thank the editor, Dr. C. Stickley, for her invaluable comments and suggestions. This is the Netherlands School of Sedimentary Geology (NSG) contribution number 2003.09.01.
REFERENCES


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**APPENDIX**

**Species List and Taxonomic Remarks**

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthaulax sp.</td>
<td>This taxon superficially resembles <em>Operculodinium israelianum</em>, but differs by having processes arranged along sutural or penitabular rows. It is provisionally assigned to <em>Acanthaulax</em>. Similar forms have been recorded in the Mediterranean Neogene (Zevenboom, 1995).</td>
</tr>
<tr>
<td>Achomosphaera andalousiensis</td>
<td></td>
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<tr>
<td>Aireiana verrucosa</td>
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<tr>
<td>Algidasphaeridium minutum var. cezare</td>
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</tr>
<tr>
<td>Algidasphaeridium minutum var. minutum</td>
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</tr>
<tr>
<td>Amiculosphaera umbracula</td>
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<tr>
<td>Apteodinium australiense</td>
<td></td>
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<tr>
<td>Areoligera sp.</td>
<td></td>
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<tr>
<td>Areoligera spp. (pars)</td>
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<tr>
<td>Ataxiodinium choane</td>
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<tr>
<td>Ataxiodinium confusum</td>
<td></td>
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<tr>
<td>Batiacasphaera spp.</td>
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<tr>
<td>Bitectatodinium tepekiense</td>
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</tr>
<tr>
<td>Brigantedinium spp.</td>
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</tr>
<tr>
<td>Caligodinium pychnum</td>
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<tr>
<td>Caligodinium spp.</td>
<td></td>
</tr>
<tr>
<td>Cannosphaeropsis sp. A</td>
<td>This rather large species of <em>Cannosphaeropsis</em> is foremost characterized by having broad distal rims connecting gonine processes; occasionally small spines are developed along the same rims.</td>
</tr>
<tr>
<td>Cannosphaeropsis spp.</td>
<td></td>
</tr>
<tr>
<td>Cerebrocysta poulsenii</td>
<td>This species of <em>Cerebrocysta</em> is characterized by being large, by having a 2P archaeopyle (loss of 2&quot;, + 3&quot;), and by developing cerebral rugulae of intermediate size. Similar forms have been recorded in the Mediterranean Middle Miocene as <em>Cerebrocysta powellii</em> (Zevenboom, 1995).</td>
</tr>
<tr>
<td>Cerebrocysta spp. (pars)</td>
<td></td>
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<tr>
<td>Chiropteridium spp.</td>
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<tr>
<td>Cleistosphaeridium spp.</td>
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<tr>
<td>Cooksonidium capricornum</td>
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<tr>
<td>Cordosphaeridium cantharellum</td>
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</tr>
<tr>
<td>Cordosphaeridium fibrospinosum</td>
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<td>Cordosphaeridium minimum</td>
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<tr>
<td>Cordosphaeridium spp. (pars)</td>
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<td>Corrudinium harlandii</td>
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<tr>
<td>Cystoceratodinium spp.</td>
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</tr>
<tr>
<td>Cystophoridium bartlesi</td>
<td></td>
</tr>
</tbody>
</table>
Corrudinium incompositum

Cribroperidinium spp.

Dalella chathamensis

Dapsilidinium spp.

Deflandrea antarctica group

Deflandrea convexa group

Deflandrea phosphoritica group

Dinopterygium spp.

Diphyes colligerum

Diphyes ficusoides

Distatodinium biffii

Distatodinium spp. (pars)

Ectosphaeropsis burdigalensis

Edwardsiella sexispinosum

Emmetrocysta urnaformis

Enneadocysta partridgei

Eocladopyxis spp.

Eurydinium spp.

Filisphaera spp.

Gelatia inflata

Glaphyrocysta spp.

Gramocysta verricula

Habibacysta tectata

Hemiplacophora semilunifera

Histiocysta spp.

Heteraulacacysta spp.

Homotryblium spp.

Hystrichokolpoma cinctum

Hystrichokolpoma pusilla

Hystrichokolpoma rigaudiae group

Hystrichokolpoma salacia group

Hystrichokolpoma sp. cf. Homotryblium oceanicum (Wilsphaar et al., 1996)

Hystrichokolpoma sp. A

Remarks: This species of Hystrichokolpoma is characterized by its relatively small size and by typically having poorly developed, deflated hollow penitabular processes.

Hystrichosphaeropsis spp.

Hystrichostrogylon spp.

Hystrichosphaeridium spp.

Impagidinium aculeatum

Impagidinium dispertitum
Impagidinium japonicum

Impagidinium maculatum

Impagidinium pallidum

Impagidinium paradoxum

Impagidinium patulum

Impagidinium sphaericum

Impagidinium strialatum

Impagidinium victorianum

Impagidinium velorum

Impagidinium spp. (pars)

Invertocysta spp.

Labyrinthodinium truncatum

Lejeunecysta spp.

Lingulodinium machaerophorum

Lophocysta spp.

Melitasphaeridium choanophorum

Melitasphaeridium pseudorecurvatum

Membranilarnacia? picenum

Membranilarnacia? sp.

Remarks: This taxon is provisionally placed in Membranilarnacia in view of its having an ectophragm distally connecting process complexes and an apical archaeopyle involving the loss of 1’ – 4’. General shape, size, and process distribution suggest affinity with Schematophora.

Mendicodinium sp. A, Wrenn and Kokinos, 1986

Nematosphaeropsis spp.

Octodinium askiniae

Operculodinium echigoense sensu McMinn, 1992

Operculodinium janduchenei

Operculodinium microtrianum

Operculodinium piaseckii

Operculodinium spp. (pars)

Pentapharsodinium dalei cysts

Pentadinium laticinctum

Phthanoperidinium comatum

Phthanoperidinium filigranum

Phthanoperidinium spp.

Polysphaeridium spp.

Pyxidinopsis spp.

Reticulatosphaera actinocoronata

Rhombodinium spp.

Samlandia chlamydophora
Remarks: This taxon resembles *S. mirabilis*, but differs by having a much larger size range (up to 120 µm) and by less well defined and developed processes.

*Spiniferites* spp.

*Stelladinium stellatum*
*Stoveracysta ornata*
*Stoveracysta cf. conerae*

Remarks: this taxon resembles *S. conerae*, but differs by having a smaller size range (up to 60 µm) and by relatively high penitabular ornamentations.

*Stenodinium* spp.

*Wetzeliella gochtii/symmetrica group*
Figure F2. Percentages of terrestrial palynomorphs and oceanic (non-neritic) dinocysts in palynological assemblages of Hole 1168A. TD = total depth.
Table 1. Selected palynological results. Site 1168A. (This table is available in an electronic format.)
<table>
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<th>Event</th>
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<th>LO (Ma)</th>
<th>FO (Ma)</th>
<th>FCO (Ma)</th>
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<th>Error</th>
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<td>702.3</td>
<td>707.9</td>
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<td>707.9</td>
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<td>78X-3</td>
<td>43–48</td>
<td>79X-2</td>
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<td>33–39</td>
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<td>Homotryblium oceanicum</td>
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<td>50X-CC</td>
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<td>41X-3</td>
<td>60–62</td>
<td>375.7</td>
<td>380.9</td>
<td>378.3</td>
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Notes: * = ages are derived from H. BRINKHUIS ET AL. (2000).
Plate P1. Illustrations of taxa, sample, slide, and England Finder (EF) coordinates. Scale bar = ~20 µm unless stated otherwise.

1–3. Acanthaulax sp. (Sample 189-1168A-24X-7, 40–42 cm); 2, V39-0.

4–8. Apteodinium australense (Sample 189-1168A-38X-2, 60–62 cm); (4, 5) 1, R40-1; (6–8) 1, P55-0.

9, 10. Areoligera semicircularis (Sample 189-1168A-70X-3, 60–62 cm); 2, P32.

11, 12. Ataxiodinium choane (Sample 189-1168A-10H-7, 60–62 cm); 1, S31-1/2. (Continued on next 12 pages.)
Plate P1 (continued). 13, 14. Ataxiodinium choane (Sample 189-1168A-8H-4, 60–62 cm); 15. Ataxiodinium confusum (Sample 189-1168A-4H-3, 60–62 cm); 16, 17. Brigantedinium spp. (Sample 189-1168A-03H-3, 60–62 cm); (16) 2, V30-3; (17) 2, U23-2. 18–20. Caligodinium pychnum (Sample 189-1168A-38X-2, 60–62 cm); (18, 19) 1, S37-1; (20) 1, R36. 21, 22. Cannosphaeropsis sp. A (Sample 189-1168A-70X-3, 60–62 cm); 1, E14-4. 23, 24. Cerebrocysta poulsenii (Sample 189-1168A-20X-2, 60–62 cm); 1, O48-3 (scale bar = ~15 µm). (Continued on next page.)
Plate P1 (continued). 25–27. *Cerebrocysta* poulsenii (Sample 189-1168A-20X-2, 60–62 cm); 1, O48-3 (scale bar = ~15 µm).

28–31. *Cerebrocysta* spp. (Sample 189-1168A-20X-2, 60–62 cm); 1, J49-4 (scale bar = ~15 µm).

32, 33. *Cerebrocysta* sp. A (Sample 189-1168A-33X-3, 60–62 cm); 2, H35-4 (scale bar = ~30 µm).

34. *Chirop-teridium* spp. (Sample 189-1168A-50X-2, 60–62 cm); 1, S26-1.

35, 36. *Cleistosphaeridium* spp. (Sample 189-1168A-64X-5, 60–62 cm); 1, J51-3. (Continued on next page.)
Plate P1 (continued). 37, 38. *Cooksonidium capricornum* (Sample 189-1168A-86X-5, 60–62 cm); 1, S49-4. 39. *Deflandrea convexa* (Sample 189-1168A-83X-4, 60–62 cm); 2, L28-2. 40. *Diphyes ficusoides* (Sample 189-1168A-84X-3, 60–62 cm); 2, D27. 41, 42. *Distatodinium biffii* (Sample 189-1168A-54X-2, 60–62 cm); 2, M21-1 (scale bar = ~35 µm). 43–45. *Ectosphaeropsis burdigalensis* (Sample 189-1168A-50X-2, 60–62 cm) (scale bar = 30 µm); (43) 1, N13-4; (44) 1, K30-3; (45) 1, L30-2. 46, 47. *Edwardsiella sexispinosum* (Sample 189-1168A-38X-2, 60–62 cm); 1, U30-1. 48. *Emmetrocysta urnaformis* (Sample 189-1168A-88X-1, 60–62 cm); 1, T27. (Continued on next page.)
Plate P1 (continued). 49. *Eurydinium* sp. (Sample 189-1168A-82X-1, 60–62 cm); 1, P28-1. 50, 51. *Gelatia inflata* (Sample 189-1168A-64X-5, 60–62 cm); 1, P63-3 (scale bar = ~10 µm). 52–54. *Glaphyrocysta intricata* (Sample 189-1168A-57X-7, 60–62 cm); 1, S22-4. 55–60. *Mendicodinium* sp. A Wrenn and Kokinos, 1986 (Sample 189-1168A-25X-4, 60–62 cm); (55–57) 1, R36-3; (58–60) 1, T51-4. (Continued on next page.)
Plate P1 (continued). 61–63. *Hystrichokolpoma pusilla* (Sample 189-1168A-65X-3, 60–62 cm); 1, O57-4.

64, 65. *Hystrichokolpoma rigaudiae* (Sample 189-1168A-42X-4, 60–62 cm); 2, G35.

66, 67. *Hystrichosphaeropsis sp. A* (Samples 189-1168A-66X-1, 60–62 cm); 1, Q15-3.

68. *Hystrichosphaeropsis obscura* (Sample 189-1168A-40X-6, 60–62 cm); 1, S19-4.

69, 70. *Impagidinium aculeatum* (Sample 189-1168A-6H-3, 60–62 cm); 1, W26-2 (scale bar = ~10 µm).

71, 72. *Impagidinium paradoxum* (Sample 189-1168A-3H-3, 60–62 cm); 2, V20-4 (scale bar = ~10 µm). (Continued on next page.)
Plate P1 (continued). 73, 74. *Impagidinium paradoxum* (Sample 189-1168A-3H-3, 60–62 cm); 2, V20-4 (scale bar = ~10 µm).

75, 76. *Impagidinium patulum* (Sample 189-1168A-20X-2, 60–62 cm); 1, F38-3.

77. *Invertocysta tabulata* (Sample 189-1168A-10H-7, 60–62 cm); 1, R32.

78, 79. *Labyrinthodinium truncatum* (Sample 189-1168A-23X-5, 60–62 cm); 2, S23-3 (scale bar = ~10 µm).

80. *Melitasphaeridium choanophorum* (Sample 189-1168A-13X-1, 60–62 cm); 2, M26.

81–84. *Membranilarnacia ?picena* (Sample 189-1168A-65X-3, 60–62 cm); 1, R57-2. (Continued on next page.)
88–90. Membranilarnacia sp. (Sample 189-1168A-84X-6, 60–62 cm); 1, U32-3 (scale bar = ~10 µm).
91–93. Nematosphaeropsis labyrinthus (Sample 189-1168A-20X-2, 60–62 cm); 1, H47-4 (scale bar = ~10 µm).
94. Ocotadium askiniae (Sample 189-1168A-93X-6, 60–62 cm); 1, R25-2.
95, 96. Operculodinium piaseckii (Sample 189-1168A-25X-4, 60–62 cm); 1, J40-3 (scale bar = ~15 µm). (Continued on next page.)
97–99. Operculodinium janduchenei (Sample 189-1168A-10H-7, 60–62 cm); 1, T22-4 (scale bar = ~15 µm).

100–102. Cyst of Pentapharsodinium dalei and Algidasphaeridium minutum cezare (Sample 189-1168A-3H-3, 60–62 cm); 2, T20-1.

103–106. Pentadinium laticinctum (Sample 189-1168A-33X-3, 60–62 cm); 1, T51-1 (scale bar = ~15 µm).

107, 108. Phthanoperidinium filigranum (Sample 189-1168A-78X-7, 60–62 cm); 2, T30-2 (scale bar = ~10 µm).

(Continued on next page.)
Plate P1 (continued). Samlandia chlamydophora (Sample 189-1168A-79X-6, 60–62 cm); 1, J39.

112, 113. Schematophora speciosa (Sample 189-1168A-94X-3, 60–62 cm); 1, T31-2 (scale bar = ~10 µm).

114, 115. Spiniferites cf. mirabilis (Sample 189-1168A-3H-3, 60–62 cm); 2, U23-4.

116, 117. Stoveracysta cf. conerae (Sample 189-1168A-38X-4, 60–62 cm); 1, Q27-1 (scale bar = ~15 µm).

118, 119. Stoveracysta ornata (Sample 189-1168A-79X-6, 60–62 cm); 1, Q32-3 (scale bar = ~15 µm).

120. Stoveracysta ornata (Sample 189-1168A-79X-6, 60–62 cm); 1, Q32-3 (scale bar = ~15 µm).
Plate P1 (continued). 121. Stoveracysta ornata (Sample 189-1168A-79X-6, 60–62 cm); 1, Q32-3 (scale bar = ~15 µm).

122, 123. Stoveracysta kakanuiensis (Sample 189-1168A-79X-5, 60–62 cm); 1, M34-1 (scale bar = ~15 µm).

124. Stoveracysta ornata (Sample 189-1168A-79X-5, 60–62 cm); 1, V22-3 (scale bar = ~15 µm).

125–127. Svalbardella sp. (Sample 189-1168A-58X-3, 60–62 cm); (125) 2, H20-1; (126, 127) 1, V57-3.

128. Apteodinium australiense (Sample 189-1168A-45X-3, 59–61 cm); scanning electron microscope (SEM).

129. Cleisotosphaeridium sp. and Eocladopyxis sp. (Sample 189-1168A-45X-3, 59–61 cm); SEM.

130. Cordosphaeridium minimum (Sample 189-1168A-45X-3, 59–61 cm); SEM.

131. Dapsilidinium sp. (Sample 189-1168A-45X-3, 59–61 cm); SEM.

132. Eocladopyxis sp. (Sample 189-1168A-45X-3, 59–61 cm); SEM. (Continued on next page.)
133. *Hystrichokolpoma rigaudiae* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

134. *Impagidinium aculeatum* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

135. *Impagidinium paradoxum* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

136. *Nematosphaeropsis labyrinthea* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

137. *Operculodinium* sp. (Sample 189-1168A-45X-3, 59–61 cm); SEM.

138. *Operculodinium centrocarpum* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

139. *Reticulatosphaera actinocoronata* (Sample 189-1168A-45X-3, 59–61 cm); SEM.

140, 142–144. Skolochorate acritarchs; SEM; (140) Sample 189-1168A-45X-3, 59–61 cm; (142-144) Sample 189-1168A-42X-4, 60–62 cm.

141. Skolochorate acritarchs and framboidal pyrite spheres (Sample 189-1168A-38X-2, 60–62 cm); SEM. (Continued on next page.)
CHAPTER NOTES*  


*Note added to this section continues...