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2. PALYNOLOGY OF NEOGENE SLOPE AND RISE DEPOSITS FROM ODP SITES 1165 AND 1167, EAST ANTARCTICA[1]

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ABSTRACT

Sites 1165 and 1167 were drilled on the continental slope and rise seaward of Prydz Bay, East Antarctica. The sediments penetrated are glacigene and independently dated as Neogene age (early Miocene and younger) using diatoms, radiolarians, nannofossils, and paleomagnetic data. In this depositional setting, most, though not all, palynomorphs recovered are not in situ but have been recycled from older sequences.

However, a number of dinoflagellate cyst taxa recovered from Site 1165 support a Neogene age, although their stratigraphic distribution requires further study. They include species referable to the genera *Batiacasphaera, Protoellipsodinium,* cf. *Cymatiosphaera,* and *Svalbardella.* Fossil pollen and spores recovered from Site 1165 include a spore species that appears to be diagnostic of early Miocene sediments encountered in the Cape Roberts Project drill hole CRP-1 in the Ross Sea. The presence of this species, referred to as *Coptospora* sp. b, strengthens the case that some other spore and pollen species may be in situ, and that a woody tundra vegetation of shrubby gymnosperms and Southern Beech (*Nothofagus*) survived in East Antarctica into Miocene time.

Recycled plant microfossils range in age from Permian and Early Jurassic to late Eocene and Oligocene. Permian taxa are most abundant on the continental shelf (Site 1167), implying that this component was transported in lithified sediments as part of the coarse bed load. Possible source beds are present in the Prince Charles Mountains. Cretaceous–Paleogene microfossils are more abundant on the continental rise (Site 1165).

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Early Jurassic taxa, present at both sites, reflect close floristic links between East Antarctica, southwestern Australia, and India during the Mesozoic. Beds of this age are known from the Mac.Robertson Shelf, west of Prydz Bay. Late Cretaceous taxa reflect Turonian–?Santonian sediments; these are known from Sites 1166 and 742 within Prydz Bay.

Relative abundance data for Site 1167 are consistent with a simple glacial unroofing model in that Permian and Jurassic–Early Cretaceous plant microfossils are most frequent in the upper part of the sequence; Paleogene–Neogene are more common in the basal intervals. The situation is less clear at Site 1165, where the obverse situation is apparent, with Permian and Jurassic taxa most abundant in the basal part of the section.

INTRODUCTION

This account of the microfloras preserved at Sites 1165 and 1167 refines and expands the information provided in an earlier, unpublished report (M.K. Macphail and E.M. Truswell, unpubl. data). It complements information provided on the palynology of Site 1166 (**Macphail and Truswell,** this volume).

The drilling program aimed to date the onset of glaciation, to determine the nature of ice cap development, and to explore related aspects of climate change through the Paleogene and Neogene. Palynological investigations were designed to contribute to establishing the age of the sediments penetrated and to ascertain patterns of terrestrial vegetation history associated with these climate changes. Site 1166 provided information on the onset of glaciation in the region and on the nature of vegetation growing contemporaneously with the first glaciers. The sedimentary sequences intersected at Sites 1165 and 1167 differ from those at Site 1166 in that they are wholly glacigene, either diamictites (Site 1167) or their deepwater correlates (Site 1165). This means, importantly, that the majority of plant microfossils recovered from Sites 1167 and 1165 are unlikely to be in situ, but are recycled from older deposits. As such, the palynostratigraphic evidence from Sites 1167 and 1165 contributes data on the subsurface geology and ice movements through the Prydz Bay region. It may also, less certainly, shed some light on the nature of the early Neogene vegetation that persisted after the initiation of large-scale glaciation.

In this account, basic data on the cores sampled, and the recovery of palynomorphs, is given in Table **T1;** Table **T2** shows the breakdown of palynomorphs, largely recycled, according to age groups and the taxa recovered from both sites, including dinocysts, fungal spores, and spores and pollen of higher taxa but excluding recycled Permian and Triassic taxa.

Photomicrographs of taxa are illustrated in Plates **P1, P2, P3,** and **P4.**

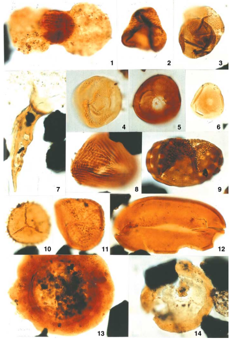
MATERIAL AND METHODS

Site 1167, in 1649 m of water, was drilled through sediments of the Prydz Channel trough mouth fan. Sediments at this site comprise debris transported to the edge of the continental shelf by the Lambert Glacier during periods of its maximum advance. Sediments penetrated consist of clayey silty sand, clayey sandy silt, and clay with silt laminae.

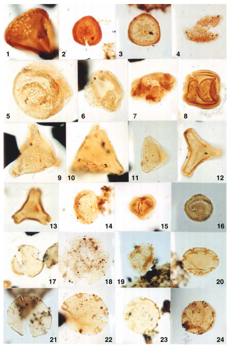
T1. Basic data, p. 15.

T2. Distribution of in situ and recycled taxa by age class, p. 16.

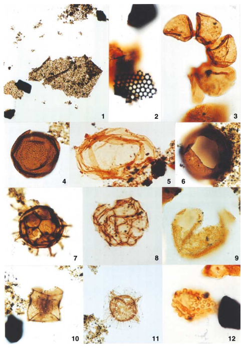
P1. Recycled Permian, Early Jurassic, and Early Cretaceous species, p. 17.



P2. Late Cretaceous and Tertiary species, p. 18.



P3. Neogene acid-insoluble marine microfossils, p. 19.

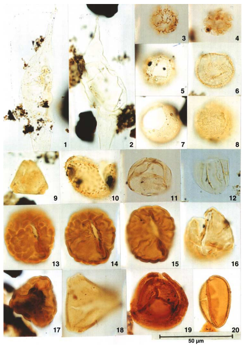


Processes of slumping and turbidity flow were important in sediment deposition. The 448 m of sediment sampled consists of Neogene to Pleistocene debris flows and minor interbedded, laminated mudstones and sandstones, marking times of glacier advance and retreat.

Site 1165, drilled in 3537 m of water on the continental rise, penetrated some 999 m of hemipelagic and contourite deposits. Sediments recovered were mostly massive to laminated clay to claystone, some diatom-rich clays, and diatom ooze. The age of the lower part of the sequence has been determined as early Miocene on the basis of diatoms, radiolarians, nannofossils, and paleomagnetism (Florindo et al., in press).

Standard palynological techniques were used to recover spores, pollen, dinocysts, other algal remains, and assorted acid-resistant microfossils (for a discussion see Traverse, 1988). Inorganic sands, silts, and clays were removed using hydrofluoric acid and heavy liquid separation ($ZnBr_2$, specific gravity = 1.65). Oxidation of the more labile compounds was accomplished with Schultze solution. The extracts were filtered through a 5-µm Millipore sieve cloth and mounted on microscope slides using Eukit. Grain counts are shown in Table T2 and were undertaken using a Zeiss Photomicroscope II fitted with Planapo objectives allowing magnification up to 1250×. Sparse recovery meant that all samples had counts <250 grains. Relative abundances of all identifiable plant microfossils (excluding recycled Permo-Triassic spores and pollen) were calculated as a percentage of the spore and pollen count. Relative abundances of the reworked Permo-Triassic forms were estimated.

P4. Neogene dinoflagellates, spores and pollen, p. 20.



RESULTS

Site 1165

Intervals sampled are listed below in meters below seafloor (mbsf), and brief summaries of the palynological data are provided. Interpretations of biostratigraphy, paleoclimates, and the significance of recycling follow.

43.50 mbsf

The sample yielded only trace numbers of modern pollen, including that of grass and *Eucalyptus,* and Permian pollen.

199.25 mbsf

The sample from this depth yielded a mixed microflora, but, unlike other intervals sampled at Sites 1165 and 1167, the microflora is wholly dominated by diverse Late Cretaceous to Tertiary species rather than Permian–Jurassic forms. For example, species of *Nothofagidites* compose 9% of the terrestrial count, compared to 5% of *Corollina* species and 1% of *Exesipollenites tumulus*.

Because many dry land taxa are long-ranging, the relative proportions are difficult to estimate, but age classes represented (diagnostic species in parentheses) include: Turonian–?Santonian (*Dilwynites* sp. A—a form reported previously from the Gippsland Basin; A.D. Partridge, unpubl. data), early Campanian (*Dacrycarpites australiensis, Forcipites sabulosus,* and *Nothofagidites senectus*), late Campanian (*Battenipollis senectus* and *Tricolporites lillei*), Maastrichtian (*Gambierina ru-*

data and *Forcipites* sp. cf. *Forcipites longus*), and Eocene (*Nothofagidites goniatus*).

The possibility of a Late Jurassic–Early Cretaceous component is reinforced by the presence of *Ceratosporites aequalis* and *Cicatricosisporites australiensis*.

The dinocyst component (25%) is dominated by unidentified or fragmentary specimens but includes significant numbers of species of the "Transantarctic Flora," including *Enneadocysta partridgei* (7%) and *Deflandrea "prydzensis"* (ms), with trace numbers of typically Neogene genera, for example, *Batiacasphaera,* and one fragment of the distinctive Santonian–Campanian species *Odontochitina porifera.*

231.74 mbsf

The microflora is dominated by Permian species, including *Didecitriletes ericianus*. In Australia, this species is widespread in the late Permian and is the nominate form for a zone in the Collie Basin of Western Australia (Backhouse, 1991). It was reported by Balme and Playford (1967) from Amery Group sediments in the Prince Charles Mountains, within the catchment of the Lambert Glacier.

There is no clear evidence for a Late Cretaceous terrestrial component. Long-ranging Late Cretaceous–Tertiary gymnosperms and *Nothofagidites* species compose 42% and 7% of the total pollen count, respectively.

The dinocyst flora is dominated by the cyst referred to *Cymatiosphaera*? *invaginata* (18%), associated with *Deflandrea "prydzensis"* (ms), *Enneadocysta partridgei* (trace), and *Selenopemphix* species (4%).

242.73 mbsf

The yield from this sample was insufficient to make statistically reliable estimates of relative abundance, but the microflora appears to be an impoverished version of that recorded at 231.74 mbsf. Three species present in this assemblage but not recorded from that above are *Microbaculispora tentula* (Permian), *Phyllocladidites reticulosaccatus* (?Turonian–Eocene), and *Protoellipsodinium* sp. (Oligocene–Miocene of the Gippsland Basin; A.D. Partridge, unpubl. data).

290.99 mbsf

This microflora is dominated by dinocysts (60%) and long-ranging gymnosperm pollen (22%). The former include late Paleogene–Neogene taxa such as *Batiacasphaera* species (33%) and infrequent (<1%) *Protoellipsodinium "simplex"* (ms), as well as representatives of the Transantarctic Flora species including *Enneadocysta partridgei* (6%) and trace numbers of *Deflandrea "prydzensis"* (ms), *Impagidinium* sp. cf. *Impagidinium victorianum,* and *Vozzhenikovia* sp. cf. *Gippslanica extensa.* Also present is an undescribed species of *Svalbardella* aff. *Svalbardella hampdenensis.* This taxon, *S. hampdenensis,* was originally described from middle Eocene sequences in North Otago, New Zealand, by Wilson (1977). It is not usually a component of the Transantarctic Flora.

Permian taxa include a range of fragmentary striate disaccate pollen and *Microbaculispora tentula.* The Late Cretaceous–Paleogene gymnosperm component includes *Phyllocladidites mawsonii* and representatives of the *Trichotomosulcites subgranulosus* complex. The angiosperm component is dominated by the *Nothofagidites lachlaniae* complex and the *Nothofagidites flemingii* complex. A single specimen of *Coptospora* sp. b was recovered.

479.60 mbsf

Unlike samples higher in the section, the acid-resistant palynodebris is dominated by sheets of an amorphous "gel" which may be algal in origin (Pl. P3, fig. 1). Otherwise, the palynoflora closely resembles that at 290.99 mbsf in being dominated by *Batiacasphaera* spp. but lacks the Transantarctic Flora elements. A possible specimen of *Brigantedinium pynei* (see Hannah et al., 1998) was recorded (Pl. P3, fig. 4). This species was previously reported from Miocene sediments in the Cape Roberts (CRP-1) borehole in McMurdo Sound (Hannah et al., 1998).

Unusually for a deepwater marine environment, the algal flora includes significant numbers of the freshwater to brackish water cyst *Botryococcus* (3%) and other types that are typical of freshwater or estuarine environments (*Selenopemphix* and *Trinovantedinium*). Numbers of foraminiferal trochospiral liners (7%) are among the highest recorded in the sequence. The terrestrial component is wholly dominated by *Nothofagidites* species (including *Nothofagidites asperus*). The assemblage includes a rare tricolpate pollen form. Gymnosperms are rare (1%); spores are infrequent (3%) but include *Coptospora* sp. b.

607.75 mbsf

The sample yielded modern pollen contaminants, rare recycled Permian pollen, and trace numbers of *Batiacasphaera* spp.

807.20 mbsf

Some of the same acid-resistant algal? gel that distinguishes the sample at 479.60 mbsf is present at this level. The dinocyst flora is dominated by unattributed dinocysts (51%) but includes significant numbers of *Cymatiosphaera*? *invaginata* (7%), *Selenopemphix* spp. (3%), and trochospiral liners (9%) as well as trace numbers of *Enneadocysta partridgei*. Also present is a cyst that closely resembles the Danian species *Glyphanodinium facetum* (Pl. P3, fig. 10), described from the Dos Palos Shale of Fresno County, California, by Drugg (1964). The record of a possibly Paleocene dinocyst is of interest; the only other instance of Paleocene sediments in the general region is from the Mac.Robertson Shelf (Quilty et al., 1999) based on spore-pollen evidence.

The terrestrial flora is dominated by gymnosperms, in particular the Jurassic–Cretaceous *Corollina* (15%) and *Exesipollenites tumulus* (4%). Rare Tertiary taxa include *Dilwynites* sp. A, *Phyllocladidites mawsonii,* the *Nothofagidites lachlaniae* complex, and *Proteacidites.* There was also a single specimen of a spore referred to fossil Selaginellaceae (*Densoisporites* sp.).

The presence of *Dilwynites* sp. A suggests that it, and possibly *Phyllocladidites mawsonii* and *Proteacidites,* have been recycled from Turonian–?Santonian sediments. Recycled Permian forms are dominated by both monosaccate and saccate striate pollen.

983.21–998.27 mbsf

The two samples yielded abundant Permian species in a matrix of angular very fine quartz and (at 998.27 mbsf) zircon grains. The same sheets of algal gel noted in the above samples are common in the material from 983.21 mbsf. The only other common acid-resistant microfossil is a featureless, very thin walled, spherical cyst which is assumed to be algal in origin. *Corollina* is present in both samples, and *Exesipollenites* is present at 983.27 mbsf.

Site 1167

Intervals sampled are listed below, with brief summaries of the palynological data. Further interpretations are given at the end of the chapter.

83.85 mbsf

The microflora is dominated by Permian species, chiefly bisaccate pollen, but also includes the distinctive spore *Triplexisporites playfordii* (see Foster, 1979). Helby et al. (1987) proposed *T. playfordii* as the nominate species for a basal Triassic zone in western Australian basins but noted that it is relatively common in late Permian assemblages in eastern and western Australia. It has not been reported from Amery Group sediments within the present catchment of the Lambert Glacier. However, there is one record from the Lashly Formation of the Transantarctic Mountains, South Victoria Land, where Kyle and Schopf (1982) list the species (as *Tigrisporites playfordii*) from their Alisporites Zone (Subzone B). A middle Triassic age was considered likely by those authors.

The non-Permian component is dominated by long-ranging gymnosperm types (88%). The high relative abundance of *Corollina torosa* (33%) and *Exesipollenites tumulus* (18%) suggests a source predominantly from Early Jurassic rocks. Inclusion of younger material is indicated by trace numbers of Late Jurassic–Early Cretaceous and Eocene–Oligocene species. Examples are *Cicatricosisporites australiensis, Foraminisporis asymmeticus,* and *Microcachryidites antarcticus* from the Early Cretaceous and *Nothofagidites* species and *Arachnodinium antarcticum* from the Eocene–Oligocene. There is no clear evidence of a Late Cretaceous component.

217.97 mbsf

The microflora from this core catcher sample is similar to that recorded at 83.85 mbsf, including *Triplexisporites playfordii* in trace numbers, but also includes possible Devonian–Carboniferous taxa. The post-Permian component is dominated by gymnosperms (25%) but also includes large numbers of long-ranging spores. *Exesipollenites* is less common (6%) than in the above sample, whereas marine dinocysts and angiosperm pollen are absent.

227.45 mbsf

The yield was insufficient to make statistically reliable estimates of relative abundance, but the microflora appears to be an impoverished version of those recorded at 83.85 and 217.47 mbsf. The assemblage includes a possible fragment of the late Early Cretaceous species *Balmeisporites holodictyus.*

326.78 mbsf

Pollen dominance is shared between Permian species, largely nontaeniate bisaccates, *Corollina torosa* (42%), and *Exesipollenites tumulus* (17%). These last two species suggest derivation from Early Jurassic rocks, a possibility that is reinforced by the absence of the predominantly Cretaceous species *Cicatricosisporites australiensis* and *Microcachryidites antarcticus*.

368.70 mbsf

The sample yielded very low numbers of Permian and Early to Late Jurassic taxa in a matrix of fine angular quartz and zircon grains. The only commonly occurring taxon is the predominantly Jurassic genus *Corollina*.

443.70 mbsf

Low numbers of spores and pollen were recovered in a matrix of strongly humified (semiopaque and opaque) woody tissues. The microflora is dominated by Early Jurassic to Cretaceous species, predominantly bisaccate and trisaccate forms, some of which may be long-ranging. There are frequent (5%) occurrences of the Tertiary *Nothofagidites*. Permian taxa are rare.

BIOSTRATIGRAPHY

Age constraints

Primary age control at these sites rests on evidence from diatoms, radiolarians, and nannofossils. At Site 1165, the lowest occurrence of diatoms at 754 mbsf indicates an early Miocene age; below this, the early Miocene age determination is constrained by nannofossils (Bohaty and Whitehead, 2001). At Site 1167, the sequence penetrated consists of sediments of the Prydz Bay Fan and is of late Neogene age, thus is considerably younger than that at Site 1165 (O'Brien, Cooper, Richter, et al., 2001). Dating rests on rare nannoplankton and paleomagnetic data (O'Brien et al., 2001).

Palynomorphs recovered from these two sites are for the most part likely to be recycled, although it remains possible that some terrestrial plant taxa reflect contemporaneous vegetation. For example, it is uncertain whether *Nothofagidites* species recorded from both drill holes are in place, as has been proposed for the lower Miocene sequence in the Ross Sea drill hole Cape Roberts-1 (Raine, 1998), or whether they have been reworked from middle to upper Eocene sediments in Prydz Bay (see **Macphail and Truswell,** Site 1166; this volume). The presence of *Coptospora sp*. b in microfloras at 290.99 and 479.60 mbsf at Site 1165, which was described from the early Miocene at Cape Roberts-1, strengthens the case that at least part of the *Nothofagidites* count might have been sourced from a Neogene tundra vegetation.

The dinocyst floras include some genera that first appear in the late Paleogene (Oligocene) to Neogene in southeast Australia and elsewhere, for example, *Protoellipsodinium* and *Batiacasphaera* (references in Head and Wrenn, 1992). Five distinctive cyst types that are rare to common at Site 1165 appear to be of potential biostratigraphic value and may warrant further study (see under Taxonomy). The high relative abundance of *Batiacasphaera* species and cf. *Cymatiosphaera*? *invaginata* offers some support for an early Miocene age for the sampled section above 807.20 mbsf at Site 1165. The presence of *Brigantedinium pynei* at 479.60 mbsf accords with this evaluation.

Other dinocysts present include elements of the late Eocene–Oligocene Transantarctic Flora and are likely to be recycled. The majority of the dinocysts recorded in Neogene marine sediments in the Murray and Gippsland basins (McMinn, 1992; Macphail and Kellett, 1993) and within the Arctic Circle (Mudie, 1992) were not recorded.

Ages of the taxa present in the two drill holes, both as recycled and as possible in situ elements, have been obtained by comparison with known time distributions in southern Australia (Helby et al., 1987; Marshall, 1988, 1989; A.D. Partridge and M.K. Macphail, unpubl. data) and by regional comparisons in West Antarctica and adjacent offshore regions (reviewed by Truswell, 1997).

Key taxa that have been used to group the dinocyst and spore-pollen assemblages into broad age classes are:

1. Early Jurassic: *Exesipollenites tumulus,* plus frequent to abundant *Corollina* (see Truswell et al., 1999);
2. Early Cretaceous: Frequent to common *Microcachryidites antarcticus, Cooksonites variabilis, Dictyophyllidites* spp., and *Retitriletes* spp.;
3. Late Cretaceous–early Paleogene: *Odontochitina porifera, Battenipollis sectilis,* and *Forcipites* spp.;
4. Late Paleogene: *Arachnodinium antarcticum, Deflandrea prydzensis, Enneadocysta partridgei* (Transantarctic Flora), and *Nothofagidites* spp.; and
5. Neogene: *Batiacasphaera* sp. A, *Protoellipsodinium* sp., cf. *Cymatiosphaera*? *invaginata,* and *Coptospora* sp. b.

TAXONOMY

Dinocysts

Dinocyst species are rare to common in the sequence at Site 1165, and those that warrant further investigation of their stratigraphic value include the following:

Batiacasphaera sp. A (Pl. **P4,** figs. 5, 6)

Remarks: This proximate cyst is characterized by a microreticulate outer wall in which the lumen size is highly variable. Further study may confirm that the species is *Batiacasphaera minuta* Matsuoka and Head, a species that occurs in early Miocene assemblages from offshore North Carolina and Japan (pl. 1, figs. 1–11 in Matsuoka and Head, 1992). Other *Batiacasphaera* species occur as early as the middle Eocene and as late as the late Miocene. A variant (*Batiacasphaera* sp. C) is characterized by a finer microreticulum (Pl. **P4,** fig. 8).

Batiacasphaera sp. B (Pl. **P4,** figs. 9, 10)

Remarks: This cyst type is slightly larger than *Batiacasphaera* spp. A and C and is characterized by a microreticulate outer wall in which the lumina are highly irregular and/or the muri are incompletely joined (labrynthine sculpture).

Protoellipsodinium sp. (Pl. **P4,** fig. 11)

Remarks: This undescribed species is found in Oligocene–early Miocene bioclastic sediments in the Gippsland Basin.

cf. *Cymatiosphaera*? *invaginata* (Pl. **P4,** figs. 3, 4)

Remarks: A very small *Impagidinium*-like cyst, characterized by an open reticulate outer wall, is here provisionally assigned to the Quaternary species *Cymatiosphaera*? *invaginata* Head et al. (see pl. 8, figs. 4, 5 in de Vernal et al., 1992).

Svalbardella sp. A. (Pl. **P4,** figs. 1, 2)

Remarks: This distinctive dinoflagellate differs from *Svalbardella hampdenensis* Wilson, found in middle?–late Eocene sediments at Site 1166, in that the periphragm is ornamented with sparse elongate baculae, or, if adpressed, rugulae.

Odontochitina porifera (Pl. **P1,** fig. 7)

Remarks: Only one Cretaceous dinoflagellate was encountered, a single specimen of the species *Odontochitina porifera*, a species that is restricted to the early Santonian–early Campanian in southern Australia (Helby et al., 1987).

Trochospiral liners of one or more unidentified planktonic? foraminifers were present in low to common numbers at Site 1165 (Pl. **P3,** fig. 3), as were protoperidiniacean cysts and other unidentified marine microfossils (Pl. **P3,** figs. 7–10).

Kerogen extracts at 290.99 and 807.20 mbsf at Site 1165 are characterized by laminar sheets of an amorphous substance that, if organic, is likely to be algal in origin (Pl. **P3,** fig. 1). Other samples yielded what may be carbonized diatom fragments (Pl. **P3,** fig. 2) and undissolved zircons, for example, at 998.27 mbsf at Site 1165.

Spores and Pollen

The majority of Mezozoic and Cenozoic fossil pollen and spores can be assigned to formally described species, although the morphological fit is inexact since many of the commonly occurring types show a high degree of variation. Examples are *Phyllocladidites, Podocarpidites, Podosporites,* and *Trichotomosulcites* (gymnosperms) and *Nothofagidites* (angiosperms). Reasons for this are discussed in **Macphail and Truswell** (this volume).

Several samples from Site 1165 yielded spores identical to one of the species described by Raine (1998) from early Miocene microfloras from the Cape Roberts Drilling Project in the Ross Sea (CRP-1)—*Coptospora* sp. b. Whereas we have retained Raine's name to facilitate comparisons between CRP-1 and Site 1165, the botanical attribution of this spore and a second type referred to *Marchantiaceae* by Raine (1998) are challenged.

Coptospora sp. b. (Pl. **P4,** figs. 14–17)

Remarks: This type, which occurs at 290.99 and 479.60 mbsf at Site 1165, closely resembles spores of ground ferns in which the sulcus is unusually short or invaginated. The coarse verrucate sculpture is diagnostic of the fossil spore genus *Polypodiisporites* and spores produced by living species within the Davalliaceae (*Davallia*) and Polypodiaceae *(Microsorium)*. The same caveat applies to a second, more finely verrucate spore type, *Coptospora* sp. c (see figs. e, f in Raine, 1998). Raine noted the similarity of these forms to recycled specimens from Ross Sea sediments figured by Truswell (1983, pl. 2, figs. 4, 5, 9).

"Marchantiaceae"

Remarks: This type is suggested to be the fossil spore of a fern ally (Selaginellaceae) in which the inner cell wall (intine) is poorly developed or poorly preserved. If correct, the type is a variant of the *Densoisporites implexus-simplex* clade of Macphail and Truswell (1993), of which the nearest living equivalent is *Selaginella uliginosa*. A related *Densoisporites* species in which the perine is nonplicate occurs at 807.20 mbsf at Site 1165 (Pl. **P4,** fig. 19).

Permian–Triassic pollen and spores

Remarks: No attempt was made to identify the full range of Permian (and, less probably, Triassic) pollen and spore types that are present in trace to very large numbers in samples from Sites 1165 and 1167. The most commonly occurring are taeniate bisaccates such as *Protohaploxypinus* and *Striatopodocarpidites* (Pl. **P1,** fig. 1).

Non-taeniate bisaccate gymnosperm pollen types are difficult to distinguish from Cretaceous *Alisporites* and Tertiary *Podocarpidites*. Age-diagnostic Permian species such as *Didecitriletes ericianus* and *Microbaculispora tentula* occur in occasional samples, as does the Permian–Triassic species *Triplexisporites playfordii* (Pl. **P1,** fig. 2).

VEGETATION AND PALEOCLIMATES

During the Early Jurassic, East Antarctica was closely juxtaposed against India and Western Australia, with the Prydz Bay area abutting the east coast of India in the region of the southern part of the Mahanadi Basin (Lawver et al., 1992). This continental configuration is reflected in the similarity of Jurassic to Early Cretaceous microfloras between East Antarctica, India, and Western Australia, with Antarctic microfloras of this age being best known from the Mac.Robertson Shelf, to the west of Prydz Bay (see Truswell et al., 1999).

Frequent to abundant recycled specimens of *Corollina* and *Exesipollenites* were encountered in samples from Sites 1165 and 1167, reflecting the presence of source beds of this age within the sediment catchment area. The parent vegetation of this assemblage has been described (in Truswell et al., 1999) as a regional variant of a community in which the overstorey consisted of parent plants of the coniferous family Chierolepidaceae, shedding *Corollina*-type pollen, and an understorey of ferns and bryophytes.

The vegetation of the Paleogene (mainly middle–late Eocene) has been described as “rainforest scrub” by **Macphail and Truswell** (this volume), with a dominance of *Nothofagus* and conifers. Much of the pollen of these groups encountered at Sites 1165 and 1167 has no doubt been recycled from beds of this age in the catchment. The fate of this vegetation in the Neogene remains controversial, but some evidence may be found in the microfloras from Site 1165. There, the presence of *Coptospora* sp. b increases the probability that at least part of the *Nothofagidites* spp. and *Podocarpidites* count may be contemporaneous with the sediment. The same may be true for *Phyllocladidites mawsonii* since the only living equivalent (*Lagarostrobus franklinii*) extends into the subalpine zone, occurring, rarely, as a prostrate shrub in the upper subalpine zone in western Tasmania (Anker et al., 2001). If correct, then the data support Raine’s (1998) interpretation that early Miocene microfloras from CRP-1 represent a tundra mosaic vegetation with low-growing *Nothofagus–Podocarpaceae-Proteaceae* scrub occupying warmer sites and mosses and herbs (not recorded) the more exposed sites.

Raine (1998, p. 546) compared the vegetation inferred from the pollen suites at CRP-1 with that growing today in the coastal Antarctic Peninsula and islands near the present Antarctic Convergence. He suggested that similar climatic conditions might have prevailed in the early Miocene of Antarctica, with mean winter temperatures above freezing, perhaps as high as 7°C in July. We note, however, that the limit of woody species lies considerably farther north, at ~55°S, in Tierra del Fuego. The pollen spectra encountered at both CRP-1 and, possibly, at Site 1165 appear to have no modern counterpart, so we are reluctant to assign climatic parameters to the assemblage.

It is noted that living Polypodiaceae (which we prefer as the botanical affinity for *Coptospora* sp. b) are concentrated in subtropical to tropical rainforest habitats, but the family does include cold-climate species (such as *Microsorium diversifolium*) occurring as far south as Auckland (50°48′S) and Campbell Islands (52°30′S) in the Southern Ocean.

It is relevant to note too the comparison with the situation in the erratic boulders at McMurdo Sound (Askin, 2000), where erratic boulders of post-Eocene age show a major drop in species diversity, with terrestrial palynomorphs either rare or absent. Only *Nothofagidites,* Podocarpaceae, and a few cryptogams were recorded. Askin has commented that the species *Nothofagidites lachlaniae* was perhaps the most notable survivor, with the capacity to adapt to growth under periglacial conditions.

TRANSPORTING MECHANISMS

Deposition of the sediments coincides with continental-scale glaciation of East Antarctica (O'Brien et al., 2001), and as such, terrestrial microfossils (like silts and clays) will have been transported offshore by a combination of ice, meltwater, and ocean currents.

Relative abundance data for Permian species (Table T2) indicate that this group of recycled microfossils was preferentially deposited on the continental shelf (Site 1167). A not unreasonable interpretation is that the palynomorphs were transported in strongly lithified sediments as part of the coarse bed load. Conversely, the higher relative abundance of younger (Cretaceous–Paleogene) species at Site 1165 is consistent with these microfossils being transported in weakly or unlithified sediments, allowing them to be part of the fine fraction carried out onto the continental rise by meltwater or sea currents.

One anomaly is the high relative abundance of Permian species in the two basal samples at Site 1165. Assuming that these microfossils have the same provenance as those recorded at Site 1167, then either coarse bed load was delivered more effectively to the site during earlier periods or the younger sediments have a different provenance.

Glacial Unroofing and Sediment Provenance

The simplest model of glacial or fluvio-glacial erosion—that of ice or meltwater cutting down through horizontally bedded strata—predicts that younger microfossils will be reworked and deposited before older microfossils in any adjacent sedimentary basin. This phenomenon (glacial unroofing) is vastly more complicated in areas of tectonic complexity or where glacier systems evolved from bodies confined to upland cirques and subsequently moved to valley glaciers and extended beyond the mountain front to thick ice sheets beyond the coastline. Nevertheless, the principle of biostratigraphic reversal should still be apparent to some degree in the offshore glacigene deposits.

Site 1165

The obverse situation to glacial unroofing is recorded at Site 1165, where Permian and Early Jurassic taxa are most abundant in the basal samples and Late Cretaceous and Paleogene–Neogene taxa are more common upsection. A possible reason is that much young sediment escaped erosion until ice sheets spread laterally across the landscape during the Miocene. Irrespective of whether the Paleogene–Neogene terrestrial component is derived in part or in whole from early Miocene tundra communities, the data are compelling that Turonian–?Santonian, Campanian, and possibly Maastrichtian sediments are buried below glacial ice in the catchment and that glacial erosion trends do not conform to a simple glacial unroofing model for the region.

Site 1167

Relative abundance data for Site 1167 are consistent with glacial unroofing in that Permian and Early Jurassic taxa are common to abundant in productive samples through the interval 443.70–83.85 mbsf, whereas Paleogene–Neogene taxa are frequent only in the basal sample. Whether this scenario is consistent with the survival of middle and late Eocene sediments at Site 1166 in the center of Prydz Bay is less clear. Nevertheless the data are compelling that ice responsible for the deposition of clasts deposited at Site 1167 traversed areas floored by Permian, Early Jurassic, and Early Cretaceous rocks, rather than by Late Cretaceous or Tertiary strata. Source beds for the Permian are known from the Prince Charles Mountains (see, for example, Balme and Playford, 1967), whereas Early Jurassic to Early Cretaceous beds are known to occur in the region on the Mac.Robertson Shelf to the west of Prydz Bay (Truswell et al., 1999).

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Table T1. Basic data.

		Yield		Preservation		
Depth (mbsf)	Sample type	Dinocysts	Spore-pollen	Dinocysts	Spore-pollen	Comment
Site 1167						
83.85	Core catcher	Trace	Medium	Good	Good	*Triplexisporites playfordii*
217.97	Core catcher	—	Medium	—	Good	Zircons; *Triplexisporites playfordii*
227.45	Core catcher	—	Low	—	Moderate	
326.78	Core catcher	—	Low	—	Moderate	Abundant zircons, fine quartz
368.70	Core catcher	—	Very low	—	Moderate	Abundant zircons, fine quartz
443.70	Core catcher	Trace	Low	Good	Variable	Zircons
Site 1165						
43.50	Core catcher	—	Trace	—	Poor	Biodegraded palynodebris
199.25	Core catcher	High	High	Poor	Moderate	Dinocysts ± fragmented
231.74	Core catcher	High	High	Poor	Moderate	Dinocysts ± fragmented
242.73	Core catcher	Trace	Very low	Moderate	Moderate	*Microbaculispora tentula*
290.99	Core catcher	High	Medium	Good	Good	*Microbaculispora tentula*
479.60	Core catcher	Trace	Very low	Good	Good	
607.75	Core catcher	Trace	—	Good	—	
807.20	Core catcher	Medium	Low	Good	Good	Trochospiral liners frequent
983.21	Core catcher	—	Very low	—	Moderate	Dominated by Permian spp.
998.27	Core catcher	—	Very low	—	Moderate	Dominated by Permian spp.

Note: — = no data.

Table T2. Stratigraphic distribution of in situ and recycled taxa by age class.

	Dinocyst floras			Spore-pollen floras					
Depth (mbsf)	Neogene	Transantarctic flora	Cretaceous	Neogene	Paleogene–Neogene	Late Cretaceous	Early Cretaceous	Early Jurassic	Permian
Site 1167 (Continental shelf)									
83.85	Trace	Trace	—	—	Trace	Rare	Rare	Abundant	Abundant
217.97	—	—	—	—	—	—	Frequent	Abundant	Abundant
227.45*	—	—	—	—	—	—	Trace	Rare	Rare
326.78	—	—	—	—	—	—	—	Abundant	Abundant
368.70*	—	—	—	—	—	—	Trace	Trace	Abundant
443.70	—	Trace	—	—	Frequent	—	Frequent	Common	Rare
Site 1165 (Continental rise)									
43.50*	—	—	—		—	—	—	—	Trace
199.25	Frequent	Common	Trace		Frequent	Frequent	Frequent	Frequent	Rare
231.74	Common	Frequent	—		Frequent	Frequent	Frequent	Rare	Rare
242.73*	Rare	—	—		Trace	Trace	Trace	Rare	Rare
290.99	Abundant	Frequent		Trace	Frequent	Frequent	Frequent	—	Rare
479.60	Abundant	Rare	—	Trace	Common	—	—	—	Rare
607.75*	Trace	—	—		—	—	—	—	Rare
807.20	Abundant	—		Trace	Rare	Frequent	Frequent	Common	Rare
983.21*	—	—	—		—	—	—	Trace	Abundant
998.27*	—	—	—		—	—	—	Trace	Abundant

Notes: abundant = >30%; Common = 15%–30%; frequent = 5%–15%; rare = 1%–5%; trace = <1%; * = low yielding samples. Abundant, frequent, and common recycled taxa are highlighted.

Plate P1. Recycled Permian, Early Jurassic, and Early Cretaceous species. All photomicrographs were taken at 788×. **1, 4.** Sample 188-1165C-15R-CC, 15 cm (807.20 mbsf); (1) *Striatopodocarpidites* sp.; (4) *Corollina torosa*. **2, 3, 9, 11.** Sample 188-1167A-12X-2, 5 cm (83.85 mbsf); (2) *Triplexisporites playfordii;* (3) *Exesipollenites tumulus* (dark brown "inner body") being shed from a specimen of *Corollina torosa* (light yellow body); (9) *Ischyosporites punctatus;* (11) *Foraminisporis asymmetricus*. **5.** *Exesipollenites tumulus* (Sample 188-1165C-27X-CC, 19 cm; 231.74 mbsf). **6, 7, 10, 14.** Sample 188-1165C-24X-CC, 50 cm (199.25 mbsf); (6) *Exesipollenites tumulus;* (7) antapical horn of *Odontochitina porifera;* (10) *Ceratosporites equalis*; (14) *Balmeopsis limbata*. **8.** *Cicatricosisporites australiensis* (Sample 188-1167A-49X-CC, 22 cm; 443.70 mbsf). **12, 13.** Sample 188-1167A-26X-1, 37 cm (217.97 mbsf); (12) *Laevigatosporites* sp.; (13) *Cooksonites variabilis*.

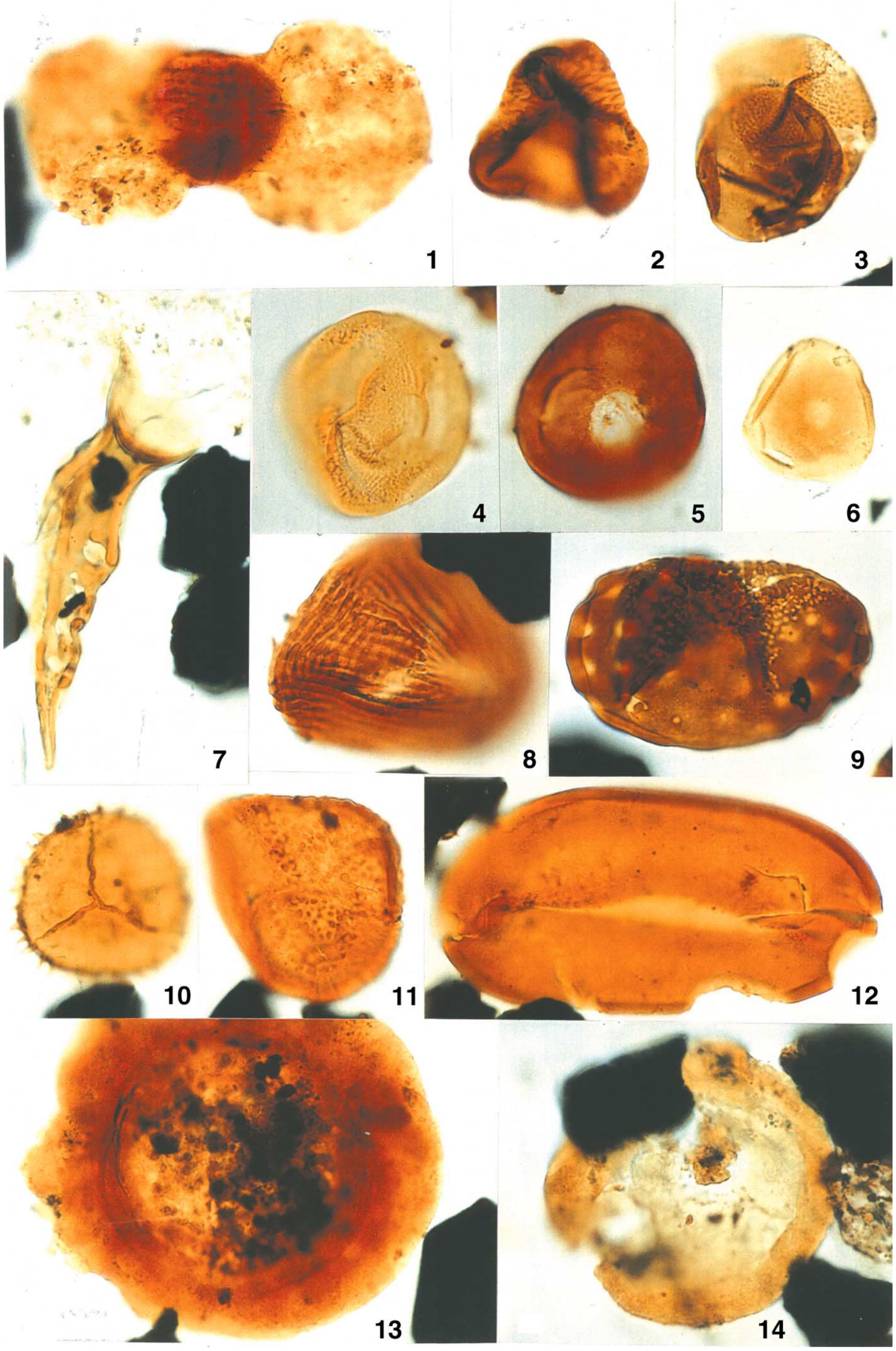

Plate P2. Late Cretaceous and Tertiary species. All photomicrographs were taken at 788×. **1.** *Foveogleicheniidites* sp. (Sample 188-1165C-27X-CC, 19 cm; 231.74 mbsf). **2, 3, 9–18, 22.** Sample 188-1165C-24X-CC, 50 cm (199.25 mbsf); (2) *Stereisporites australis;* (3) *Stereisporites regium;* (9) *Forcipites sabulosus;* (10) *Forcipites* sp. cf. *Forcipites longus;* (11) *Forcipites* sp.; (12) *Battenipollis sectilis;* (13) *Gambierina rudata;* (14) *Tricolporites lilliei* (oblique equatorial view); (15) *Tricolporites* sp. cf. *Tricolporites apoxyexinus* (equatorial view); (16) cf. *Asteropollis asteroides;* (17, 18) *Tricolpites/Phimopollenites* sp.; (22) *Nothofagidites flemingii.* **4.** *Dilwynites* sp. A. (Sample 188-1165C-15R-CC, 15 cm; 807.20 mbsf). **5.** *Trisaccites* sp. (Sample 188-1167A-26X-1, 37 cm; 217.97 mbsf). **6.** *Microcachryidites antarcticus* (Sample 188-1167A-27X-1, 25 cm; 227.45 mbsf). **7, 19, 20, 23, 24.** Sample 188-1167A-49X-CC, 22 cm (443.70 mbsf); (7) *Microcachryidites antarcticus;* (19) *Nothofagidites* sp. cf. *Nothofagidites senectus;* (20) *Nothofagidites* sp. cf. *Nothofagidites lachlaniae;* (23) *Nothofagidites saraensis;* (24) *Nothofagidites brachyspinulosus*. **8, 21.** Sample 188-1165C-24X-CC, 50 cm (290.99 mbsf); (8) *Phyllocladidites mawsonii;* (21) *Nothofagidites lachlaniae.*

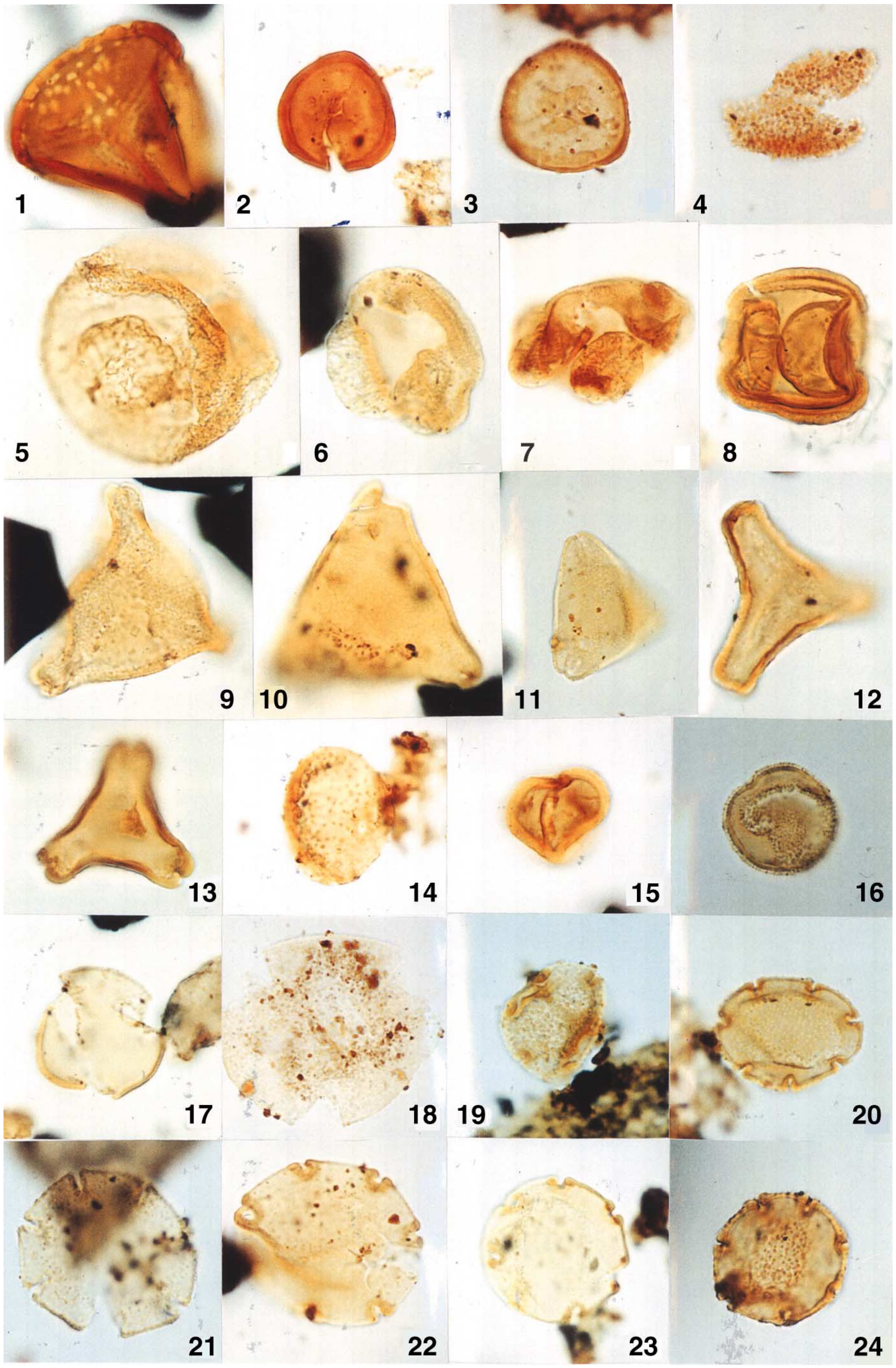

Plate P3. Neogene acid-insoluble marine microfossils. All photomicrographs were taken at 788× unless otherwise indicated. **1, 2.** Sample 188-1165C-34X-CC, 35 cm (290.99 mbsf); (1) laminar/amorphous kerogen (125×); (2) carbonized diatom fragment. **3, 4, 6, 9, 11.** Sample 188-1165C-54X-CC, 22 cm (479.60 mbsf); (3) trochospiral liner (planktonic foraminifer); (4) *Brigantedinium pynei;* (6) Protoperidiacean cyst showing well-developed archaeopyle (cf. *Brigantedinium simplex*); (9) unidentified marine microfossil; (11) *Pterosperma* sp. **5, 7, 8, 10.** Sample 188-11685C-15R-CC, 15 cm (807.20 mbsf); (5) *Selenopemphix* sp. cf. *Selenopemphix nephroides;* (7, 8) unidentified marine microfossil; (10) unidentified marine microfossil cf. *Glyphanodinium facetum* Drugg 1964. **12.** Unidentified marine microfossil (Sample 188-1165C-24X-CC, 50 cm; 199.25 mbsf).

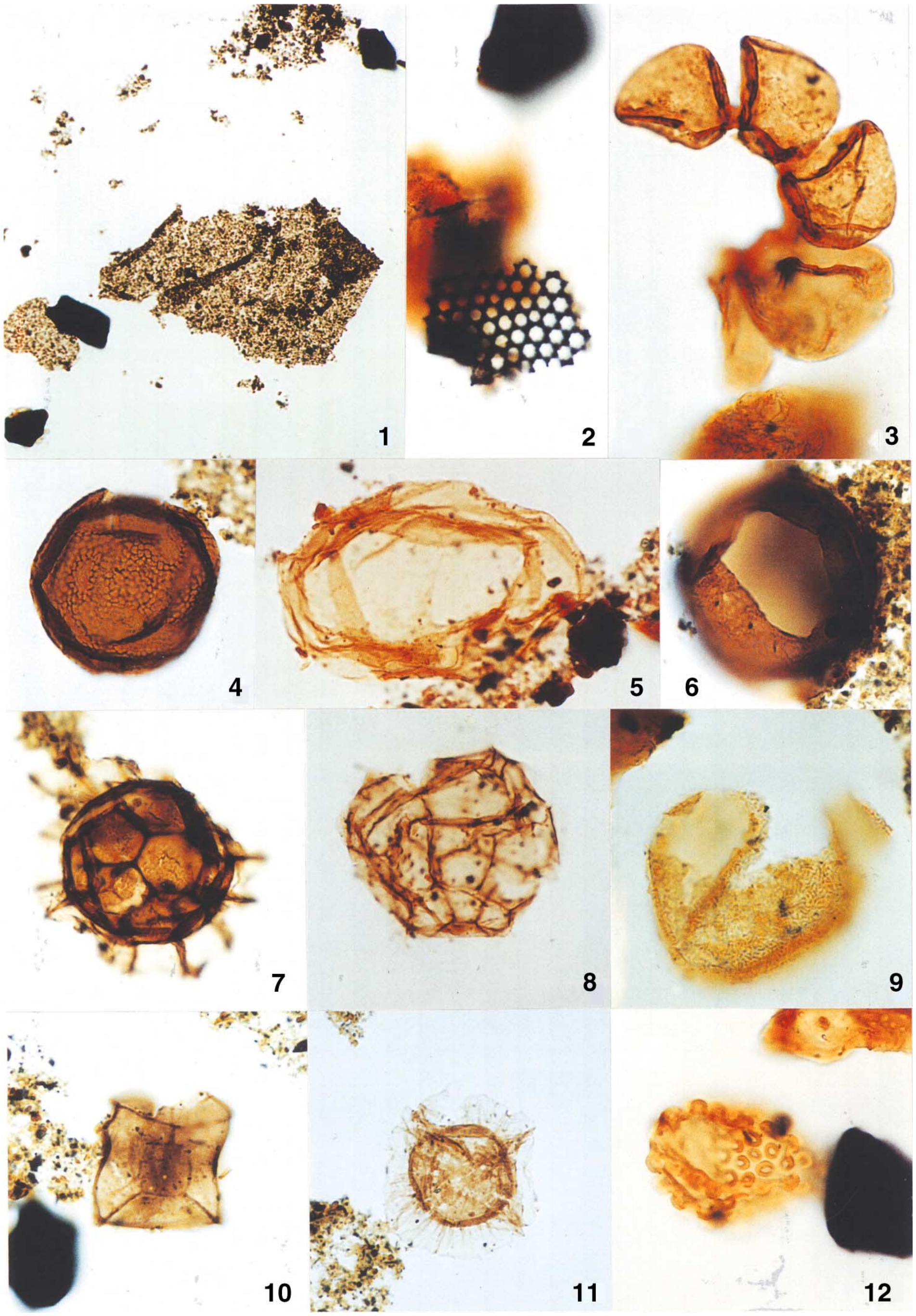

Plate P4. Neogene dinoflagellates, spores, and pollen (scale bar = 50 µm). **1, 2, 5, 6, 9, 10.** Sample 188-1165C-34X-CC, 35 cm (290.99 mbsf); (1, 2) *Svalbardella* sp. A.; (5) *Batiacasphaera* sp. A (archaeopyle); (6) *Batiacasphaera* sp. A open regular microreticulum); (9) *Proteacidites scaboratus*; (10) *Protoellipsodinium* sp. **3, 4, 18.** Sample 188-1165C-27X-CC, 19 cm (231.74 mbsf); (3, 4) cf. *Cymatiosphaera*? *invaginata;* (18) *Proteacidites* sp. cf. *Proteacidites scaboratus*. **7, 12, 13–17.** Sample 188-1165C-54X-CC, 22 cm (479.60 mbsf); (7) *Batiacasphaera* sp. B (archaeopyle); (12) *Batiacasphaera* sp. B (fine regular microreticulum); (13–15) "*Coptospora* sp. b" of Raine 1998; (16) "*Coptospora* sp. b" of Raine 1998 (crushed); (17) cf. "*Coptospora* sp. b" of Raine 1998. **8, 20.** Sample 188-1165C-24X-CC, 50 cm (199.25 mbsf); (8) *Batiacasphaera* sp. C (irregular microreticulum); (20) *Arecipites* sp. **11, 19.** Sample 188-1165C-15R-CC, 15 cm (807.20 mbsf); (11) *Batiacasphaera* sp. B (fine regular microreticulum); (19) *Densoisporites* sp. cf. *Densoisporites simplex*.