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3. MID-CRETACEOUS PALEOBOTANY AND PALYNOLOGY OF THE CENTRAL KERGUELEN PLATEAU, SOUTHERN INDIAN OCEAN (ODP LEG 183, SITE 1138)[1]

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ABSTRACT

Mid-Cretaceous sediments recovered during Ocean Drilling Program Leg 183 (Cores 183-1138A-69R to 73R) on the central Kerguelen Plateau have been analyzed palynologically and paleobotanically to determine the age of the strata and to reconstruct vegetational development and paleoecology. The lower strata (Cores 183-1138A-71R to 73R), a dark, organic-rich silty claystone with many wood fragments and fern remains (sedimentary Unit VI), certainly of terrestrial origin, directly overlies the volcanic basement, which is dated as latest Albian (~95 to 103 Ma) to earliest Cenomanian. The age of the terrestrial strata can be determined by sporomorphs as late Albian to earliest Cenomanian as well. This shows that parts of the central Kerguelen Plateau must have been subaerial at least until the late Albian and were covered with a diverse high-latitude flora, probably dense conifer forest with various fern taxa in the undergrowth. Early angiosperms are also present. The vegetational character represented in Unit VI did not change significantly through time. However, varying percentages of several sporomorph groups seem to show recurring abundance variations, which might possibly be cyclic, caused by Milankovitch-type cyclic events.

Cores 183-1138A-67R through 69R, of open marine origin, contain medium- to high-diversity dinocyst assemblages. Based on previous stratigraphic zonation schemes, the ages of these strata range within the *Heterosphaeridium* Superzone, from the *Palaeohystrichophora infusor-*

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[1] Mohr, B.A.R., Wähnert, V., and Lazarus, D., 2002. Mid-Cretaceous paleobotany and palynology of the central Kerguelen Plateau, southern Indian Ocean (ODP Leg 183, Site 1138). *In* Frey, F.A., Coffin, M.F., Wallace, P.J., and Quilty, P.G. (Eds.), *Proc. ODP, Sci. Results,* 183, 1–39 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/183_SR/VOLUME/CHAPTERS/008.PDF>. [Cited YYYY-MM-DD]

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ioides Zone to the *Conosphaeridium striatoconus* Zone, which correlates to the latest Cenomanian to Coniacian.

INTRODUCTION

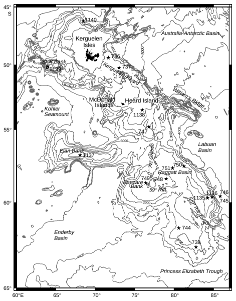
The Cretaceous paleovegetation of the Kerguelen Plateau (KP), today located in the southern Indian Ocean between the Australian-Antarctic and the African-Antarctic Basins, was part of the southernmost (Antarctic) floral province. The plateau, today more or less completely submerged, exhibits only in the northern and central parts a few subaerial islands: the volcanic Kerguelen, Heard, and McDonald Islands. The Southern Kerguelen Plateau (SKP) lies generally at a water depth between 1000 and 2000 m.

The drilling campaigns of Ocean Drilling Program (ODP) Legs 120 and 183 (Schlich, Wise, et al., 1989; Coffin, Frey, Wallace, et al., 1999) focused partly on the development of the basaltic basement and the subsequent subsidence history of the central Kerguelen Plateau. The age for the basement and immediately overlying sediments at the southern central Kerguelen Plateau seems to be late Early Cretaceous, or 110 Ma (Whitechurch et al., 1992). There, purely terrestrial sediments directly overlying the basalt contain a rich paleoflora (Francis and Coffin, 1992; Mohr and Gee, 1992a). The preliminary stratigraphy of the overlying marine Cretaceous strata has been elucidated partly by nannoplankton and foraminifers and also by organic walled microfossils, including sporomorphs and dinocysts (Watkins et al., 1992; Mohr and Gee, 1992b).

The basement age of the central Kerguelen Plateau (CKP) seems to be slightly younger. Previous studies reported ages of the oldest sediments at the central plateau as late Cenomanian to early Turonian (Mohr and Gee, 1992b). Newly gathered geochemical data show an age of ~95 to 102–103 Ma (Coffin, Frey, Wallace, et al., 1999), which is equivalent to the latest Albian and earliest Cenomanian.

Paleobotanical and palynological data from Hole 1138A on the CKP, on which this paper is focused, give an even more detailed picture of the mid-Cretaceous geological and paleovegetational history and add new information to the previous stratigraphic and paleogeographical analyses of Upper Cretaceous strata recovered at Site 747 (Mao and Mohr, 1992; Mohr and Mao, 1997). Studies of Cretaceous southern high-latitude terrestrial and marine floras, to which the Kerguelen Plateau vegetation and marine phytoplankton belong, began during the 1950s with the classic taxonomic descriptions of Australian material by Cookson and co-workers, later also by Dettmann (e.g., Cookson and Eisenack, 1958, 1960, 1974; Cookson and Manum, 1964; Dettmann, 1963). Backhouse, Burger, and Helby and co-authors (Backhouse, 1988; Burger, 1980; Helby et al., 1987) completed comprehensive studies on Australian sections and Couper (1953, 1960) and Wilson (1984) on New Zealand strata. During the last decades, studies on late Early and early Late Cretaceous palynomorphs and dinocysts were also conducted on material from the Antarctic Peninsula area (Dettmann and Thomson, 1987; Keating et al., 1992; Mohr, 1990).

F1. Geography and bathymetry of the central Kerguelen Plateau, p. 24.



Geographic and Geologic Setting

The KP forms a large topographic high located in the southern Indian Ocean (Fig. **F1**). The plateau stretches ~2300 km between 46° and

64°S toward the Antarctic continental margin. The structure is between 200 and 600 km wide. Today, most of the Kerguelen Plateau lies south of the present-day Polar Front and its northern and central parts are situated in >1000 m water depth. The southern parts are located mostly at a depth of 1000 to 2000 m below sea level. The northern Kerguelen Plateau (NKP) and CKP includes the plateau's only subaerial parts: Kerguelen, Heard, and McDonald Islands.

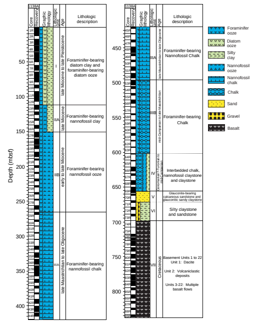
The Kerguelen Plateau province has been divided into five distinct geological domains: northern, central, and southern Kerguelen Plateau, Elan Bank, and the Labuan Basin. A lack of rocks older than ~40 Ma from the Kerguelen archipelago and plate reconstructions suggest that the age of this structure is indeed not older than 40 Ma. The central and southern domains of the submarine Kerguelen Plateau are, however, of Cretaceous age (see above).

The CKP, 50° to 55°S, is relatively shallow, contains a major sedimentary basin, the Kerguelen-Heard Basin, and includes the volcanically active Heard and McDonald Islands. During ODP Leg 120, an extended section in the Central Kerguelen Basin was drilled at Site 747, where the oldest sediments, nannofossil chalk, have been dated as late Cenomanian/early Turonian by palynomorphs. The upper Upper Cretaceous sequence consists of upper Santonian to Maastrichtian sediments with a possible large gap during the early to mid-Campanian (Watkins, 1992; Watkins et al., 1992, 1996).

Site 1138

Site 1138, on which this paper is focused, lies on the CKP, 180 km east-southeast of Heard Island (Fig. F1), ~150 km north-northwest of Site 747. The site was drilled in a water depth of ~1150 m. Hole 1138A was rotary cored continuously to a depth of ~840 m. The marine sedimentary section above the volcanic basement, which was reached at 698 meters below seafloor (mbsf), consists of upper Pleistocene to Upper Cretaceous strata (Fig. F2). The upper Pleistocene to Pliocene is represented by a relatively expanded section (110 m) and high sedimentation rates and consists of predominantly foraminifer-bearing diatom clay with interbedded foraminifer-bearing diatom ooze (Unit I). Unit II, foraminifer-bearing nannofossil clay, is dated as late to early Miocene. Unit III is Oligocene to Campanian and consists of white to light greenish gray foraminifer-bearing nannofossil chalk. Core 183-1138A-52R contains the Cretaceous/Tertiary boundary, where no lithologic changes were discovered.

F2. Composite stratigraphic section for Site 1138, p. 25.



Units IV to VI contain Upper Cretaceous sections. The interval 183-1183A-64R-1, 0 cm, to 69R, 112 cm (Unit IV), consists of cyclic alternations of light gray foraminifer-bearing chalk with gray to greenish gray to black intervals of nannofossil claystone. The clay-rich intervals also contain a planktonic foraminifer assemblage that can be placed in the *Whiteinella baltica* Zone, which is considered to be of Turonian age (Section 183-1138A-67R-4). The oldest calcareous microfossils encountered on board ship are of early Turonian age. They are present in dark gray and green horizons within highly bioturbated organic-rich chalks and clays (Unit V). These strata immediately overlie an ~1-m-thick marine black shale unit with 2.2 wt% organic carbon (for measurement methods, see Coffin, Frey, Wallace, et al., 1999). Nannofossil and planktonic foraminifer biostratigraphy suggest that this might represent the Cenomanian–Turonian anoxic event (OAE2, the "Bonarelli" horizon). The black terrestrial sediments of sedimentary Unit VI (dark brown silty claystone to siltstone) are rich in fossil plant remains and are discussed in detail in this chapter.

MATERIALS AND METHODS

For this study, >40 samples from Hole 1138A, lithologic Units IV to VI, were processed, screened, and studied, some in detail. Unit IV, a cyclic alternation of light gray chalk to dark gray/black nannofossil claystone, has carbonate contents of ~95 wt% at the top of the unit. The dark gray to black nannofossil claystone is more prominent at the base of the unit in Cores 183-1138A-68R and 69R. There, the organic carbon content reaches 2.25 wt% (see above). Unit V is represented in our study only by two samples (183-1138A-69R-5, 124–126 cm, and 69R–6, 50–52 cm) and consists of glauconite-bearing to glauconitic calcareous sandstone and claystone. Throughout Core 183-1138A-72R, small and sometimes large shell fragments of pectinid bivalves and serpulid tubes are common.

Unit VI consists predominantly of dark brown silty claystone to sandstone. The carbonate content is uniformly low (1–14 wt%). The upper part (interval 183-1138A-71R-2, 38 cm, to 73R-1, 13 cm) is mostly dark brown silty claystone with very fine grained sandstone layers that contain some glauconite grains. The underlying brown sandy claystone and sandy clayey siltstone contain, in part, pebbles, shell fragments, and small wood fragments. The lowermost portion of Unit VI (interval 183-1138A-73R-3, 126 cm, through 73R-CC) is silty claystone of various colors that overlies brecciated, weathered? basaltic basement.

All samples from Hole 1138A were processed using standard paleobotanical and palynological processing methods. To concentrate the organic material, samples were first treated with 10% HCl to dissolve carbonates. After several washings and centrifugation, high-strength HF was added to dissolve silicates. The samples were sieved with a 20-µm sieve onboard ship. Samples sieved later onshore were treated with a 12-µm sieve, and several were treated with a 6-µm sieve.

Preparation for analyzing (macro-)plant fossils included four-fraction wet sieving with 750-, 250-, 125-, and 45-µm sieves. Some of the samples were difficult to dissolve, so the material was frozen and thawed several times to loosen it and was sieved with 500- and 200-µm sieves. The pieces range in size from <1 mm to 3 cm, most commonly ~1–3 mm. The material consists of partly charcoalified material (fusinite) and partly vitrinite.

The residual objects—pieces of wood and parts of fern fronds, as well as leaves and resin—were picked under a binocular microscope. Most of the palynological slides (up to 12 per sample) were prepared with glycerine jelly and surrounded by wax. In many samples finely shredded organic debris masked the taxonomic features of dinocysts, which necessitated the preparation of single-grain slides. Photographs were taken with a Zeiss light microscope. A few wood fragments and other charcoalified plant debris were studied with a scanning electron microscope (SEM).

An overview table was created while screening through most of the existing slides. For (semi)quantitative counts, an average of a half-dozen slides per sample were used and 50 to 150 sporomorphs per sample were counted. The following abundance categories, of total palynomorphs per analyzed slide, were used:

A = abundant (>200 palynomorphs).
C = common (100–200 palynomorphs).
F = frequent (50–100 palynomorphs).
R = rare (10–50 palynomorphs).
P = present (<10 palynomorphs).
B = barren.

RESULTS

Kerogen Analysis

The organic matter of lithologic Units V and VI consists ~50%–80% of well-defined plant debris, such as wood fragments of various sizes, fern leaves, fern sporangia, seeds, and cuticles (Table **T1**), and can thus be classified as structured terrestrial palynodebris. About 20%–40% of the organic debris is finely shredded.

T1. Kerogens and organic analysis, p. 30.

In some samples, especially in Samples 183-1138A-72R-3, 17–20 cm, and 72R-3, 20–25 cm, many resin pieces were found. Usually, these unrounded fragments are not >1 mm in diameter, are translucent or opaque, and are whitish to yellowish in color. Several of these pieces were unsuccessfully analyzed by A. Otto for terpenoid biomarkers, which are typical for conifers.

Most of these samples contain either abundant or frequent sporomorphs, which are usually well preserved and relatively unaltered. The color of these sporomorphs is dark yellow (e.g., conifer pollen) to light brown (spores). The value on the thermal alteration scale (TAS) is estimated to be 2 to 2.5 (Batten, 1996).

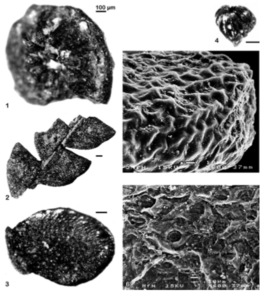
The organic matter of lithologic Unit IV is quite different. In Cores 183-1138A-67R to 69R, well-defined terrestrial material is virtually absent. In Cores 183-1138A-68R and 69R, dark brown to black highly altered small wood chips are observed. Core 183-1138A-67R seems to contain nearly exclusively light yellow finely disseminated marine organic matter <10 µm in size.

Mesoflora

Remains of Ferns and Fern Allies

Among the mesofossils of Cores 183-1138A-71R through 73R, fern remains are by far the most common. There are axes with fern leaves partly still attached and young, spirally curved fern pinnae, so-called fiddle heads (Pl. **P1,** fig. 1). The individual leaflets of these fern pinnules show, in part, epidermal structures and stomata (Pl. **P1,** figs. 5, 6). Hundreds of sporangia of the Schizaeales type were picked, comparable with recent *Anemia* (Pl. **P1,** fig. 4). Some of these sporangia seem to yield in situ spores because among the kerogen in strewn slides, spore clusters partly inside or close to sporangia are encountered, in one case certainly of gleicheniaceous origin.

P1. Fern remains, p. 31.



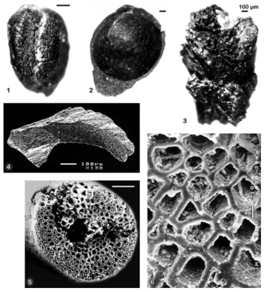
Megaspores have been identified in sieved material as well as among the HF-processed palynoflora. These megaspores are derived from lycophytes, more precisely from various *Selaginella* species and possibly from hitherto unknown taxa.

Conifer Remains

Wood remains are very common in sedimentary Unit VI. Their sizes range from <1 mm to 3 cm. Some of the wood particles, mainly charcoalified pieces, show excellent preservation of structural detail. In some of these particles, light-microscopic as well as SEM pictures reveal cell structures, mainly tracheids with pits. Thus, most of these particles seem to be conifer wood.

Several seeds are identified by D.H. Mai (pers. comm., 2001) as conifer seeds (Pl. **P2,** figs. 1, 2), and a small piece of a twig is very similar in appearance to *Microcachrys* sp., an extant taxon of Tasmania (Pl. **P1,** fig. 3).

P2. Conifer remains and axes, p. 32.



Palynoflora

The palynoflora of Cores 183-1138A-67R through 72R consists of marine and terrestrial elements. The terrestrial elements (fungal remains, macro- and miospores, and freshwater algae) are diverse, more than 80 taxa. In the cored interval from Cores 183-1138A-71R through 73R, terrestrial palynomorphs dominate the palynoassemblages but phytoplankton are very rare, whereas in the interval from Cores 183-1138A-67R to 69R, marine elements are absolutely dominant (see Table **T1**). They consist mainly of dinoflagellate cysts, a few acritarchs, and foraminiferal linings.

This chapter is focused mainly on paleofloristic aspects, such as the reconstruction of the paleovegetation, but also on biostratigraphy. Taxonomic treatment of the terrestrial sporomorphs is based mainly on the publications of Couper (1953), Dettmann (1963, 1973), Filatoff (1975), Norvick and Burger (1975), Burger (1980, 1993), and Backhouse (1988). A complete list of taxonomic references may be found in these papers.

The dinocyst taxonomy used here generally follows the dinoflagellate index of Williams et al. (1998), which contains the full citations of the original papers, and thus these citations are not repeated here. Taxonomic remarks are added in **"Appendix A,"** p. 18. **"Appendix B,"** p. 20, and **"Appendix C,"** p. 22, provide lists of the sporomorph and dinocyst taxa encountered in this material.

Sporomorphs and Their Affinities

The qualitative and quantitative composition of the spore and pollen flora compares very well with mid-Cretaceous floras known from previous studies on material from the Kerguelen Plateau (Mohr and Gee, 1992a, 1992b), as well as with Australian and Antarctic floras of this time interval.

Various botanical groups, such as mosses (bryophytes s.l.), lycopods (Lycophyta), horsetails (Artrophyta), ferns (Filicophyta), Mesozoic seed ferns, conifers (Coniferophyta) and angiosperms (Anthophyta) are present. The botanical affinities of many of these taxa have been discussed previously by Mohr and Gee (1992a). There, botanical as well as paleobotanical literature of in situ occurrences of certain pollen taxa has been summarized. Here, additional information is provided on taxa that have not been observed from the Kerguelen Plateau previously and on new in situ discoveries of the last decade.

Mosses (Bryophyta)

The hornwort, liverwort, and moss spore species are quantitatively minor constituents of the sporomorph flora. Compared to the early Albian flora of Site 750, diversity and number of species per sample is slightly higher.

Aequitriradites spinulosus and *Foraminifersporis asymmetricus* are considered by Dettmann (1963) as spores that might have been produced by Sphaerocarpaceae and Anthocerotaceae. *Triporoletes reticulatus* might be related to extant *Riella/Riccia* (Riellaceae). Several fossil spore specimens, most likely of moss origin, are similar in appearance to extant taxa of *Asterella* (see Playford and Dettmann, 1996).

The spore taxa *Stereisporites antiquasporites* and *Stereisporites granuloides* (Filatoff, 1975) belong, most probably, to the Sphagnaceae.

Fern Allies and Ferns (Pteridophyta)

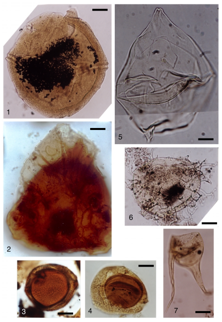
Trilete as well as monolete spores are preserved. The majority of trilete spores were certainly produced by ferns; the monolete spores also come from ferns.

The fernlike plants are represented by various taxa, which are found only occasionally. *Calamospora mesozoica* is considered to belong to *Equisetites*. *Densoisporites velatus,* which is found regularly at a few percentage abundance in the spore spectra, may be derived from Lycopodiaceae or Selaginellaceae. Species of *Retitriletes* can be correlated to extant Lycopodiaceae. *Camarozonosporites, Foveosporites canalis,* and *Sestrosporites* are also considered to be of lycophyte origin (Mohr and Gee, 1992a).

A megaspore, similar to *Balmeisporites holodictyus* (Cookson and Dettmann, 1958), is common in some of the samples, especially in 183-1138A-72R-1, 122–124 cm. A similar type of megaspore is known from Aptian to Albian strata of South America (Baldoni and Batten, 1991). Krassilov and Golovneva (1999) observed remains of a heterosporous plant from the Cenomanian of West Siberia. This plant produces megaspores that have lateral pockets filled with monolete microspores. Megaspores with attached microspores of the *Perinomonoletes* type have been identified (Wilde and Hemsley, 2000) from the terrestrial Barremian of western Germany. In the Kerguelen Plateau specimens, we observe adherent microspores as well. Krassilov and Golovneva (1999) suggest either an affinity to lycopsids or water ferns, even though neither group shows the same biological characteristics. Wilde and Hemsley (2000) consider Selaginellales and/or Isoetales as closely connected to these megaspores. *Aratrisporites*-type spores (Pl. P3, figs. 3, 4), which are found in Cores 183-1138A-72R to 73R, are considered to be related to Isoetalean plants.

Among the ferns, the taxon *Cyathidites* is most common. Various fossil and extant taxa might be related, such as *Coniopteris, Onychiopsis,* and extant *Dicksonia* (Dicksoniaceae) (Traverse, 1988; van Konijnenburg-van Cittert, 1989). Other spore genera such as *Cibotiumspora* and *Ischyosporites* might also belong to the Dicksoniaceae. Spores of Gleicheniaceae (*Gleicheniidites* sp.) are found also in situ in sporangia. Cyatheaceae also probably grew at this location. Spores of *Reticulisporites* (sensu Uwins and Batten, 1988) are similar to spores of recent *Cyathea* and *Alsophila* (Large and Braggins, 1991). More rarely, spores of Osmundaceae (*Baculatisporites*), Pteridaceae (*Contignisporites*), and

P3. Dinoflagellate cysts and spores, p. 33.



Schizaeaceae, probably including *Lygodium* (*Impardecispora* and *Biretisporis*) were encountered.

Schizaeaceae were rather diverse. Several members of the *Cicatricosisporites-Appendicisporites-Plicatella* complex were found in this material. *Cicatricosisporites* accommodates spores consistent with those of *Anemia* and *Mohria*. *Appendicisporites* and *Plicatella* are also diagnostic of *Anemia*-type spores, representing the *Anemia oblongifolia, Anemia raddiana,* and *Anemia phyllitidis* types (Dettmann and Clifford, 1992). *Ruffordiaspora,* defined as spores that are similar to those of the fossil taxon *Ruffordia goeppertii,* belong certainly also to the Schizaeaceae. The same is probably true for the monolete reticulate spore taxon *Microfoveolatosporis fromensis.*

Pollen of Gymnosperms

Nonconifer pollen are rare in the studied material. A few bisaccate *Vitreisporites* pollen, known to belong to Caytoniales (*Caytonanthus*) and *Alisporites,* considered to belong at least partially in the group of Mesozoic seed ferns (Mohr and Gee, 1992a), were encountered. *Cycadopites* might belong to cycadophytes, which include, besides true cycads, the Bennettitales. *Callialasporites* and *Balmeiopsis limbata* have been identified from taxa of *Brachyphyllum;* however, the question of whether or not *Callialasporites* is ultimately of araucariacean or possibly podocarpacaen affinity has not been resolved (Archangelsky, 1994). *Corollina* is known to belong to the extinct conifer family Cheirolepidiaceae.

Podocarpidites might be related to *Podocarpus* (Podocarpaceae) and *Rugubivesiculites* and *Lygistepollenites* to extant *Dacrydium* (Dettmann, 1994). *Microcachrydites antarcticus* is usually matched with extant *Microcachrys* (Cookson, 1947) and *Trichotomosulcites* with *Trisacocladus* (Dettmann, 1994).

Pollen of Angiosperms

Angiosperm pollen generally contribute 1% to 3% of the sporomorph assemblage and comprise monocolpate types, such as two species of the genus *Clavatipollenites* that are generally considered to be of Chloranthaceous origin. Tricolpate and possibly tricolporoidate pollen are present, partly preserved as tetrads. Among the tricolpate specimens, we found the zonal marker *Phimopollenites pannosus,* indicative of the *Phimopollenites pannosus* Zone, correlatable to the late Albian. One pollen species might be related to the taxon *Afropollis,* common in mid-Cretaceous low latitudes.

The general level of development fits very well with descriptions of early angiosperm pollen from Australia and Antarctica (Burger, 1993; Dettmann, 1973; Dettmann and Thomson, 1987), where monocolpate and tricolpate taxa are dominant. At the present time these taxa are not correlatable with extant angiosperms.

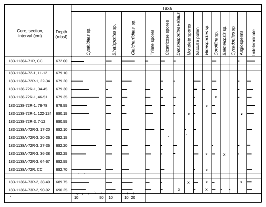
Quantitative Studies in Cores 183-1183A-71R through 73R

In order to understand the floral development through time, 12 samples from Cores 183-1138A-71R to 73R were quantitatively analyzed. They comprise an interval of ~18 m (672–690 mbsf) with two gaps each of ~7 m between 672–679 and 682–689 mbsf. The 3.50-m interval between these gaps is sampled relatively intensely. Thirteen major pollen/

spore categories were identified, and 50 to 150 sporomorphs were counted per sample.

All samples show, in principle, a common pattern (Fig. F3). The majority of all sporomorphs of Cores 183-1138A-71R to 73R consist of fern spores (average = 70%–80%). Moss and lycophyte spores are much less common (2%–3%). Podocarp conifers are usually present, with 5% to 8%, *Corollina* (Cheirolepidiaceae) with 3%–10%. Angiosperms are present in a typical range of 1%–3%. Mesozoic seed ferns, such as Caytoniales (*Vitreisporites*) and Corystospermales (*Alisporites,* in part), are very poorly represented.

F3. Major sporomorph groups, p. 26.

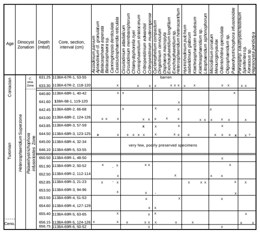


During the time interval studied, the pattern did not change significantly. However, in the 3.50-m interval we observe three spikes of *Cyathidites* spores, which might express some kind of cyclicity. In saccate as well as *Corollina* pollen we see a similar pattern, and also with *Densoisporites velatus,* but the counted numbers for these latter groups are statistically insufficient.

Stratigraphic Indicators of Cores 183-1183A-71R through 73R

Several of the taxa encountered in Cores 183-1138A-71R through 73R are stratigraphic index taxa that have well-defined ranges and were used by various authors, such as Dettmann and Playford (1969), Helby et al. (1987), and Dettmann (1994), for correlation purposes. The following taxa are considered to be time indicative (see Fig. F4): the megaspore *Balmeisporites* sp. and closely related taxa have been reported from the Barremian through the Cenomanian. *Balmeisporites holodictyus* has been observed in Australian upper Lower Cretaceous strata; a species that is less sculptured has been found in the lower Upper Cretaceous sediments of Victoria (Cookson and Dettmann, 1958). *Clavifera triplex* has its first appearance during the mid-Albian. *Phimopollenites pannosus* has a consistent appearance during the late Albian. *Interulobites intraverrucatus* and *Plicatella distocarinata* are slightly younger and are not seen in Southern Australian sections before the uppermost Albian. *Balmeiopsis limbata, Callialasporites dampieri,* and *Klukisporites scaberis* made their last appearances during the uppermost Cenomanian. *Cicatricosisporites hughesii* disappeared in the lower Cenomanian. A thorough discussion of various stratigraphic aspects is given below.

F4. Dinoflagellate cyst taxa, Cores 183-1138A-68R and 69R, p. 27.

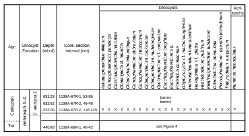


Phytoplankton

Most of the phytoplankton observed in Sections 183-1138A-67R-1 through 72R-1 consists of dinocysts. In a few samples, such as 183-1138A-68R-3, 123–125 cm, acritarchs, mainly *Verihachium* sp., are also moderately common.

The cyst assemblages are, except for a few samples, not diverse. The most diverse sample (183-1138A-68R-3, 123–125 cm) contains ~20 taxa. Overall, >40 taxa have been determined (Figs. F4, F5). Since many of the analyzed samples are very poor in abundance, (semi)quantitative counts were not possible.

F5. Dinoflagellate cyst taxa, Core 183-1138A-67R, p. 28.



The most common taxa are *Cassiculosphaeridia reticulata, Cribroperidinium edwardsii, Cibroperidinium muderongense, Cyclonephelium compactum, Heterosphaeridium heteracanthum, Odontochitina operculata, Palaeohystrichophora infusorioides,* and *Spiniferites* sp.

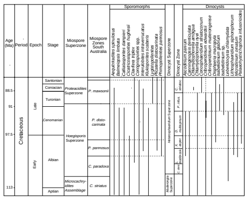
Several of the taxa encountered are only present in the lower part of the section, such as *Ascodinium* and *Hapsocysta peridictya* (Sample 183-

1138A-69R-5, 124–126 cm), which was formerly observed in Albian to Cenomanian strata of Australia (Eisenack and Cookson, 1960) and from Albian strata of the Weddell Sea (Mohr, 1990). *Conosphaeridium striatoconum* and *Chatangiella* sp. were seen in the upper part of the section (Samples 183-1138A-67R-2, 118–120 cm, to 68R-3, 123–125 cm).

Stratigraphic Indicative Dinocysts of Cores 183-1138A-67R to 69R

Several of the observed dinocysts are stratigraphic marker taxa, indicative of a late Albian to Coniacian time interval (Helby et al., 1987), as shown in Figure F6.

F6. Sporomorphs and dinoflagellate cysts, p. 29.



Short-ranging taxa are *Ascodinium parvum* (mid-Albian to late Cenomanian), *Disphaeria macropyla* (latest Albian to Santonian), *Litosphaeridium siphonophorum* (mid-Albian to mid-Turonian), *Microdinium* sp. (early Albian to late Turonian), and *Conosphaeridium striatoconum* (Coniacian to Santonian). *Chlamydophorella ambigua* was used by Schiøler and Wilson (1998) as an index taxon for their *C. ambigua* Zone, which marks the mid-Coniacian of New Zealand. *Glaphyrocysta marlboroughensis,* a new species from New Zealandian strata, has been recorded by these authors through the late Coniacian and early Santonian. Acme time intervals of certain taxa, such as *Cribroperidinium edwardsii* (late Cenomanian to mid-Turonian), *Microdinium ornatum,* and *Palaeohystrichophora infusorioides* (both latest Cenomanian to Turonian), also seem to be useful for stratigraphic purposes. A detailed stratigraphic discussion is given below.

Discussion

Paleovegetation and Floral Development

The affinities of many of the sporomorphs are well known (see above) and reflect the composition and diversity of late Early Cretaceous southern high-latitude floras. The composition of megafloras of the Antarctic and Australian late Early Cretaceous support our palynological results (Douglas, 1994).

Wood remains have been found and described from various localities at southern high latitudes. Falcon-Lang and Cantrill (2000) discussed the anatomical features of silicified tree trunks and stumps from upper Albian strata of Alexander Island, Antarctic Peninsula, and concluded that four taxa might have been present that seem to be related to extant Podocarpaceae, Araucariaceae, and Taxodiaceae (*Athrotaxis*).

Francis and Coffin (1992) analyzed wood from Core 120-750B-13W of early Albian age. Their conclusion was that these wood pieces all belong to conifers, more precisely to the form genera *Podocarpoxylon* or *Mesembrioxylon,* which partly have features of modern Podocarpaceae. At the Kerguelen Plateau, we found, besides conifer wood, which was difficult to determine more precisely, conifer seeds and twigs (probably of *Microcachrys*). These remains seem to be related mostly to podocarps, but a relationship to Araucariaceae or other conifer families cannot be ruled out completely. The well-studied late Aptian to early Albian southern Australian Koonwarra flora gives additional insight to the understanding of the vegetation of this time period (Drinnan and Chambers, 1986). In the Koonwarra material, Bryophytes, Equisetophytes, and Lycophytes are present and the diversity of ferns is rather high, with 11 taxa. Gymnosperms were also very common with three taxa of

Ginkgophytes, Coniferophytes (nine taxa), Mesozoic seed ferns (four taxa), and probably also a few taxa of Gnetophytes. Angiosperm remains were, however, still extremely rare (Taylor and Hickey, 1990).

The studied pollen spectra fit best with the general picture of the early Albian palynoflora from the Kerguelen Plateau (Mohr and Gee, 1992a) but equally reflect differences resulting from the late Albian age of the flora discussed in this paper. By ~100 Ma, angiosperms had become more diverse and more common, whereas Mesozoic seed ferns such as the Caytoniales seem to have diminished as a percentage of the vegetational cover.

The quantitative sporomorph data seem to support the following conclusions about Kerguelen Plateau vegetation and floral change through time: probably a large part of the canopy consisted of podocarp and other conifers. The understory and especially the ground cover was mostly made up of ferns of various growth forms, including tree ferns (e.g., Dicksoniaceae), climbing ferns (*Lygodium*), and ground species. Angiosperms were certainly present, possibly severely underrepresented in the pollen record. Mesozoic seed ferns seem to have been remarkably rare, perhaps diminished by more competitive early angiosperm taxa. On swampy ground, Isoetalean plants might have covered larger areas, as *Isoetes* does today.

Stratigraphy

Cores 183-1138A-71R through 73R contain mostly sporomorphs and very few dinocyst specimens that are not time indicative. Therefore, stratigraphic conclusions are based solely on sporomorph taxa. Cores 183-1138A-67R through 69R, however, contain nearly exclusively dinocysts, which are here used for stratigraphic purposes. We follow the widely applied stratigraphic zonation schemes for palynomorphs and dinocysts based on the works of Helby et al. (1987) and their definitions of superzones and zones to correlate the Kerguelen Plateau sections with the Australian Mesozoic (see Fig. F4). We also list the ranges of the stratigraphic index taxa, of which several are found in our material, mostly according to their data (see Fig. F4). Additional data used are from Stover et al. (1996) and Burger (1988).

Stratigraphy of Cores 183-1138A-71R through 73R

The spores and pollen encountered at Cores 183-1138A-71R through 73R directly overlying the basaltic basement (radiometric age = 103–95 Ma) are, generally speaking, well known from the Australian late early to early late Cretaceous, and most of these sporomorphs have already been described from the KP (Mohr and Gee, 1992a, 1992b). Several of the taxa encountered in this material are stratigraphic index taxa that have well-defined ranges and were used by various authors, such as Helby et al. (1987) for correlation purposes. According to Helby et al.'s (1987) miospore zonation scheme, the Kerguelen Plateau assemblage is part of the *Hoegisporis* Superzone, which ranges from mid-Albian to early Turonian in age. To pinpoint the age of the section more precisely, several spore and pollen taxa proved to be useful, such as the cicatricose spores *Cicatricosisporites hughesii* and *Plicatella distocarinata*. Their ranges overlap in the upper part of the *Phimopollenites pannosus* Zone and the lowermost part of the *Plicatella distocarinata* Zone (formerly *Appendicisporites distocarinatus* Zone), which indicates a late Albian to earliest Cenomanian age. This age estimate is in good agreement with the presence of a taxon of *Balmeisporites,* which was morphologically similar to the two species, *B. holodictyus* and *B. glenelgensis.* The first species is common in upper Lower Cretaceous strata in South Australia and Victoria, the latter in Cenomanian strata of Victoria.

Another criterion to evaluate the age of the studied section is the evolutionary stage of the angiosperm pollen. In contrast to the lower Albian section of Site 750, where only one of the most basal angiosperm pollen types, *Clavatipollenites,* has been reported, the material from Hole 1138A yields a variety of angiosperm pollen, about a half-dozen taxa. Among these the tricolpate genus *Phimopollenites* is characteristic of the *Phimopollenites pannosus* Zone (late Albian) (Burger, 1993). Younger sediments of Cenomanian to Coniacian age recovered at Site 747 have an even larger diversity of more than a dozen taxa, of which several are already clearly tricolporate, a developmental state that evolved only later (Mohr, 1995). Thus, the flora recovered during Leg 183 is of an intermediate age, most probably late Albian, according to the angiosperm development.

We conclude that the age of the section studied can be only slightly younger than the ages given for the volcanic basement, probably very latest Albian.

Stratigraphy of Cores 183-1138A-67R through 69R

The overall composition is very close to dinocyst assemblages described previously from the Kerguelen Plateau, Site 748 (Mohr and Gee, 1992b), of late Cenomanian to early Santonian age, and from the Australian Perth Basin (Cookson and Eisenack, 1974, 1982) Gingin Brook borehole (404–414 ft), which was considered to be of mid-Cretaceous age, and the Balcatta borehole, of possible Albian to Cenomanian age.

When Helby et al.'s (1987) zonation scheme is applied to the Kerguelen Plateau material of Cores 183-1138A-67R through 69R, the dinocyst assemblages fit well with the *Heterosphaeridium* Superzone because the bulk of our species have their occurrences in this interval (see Fig. **F4**), which is considered to be of late Albian to Coniacian age.

Several of Helby et al.'s (1987) index taxa, such as *Cribroperidinium edwardsii, Microdinium ornatum,* and *Palaeohystrichosphora infusorioides,* all recorded in Cores 183-1138A-68R through 69R, and very common in the *Palaeohystrichophora infusorioides* Zone, which equates to the latest Cenomanian to late Turonian. Thus, we conclude that most of the samples from Cores 183-1138A-68R through 69R are of this age.

First appearance datums and last appearance datums of a few taxa, recorded in Cores 183-1138A-67R through 68R allow an even more precise dating of the section. The presence of *Ascodinium parvum* and *Canninginopsis* cf. *denticulata,* together with *Isabelidinium glabrum* in Sample 183-1138A-69R-5, 124–126 cm, makes it probable that this part of the core is still of Cenomanian age.

Litosphaeridium siphonophorum is recorded worldwide from the mid-Albian to the mid-Turonian (Stover et al., 1996). The last occurrence in the Kerguelen Plateau cores is in Sample 183-1138A-68R-2, 124–126 cm. This means that this sample must be mid-Turonian or older. This is also in accordance with the observation that *Cribroperidinium muderongense* and *C. edwardsii* are seen often in Sample 183-1138A-68R-3, 57–59 cm, and in Sample 183-1138A-68R-2, 124–126 cm, but only rarely in Sample 183-1138A-67R-2, 118–120 cm. *Cribroperidinium edwardsii* has its peak occurrence in the *Diconodinium multispinum* and *Palaeohystrichophora infusorioides* Zones, which correlate with the mid-Cenomanian to earliest Coniacian, and is only rarely seen later. *Kleithriasphaeridium tubulosum* (formerly *Conosphaeridium tubulosum*) in Sample 183-1138A-67R-2, 118–120 cm, might indicate that these strata belong to the *Conosphaeridium striatoconus* Zone, which is considered to represent the Coniacian. More precisely, the sample might belong to the *Chlamydophorella ambigua* Zone of Schiøler and Wilson (1998), which is correlatable to the mid-Coniacian (see above). This might explain why common taxa such as *Odontochitina porifera* and a variety of *Chatangiella* species, which are usually common during the late Coniacian and Santonian, have not yet been seen.

These age estimates fit very well with those gathered for other microfossil groups. According to calcareous nannofossils, the cored interval from Cores 183-1138A-67R through 69R might belong to the (mid) Coniacian to the early Turonian, perhaps latest Cenomanian. Core catcher Sample 183-1138A-67R-CC might be of mid to late Turonian age (S.W. Wise, pers. comm., 2000), whereas Sample 183-1138A-67R-2, 34–35 cm, might be of mid-Coniacian age (Coffin, Frey, Wallace, et al., 1999). Cores from Sections 183-1138A-69R-3 and 69R-4 probably represent the mid and early Turonian. The planktonic foraminifers indicate similar ages (Coffin, Frey, Wallace, et al., 1999). Samples 183-1138A-67R-4, 68–71 cm, to 68R-4, 5–7 cm, seem to belong to the Turonian *Whiteinella baltica* Zone. Sample 183-1138A-69R-5, 81–83 cm, belongs possibly to the upper part of the *Praeglobotruncana* spp. Zone and might represent the early Turonian.

CONCLUSIONS

The meso- and palynofloras recovered from sedimentary Units IV to VI in Hole 1138A on the CKP are useful in reconstructing the vegetational cover on land and are utilized for stratigraphic interpretations.

The sporomorph flora of Cores 183-1138A-71R through 73R reflects a dense conifer forest with many ferns in the understory and rare angiosperms. During the time interval represented, this vegetation cover did not change significantly. The sporomorphs show several spikes in the cored interval, but no major trends are seen. We interpret this pattern as signs of some kind of cyclicity, probably Milankovitch-type cycles.

According to sporomorph zonation schemes developed in the Australian realm, the age of the interval is most probably latest Albian, possibly earliest Cenomanian.

The marine dinocyst floras recovered in Cores 183-1138A-67R through 69R suggest age ranges from the late Cenomanian to the mid-Coniacian, which is in agreement with other microfossil data.

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APPENDIX A

Taxonomic Remarks

Sporomorphs

Megaspores

Balmeisporites cf. *holodictyus* Cookson and Dettmann, 1958
Pl. P3, fig. 2

This megaspore shares all the major characteristics of the genus, as described by Cookson and Dettmann (1958), but seems to be intermediate between the species *Balmeisporites holodictyus* and *Balmeisporites glenelgensis.* The transparent outer exoexine, which covers the central body, forms only at the edges a reticulum, especially the proximate side around the triletum of the spore is smooth. Small monolete spores of the *Perinomonoletes* type are attached to the megaspore.

Pollen

Afropollis? sp.
Pl. P4, fig. 8

One pollen specimen (Pl. P4, fig. 8) might be related to the pollen genus *Afropollis* sp.; however, the preservational state is relatively poor. Pollen grains are ovoidal in shape and sulcate?; the pollen grain might split in a similar way as in *Afropollis zonatus* Doyle et al. (1982). The exine of the grain of Core 183-1138A-73R seems to be detached from the nexine over most of the surface of both hemispheres. The exine is semitectate and reticulate. The reticulum is slightly finer at the aperture.

Diameter of the complete grain = ~35 µm, thickness of exine = <1 µm, diameter of lumina in the reticulum = ~0.2–0.3 µm.

Clavatipollenites hughesii Couper 1958
Pl. P4, fig. 3; Pl. P5, fig. 5

The pollen specimens in our material show the typical features of the genus. Most of the specimens encountered have a thin exine and short clavae with very small heads. This type, here referred to as *C. hughesii,* Type A (Pl. P4, fig. 3) is identical to previously published records from the Australian region (Dettmann, 1973; Helby et al., 1987; Burger, 1993). In the Kerguelen Plateau material a second type also exists, here referred to as *C. hughesii,* Type B (Pl. P5, fig. 5) with a thicker exine and more robust clavae. This type is observed only rarely.

Cupuliferoidaepollenites sp.
Pl. P4, fig. 4

The surface of the small tricolpate grain (length = ~12 µm; equatorial diameter = ~8 µm) seems to be more or less smooth, and the features fit in principle with those given by Dettmann (1973). However, in the area of the intercolpium the columellae seem to be somewhat more widely spaced so that single elements are visible at a magnification of ~1200×.

Phimopollenites augathellaensis (Burger, 1970) Dettmann, 1973
Pl. P5, fig. 2

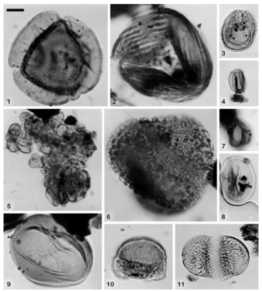
Here, pollen of this taxon is united in a tetrahedral tetrade. Otherwise, all the features described by Dettmann (1973) and Burger (1993) are present in the Kerguelen Plateau material.

Length = ~40 µm; polar diameter = ~30 µm.

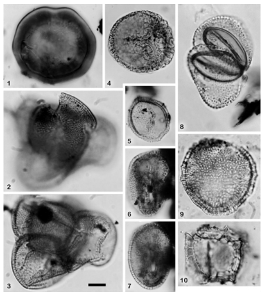
Dinoflagellate Cysts

Apteodinium cf. *A. granulatum* Eisenack, 1958
Pl. P3, fig. 1

P4. Unit VI sporomorphs, p. 34.



P5. Unit VI and IV sporomorphs, p. 35.



Several of the specimens encountered are close in appearance to the decription of *A. granulatum* given by Lucas-Clark (1987). However, some of the specimens, especially in Sample 183-1138A-68R-3, 123–125 cm, seem to have a broad morphological range. Several of these show extremely thick but more or less smooth walls with internal structures. Other specimens show relatively long apical horns and thick rugulate wall surfaces.

APPENDIX B

List of Sporomorphs

Cryptogamic Spores

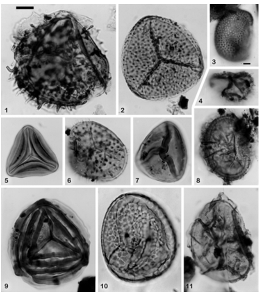
Megaspores

Balmeisporites cf. *holodictya* Cookson and Dettmann, 1958 (Pl. **P3,** fig. 2)

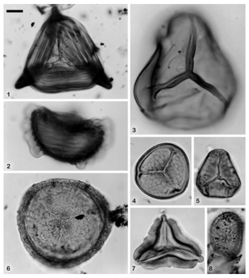
Trilete Spores

Aequitriradites spinulosus (Cookson and Dettmann, 1958) Cookson and Dettmann, 1961 (Pl. **P6,** fig. 1)
Antulsporites sp. (Pl. **P7,** fig.4)
Appendicisporites auritus Agasie, 1969 (Pl. **P7,** figs. 1, 2)
Appendicisporites cf. *A. insignis* (Markova, 1961) Chlonova, 1976
Baculatisporites comaumensis (Cookson, 1953) Potonié, 1956
Biretisporis eneabbaensis Backhouse 1978 (Pl. **P7,** fig. 3)
Bullasporis aequatorialis Krutzsch, 1959
Calamospora mesozoica Couper, 1958
Camarazonosporites sp.
Ceratosporis equalis Cookson and Dettmann, 1958 (Pl. **P6,** fig. 6)
Ceratosporis sp.
Cibotiumspora juriensis (Balme, 1957) Filatoff, 1975 (Pl. **P7,** fig. 5)
Cicatricosisporites hughesii Dettmann, 1963 (Pl. **P6,** fig. 9)
Clavifera triplex (Bolkhovitina, 1953) Bolkhovitina, 1966 (Pl. **P7,** fig. 7)
Contignisporites sp. *C.* cf. *fornicatus* Dettmann, 1963
Crybelosporites striatus (Cookson and Dettmann, 1958) Dettmann, 1963
Cyathidites australis Couper, 1953
Cyathidites minor Couper, 1953
Cyathidites asper (Bolkhovitina., 1953) Dettmann, 1963
Cyathidites sp.
Densoisporites velatus Weyland and Krieger, 1953 (Pl. **P7,** fig. 6)
Distaltriangulisporites sp. *D.* cf. *costatus* Singh, 1971
Foraminisporis asymmetricus (Cookson and Dettmann, 1958) Dettmann, 1963
Foveotriletes parviretus (Balme, 1957) Dettmann, 1963
Gleicheniidites cercinidites (Cookson, 1953) Dettmann, 1963 (Pl. **P6,** fig. 5)
Gleicheniidites confossus (Hedlund, 1966)
Gleicheniidites echinatus (Bolkhovitina, 1953) Krutzsch, 1959
Klukisporites scaberis (Cookson and Dettmann, 1958) Dettmann, 1963
Klukisporites sp.
Kuylisporis? sp.
Leiotriletes sp.
Leptolepidites verrucatus Couper, 1953
Lycopodiacidites sp.
Matonisporites crassiangulatus (Balme, 1957) Dettmann, 1963
Matonisporites impensus Hedlund, 1966
Obtusisporites canadensis
Pilosisporites trichopapillosus (Thiergart, 1949) Delcourt and Sprumont, 1955
Plicatella distocarinata (Dettmann and Playford, 1968) Davies, 1985
Plicatella sp. *P.* cf. *jansonii* (Pocock, 1962) Davies, 1985
Plicatella sp. *P.* cf. *gigantica* (Groot and Groot, 1962) Davies, 1985
Ruffordiaspora australiensis (Cookson, 1953) Dettmann and Clifford, 1992 (Pl. **P4,** fig. 2)
Sestrosporites pseudoalveolatus (Couper, 1958) Dettmann, 1963 (Pl. **P6,** fig. 2)
Stereisporites antiquasporites (Wilson and Webster, 1946) Dettmann, 1963
Stereisporites granuloides Krutzsch, 1963
Trilites kopukuensis Couper, 1957 (Pl. **P4,** fig 6)
Trilites tuberculiformis Cookson, 1947
Triporoletes reticulatus (Pocock, 1962) Dettmann, 1994
Verrucosisporites rarus Burger, 1966

P6. Unit VI sporomorphs, p. 36.



P7. Unit VI sporomorphs, p. 37.



Undulatisporites sp. (Pl. **P6,** fig. 7)
Uvaesporites pseudocingulatus Döring, 1966

Monolete Spores

Aratrisporites sp. (Pl. **P3,** figs. 3,4)
Laevigatosporites sp.
Microfoveolatosporis fromensis (Cookson and Dettmann, 1957) (Pl. **P6,** fig. 3)
Perinomonoletes sp. A (Pl. **P6,** fig. 8)
Perinomonoletes sp. B (Pl. **P6,** fig. 11)
Polypodiites horridus Backhouse, 1988 (Pl. **P6,** fig. 4)
Punctatosporites scabratus (Couper, 1953) Singh, 1971 (Pl. **P7,** fig. 8)

Gymnosperm Pollen

Alisporites? sp.
Araucariacites australis Cookson, 1947
Balmeiopsis limbata (Balme, 1957) Archangelsky, 1979 (Pl. **P4,** fig. 9)
Callialasporites dampieri (Balme, 1957) Sukh Dev, 1961 (Pl. **P4,** fig. 1)
Callialasporites segmentatus (Balme, 1957) Srivastava, 1963
Callialasporites trilobatus (Balme, 1957) Sukh Dev, 1961
Cyclusphaera radiata Archangelsky, 1983
Corollina sp.
Cycadopytes sp.
Lygistepollenites florinii (Cookson and Pike, 1953) Stover and Evans, 1973 (Pl. **P5,** fig. 4)
Microcachryidites antarcticus Cookson, 1947 (Pl. **P4,** figs. 5, 10)
Podocarpidites sp., *P.* cf. *ellipticus* Cookson, 1947
Podocarpidites sp.
Rugubivesiculites minimus Burger, 1966
Trichotomosulcites subgranulatus Couper, 1953
Vitreisporites pallidus (Reissinger, 1950) Nilsson, 1958 (Pl. **P4,** fig. 11)

Angiosperm Pollen

Afropollis? sp. (Pl. **P5,** fig. 8)
Clavatipollenites hughesii Couper, 1958; Type A (Pl. **P4,** fig. 3)
Clavatipollenites hughesii Couper, 1958; Type B (Pl. **P5,** fig. 5)
Cupuliferoidaepollenites sp. (Pl. **P4,** fig. 4)
Tricolpites sp. (Pl. **P4,** fig. 7)
Phimopollenites pannosus (Dettmann and Playford, 1968) Dettmann, 1973 (Pl. **P4,** fig. 8)
Phimopollenites augathellaensis (Burger, 1970) Dettmann, 1973 (Pl. **P5,** fig. 2)
Senectotriradites? sp. (Pl. **P5,** fig. 8)

APPENDIX C

List of Dinocysts

Adnatosphaeridium filiferum (Cookson and Eisenack, 1958) Williams and Downie, 1968 (Pl. **P8,** fig. 1)

Apteodinium sp., cf. *A. granulatum* Eisenack, 1958 (Pl. **P3,** fig. 1)

Ascodinium parvum (Cookson and Eisenack, 1958) Cookson and Eisenack 1960

Batiacasphaera asperata Backhouse, 1987

Batiacasphaera sp.

Canninginopsis sp., *C.* cf. *denticulata* Helby et al., 1987

Cassiculosphaeridia reticulata Davey, 1969

Circulodinium attadalicum (Cookson and Eisenack, 1962) Helby, 1987

Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986

Chatangiella cf. *tripartita* (Cookson and Eisenack, 1960a) Lentin and Williams, 1976 (Pl. **P8,** fig. 5)

Chlamydophorella nyei Cookson and Eisenack, 1958 (Pl. **P5,** fig. 9)

Chlamydophorella ambigua (Deflandre, 1937) Stover and Helby, 1987 (Pl. **P9,** fig. 8)

Conosphaeridium abbreviatum (Wilson, 1984) (Pl. **P9,** fig. 6)

Cribroperidinium cooksoniae Norwick, 1976 (Pl. **P8,** figs. 3, 6)

Cribroperidinium edwardsii (Cookson and Eisenack, 1958) Davey, 1969

Cribroperidinium muderongense (Cookson and Eisenack, 1958) Davey, 1969 (Pl. **P8,** figs. 8, 9)

Cyclonephelium compactum Deflandre and Cookson, 1955 (Pl. **P3,** fig. 6)

Cyclonephelium membraniphorum Cookson and Eisenack, 1962

Disphaeria macropyla Cookson and Eisenack, 1960

Exochosphaeridium longifilum Cookson and Eisenack, 1982

Exochosphaeridium bifidum (Clarke and Verdier, 1967) Clarke et al., 1968 (Pl. **P9,** fig. 4)

Florentinia cooksoniae (Singh, 1971) Duxbury, 1980 (Pl. **P9,** fig. 5)

Glaphyrocysta cf. *marlboroughensis* Schiøler and Wilson, 1998 (Pl. **P9,** fig. 9)

Hapsocysta peridictya (Eisenack and Cookson, 1960) Stover and Evitt, 1978 (Pl. **P8,** fig. 2)

Heterosphaeridium heteracanthum (Deflandre and Cookson, 1955) Eisenack and Kjellström, 1972

Hexagonifera cf. *glabra* Cookson and Eisenack, 1961 (Pl. **P8,** fig. 7)

Hystrichodinium pulchrum Deflandre, 1935

Isabelidinium glabrum (Cookson and Eisenack, 1969) Lentin and Williams, 1969 (Pl. **P3,** fig. 2)

Kleithriasphaeridium tubulosum (Cookson and Eisenack, 1969) Stover and Evitt, 1978 (Pl. **P9,** fig. 2)

Leberidocysta chlamidata (Cookson and Eisenack, 1962) Fechner, 1985

Litosphaeridium siphoniphorum (Cookson and Eisenack, 1958) Davey and Williams, 1966

Meiourogonyaulax sp.

Microdinium ornatum Cookson and Eisenack, 1960

Odontochitina operculata (O. Wetzel, 1933) Deflandre and Cookson, 1955 (Pl. **P3,** fig. 5)

Oligosphaeridium sp.

Palaeohystrichophora infusorioides Deflandre, 1935

Pervosphaeridium pseudhystrichodinium (Deflandre, 1937) Yun, 1981

Rhiptochorys veligera (Deflandre, 1937) Lejeune-Carpentier and Sarjeant, 1983 (Pl. **P5,** fig. 10)

Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854

Spiniferites sp.

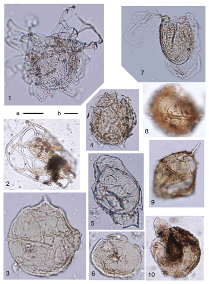
Trithyrodiniun suspectum (Manum and Cookson, 1964) Davey, 1969b (Pl. **P9,** fig. 3)

Trithyrodinium? sp. (Pl. **P8,** fig. 10)

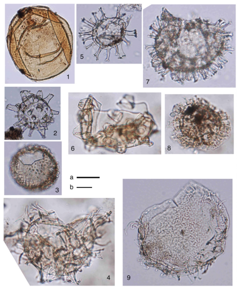
Xenascus sp.?

Indet. (Pl. **P8,** fig. 4)

P8. Dinoflagellate cysts, p. 38.



P9. Sporomorphs, p. 39.



Acritarchs

Nummus monoculatus Morgan, 1975 (Pl. P9, fig. 1)
Veryhachium sp.

Figure F1. Geography and bathymetry of the central Kerguelen Plateau showing Leg 199, 120, and 183 drill sites.

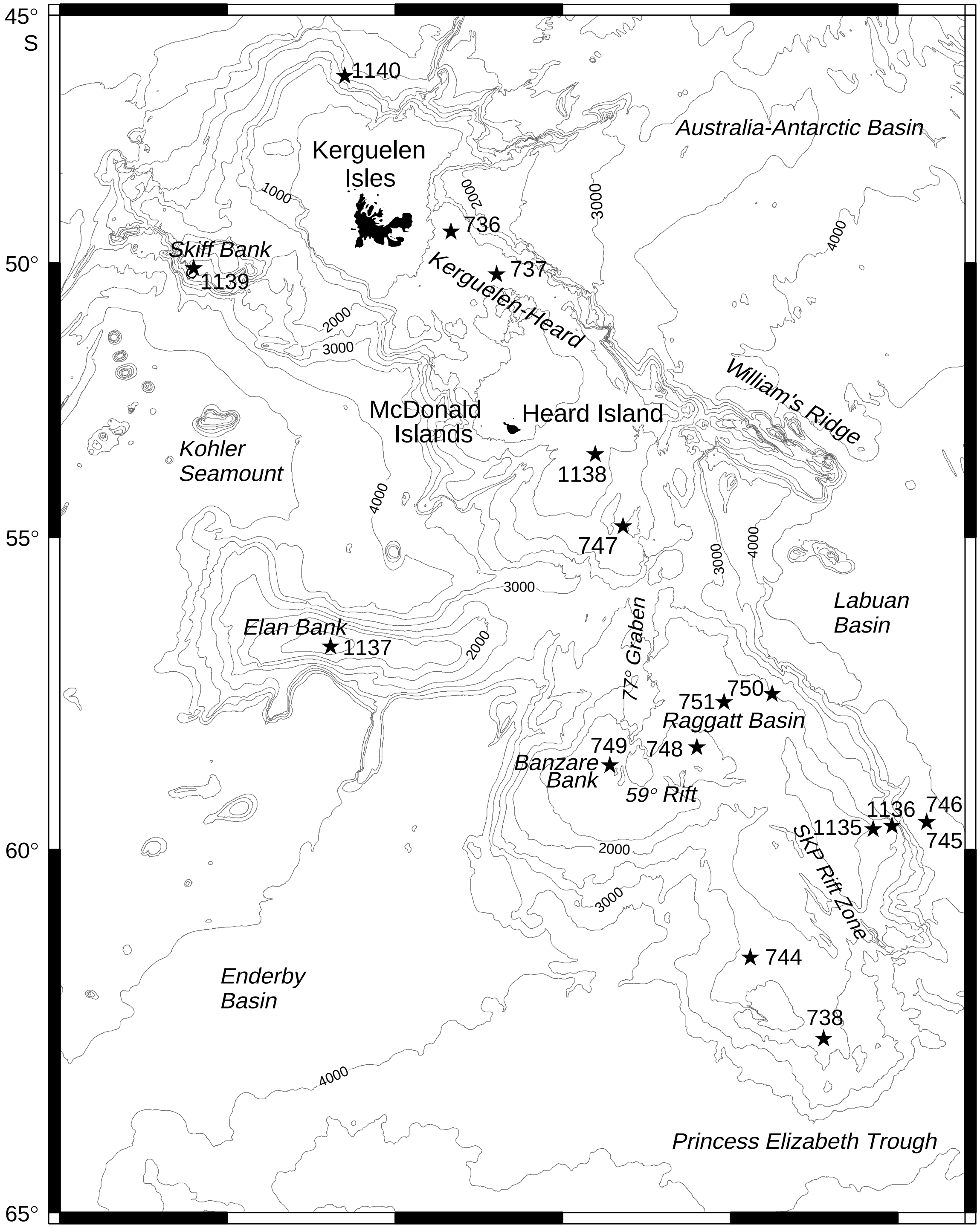


Figure F2. Composite stratigraphic section for Site 1138 showing core recovery, a simplified summary lithology, lithologic unit boundaries, ages of units, and names of lithologies.

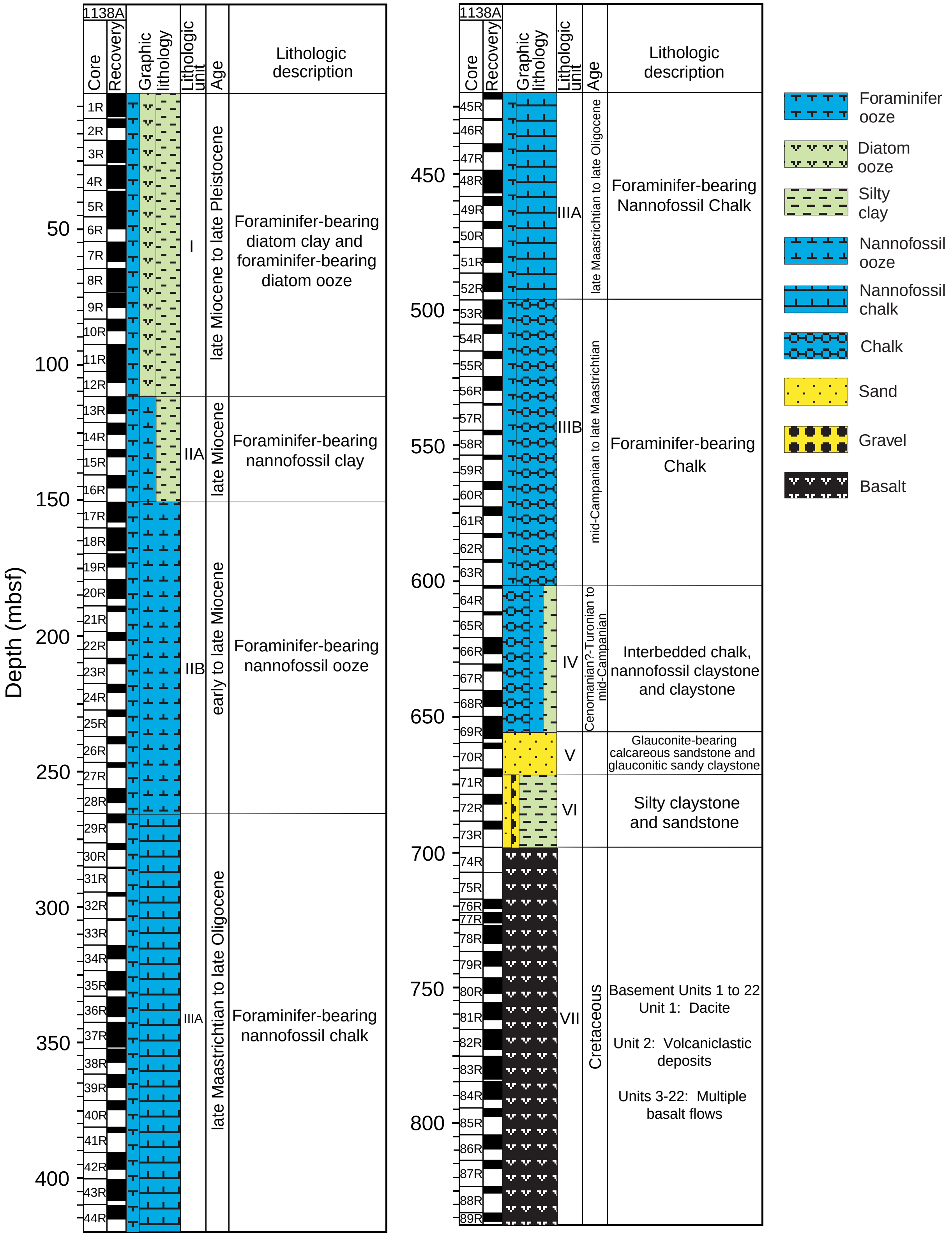


Figure F3. Quantitative analysis of the major sporomorph groups of Cores 183-1138A-71R-CC through 73R.

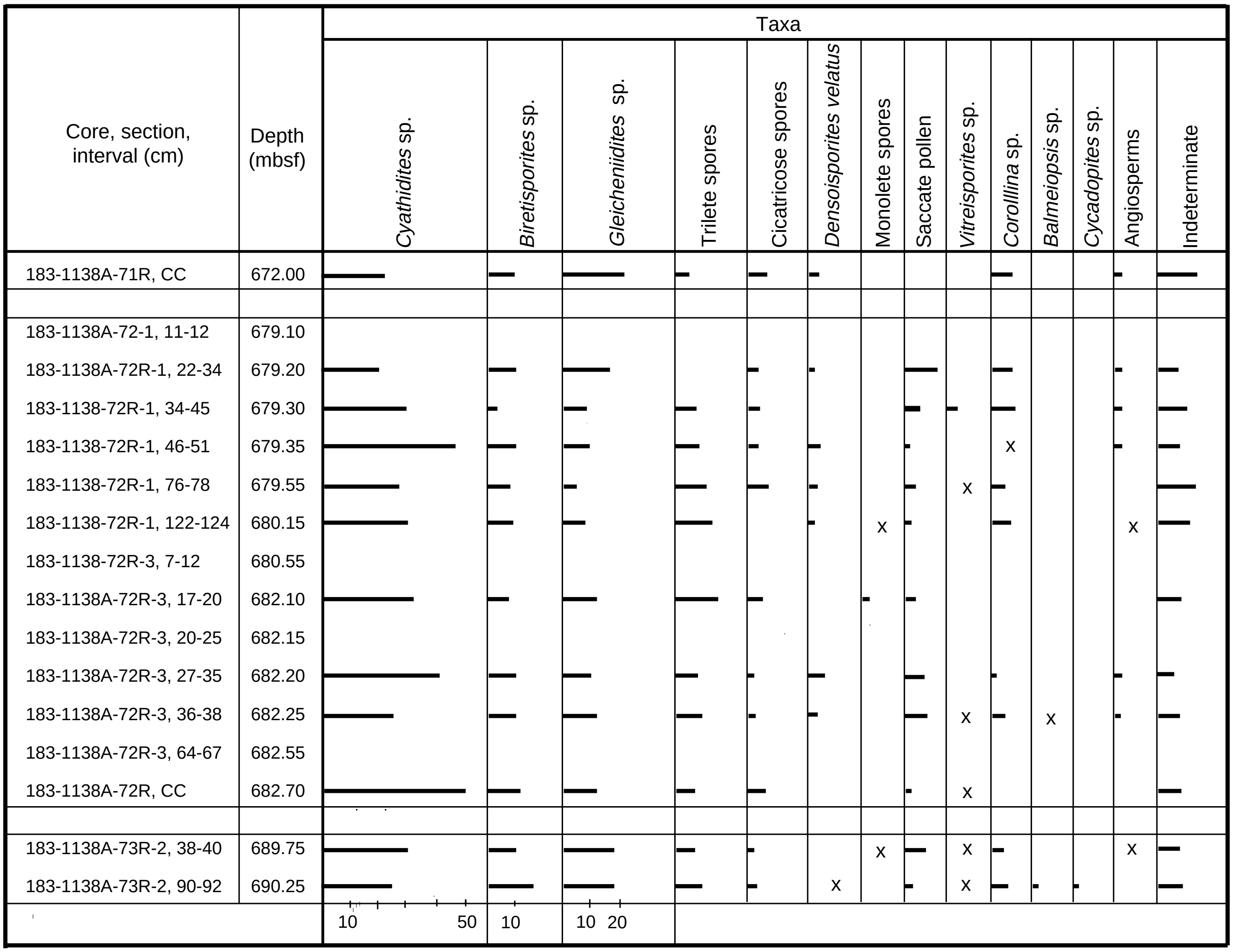


Figure F4. Occurrences of dinoflagellate cyst taxa in Cores 183-1138A-68R through 69R.

Age	Dinocyst Zonation		Depth (mbsf)	Core, section, interval (cm)	*Ascodinium parvum*	*Apteodinium* cf. *granulatum*	*Batiacasphaera asperata*	*Batiacasphaera* sp.	*Canninginopsis denticulata*	*Cassiculosphaeridia reticulata*	*Circulodinium attadalicum*	*Circulodinium membraniphorum*	*Chlamydophorella nyei*	*Conosphaeridium striatoconum*	*Cribroperidinium edwardsii*	*Cribroperidinium muderongense*	*Cyclonephelium compactum*	*Dingodinium cerviculum*	*Disphaeria macropyla*	*Exochosphaeridium longifilum*	*Exochosphaeridium* sp.	*Heterosphaeridium heteracanthum*	*Hystrichodinium pulchrum*	*Isabelidinium glabrum*	*Kleithriasphaeridoim tubulosum*	*Kleithriasphaeridium* sp.	*Litosphaeridium siphonophorum*	*Microdinium ornatum*	*Meiourogonyaulax*	*Odontochitina operculata*	*Oligosphaeridium* sp.	*Palaeohystrichophora infusorioides*	*Pervosphp. seudhystrichodinium*	*Spiniferites* sp.	*Xenascus* sp.	*Hapsocysta peridictya*
Coniacian	*Heterosphaeridium* Superzone	*C. stria.* Zone	631.25	1138A-67R-1, 53-55															barren																	
			633.30	1138A-67R-2, 118-120						x				x		x	x			x	x	x	x		x					x	x		x	x		
		Palaeohystrichophora infusorioides Zone	640.80	1138A-68R-1, 40-42						x	x																					x				
			641.60	138A-68-1, 119-120																		x														
Turonian			642.45	1138A-68R-2, 66-68							x						x					x						x								
			643.00	1138A-68R-2, 124-126			x	x		x					x	x	x		x			x				x	x	x		x	x			x		
			643.85	1138A-68R-3, 57-59											**x**		x					x								x						
			644.50	1138A-68R-3, 123-125		**x**				x		x	x	x	x		x				x	x		x					x	x	x	**x**		x	?	
			645.00	1138A-68R-4, 32-34															very few, poorly preserved specimens																	
			646.10	1138A-68R-5, 53-55																																
			650.50	1138A-69R-1, 48-50																										x						
			651.90	1138A-69R-2, 50-52			x			x					x	x															x					
			652.50	1138A-69R-2, 112-114						x											x							x		x						
			652.85	1138A-69R-3, 21-23			x			x														x		x	x					x		x		
			653.50	1138A-69R-3, 94-96						x					x																	x				
			653.50	1138A-69R-4, 51-53											x							x								x						
			654.60	1138A-69R-4, 127-129												x	x																			
			655.40	1138A-69R-5, 63-65						x						x	x																	x		
Ceno.			656.15	1138A-69R-5, 124-126	x					x		x			x	x	x				x				x								x			x
			656.75	1138A-69R-6, 50-52												x														x						

Figure F5. Occurrences of dinoflagellate cyst taxa in Core 183-1138A-67R.

Age	Dinocyst Zonation		Depth (mbsf)	Core, section, interval (cm)	Dinocysts																					Acri-tarchs
					Adnatosphaeridium filiferum	*Cannosphaeropsis peridictya*	*Cassiculosphaeridia reticulata*	*Chatangiella* cf. *tripartita*	*Chlamydophorella ambigua*	*Conosphaeridium abbreviatum*	*Conosphaeridium striatoconum*	*Cribroperidinium cooksoniae*	*Cribroperidinium muderongense*	*Cyclonephelium* cf. *compactum*	*Exochosphaeridium longifilum*	*Exochosphaeridium* sp.	*Florentinia cooksoniae*	*Glaphyrocysta* cf. *marlborouoghensis*	*Heterosphaeridium heteracanthum*	*Hexagonifera* cf. *glabra*	*Hystrichodinium pulchrum*	*Kleithriasphaeridium tubulosum*	*Odontochitina operculata*	*Pervosphaeridium pseudhistrichodinium*	*Trithyrodiniun suspectum*	*Nummus monoculatus*
Coniacian	*Heterosph.* S.Z.	*C. ambigua* Z.	631.25	1138A-67R-1, 53-55	barren																					
			632.62	1138A-67R-2, 46-48	barren																					
			633.30	1138A-67R-2, 118-120	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tur.			440.80	1138A-68R-1, 40-42	see Figure 4																					

Figure F6. Stratigraphic ranges of sporomorphs and dinoflagellate cysts from Cores 183-1138A-67R through 73R.

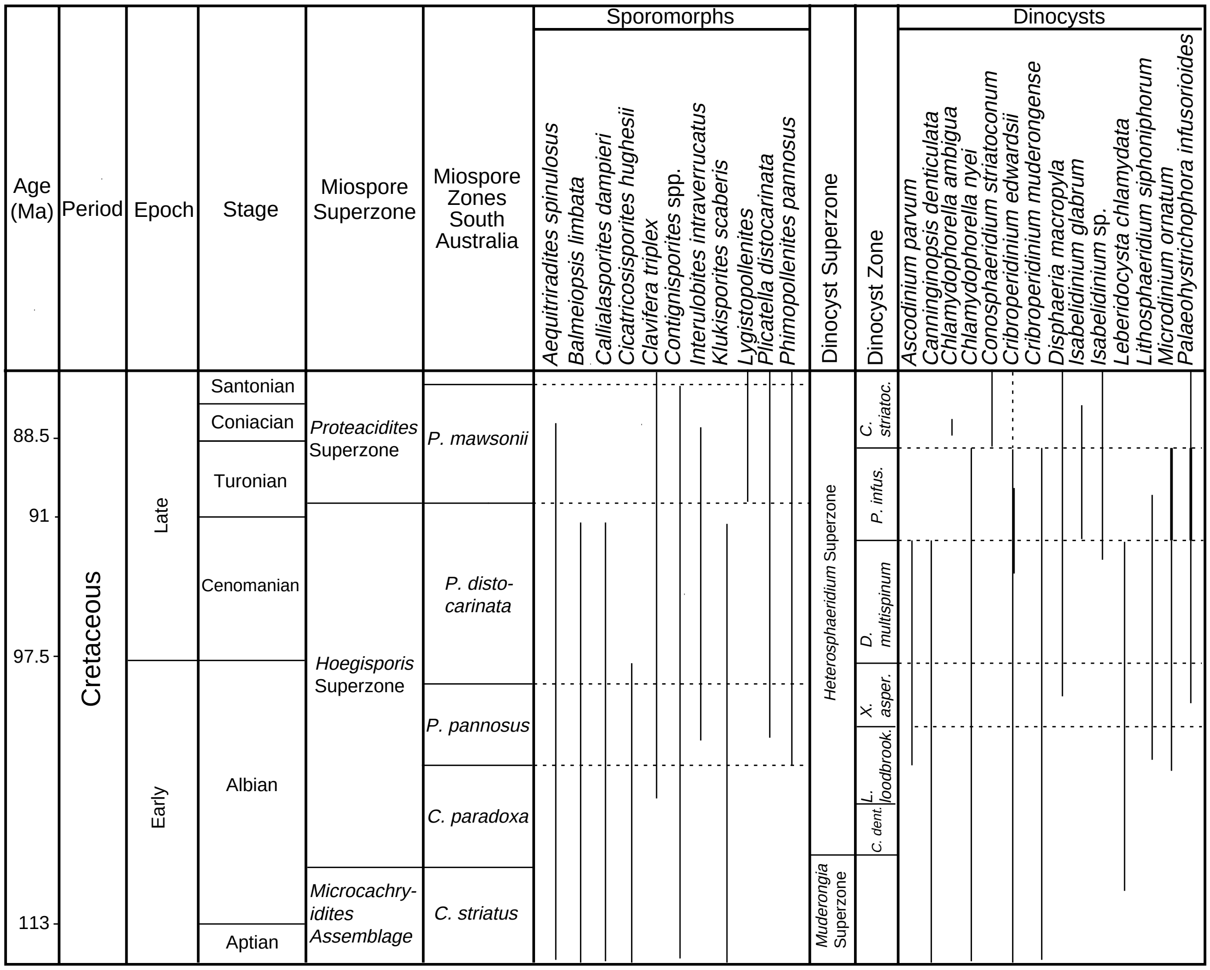
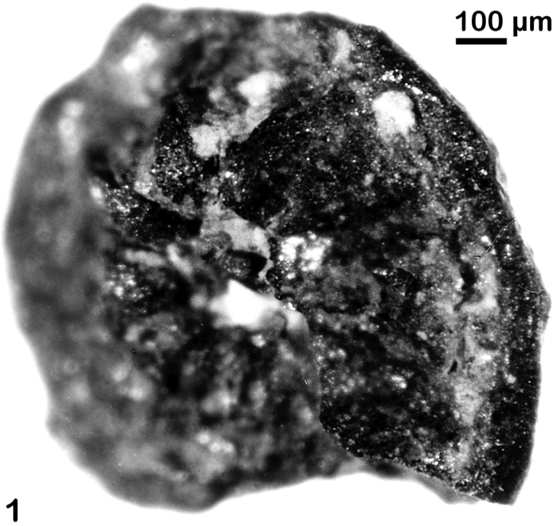


Table T1. Kerogen analysis and organic constituents of Cores 183-1138A-67R to 73R.

Lithologic unit	Core, section, interval (cm)	Depth (mbsf)	Mesofossils/Kerogen	Resin	Megaspores	Miospores	Dinocysts	Foram linings
	183-1138A-							
IV	67R-1, 53–55	631.25	No terrestrial remains			Barren	Barren	
	67R-2, 46–48	632.60	No terrestrial remains			Barren	Barren	
	67R-2, 118–120	633.30	No terrestrial remains			Barren	Present to frequent	x
	68R-1, 40–42	640.80	No terrestrial remains			Barren	Very rare	x
	68R-1,119–120	641.60	No terrestrial remains			Barren	Very rare	
	68R-2, 66–68	642.45	No terrestrial remains			Barren	Very rare	
	68R-2, 124–126	643.00	Rare highly altered small wood particles			Barren	Rare	
	68R-3, 57–59	643.85	Rare highly altered small wood particles			Present	Very rare	
	68R-3, 123–125	644.50	Rare highly altered small wood particles			Barren	Barren	x
	68R-4, 32–34	645.00	Rare highly altered small wood particles			Present	Frequent	
	68R-5, 53–55	646.10	Rare highly altered small wood particles			Barren	Very rare	
	69R-1, 48–50	650.50	Rare highly altered small wood particles			Barren	Barren	
	69R-2, 50–52	651.90	Rare highly altered small wood particles			Barren	Frequent	
	69R-2, 112–114	652.50	Rare highly altered small wood particles			Barren	Rare	
	69R-3, 21–23	652.85	Small altered wood particles			Present	Rare, fragmented	
	69R-3, 94–96	653.50	Altered wood fragments			Barren	Barren	
	69R-4, 51–53	654.60	Altered wood fragments			Barren	Rare	
	69R-4, 127–129	655.40	Altered wood fragments			Present	Abundant	
	69R-5, 63–65	656.15	Altered wood fragments			Present	Frequent	
IV	69R-5, 124–126	656.75	Altered wood fragments			Barren	Rare to frequent	
V	69R-6, 50–52	657.60	Altered and extremely fragmented wood particles			Barren	Rare	
V	113A-70R		No samples					
VI	71R-2, 146–150	671.50	Wood fragments			Present	Very rare?	
	71R, CC	672.00	Fern leaves, sporangia, seeds, cuticles, wood		Selaginella?	Frequent	Very rare	
	72R-1, 11–12	679.10	Wood and cuticles, very fragmented			Present	Very Rare	
	72R-1, 22–34	679.20	Fern leaves, sporangia, seeds, cuticles, wood	Abundant		Frequent	Rare	x
	72R-1, 34–45	679.30	Fern leaves, sporangia, seeds?, cuticles, wood			Frequent	Very rare	
	72R-1, 46–50	679.35	Sporangia, seeds?, cuticles	Common		Abundant	Present	x
	72R-1, 76–78	679.55	Fern leaves, sporangia, seeds, cuticles,	Rare		Frequent	Barren	
	72R-1, 89–90	679.80	Fern leaves, sporangia, cuticles, seeds, wood					
	72R-1, 122–124	680.15	Fern leaves, sporangia, seeds, cuticles, wood	Common	X?	Common	Barren	
	72R-2, 7–12	680.55	Wood and cuticle fragments			Present	Barren	
	72R-3, 13–17	682.05	Wood and cuticle fragments			Present to frequent	Barren	
	72R-3, 17–20	682.10	Fern leaves, sporangia, seeds, cuticles, wood	Abundant		Present	Barren	
	72R-3, 20–25	682.15	Fern leaves, seeds, wood	Abundant		Present	Barren	
	72R-3, 27–32	682.20	Fern leaves, sporangia, seeds, wood			Frequent	Barren	
	72R-3, 35–37	682.25	Fern leaves, sporangia, cuticles, wood	Rare		Abundant	Present	x
	72R-3, 64–67	682.55	Fern leaves, sporangia, seeds, cuticles	Common		Frequent	Barren	
	72R, CC	682.70	Fern and conifer? leaves, cuticles, seeds, wood		X?	Frequent to common	Barren	
	73R-2, 38–40	689.75	Small wood and cuticle fragments			Abundant	Barren	
	73R-2, 90–92	690.25	Small wood and cuticle fragments			Abundant	Barren	
	73R-3, 36–38	690.70	Wood and cuticle fragments			Common	Barren	

Plate P1. Fern remains from Cores 183-1138A-71R and 72R. Scale bars = 100 µm. **1.** "Fiddle head," enrolled tip of a young fern frond. **2.** Part of a fern frond. **3.** Single fern leaflet. **4.** Sporangium. **5.** Fern leaflet surface structure (SEM; scale bar = 10 µm). **6.** Fern leaflet epidermis with stomata (SEM; scale bar = 10 µm).



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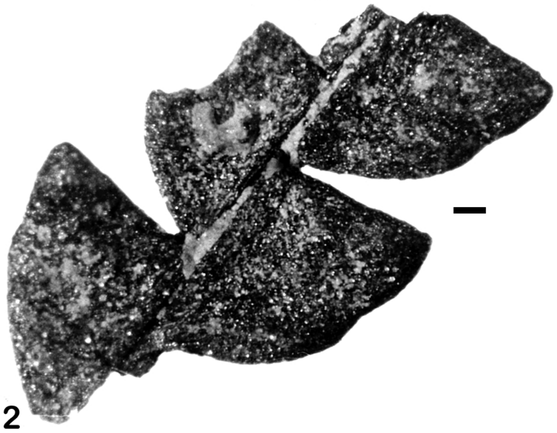

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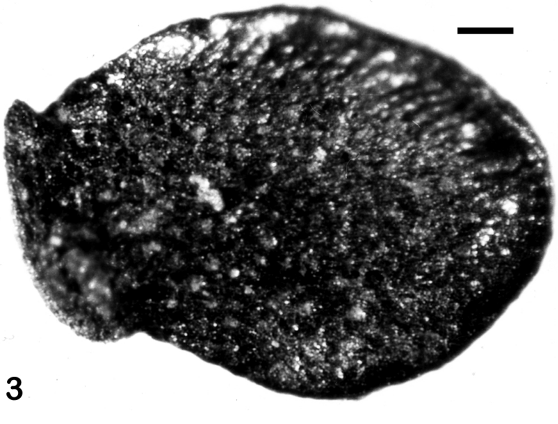

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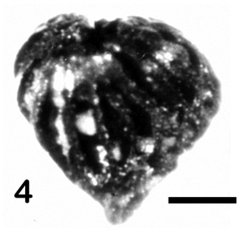

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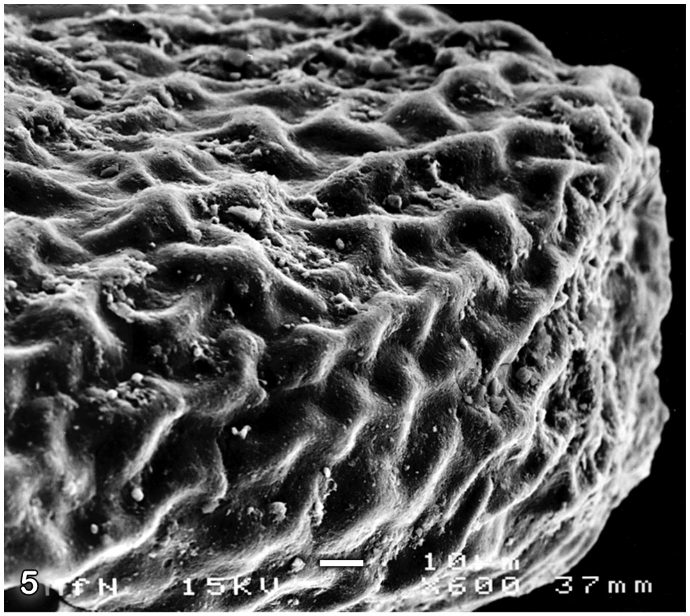


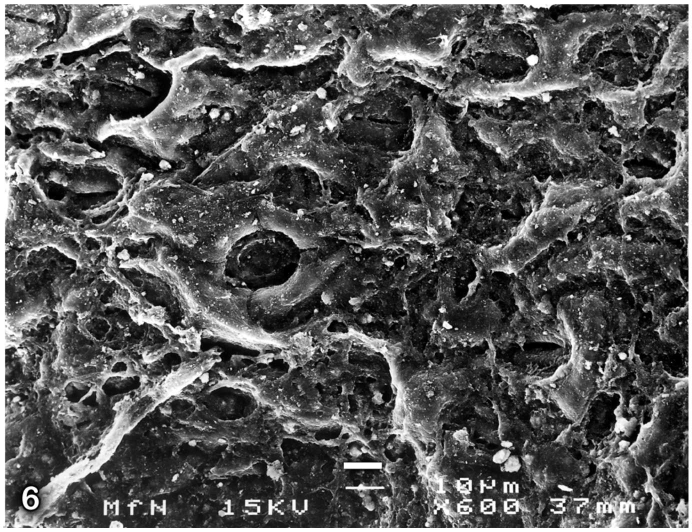


Plate P2. Conifer remains and axes from Cores 183-1138A-71R and 72R. Scale bars = 100 µm. **1**, **2.** Conifer seeds. **3.** Part of a conifer twig with scalelike leaves, perhaps *Microcachrys*? **4.** Piece of wood (SEM). **5**, **6.** Piece of an axis, transverse view (SEM) (5) Scale bar = 100 µm; (6) scale bar = 10 µm.

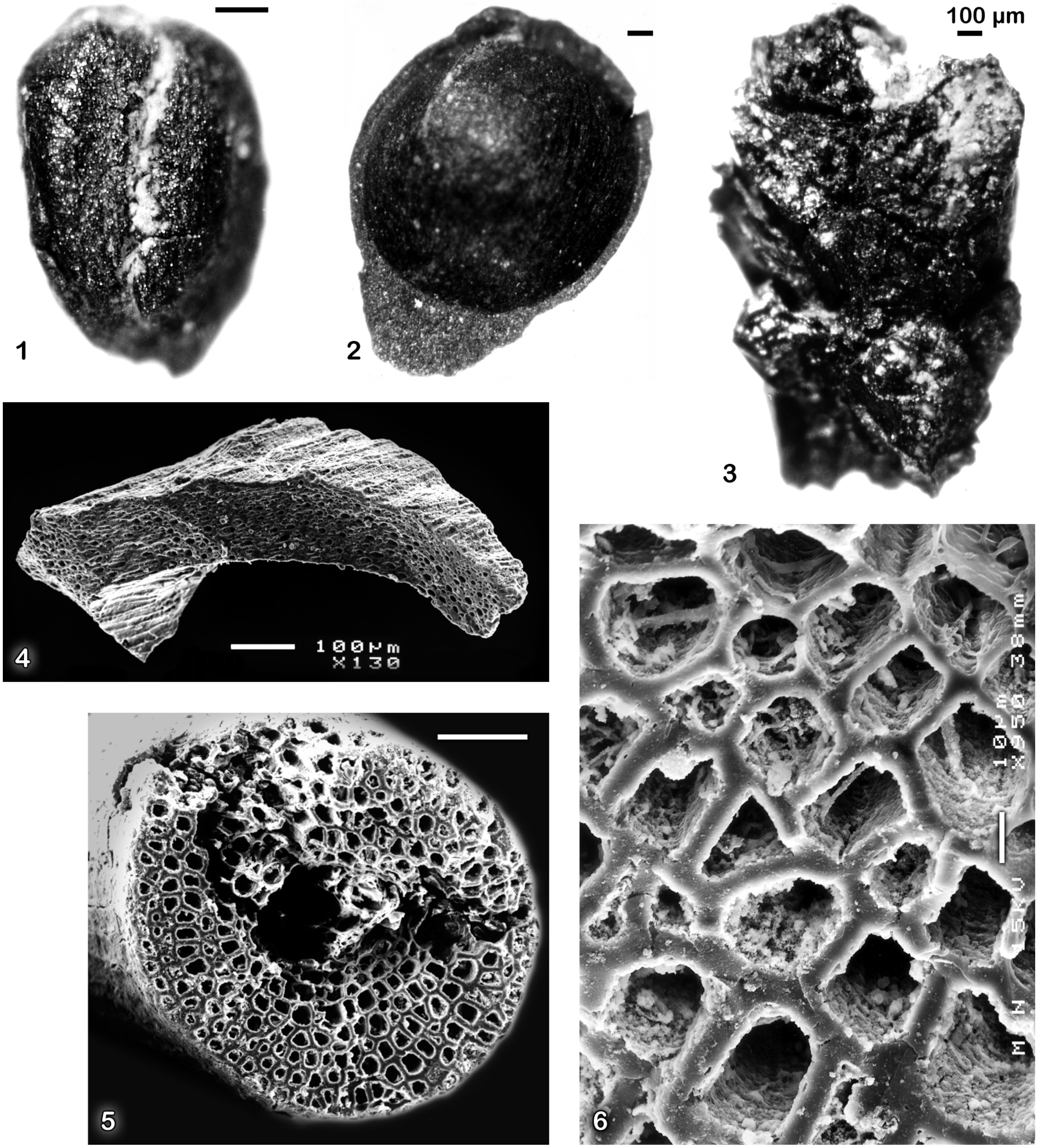


Plate P3. Dinoflagellate cysts and spores from lithologic Units IV and VI, Hole 1138A. **1, 7.** Sample 183-1138A-68R-2, 124–126 cm. (1) *Apteodinium* cf. *granulatum* Eisenack, 1958 (scale bar = 20 µm) (slide 2). (7) *Odontochitina operculata* (Wetzel, 1933) Deflandre and Cookson, 1955 (scale bar = 25 µm) (slide 2). **2.** *Balmeisporites* cf. *holodictyus* Cookson and Dettmann, 1958 (Sample 183-1138A-72R-1, 122–124 cm) (scale bar = 20 µm) (slide 16). **3, 4.** *Aratrisporites* sp. (Sample 183-1138R-73R-3, 36–38 cm) (scale bar = 10 µm). (3) Slide 6. (4) Slide 7. **5, 6.** Sample 183-1138A-68R-3, 123–127 cm (scale bar = 20 µm). (5) *Isabelidinium glabrum* (Cookson and Eisenack, 1969) Lentin and Williams, 1977 (slide 1). (6) *Cyclonephelium compactum* Deflandre and Cookson, 1955 (slide 10).

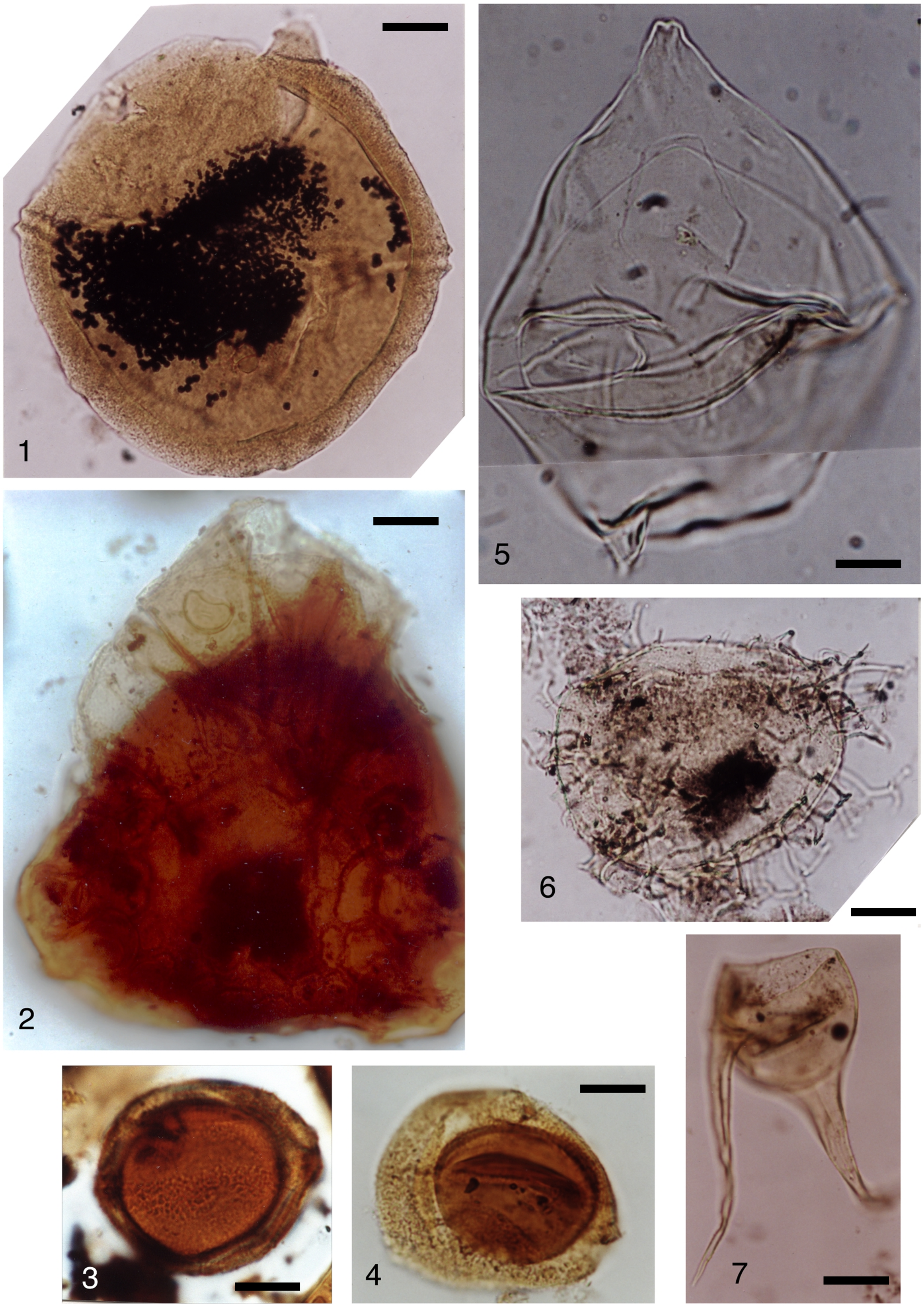


Plate P4. Sporomorphs from lithologic Unit VI, Hole 1138A. Scale bar = 10 µm. **1.** *Callialasporites dampieri* (Balme, 1957) Sukh Dev, 1961 (Sample 183-1138A-72R-3, 64–67 cm) (slide 2). **2, 6, 9.** Sample 183-1138A-73R-2, 36–38 cm. (2) *Ruffordiaspora australiensis* (Cookson, 1953) Dettmann and Clifford, 1992 (slide 2). (6) *Trilites kopukuensis* Couper, 1960 (slide 1). (9) *Balmeiopsis limbata* (Balme, 1957) Archangelsky, 1979 (slide 7). **3–5, 8, 10, 11.** Sample 183-1138A-73R-2, 38–40 cm. (3) *Clavatipollenites hughesii* Couper, 1958, Type A (slide 2). (4) *Cupuliferoidaepollenites* sp. (slide 2). (5) Massula of *Microcachryidites antarcticus* Cookson, 1947 (slide 2). (8) *Phimopollenites pannosus* (Dettmann and Playford, 1968) Dettmann, 1973 (slide 2). (10) *Microcachryidites* sp. (slide 2). (11) *Vitreisporites pallidus* (Reissinger, 1950) Nilsson, 1958 (slide 5). **7.** *Tricolpites* sp. (Sample 183-1138A-73R-2, 90–92 cm) (slide 2).

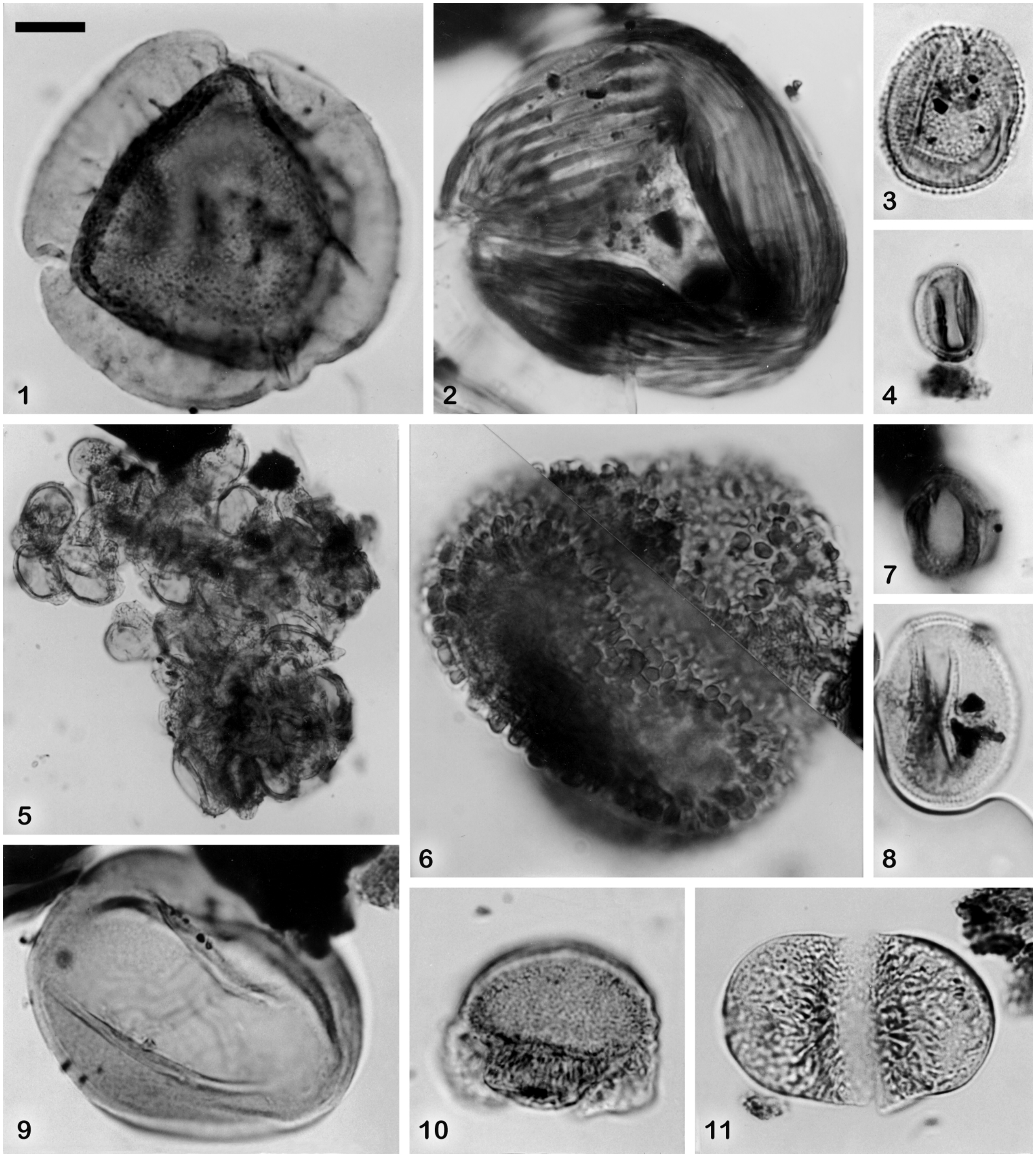


Plate P5. Sporomorphs from lithologic Units IV and VI, Hole 1138A. Scale bar = 10 µm. **1.** *Cyclusphaera radiata* Archangelsky, 1983 (Sample 183-1138A-73R-2, 90–92 cm) (slide 2). **2, 3.** *Phimopollenites augathellaensis* (Burger, 1970) Dettmann, 1973 (Sample 183-1138A-72R-1, 46–51 cm) (slide 1). **4, 6–8.** Sample 183-1138A-73R-3, 36–38 cm. (4) *Lygistepollenites florinii* (Cookson and Pike, 1953) Stover and Evans, 1973 (slide 1). (6, 7) *Senectotriradites*? sp. (slide 2). (8) *Afropollis*? sp. (slide 5). **5.** *Clavatipollenites hughesii* Couper 1958, Type B (Sample 183-1138A-73R-2, 38–40 cm) (slide 2). **9.** *Chlamydophorella nyei* Cookson and Eisenack, 1958 (Sample 183-1138A-68R-1, 40–42 cm) (slide 1). **10.** *Rhiptochorys veligera* (Deflandre, 1937) Lejeune-Carpentier and Sarjeant, 1983 (Sample 183-1138A-68R-2, 124–126 cm) (slide 2).

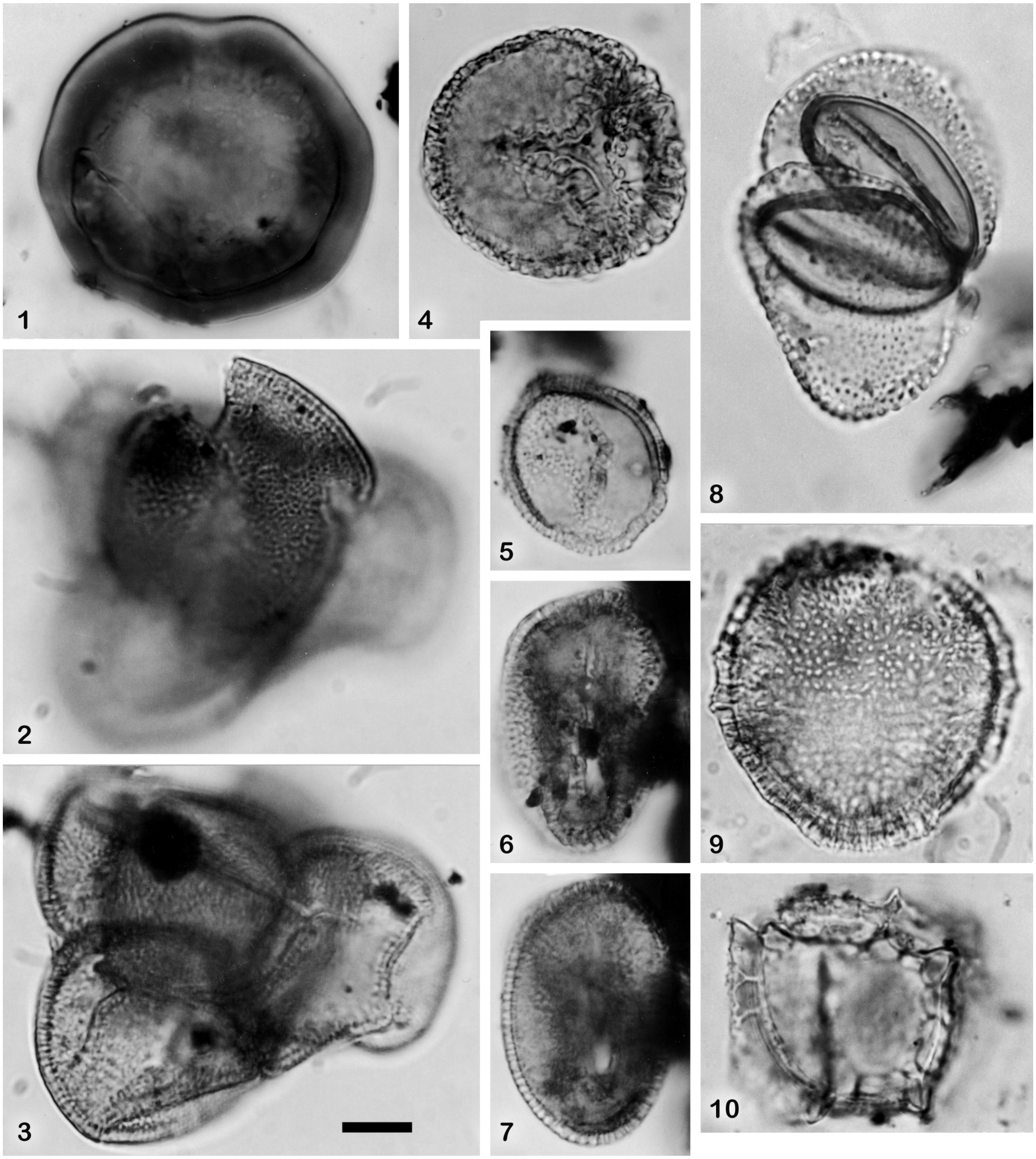


Plate P6. Sporomorphs from lithologic Unit VI, Hole 1138A. Scale bars = 10 µm. **1, 2, 4, 6–11.** Sample 183-1138A-73R-3, 36–38 cm. (1) *Aequitriradites spinulosus* (Cookson and Dettmann, 1958) Dettmann 1963 (slide 1). (2) *Sestrosporites pseudoalveolatus* (Couper, 1958) Dettmann, 1963 (slide 1) (4) *Polypodiidites horridus,* Backhouse, 1988 (slide 1). (6) *Ceratosporites equalis* Cookson and Dettmann, 1958 (slide 3). (7) *Undulatisporites* sp. (slide 3). (8) *Perinomonoletes* sp. A (slide 2). (9) *Cicatricosisporites hughesii* Dettmann, 1963 (slide 4). (10) *Verrucosisporites rarus* Burger, 1966 (slide 4). (11) *Perinomonoletes* sp. B (slide 2). **3.** *Microfoveolatosporis fromensis* (Cookson and Dettmann, 1957) (Sample 183-1138A-72R-3, 7–12 cm) (slide 5). **5.** *Gleicheniidites cercinidites* (Cookson, 1953) Dettmann, 1963 (Sample 183-1138A-73R-2, 38–40 cm) (slide 2).

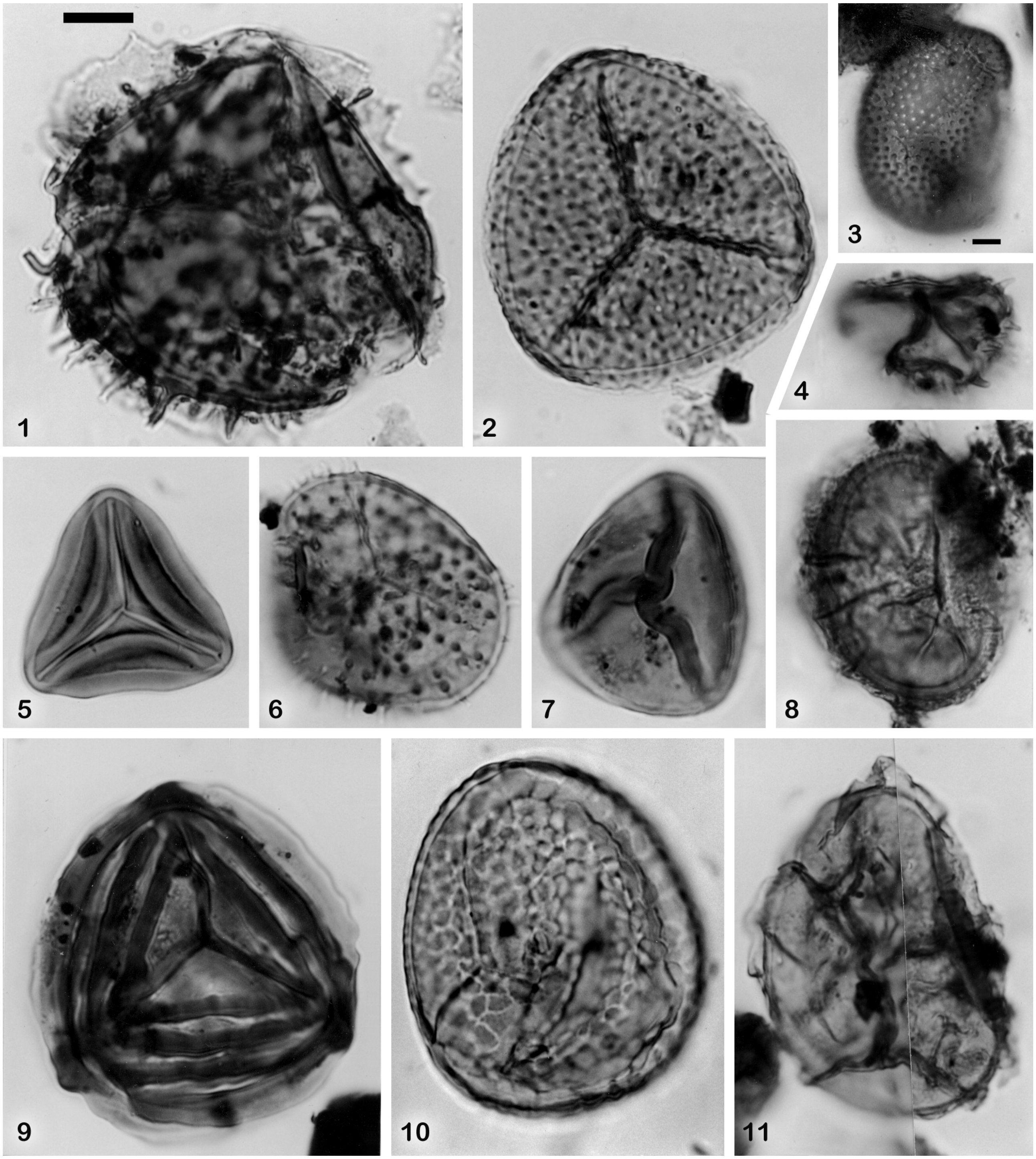
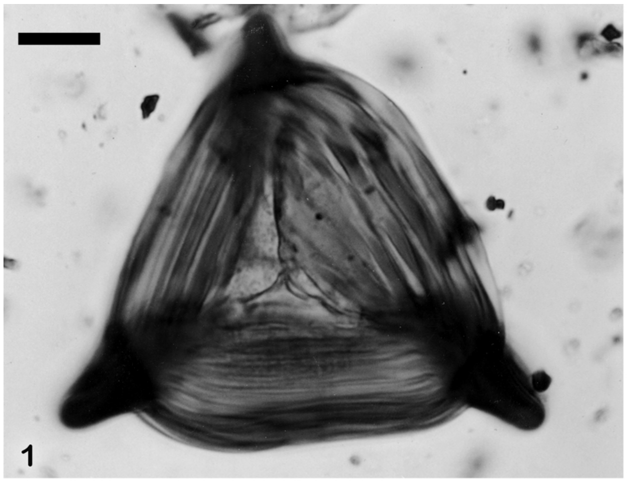


Plate P7. Sporomorphs from lithologic Unit VI, Hole 1138A. Scale bar = 10 µm. **1, 2.** *Appendicisporites auritus* Agasie, 1969. (1) Sample 183-1138A-73R-2, 90–92 cm (slide 1). (2) Sample 183-1138A-72R-CC (slide 2). **3.** *Biretisporites eneabbaensis* Backhouse, 1988 (Sample 183-1138A-72R-3, 27–32 cm) (slide 6). **4, 6, 8.** Sample 183-1138A-73R-3, 36–38 cm. (4) *Antulsporites* sp. (slide 3). (6) *Densoisporites velatus* Weyland and Krieger, 1953 (slide 1). (8) *Punctatosporites scabratus* (Couper, 1953) Singh, 1971 (slide 2). **5.** *Cibotiumspora juriensis* (Balme, 1957) Filatoff, 1975 (Sample 183-1138A-72R-3, 13–17 cm) (slide 2). **7.** *Clavifera triplex* (Bolkhovitina, 1953) Bolkhovitina, 1966 (Sample 183-1138A-73R-2, 38–40 cm) (slide 1).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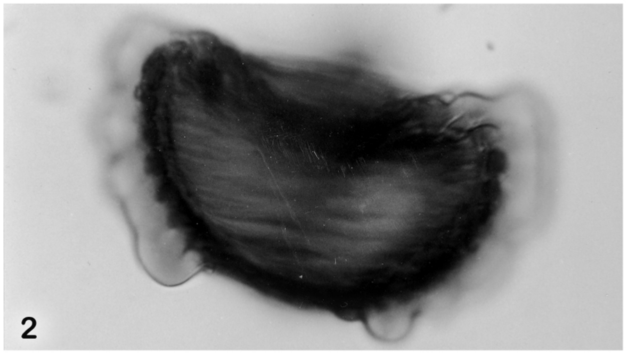
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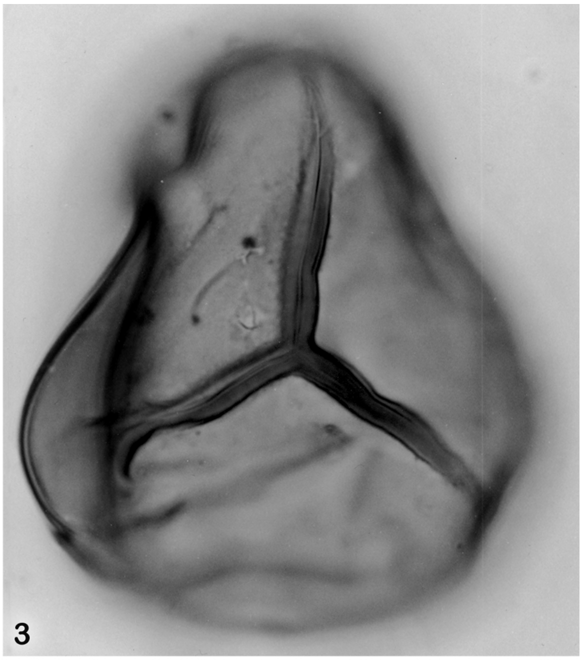
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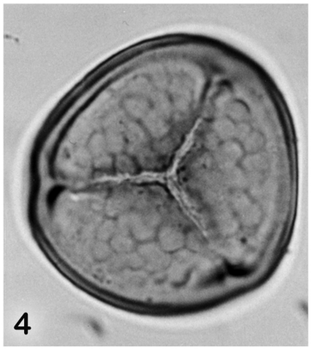
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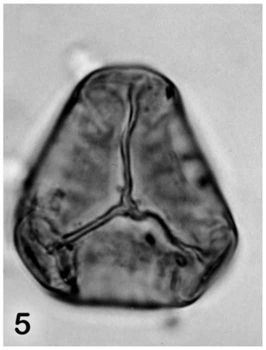
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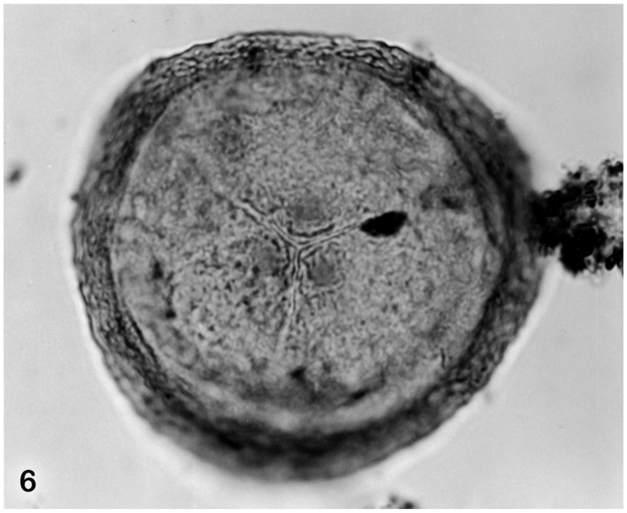
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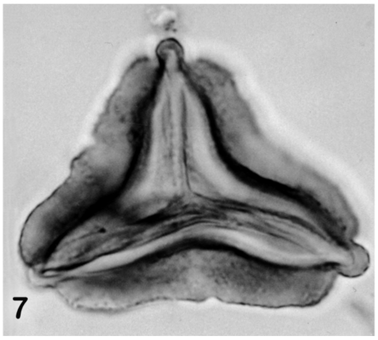
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Plate P8. Dinoflagellate cysts from lithologic Unit IV, Hole 1138A. Scale bars = 20 µm. **1, 3–10.** Sample 183-1138A-67R-2, 118–120 cm (smear slide). (1) *Adnatosphaeridium filiferum* (Cookson and Eisenack, 1958) Williams and Downie, 1968 (scale bar a). (3, 6) *Cribroperidinium cooksoniae* Norwick, 1976 (scale bar b). (4) Indeterminate (scale bar b). (5) *Chatangiella* cf. *tripartita* (Cookson and Eisenack, 1960a) Lentin and Williams, 1976 (scale bar b). (7) *Hexagonifera* cf. *glabra* Cookson and Eisenack, 1961a (scale bar a). (8, 9) *Cribroperidinium muderongense* (Cookson and Eisenack, 1958) Davey, 1969 (scale bar b). (10) *Trithyrodinium*? sp. (scale bar b). **2.** *Hapsocysta peridictya* (Eisenack and Cookson, 1960) Stover and Evitt, 1978 (Sample 183-1138A-69R-5, 124–125 cm) (scale bar a) (smear slide).

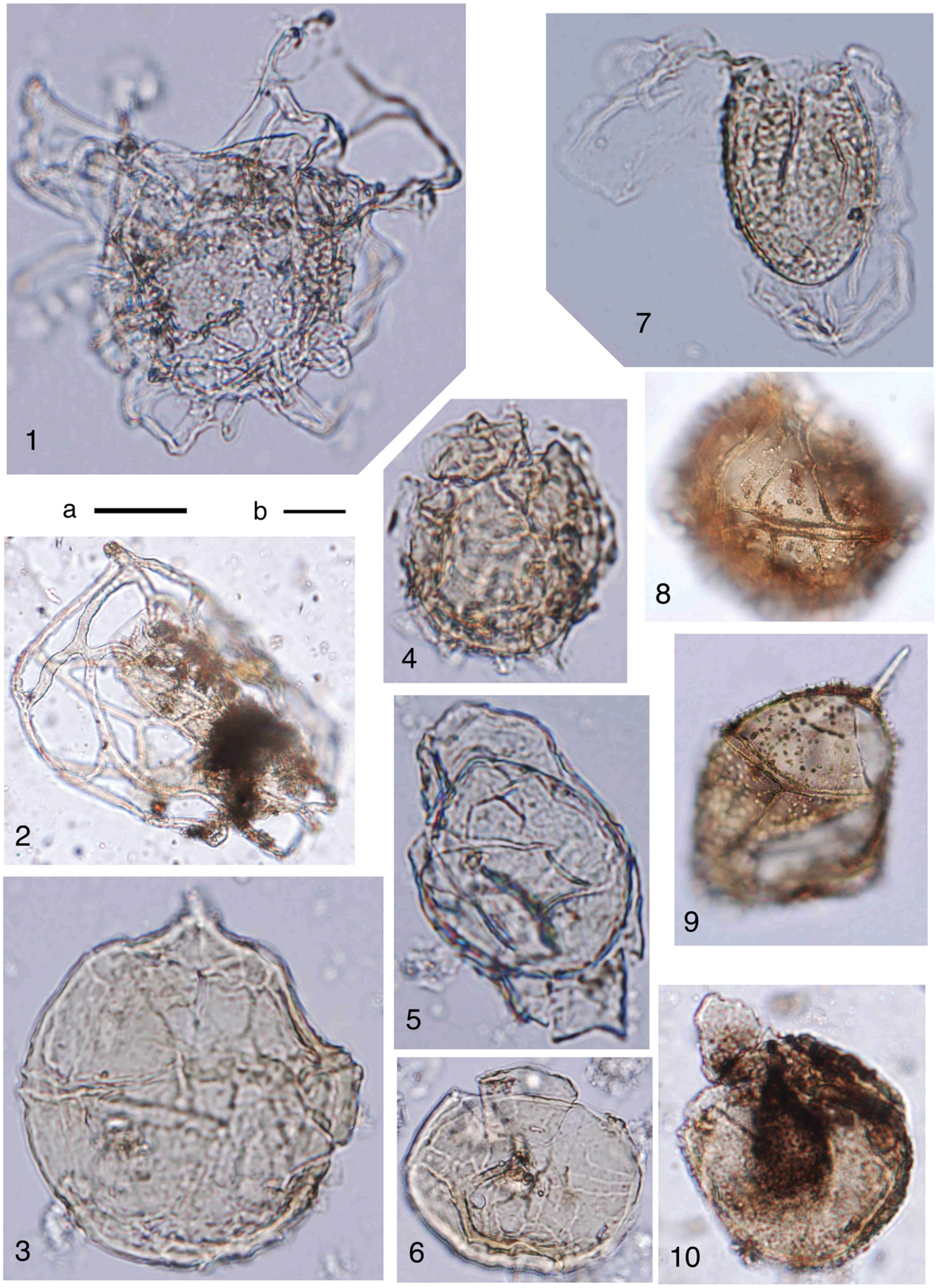

Plate P9. Sporomorphs from smear slides from Sample 183-1138A-67R-2, 119–120 cm. Scale bars = 20 µm. **1.** *Nummus monoculatus* Morgan, 1975 (scale bar a). **2.** *Kleithriasphaeridium tubulosum* (Cookson and Eisenack, 1969) Stover and Evitt, 1978 (scale bar b). **3.** *Trithyrodinium suspectum* (Manum and Cookson, 1964) Davey, 1969b (scale bar a). **4.** *Exochosphaeridium bifidum* (Clarke and Verdier, 1967) Clarke et al., 1968 (scale bar a). **5.** *Florentinia cooksoniae* (Singh, 1971) Duxbury, 1980 (scale bar b). **6.** *Conosphaeridium abbreviatum* (Wilson, 1984c) (scale bar b). **7.** *Cyclonephelium* cf. *compactum* Deflandre and Cookson, 1955 (scale bar a) **8.** *Chlamydophorella ambigua* (Deflandre, 1937) Stover and Helby, 1987 (scale bar a). **9.** *Glaphyrocysta* cf. *marlboroughensis* Schiøler and Wilson, 1998 (scale bar a).