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# 25. PALYNOSTRATIGRAPHY, PALYNOFACIES, AND THERMAL MATURATION OF CRETACEOUS–PALEOCENE SEDIMENTS FROM THE CÔTE D'IVOIRE-GHANA TRANSFORM MARGIN[1]

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## ABSTRACT

Cretaceous to Paleocene sediments from Ocean Drilling Program Sites 959 to 962 in the Côte d'Ivoire-Ghana Transform Margin yield a rich assemblage of dinoflagellate cysts, few acritarchs, spores and pollen, and 12 types of dispersed organic matter. Dinoflagellate cysts proved invaluable in the refinement of shipboard-generated age determinations for Turonian to Paleocene sediments and identification of the Cretaceous/Paleocene boundary at Site 959. A few spore and pollen taxa are of stratigraphic significance. All but two samples of the tectonized basal siliciclastic sediments are barren of dinoflagellate cysts at Sites 959 and 960, but a few samples yield a very low diversity assemblage of spores and pollen. Palynofacies analysis indicates that amorphous organic matter is the dominant organic component in the sediments. However, the tectonized siliciclastic sedments are richer in identifiable terrestrially derived components (wood, black debris, and cuticles) or amorphous organic matter of terrestrial origin. Samples immediately below post-Albian unconformity surfaces at Sites 959 to 961 are enriched in wood and black debris. Thermal alteration indices (TAI) were derived from semiquantitative assessment of spore and pollen colors and used to interpret the thermal maturation of the sediments. TAI values indicate (1) a mature to overmature stage (values >2.5, occasionally dark) for the tectonized basal siliciclastic sediments at all four sites; (2) a moderately mature stage (2–2.5) for some Upper Cretaceous sediments at Sites 959, 960, and 962; and (3) an immature stage (<2) for the rest of the stratigraphic section. The most mature sediments were deposited during the syntransform phase of basin evolution.

## INTRODUCTION

During Leg 159, Sites 959 through 962 (Fig. 1) were drilled along the transform passive margin of Côte d'Ivoire-Ghana (CIG). These sites reveal a sedimentary sequence that included Cretaceous to Pliocene strata and helped to obtain stratigraphic and structural information on the area. The data obtained helped to interpret the tectonic and sedimentary processes involved in the creation of the transform margin and its geologic evolution. Additionally, this data helped to recognize the paleoceanographic history of the area (Mascle, Lohmann, Clift, et al., 1996). Site 959 is situated on the flanks of the Deep Ivorian Basin and drilled the most complete stratigraphic record from Albian to Pleistocene sediments. Sites 960, 961, and 962 are located closer to the CIG Marginal Ridge, which is a fossil ridge that connects laterally with the extinct Romanche Fracture Zone (Fail et al., 1970). The stratigraphic sequences drilled in these three sites are marked by hiatuses and condensed sections.

The sedimentation history of the transform margin has been summarized by the Shipboard Scientific Party (1996a). The sedimentary sequences drilled were divided into five lithologic units each at Sites 959 and 960, and three each at Sites 961 and 962 (Shipboard Scientific Party, 1996b–1996e; see Figs. 4–7 for Cretaceous–Paleocene lithologic units, this paper).

This paper focuses on the palynology of Cretaceous to Paleocene sediments at Sites 959 to 962. Our main objectives are to present the identification of the marine and terrestrial palynomorphs contained in the sediments drilled, and a biostratigraphic subdivision of these sediments, based mainly on their content of dinoflagellate cysts. We also present our interpretation of the origin and depositional environments of the sequences drilled, based on the dispersed organic matter in the sediments, and present a thermal maturation analysis, based on the sporomorph thermal maturation index.

## METHODS

Eighty-six samples were processed from Holes 959D (33 samples), 960A (23), 961A (11), 961B (eight), 962B (four), and 962D (seven). Each sample was macerated and dissolved with HCl and HF before the organic matter fraction was separated in heavy liquid (Faegri and Iversen, 1989). Residues used for palynomorph identification were oxidized, sieved, and stained red with safranin. One slide per sample was scanned with transmitted light microscope for dinoflagellate cysts, acritarchs, spores, and pollen; and the abundance of each taxon observed was recorded. At least 300 specimens were counted in samples with very good recovery of dinoflagellate cysts. Several samples were barren of dinoflagellate cysts, whereas spores and pollen were generally rare. Selected palynomorph taxa, in particular those with biostratigraphical value and good preservation, are illustrated in Plates 1 through 10.

Residues used for identification of dispersed organic matter (palynodebris) were not oxidized or sieved because the colors of the organic components were used for identification purposes. This also ensured that amorphous organic matter (AOM) was not removed through sieving. Three hundred particles of palynodebris (each with a minimum size of 5 µm) were counted per slide. Fluorescence light microscopy was used to differentiate between marine-derived and terrestrially derived AOM since the former tends to fluoresce (Lorente, 1990). However, the results obtained are considered as tentative because highly degraded, liptinite-rich terrestrial organic matter types also have a tendency to fluoresce (T. Wagner, pers. comm., 1995). Twelve types of organic matter were identified, using a modified version of the classification system of Jaramillo (1995). They are AOM, marine palynomorphs, terrestrial algae, resins, black debris, yellow-brown fragments, black-brown fragments, cuticles, plant tissue, wood, sporomorphs (spores and pollen), and fungi (Pl. 11, Figs. 1–12). These organic matter types are described in Oboh-Ikuenobe et al. (1997). Details of how thermal maturation indices were derived from colors of spores and pollen can also be found in Oboh-Ikuenobe et al. (1997). Average linkage cluster analysis (Q- and R-mode, SYSTAT, 1990–92) was used to interpret the relative abundances of the organic matter components. Cluster analysis was performed on a data matrix of Euclidean correlation coefficients. Al-

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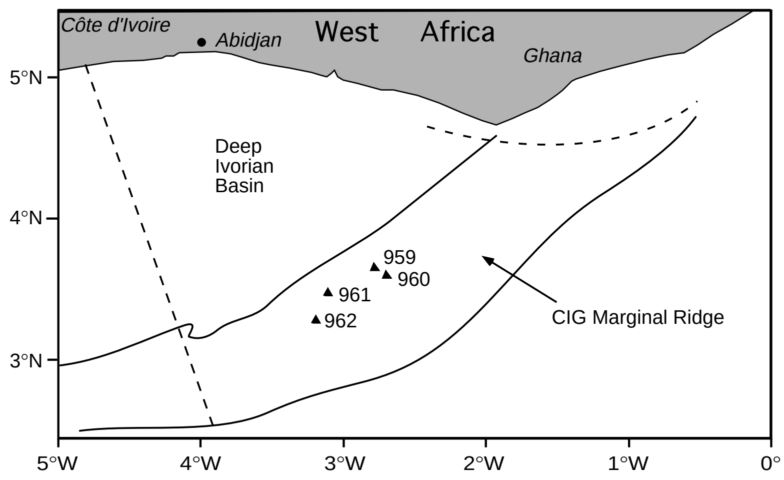


Figure 1. Locations of Sites 959 through 962 in the Côte d'Ivoire-Ghana (CIG) Transform Margin.

though statistical analysis was performed on data from Cretaceous to Pleistocene samples, only data for the Cretaceous to Paleocene will be discussed in this paper.

## BIOSTRATIGRAPHY

The biostratigraphic interpretations presented for each site are based largely on the dinoflagellate cysts identified in the samples. A total of 152 taxa of dinoflagellate cysts, 10 species of acritarchs, and three species of chlorophytes have been identified at the four sites (see Appendix A). Additionally, 47 sporomorph taxa, 24 of which are illustrated in Plate 10 (Appendix B), are integrated with dinoflagellate cysts for interpretation. Since most of the marine taxa were recovered from Hole 959D (Fig. 2; Pls. 1–9), the discussion of Site 959 is more detailed and organized in ascending chronological order. By contrast, only general biostratigraphic interpretations are made for Sites 960 to 962 on the basis of the sparse occurrences of dinoflagellate cysts.

The Upper Cretaceous from low-latitude areas lack detailed, reliable and globally accepted dinoflagellate cyst zones. For that reason, age determinations in this study are based on comparison with dinoflagellate cyst assemblages described from different Turonian to Danian sections around the world (the oldest sample dated by dinoflagellate cysts in our study was Turonian). The stratigraphic ranges used here for selected dinoflagellate taxa (Fig. 3) are those reported in Williams and Bujak (1985), Helby et al. (1987), and Williams et al. (1993).

### Site 959

Thirty-three samples from Cretaceous to Paleocene sediments in Hole 959D were analyzed (Table 1). Samples from the interval from 1094.26 to 1157.4 m below seafloor (mbsf; 159-959D-72R-3, 6–11 cm, through 78R-6, 70–73 cm) are barren of palynomorphs. These samples were obtained from tectonized siliciclastic sediments of lithologic Unit V, which represents a mature to overmature thermal stage (see "Thermal Maturation Analysis" section). This unit is also barren of planktonic foraminifers and calcareous nannofossils (Shipboard Scientific Party, 1996b). Late Turonian to Danian samples (159-959D-68R-1, 16–19 cm, through 46R-1, 7–12 cm) from lithologic Units III and IV at Hole 959D yield rich assemblages of dinoflagellate cysts (illustrated in Plates 1–9). These lithologic units are comprised of deep marine (bathyal) black claystones, shelf limestones, and sandy limestones, respectively (see Fig. 4; Shipboard Scientific Party, 1996b; Oboh-Ikuenobe et al., 1997). With the exception of the claystone with nannofossils at the basal part of Unit III (Core 159-959D-66R), the black claystones from Cores 159-959D-48R to 65R (860.6–1033.7 mbsf) lack planktonic foraminifers and calcareous nannofossils. As a result, this interval was tentatively dated by pollen as Late Cretaceous to Paleocene (Shipboard Scientific Party, 1996b).

Low sedimentation rates in bathyal environments produce condensation in the stratigraphic record. Furthermore, the fossil record of dinoflagellate cysts in bathyal environments most likely reflects a thanatocoenosis of cysts brought together from the shelf by different sedimentary processes, rather than by virtue of having originally lived there collectively. Consequently, the preservation of the fossil record is random for dinoflagellate cysts in bathyal environments. This may be reflected in the stratigraphic record by the recovery of apparently "short-ranging" species (e.g., occurrences of taxa restricted to one sample because of the randomness of the fossil record), and the mixing of taxa because of condensation. There is also the possibility that some of the "short-ranging" species occur in strata between sample points. Only a continuous trench sampling would document all floral horizons.

#### *Late Turonian to Coniacian*

Two samples from lithologic Subunit IVA contain dinoflagellate cysts. Sample 159-959D-68R-1, 16–19 cm (1053.16 mbsf), yields only two specimens of nondiagnostic dinoflagellate cysts. Sample 159-959D-68R-1, 24–25 cm (1053.24 mbsf), located 5 cm below, was dated early Turonian by shipboard paleontologists based on calcareous nannoplankton. Of the 20 species of dinoflagellates and three acritarchs identified in Sample 159-959D-67R-1, 10–14 cm (1043.40 mbsf), many are long-ranging species, and only three taxa are of stratigraphic importance. *Circulodinium vannophorum* has its only occurrence at this site in this sample. Since this dinoflagellate cyst has its last occurrence (LO) in Coniacian strata (Williams and Bujak, 1985), its presence here indicates a Coniacian or older age for this sample. A late Turonian to Coniacian age is proposed for this sample based on the presence of *C. vannophorum* together with the first occurrences (FO) of *Dinogymnium acuminatum* and *D. cretaceum.* The first appearance of the genus *Dinogymnium* occurs in upper Turonian to lower Coniacian rocks in Australia (Helby et al., 1987), in the Northern Hemisphere (Williams et al., 1993) and in Venezuela (J. Helenes, pers. comm., 1996). *Tricolpites reticulominutus*, *Tricolpites* sp. 1, *Tricolpites* sp. 2, *Tricolpites* sp. 3, *Ephedripites multicostatus, Ephedripites* sp. 1, and *Monosulcites* spp. are some of the sporomorph taxa present in this sample. Jardiné and Magloire (1965) described *T. reticulominutus* in Maastrichtian rocks in Senegal and Côte d'Ivoire, but noted that similar forms were also recovered from Cenomanian to Turonian rocks. *Tricolpites* sp. 3 and *Monosulcites* spp. occur in several Upper Cretaceous and Paleocene samples.

### *Santonian*

The interval between Samples 159-959D-62R-1, 21–24 cm, and 65R-6, 10–13 cm (995.61–1031.70 mbsf), yields the FO of *Dinogymnium undulosum* (Sample 159-959D-65R-6, 10–13 cm), the LO of *Canningia senonica* (Sample 159-959D-64R-5, 89–93 cm) and the only occurrence of the short-ranging and morphologically characteristic *Odontochitina porifera* (Sample 159-959D-62R-1, 21–24 cm). *Dinogymnium undulosum* first appears in the lower Santonian rocks in the North Atlantic (Williams and Bujak, 1985) and Venezuela (J. Helenes, pers. comm., 1996). *Canningia senonica* has a reported stratigraphic range from Cenomanian to Santonian (Williams and Bujak, 1985). The LO of *Odontochitina porifera* has been reported in the upper Santonian in Colombia (Jaramillo and Yepes, 1994), upper Santonian to lower Campanian rocks in Australia (Helby et al., 1987) and Venezuela (J. Helenes, pers. comm., 1996), and middle Santonian in the North Atlantic (Williams et al., 1993). Based on the above discussion, a Santonian age is assigned to this interval. The LO of *O. porifera* has been used as Site 959's Santonian/Campanian boundary, assuming that the only occurrence of *O. porifera* in Sample 159-959D-62R-1, 21–24 cm, corresponds to the LO of this species.

A single specimen of *Subtilisphaera zawia* has its only occurrence at this site in Sample 159-959D-65R-6, 10–13 cm. The uppermost documented occurrence of this species is in lower Cenomanian rocks (Uwins and Batten, 1988). Below (1981) and Helenes (1984) reported the occurrence of this species in the Albian of Morocco and Baja California (Mexico, respectively. We interpret its occurrence as a reworked specimen from pre-Cenomanian sediments from lithologic Unit V. *Circulodinium distinctum* and *Spiniferites twistringiensis* are the dominant species in the dinoflagellate cyst assemblage of this interval. *Dinogymnium undulosum* and *D. acuminatum* are common in Sample 159-959D-64R-5, 89–93 cm, which also contained a specimen of the Albian spore *Corrugatisporites ivoriensis.* In Sample 159-959D-63R-6, 2–5 cm (1012.52 mbsf), the relative abundance of dinoflagellate cysts and species diversity decrease with respect to the samples below this depth. Only two species were recovered in this sample: *Spiniferites twistringiensis* (which predominates) and *Palaeohystrichophora infusorioides.* Specimens of the acritarch *Leiosphaeridia* spp. are common in the sample.

Based on poor to moderately preserved calcareous nannoplankton specimens, shipboard paleontologists assigned, tentatively, a late Santonian age for Samples 159-959D-65R-CC (1033.7 mbsf) and 66R-2, 61–62 cm (1035.9 mbsf), and an early Coniacian age for interval 159-959D-66R-7, 19–20 cm, through 66R-CC (1042.9–1043.3 mbsf). Age assignments based on dinoflagellate cysts and calcareous nannoplankton indicate that the lower Santonian and probably part of the upper Coniacian are represented by a relatively condensed section (7 m of nannofossil claystone) located between the upper Santonian Sample 159-959D-66R-2, 61–62 cm (1035.9 mbsf) and the uppermost lower Coniacian Sample 159-959D-66R-7, 19–20 cm (1042.9 mbsf). The presence of three phosphatic hardgrounds interbedded with this 7 m of nannofossil claystone (Shipboard Scientific Party, 1996b) supports a condensed section that may indicate hiatuses due to prolonged history of exposure of the seafloor.

### *Early Campanian*

Sample 159-959D-60R-4, 94–96 cm (981.54 mbsf), records the FO of *Cerodinium* sp., and contains few dinoflagellate specimens. Although the lowermost documented occurrence of species of this genus is Cenomanian (J. Helenes, pers. comm., 1996), there is approximately 15 m of stratigraphic section below this depth that was not sampled. The pollen *Rugulatisporites caperatus,* which is present in this sample, occurs in Upper Cretaceous (mainly Campanian to Maastrichtian) sediments in Nigeria (van Hoeken-Klinkenberg, 1964; Salami, 1990). Sample 159-959D-60R-2, 100–104 cm (978.60 mbsf), yields high species diversity and abundance of dinoflagellate cysts, with *Trichodinium castanea* and *Spiniferites* cf. *S. lenzii* as the dominant species. The concurrent presence of *T. castanea* and *Palaeocystodinium lidiae* in this sample, below the FO of *Areoligera senonensis* in Sample 159-959D-60R-4, 94–96 cm, indicates an early Campanian age for this interval.

### *Late Campanian*

The interval from Sample 159-959D-58R-1, 2–5 cm, to 59R-2, 45–50 cm (956.82–968.45 mbsf), is dated as late Campanian, based on the LO of *Trichodinium castanea* and *Palaeohystrichophora infusorioides,* and the FO of *Areoligera senonensis, Cerodinium diebelii* and *C. leptoderma* (see Fig. 2; Helby et al., 1987; Williams et al., 1993). The dinoflagellate cyst *Geiselodinium psilatum* and the spore *Foveotriletes margaritae* occur in this interval and in the lower Campanian Sample 159-959D-60R-2, 100–104 cm (978.60 mbsf). This dinoflagellate species is present in the Campanian to Maastrichtian rocks in Senegal (Jain and Millepied, 1973), whereas the spore occurs in Maastrichtian to Paleocene rocks in Nigeria and the Caribbean (Germeraad et al., 1968). The specimens of *F. margaritae* in two Campanian samples (Table 1) may be reworked.

### *Early Maastrichtian*

The interval between Samples 159-959D-55R-3, 85–88 cm, and 57R-1, 31–34 cm (930.41–947.41 mbsf), is dated as early Maastrichtian, based on the FO of *Systematophora placacantha* and *Spiniferites supparus,* and the LO of *Hystrichodinium pulchrum* (Fig. 2). *Areoligera coronata* has its lowermost occurrence in the section in Sample 159-959D-57R-1, 31–34 cm (947.41 mbsf).

### *Late Maastrichtian*

Samples 159-959D-49R-4, 99–102 cm, to 54R-1, 37–39 cm (875.69–918.47 mbsf), yield stratigraphically significant taxa that are used to assign a late Maastrichtian age to this interval. Sample 159-959D-54R-1, 37–39 cm (918.47 mbsf), yields the FO of *Manumiella raijae* and *Cordosphaeridium fibrospinosum.* The first fossil record of *C. fibrospinosum* is documented in uppermost lower Maastrichtian rocks in the North Atlantic (Williams et al., 1993). *M. raijae* occurs in uppermost lower Maastrichtian to upper Maastrichtian sediments in Sweden (Kjellström, 1973), and Maastrichtian rocks in Morocco (Rauscher and Doubinger, 1982). *Spiniferites fluens* has its lowermost occurrence in the section in Sample 159-959D-54R-1, 37–39 cm (918.47 mbsf). This species is present in the upper Maastrichtian rocks in the Atlantic Coastal Plain of the United States. (Habib and Miller, 1989), Maastrichtian to Danian rocks in Denmark (Hansen, 1977), Maastrichtian rocks in Baja California, Mexico (Helenes, 1984), upper Maastrichtian to Danian rocks in South Scandinavia (Hultberg, 1985), and lower Maastrichtian to Paleocene rocks in Morocco (Soncini and Rauscher, 1988).

The eight samples analyzed in the interval 159-959D-49R-4, 99–102 cm, through 53R-4, 67–70 cm (875.69–912.46 mbsf), contain the FO of *Cerodinium speciosum, Cyclapophysis monmouthensis, Manumiella seelandica, Pierceites pentagona, Kenleyia leptocerata, Kenleyia* sp. *A, K.* cf. K. *lophophora, Cribroperidinium wetzelii, Diphyes colligerum, Thalassiphora pelagica, Palaeocystodinium australinum, Cordosphaeridium inodes, Cordosphaeridium exilimurum, Glaphyrocysta perforata, Cyclonephelium*? *castelcasiense,* and

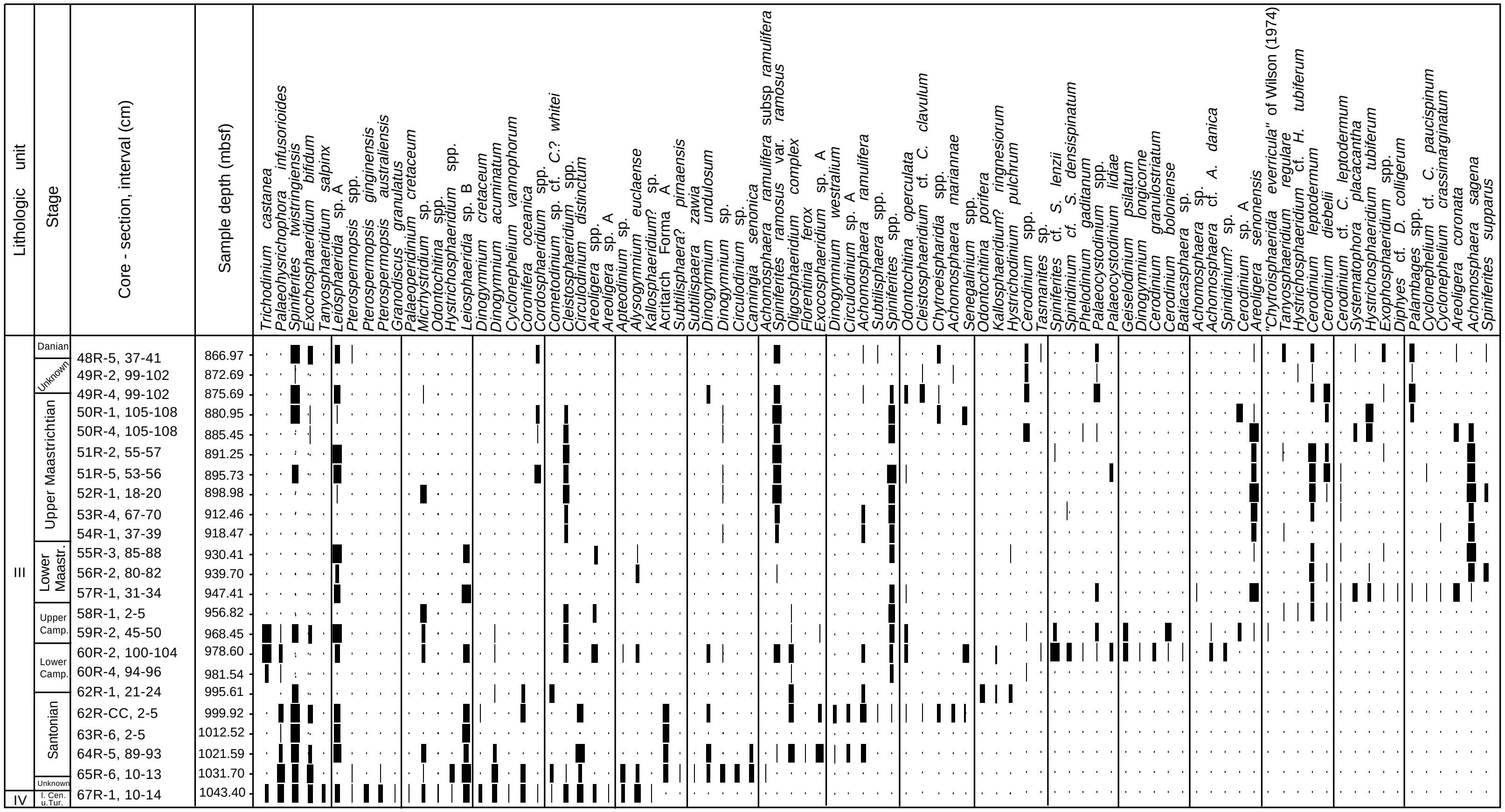


Figure 2. Range chart of phytoplankton species from Site 959. At least 300 specimens per slide were counted in samples with very good recovery. In samples with poorer recovery, the entire slide was scanned.

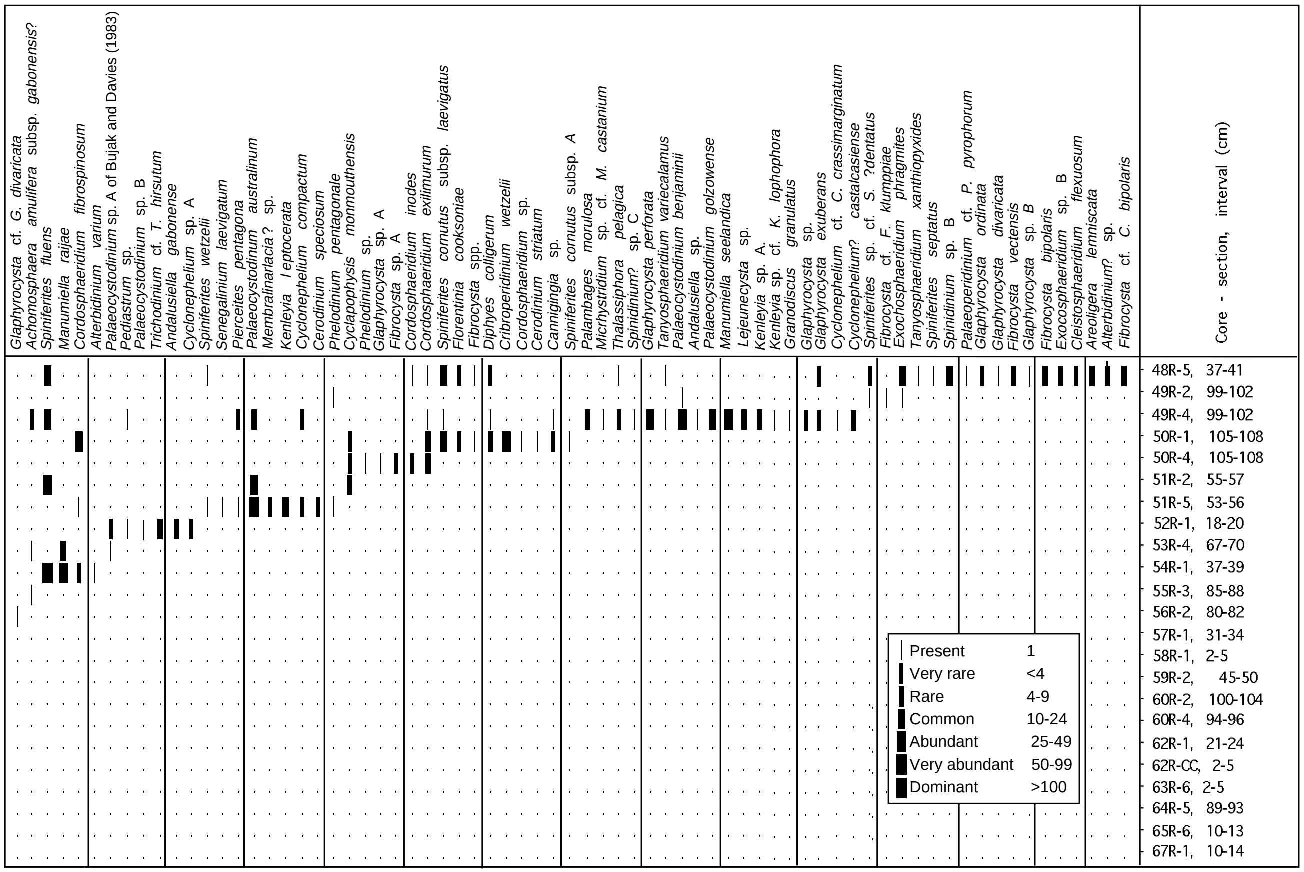


Figure 2 (continued).

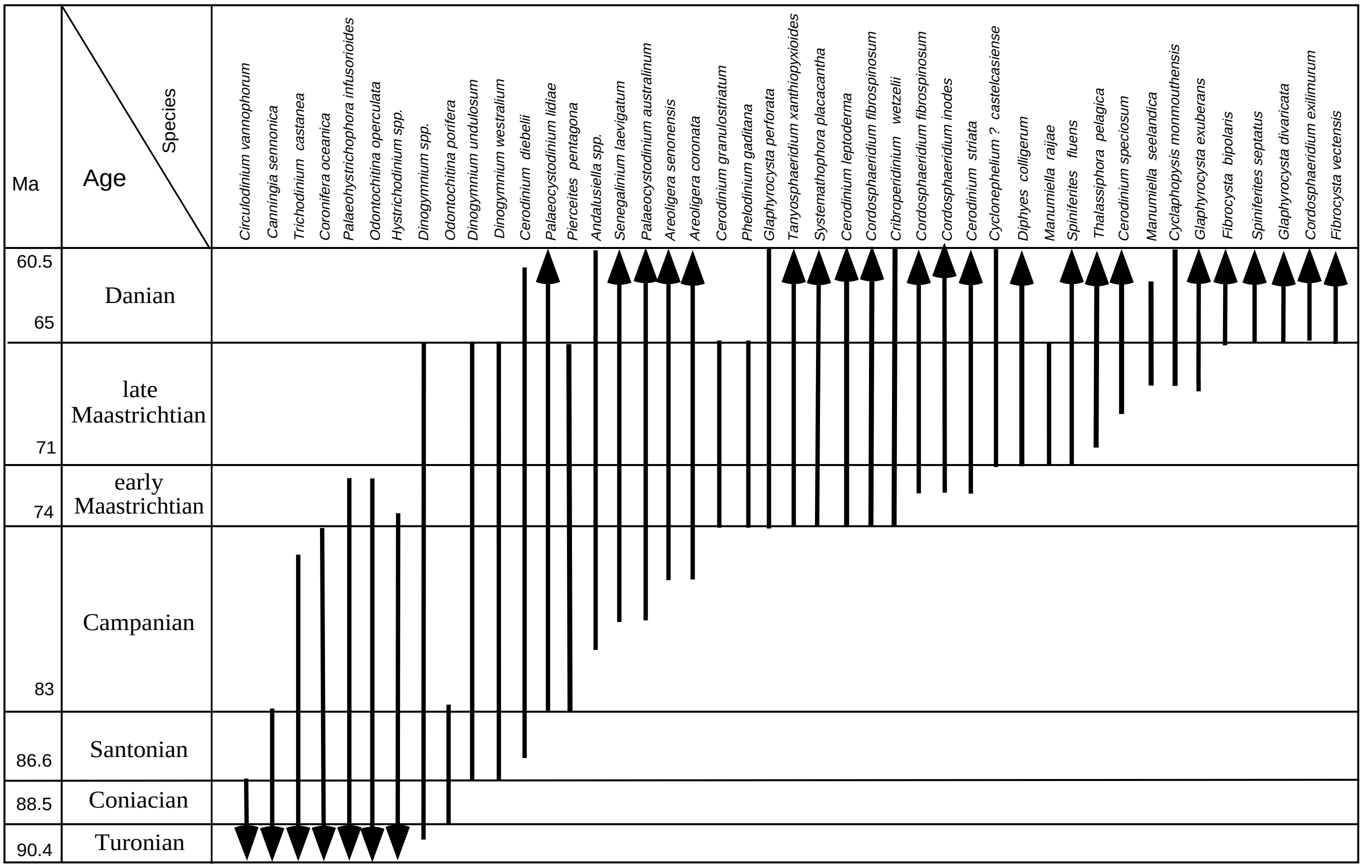


Figure 3. Stratigraphic ranges of selected dinoflagellate cysts from Site 959.

*Palambages morulosa*, in co-occurrence with *Dinogymnium* spp. Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), records the LO of *Dinogymnium undulosum.* The last fossil record of *Dinogymnium* spp. is found worldwide in uppermost Maastrichtian rocks, before the Maastrichtian/Danian boundary.

The first documented occurrences of *Cyclapophysis monmouthensis* and *Manumiella seelandica* are in uppermost Maastrichtian rocks elsewhere (Benson, 1976; Hansen, 1977; Koch and Olsson, 1977; Wilson, 1978; Firth, 1987; Helby et al., 1987; Brinkhuis and Leereveld, 1988). *Pierceites pentagona* has not been recovered above the Maastrichtian/Danian boundary (Firth, 1987). Other common taxa in this interval include *P. australinum, C. exilimurum,* and *C. inodes.*

### *Latest Maastrichtian to Danian*

Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), which yields the LO of *Dinogymnium* spp. and *Pierceites pentagona,* probably marks the top of the upper Maastrichtian interval. As mentioned above, these species have not been recovered above the Maastrichtian/Danian boundary elsewhere. This sample also yields the only occurrence of *Manumiella seelandica.* Its relative abundance of 10% in this sample is high in comparison with the other taxa in the assemblage. The abundance of *M. seelandica* is a significant stratigraphic event at the Maastrichtian/Danian boundary. The relatively high abundance of this species correlates well with abundance events of the same species just below the Maastrichtian/Danian boundary in Georgia (Firth, 1987), in the Middle Waipara River Section in New Zealand (Helby et al., 1987), and within the Fish Clay boundary in Denmark (Hultberg, 1986). The abundance of this species above the Maastrichtian/Danian boundary at the Woodside Creek section in New Zealand (Wilson, 1978) was reinterpreted by Helby et al. (1987) as representing mixing of ages in a condensed section at the boundary.

Other stratigraphically significant species that have their first and only occurrences in Sample 159-959D-49R-4, 99–102 cm, are *Glaphyrocysta perforata, Cyclonephelium*? *castelcasiense* and *Thalassiphora pelagica.* The FO of *G. perforata* is documented in upper Maastrichtian rocks from south Scandinavia (Hultberg, 1985), Maastrichtian rocks in Sweden and Denmark (Hultberg and Malmgren, 1987), Maastrichtian rocks in New Jersey (Koch and Olsson, 1977), Maastrichtian rocks in Venezuela (D.T. Pocknall, pers. comm., 1996). *Cyclonephelium*? *castelcasiense* can also be found in Maastrichtian rocks in Germany (Marheinecke, 1992). De Coninck and Smit (1982) reported a species with a strong morphological similarity to *Cyclonephelium*? *castelcasiense* in the Maastrichtian/Danian transition of Spain (as *Glaphyrocysta sp.* cf. *Cyclonephelium castelcasiense*). The lowest occurrence of *T. pelagica* has been documented in upper Maastrichtian rocks (Wilson, 1974; Hansen, 1977; Firth, 1987; Williams et al., 1993), and in lower to uppermost lower Maastrichtian rocks (Williams and Bujak, 1985; Firth, 1993). The pollen *Tricolpites reticulominutus,* which is present in this sample, occurs in upper Maastrichtian rocks in Senegal and Côte d'Ivoire (Jardiné and Magloire, 1965).

The FO of the lower latitude dinoflagellate *Kenleyia* spp. (see Pl. 5, Figs. 6–8, Pl. 7, Figs. 4–9) has been reported in upper Maastrichtian sediments where they are not common. They do, however, become more common in Danian sediments at lower latitudes, but are absent at higher latitudes (H. Brinkhuis, pers. comm., 1996). The FO of *K. leptocerata* is recorded in Sample 159-959D-51R-5, 53–56 cm

**Table 1. List of samples, sample depths, recovery of dinoflagellate cysts and acritarchs, and pollen and spores identified in Hole 959D.**

| Core, section, interval (cm) | Depth (mbsf) | Dinoflagellate cysts and acritarchs | Pollen and spores | Remarks |
|---|---|---|---|---|
| 159-959D- | | | | |
| 46R-1, 7-12 | 841.37 | Good recovery | | Danian |
| 47R-1, 66-69 | 851.56 | Good recovery | *Monosulcites* spp.<br>*Granulatisporites* sp. | Danian |
| 48R-5, 37-41 | 866.97 | Very good recovery | *Buttinia andreevi*<br>*Longapertites vaneendenburgi*<br>*Laevigatosporites gracilis*<br>*Leiotriletes* spp.<br>*Tricolporopollenites* spp.<br>*Arecipites* sp.<br>*Monosulcites* spp. | Danian |
| 49R-2, 99-102 | 872.69 | Poor recovery | *Monosulcites* spp. | |
| 49R-4, 99-102 | 875.69 | Very good recovery | *Parvisaccites* cf. *P. radiatus*<br>*Tricolpites reticulominutus*<br>*Tricolpites* sp. 3<br>*Tricolpites* sp. 4<br>*Monosulcites* spp.<br>*Monocolpopollenites* sp.<br>*Toroisporis* sp.<br>*Laevigatosporites gracilis* | late Maastrichtian |
| 50R-1, 105-108 | 880.95 | Very good recovery | *Foveotricolpites* sp. | late Maastrichtian |
| 50R-4, 105-108 | 885.45 | Very good recovery | | late Maastrichtian |
| 51R-2, 55-57 | 891.25 | Very good recovery | | late Maastrichtian |
| 51R-5, 53-56 | 895.73 | Very good recovery | | late Maastrichtian |
| 52R-1, 18-20 | 898.98 | Very good recovery | *Corollina*? sp.<br>*Triporopollenites* sp. | late Maastrichtian |
| 53R-4, 67-70 | 912.46 | Moderate recovery | *Tricolpites* sp. 3 | late Maastrichtian |
| 54R-1, 37-39 | 918.47 | Very good recovery | | late Maastrichtian |
| 55R-3, 85-88 | 930.41 | Good recovery | *Deltoidospora* sp.<br>*Dicolpites* sp. | early Maastrichtian |
| 56R-2, 80-82 | 939.70 | Poor recovery | | early Maastrichtian |
| 57R-1, 31-34 | 947.41 | Good recovery | | early Maastrichtian |
| 58R-1, 2-5 | 956.82 | Poor recovery | *Monosulcites* spp. | late Campanian |
| 59R-2, 45-50 | 968.45 | Very good recovery | *Monosulcites* spp.<br>*Foveotriletes margaritae* | late Campanian |
| 60R-2, 100-104 | 978.60 | Very good recovery | *Foveotriletes margaritae*<br>*Deltoidospora* sp. | early Campanian |
| 60R-4, 94-96 | 981.54 | Poor recovery | *Rugulatisporites caperatus*<br>*Striamonocolpites* sp. | early Campanian |
| 62R-1, 21-24 | 995.61 | Poor recovery | *Tricolporopollenites* spp. | Santonian |
| 62R-CC, 2-5 | 999.92 | Very good recovery | *Ephedripites* sp. 3 | Santonian |
| 63R-6, 2-5 | 1012.52 | Good recovery | | Santonian |
| 64R-5, 89-93 | 1021.59 | Good recovery | *Proxapertites*? sp.<br>*Corrugatisporites ivoriensis* | Santonian |
| 65R-6, 10-13 | 1031.70 | Very good recovery | *Ephedripites* sp. 1<br>*Ephedripites* sp. 3<br>*Monosulcites* spp.<br>*Tricolpites* sp. 3<br>*Arecipites* sp. | Santonian |
| 67R-1,10-14 | 1043.40 | Good recovery | *Tricolpites reticulominutus*<br>*Tricolpites* sp. 1<br>*Tricolpites* sp. 2<br>*Tricolpites* sp. 3<br>*Ephedripites multicostatus*<br>*Ephedripites* sp. 1<br>*Tricolporopollenites* spp.<br>*Verrutriletes* sp.<br>*Monosulcites* spp. | late Turonian-Coniacian |
| 68R-1, 16-19 | 1053.16 | Very poor recovery | Barren | late Turonian-Coniacian |
| 72R-3, 6-11 | 1094.26 | Barren | Barren | |
| 74R-2, 79-83 | 1112.79 | Barren | Barren | |
| 75R-1, 65-69 | 1120.85 | Barren | Barren | |
| 76R-2, 49-53 | 1131.79 | Barren | Barren | |
| 76R-CC, 0-4 | 1132.23 | Barren | Barren | |
| 78R-5, 70-73 | 1155.90 | Barren | Barren | |
| 78R-6, 70-73 | 1157.40 | Barren | Barren | |

Notes: The dinoflagellate cyst and acritarch taxa recovered in this hole can be found in Figure 2. The categories of recovery are as follows: very poor = 1–5 specimens per slide, poor = 5–50, moderate = 50–100, good = 100–300, very good = >300. For pollen and spores, single specimens were recovered with the exception of *Tricolpites* sp. 2, *Tricolpites* sp. 3, *Monosulcites* spp., and *Ephedripites* spp.

(895.73 mbsf). *Kenleyia* spp. are common in Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf). We believe that the common co-occurrence of *Kenleyia* spp. with well-known uppermost Maastrichtian dinoflagellate cysts (e.g., *Dinogymnium* spp. and *Pierceites pentagona*) represents a condensed Maastrichtian to Danian section in Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf). Condensation due to low sedimentation rates can be found associated with bathyal environments of deposition, like those proposed for the black claystones of lithologic Unit III from benthic foraminifers and the presence of *Zoophycos* ichnofacies (Shipboard Scientific Party, 1996b; Kuhnt et al., 1996; Oboh-Ikuenobe et al., 1997). The presence of glauconite in this part of the section (Fig. 4) also supports this interpretation. Although the higher percentage of nonfluorescing amorphous organic matter seems contradictory, an increase in terrestrially derived organic matter (wood, black debris, and black-brown fragments) is probably indicative of a drop in sea level just below the Cretaceous/Paleocene boundary (see “Palynofacies Analysis” section).

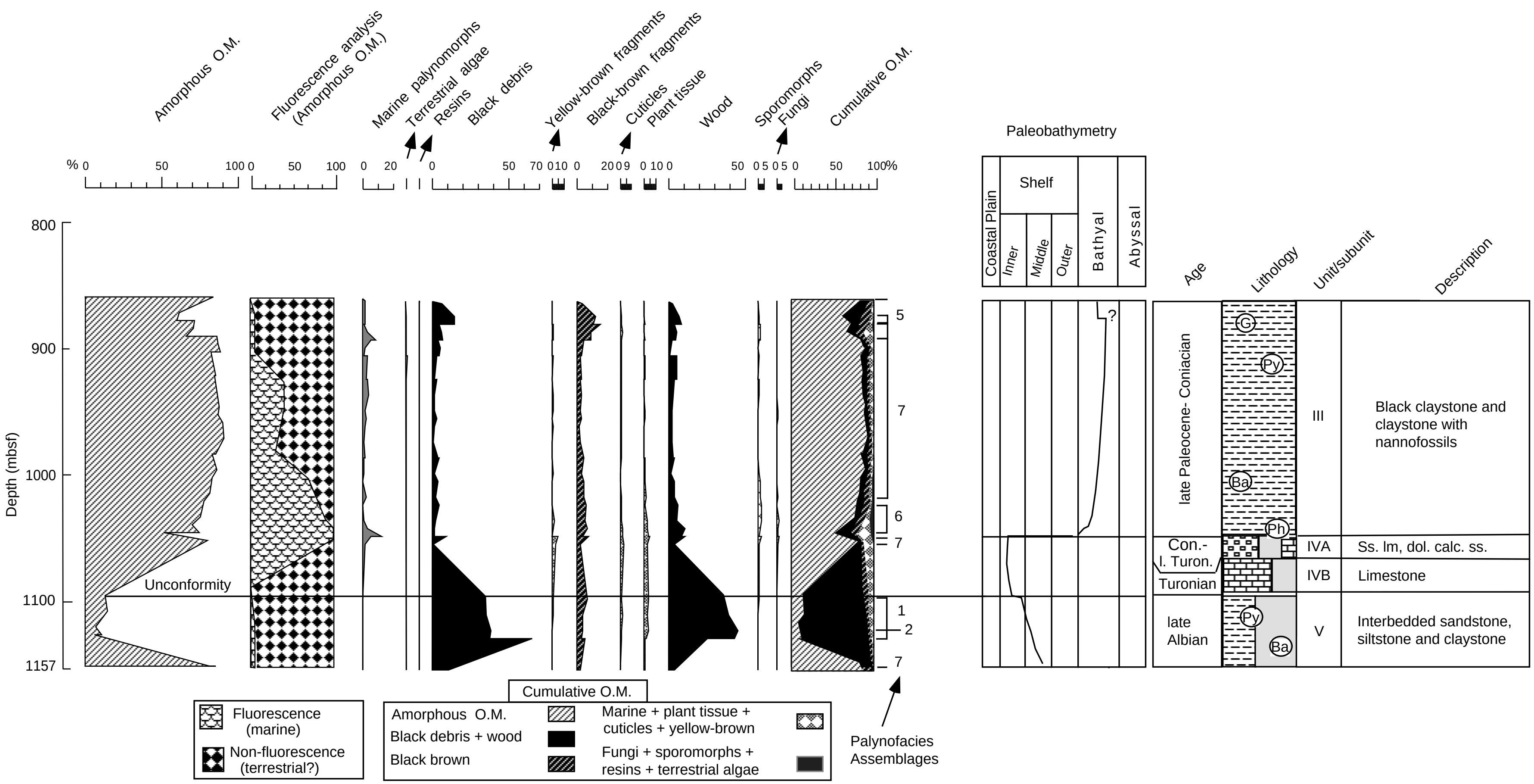


Figure 4. Composite chart of data at Site 959 showing the percent distribution of dispersed organic matter, cumulative organic matter types derived from R-mode cluster analysis, sample positions of palynofacies assemblages, reconstructed paleobathymetric curve and lithofacies. Fluorescence analysis is used to separate the marine and possibly terrestrial fractions of AOM. In the lithofacies column, Py = pyrite; G = glauconite; Ba = barite nodule; Ph = phosphatic hardground. The current water depth at this site is 2100 m (modified from Oboh-Ikuenobe et al., 1997). Age assignments and lithology for lithologic Subunit IVB and Unit V are taken from Shipboard Scientific Party (1996b).

Sample 159-959D-49R-2, 99−102 cm (872.69 mbsf), yields a poor assemblage of dinoflagellate cysts, and none of the taxa is stratigraphically diagnostic. Core 159-959D-49R was dated as late Maastrichtian by Kuhnt et al. (1996) on the basis of benthic foraminifers, and by Shipboard Scientific Party (1996b) because of the presence of *Buttinia andreevi* (see statement about this pollen below) in the core catcher (Section 49R-CC).

Sample 159-959D-48R-5, 37−41 cm (866.97 mbsf), is dated as Danian, based on the FO of *Spiniferites septatus, Fibrocysta bipolaris, Fibrocysta vectensis,* the co-occurrence of *Cerodinum diebelii,* and the absence of typical Maastrichtian species, such as *Dinogymnium* spp. and *Pierceites pentagona*. The absence of *Manumiella seelandica,* which ranges from upper Maastrichtian to lower Danian, suggests that part of the lowermost Danian is below Sample 159-959D-48R-5, 37−41 cm (866.97 mbsf). Based on the above discussion we have placed the Maastrichtian/Danian boundary between Samples 159-959D-48R-5, 37−41 cm (866.97 mbsf), and 159-959D-49R-4, 99−102 cm (875.69 mbsf), being perhaps represented by a condensed interval in Sample 159-959D-49R-4, 99−102 cm (875.69 mbsf).

*Longapertites vaneendenburgi* and *Buttinia andreevi* occur in Sample 159-959D-48R-5, 37−41 cm. *L. vaneendenburgi* has been reported in Maastrichtian to Danian rocks in Nigeria and the Caribbean (Germeraad et al., 1968). On the other hand, *B. andreevi* has a known LO in uppermost Maastrichtian rocks (Jardiné and Magloire, 1965; Germeraad et al., 1968). The presence of a poorly preserved specimen of this pollen in this sample (Pl. 10, Fig. 24) indicates that either (1) the specimen is reworked, although there is no other evidence from dinoflagellate cysts or lithologic features to support this hypothesis, or (2) *B. andreevi* probably ranges into the Danian. Sample 159-959D-44R-3, 72−73 cm (825.6 mbsf), is dated as late Paleocene based on calcareous nannofossils (Shipboard Scientific Party, 1996b).

## Site 960

Twenty-three samples were analyzed from Hole 960A. Among the lithologies sampled were glauconitic claystone from lithologic Subunit IVA at 159-960A-21R-1, 43−48 cm (184.53 mbsf), and the siliciclastics of Subunits VA and VB from interval 159-960A-37R-2, 1−4 cm, through 61R-1, 19−21 cm (interval 329.34−446.39 mbsf; see Fig. 5 for lithology). According to Shipboard Scientific Party (1996c), sediments below Section 159-960A-21R-CC (193.8 mbsf) are barren of calcareous nannoplankton and planktonic foraminifers. A majority of the samples we analyzed are barren of dinoflagellate cysts, and have very poor recovery of spores and pollen (Table 2).

Sample 159-960A-21R-1, 43−48 cm (184.53 mbsf), contains an Upper Cretaceous assemblage of dinoflagellate cysts, with abundant occurrences *of Palaeohystrichophora infusorioides* (45%) and *Dinogymnium* spp. (25%). The co-occurrence of *Isabelidinium cooksoniae, Dinogymnium undulosum,* and *P. infusorioides* indicates an age not younger than early Maastrichtian but not older than Santonian for this sample. *Chenopodipollis* sp. is the only pollen present in this sample. Lithologic Subunit IVA was interpreted as a condensed Coniacian to Maastrichtian section by Shipboard Scientific Party (1996c). Sample 159-960A-42R-2, 35−38 cm (355.35 mbsf), from Subunit VA yields a single occurrence of *Cerodinium* sp. This genus is not older than Cenomanian. One poorly preserved specimen of the Upper Cretaceous pollen *Buttinia andreevi* occurs in Sample 159-960A-53R-2, 29−32 cm (404.59 mbsf). The presence of this palynomorph taxa in Subunit VA suggests a Late Cretaceous age, which is not in agreement with the assignment of a pre-Turonian age for the tectonized basal siliciclastic sediments (Shipboard Scientific Party, 1996c). Its presence here is probably due to caving during sample drilling operations. The lowermost sample from Subunit VB (159-960A-61R-1, 19−21 cm; 446.39 mbsf) contains the bisaccate pollen *Parvisaccites* cf. *P. radiatus*, which is common in Aptian to Cenomanian sediments (Brenner, 1963; Kemp, 1970).

## Site 961

Nineteen core samples were analyzed from the site. Eleven samples were obtained from Hole 961A, from the interval from 167.75 to 305.32 mbsf (159-961A-19R-1, 35−38 cm, through 34R-2, 32−37 cm). These samples were obtained from zeolite claystone and glauconite-rich porcellanite from Subunit IIB, and siliciclastic sediments from Unit III (see Fig. 6 for lithology). Eight samples were analyzed from Unit III in Hole 961B, from 323.08 to 369.91 mbsf (interval 159-961B-12R-1, 68−71 cm, through 19R-CC, 1−3 cm). The samples are barren of dinoflagellate cysts but contain a few spores and pollen (Table 3). The interval between Cores 159-961A-19R and 20R is dated late Paleocene on the basis of calcareous nannofossils and benthic foraminifers (Shipboard Scientific Party, 1996d). Unit III is generally barren of calcareous nannoplankton and planktonic foraminifer, although it has been assigned an early Cenomanian to late Albian age (J. Mascle, per. comm., 1996). The presence of very poorly preserved specimens of the long-ranging nannofossil *Watznaueria barnesae* (Bajocian–Maastrichtian age) in core-catcher samples from Cores 159-961B-9R (313.2 mbsf) and 11R (322.4 mbsf) is documented by Shipboard Scientific Party (1996d). All eight Unit III samples analyzed in Hole 961B are below 313.2 mbsf and are barren of dinoflagellate cysts. However, they contain specimens of the long-ranging pollen *Ephedripites* spp., *Cyathidites minor*, and *Monosulcites* sp., which are common in Aptian to Cenomanian rocks (Brenner, 1963; Kemp, 1970; Kotova, 1978).

## Site 962

Eleven samples were analyzed from this site. They were obtained from palygorskite claystone of Subunit IIB at 64.9 mbsf (interval 159-962B-8H-1, 40−45 cm), chert and porcellanite of Subunit IIC from the interval from 72.61 to 94.33 mbsf (159-962B-8H-6, 61−66 cm, through 13X-CC, 3−5 cm), and alternating tectonized siliciclastic and carbonate-bearing sediments of Unit III from the interval from 191.23 to 393.81 mbsf (159-962D-13R-1, 23−25 cm, through 37R-4, 81−84 cm). These lithologies are shown in Figure 7. Table 4 lists the palynomorphs contained in the samples.

Three of the four samples analyzed in Hole 962B yield a very poor assemblage of dinoflagellate cysts. An age not older than late Albian is indicated for Sample 159-962B-13X-CC, 3−5 cm (94.33 mbsf), based on the presence of *Palaeohystrichophora infusorioides,* which has its lowermost documented occurrence in upper Albian sediments (Fig. 3). Williams et al. (1993) reported the FO of *P. infusorioides* in lower Cenomanian sediments in the Northern Hemisphere. This is in agreement with Clarke and Verdier (1967) who erected the *Hystrichosphaeridium siphoniphorum* Zone of Cenomanian to Turonian? age, the base of which is defined by the FO of *P. infusorioides.* However, Below (1984) reported the FO of *P. infusorioides* below the base ranges of well-known upper Albian dinoflagellate cysts from onshore sections in Morocco. Helby et al. (1987) recorded the base stratigraphic range of *P. infusorioides* in the upper part of the *Xenascus asperatus* Zone, which they indicated was Vraconian (late Albian) in age.

Sample 159-962B-9H-1, 69−73 cm (74.69 mbsf), yields a dinoflagellate cyst assemblage dominated by *Palaeohystrichophora infusorioides* (68% of 107 taxa in one slide). An age not older than Cenomanian and not younger than late Campanian is assigned to this core sample, based on the co-occurrence of *Cerodinium* sp., *Trichodinium castanea,* and *Palaeohystrichophora infusorioides.* The latter has its uppermost documented occurrence in lower Maastrichtian rocks,

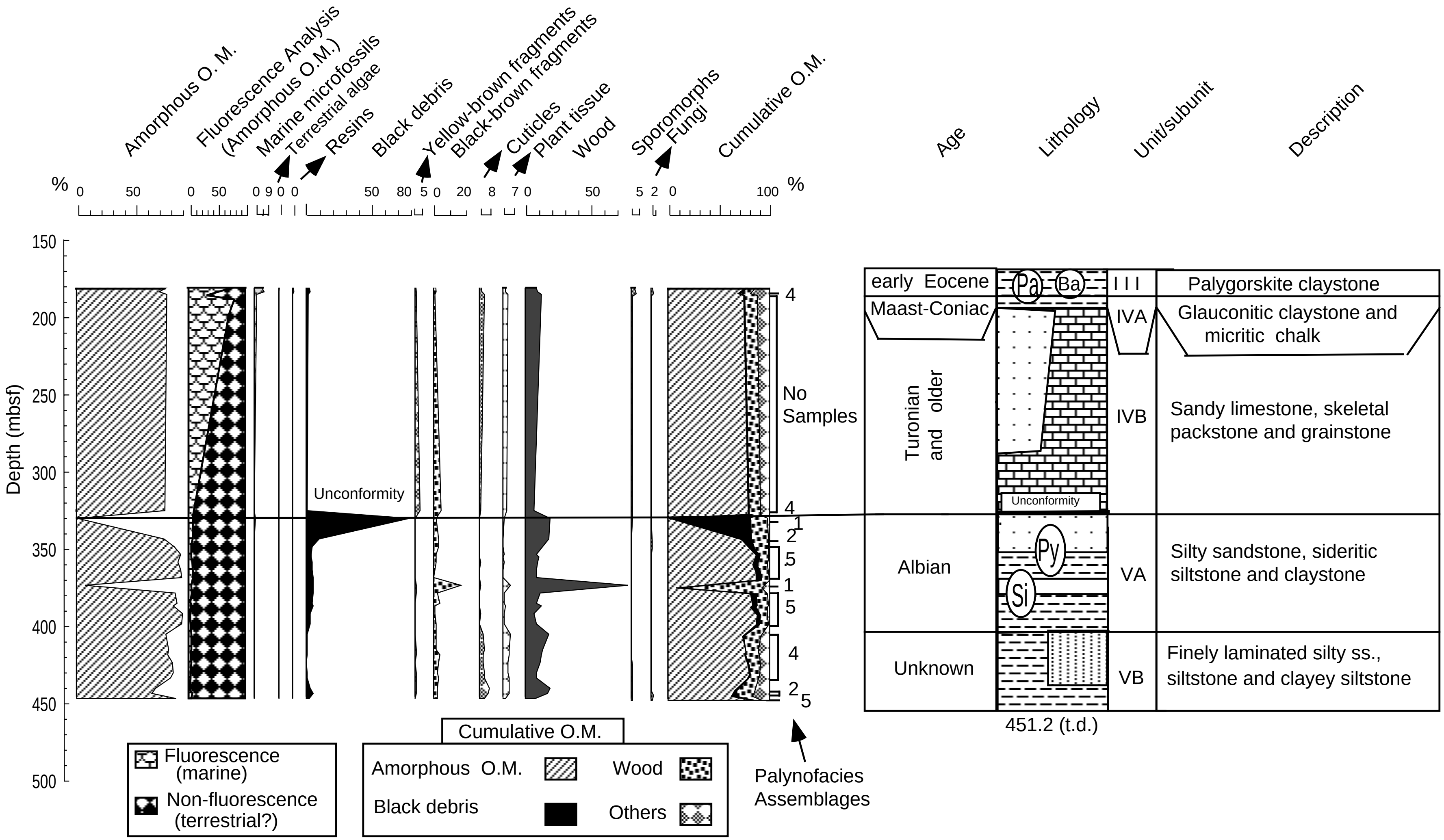


Figure 5. Percent distribution of dispersed organic matter at Site 960, including the fluorescence analysis of AOM, cumulative organic matter types derived from R-mode cluster analysis, sample positions of palynofacies assemblages, and lithofacies. In the lithofacies column, Py = pyrite; Pa = palygorskite claystone; Ba = barite nodule; Si = silica. The current water depth at this site is 2061 m (modified from Oboh-Ikuenobe et al., 1997). Because of poor recovery of palynomorphs at this site, age assignments and lithology for all three lithologic Units shown (III through V) are taken from Shipboard Scientific Party (1996c).

**Table 2. List of samples, sample depth, and palynomorphs identified in Hole 960A.**

| Core, section, interval (cm) | Depth (mbsf) | Dinoflagellate cysts and acritarchs | Pollen and spores | Remarks |
|---|---|---|---|---|
| 159-960A- | | | | |
| 21R-1, 43-48 | 184.53 | *Palaeohystrichophora infusorioides* (120)<br>*Achomosphaera ramosus* subsp. *ramosus* (6)<br>*Dinogymnium undulosum* (25)<br>*Cerodinium*? sp.<br>*Spinidinum* sp.<br>*Dinogymnium acuminatum* (36)<br>*Dinogymnium* sp.<br>*Fibrocysta* sp. (5)<br>*Spiniferites ramosus* subsp. *multibrevis*<br>*Isabelidinium cooksoniae* (3)<br>*Exocosphaeridium* sp.<br>*Alisogymniun euclaense* (6)<br>*Spiniferites ramosus* subsp. *ramosus* (15)<br>*Leiosphaeridia* sp. (15) | *Chenopodipollis* sp. | Not younger than early Maastrichtian, not older than Santonian<br>Maastrichtian, not older than Santonian |
| 37R-2, 1-4 | 329.34 | Barren | Barren | |
| 38R-4, 22-26 | 342.92 | Barren | Barren | |
| 40R-1, 31-34 | 348.61 | *Manumiella*? sp. | *Multiporopollenites* sp. 2 | |
| 41R-2, 18-21 | 352.68 | Acritarch forma A | Barren | *Pediastrum* sp. |
| 42R-2, 35-38 | 355.35 | *Cerodinium* sp.<br>*Spiniferites ramosus* subsp. *multibrevis* | Barren | Not older than Cenomanian |
| 43R-1, 75-80 | 358.25 | Barren | Barren | |
| 44R-2, 24-28 | 364.04 | Barren | Barren | |
| 45R-2, 21-25 | 368.91 | Barren | Barren | |
| 46R-2, 29-32 | 373.59 | Barren | Barren | |
| 47R-1, 81-86 | 377.61 | Barren | Barren | |
| 48R-4, 64-68 | 384.44 | Barren | Barren | |
| 49R-1, 41-43 | 386.81 | Barren | Barren | |
| 50R-1, 7-11 | 391.17 | Barren | Barren | |
| 52R-1, 21-24 | 397.51 | Barren | Barren | |
| 53R-2, 29-32 | 404.59 | Dinocyst specimen | *Leiotriletes* spp.<br>*Buttinia andreevi* | |
| 54R-2, 38-42 | 414.98 | Barren | Barren | |
| 55R-1, 18-22 | 417.98 | Barren | Barren | |
| 56R-1, 80-85 | 423.60 | Barren | Barren | |
| 58R-1, 14-18 | 432.54 | Barren | Barren | |
| 59R-3, 26-29 | 440.02 | Barren | *Brevicolporites* sp. | |
| 60R-2, 73-76 | 444.06 | Barren | *Ephedripites* sp. 1 | |
| 61R-1, 19-21 | 446.39 | Barren | *Monosulcites* spp.<br>*Parvisaccites* cf. *P. radiatus*<br>Trilete spore | |

Note: The numbers in parentheses indicate the number of specimens counted for each species, whereas taxa without numbers indicate a single occurrence in the sample.

while the LO of *T. castanea* is in upper Campanian rocks (Williams et al., 1993). The lowermost documented occurrence of *Cerodinium sp.* is in Cenomanian rocks.

One specimen of the dinoflagellate cyst *Cerodinium* cf. *C. leptodermum* is present in Sample 159-962B-8H-6, 61–66 cm (72.61 mbsf). This dinoflagellate cyst also occurs at Site 959 and has its site base-stratigraphic range in Sample 159-959D-58R-1, 2–5 cm (956.82 mbsf), which is dated as late Campanian (see discussion for Site 959). Assuming that the FO of *Cerodinium* cf. *C. leptodermum* in Hole 959D corresponds to its lowermost occurrence in the stratigraphic record (regardless of preservation factors and/or condensation at that site), Sample 159-962B-8H-6, 61–66 cm (72.61 mbsf) is probably not older than late Campanian. The pollen *Multiporopollenites* sp. (Pl. 10, Fig. 26), which is present in this sample, occurs in upper Campanian rocks in the Book Cliffs, Utah, U.S.A. (Oboh-Ikuenobe, unpubl. data). A Campanian to Maastrichtian age assignment is supported by the presence of the Late Cretaceous pollen *Buttinia andreevi.* Thus, palynological data can be used to bracket the age of Subunit IIC as late Albian to Maastrichtian. The interval from Core 159-962B-11H through 13H is barren of calcareous nannofossils and planktonic foraminifers, although Core 159-962B-10H-CC (93 mbsf) was assigned a probable late Albian age on the basis of these microfossils (Shipboard Scientific Party, 1996e).

Two of seven samples from Hole 962D (Cores 159-962D-13R through 37R) yield single specimens of dinoflagellate cyst and acritarch taxa (Table 4). The dinoflagellate cysts reported in Samples 962D-24R-2, 41–45 cm (298.91 mbsf), and 962D-27R-1, 80–83 cm (312.10 mbsf), are not age diagnostic. On the contrary, stratigraphically important sporomorph taxa are present in this interval. The taxa include *Triorites africaensis, Elaterosporites jardinei, Ephedripites multicostatus, Ephedripites* spp.*, Circulina parva, Corollina jardinei,* and *C. torosus,* which have been recovered in lower Albian to lower Cenomanian sediments in Senegal and Côte d'Ivoire (Jardiné and Magloire, 1965), lower Albian rocks in England (Kemp, 1970), Albian rocks in Maryland, U.S.A. (Brenner, 1963), and Albian to Cenomanian rocks in Brazil (Hengreen, 1972). The sporomorph data support the late Albian age assigned to this interval on the basis of calcareous nannofossils (Shipboard Scientific Party, 1996e).

## PALYNOFACIES ANALYSIS

The dispersed organic matter in the sediments (Pl. 11, Figs. 1–12) are useful in deciphering the sources and depositional conditions of the drilled sequences. Several factors control the amount and types of dispersed organic matter in sedimentary rocks, and they include the sources of organic matter, depositional environment, lithology, tectonic setting, sea-level fluctuations, paleoclimate, paleoproductivity, sedimentation rate, diagenesis, and paleoceanography. In a marine setting, the narrow width of the continental shelf, such as the present shelf in the Côte d'Ivoire-Ghana Transform Margin (Mascle, Lohmann, Clift, et al., 1996), will exert an important control on the relative positions of proximal and distal facies of the different environments.

The palynofacies data presented in this study represent a subset of the Cretaceous to Pleistocene data discussed by Oboh-Ikuenobe et al. (1997). Qualitative analysis and R-mode cluster analysis indicate that the dominant palynodebris in most samples is AOM. A reduction in

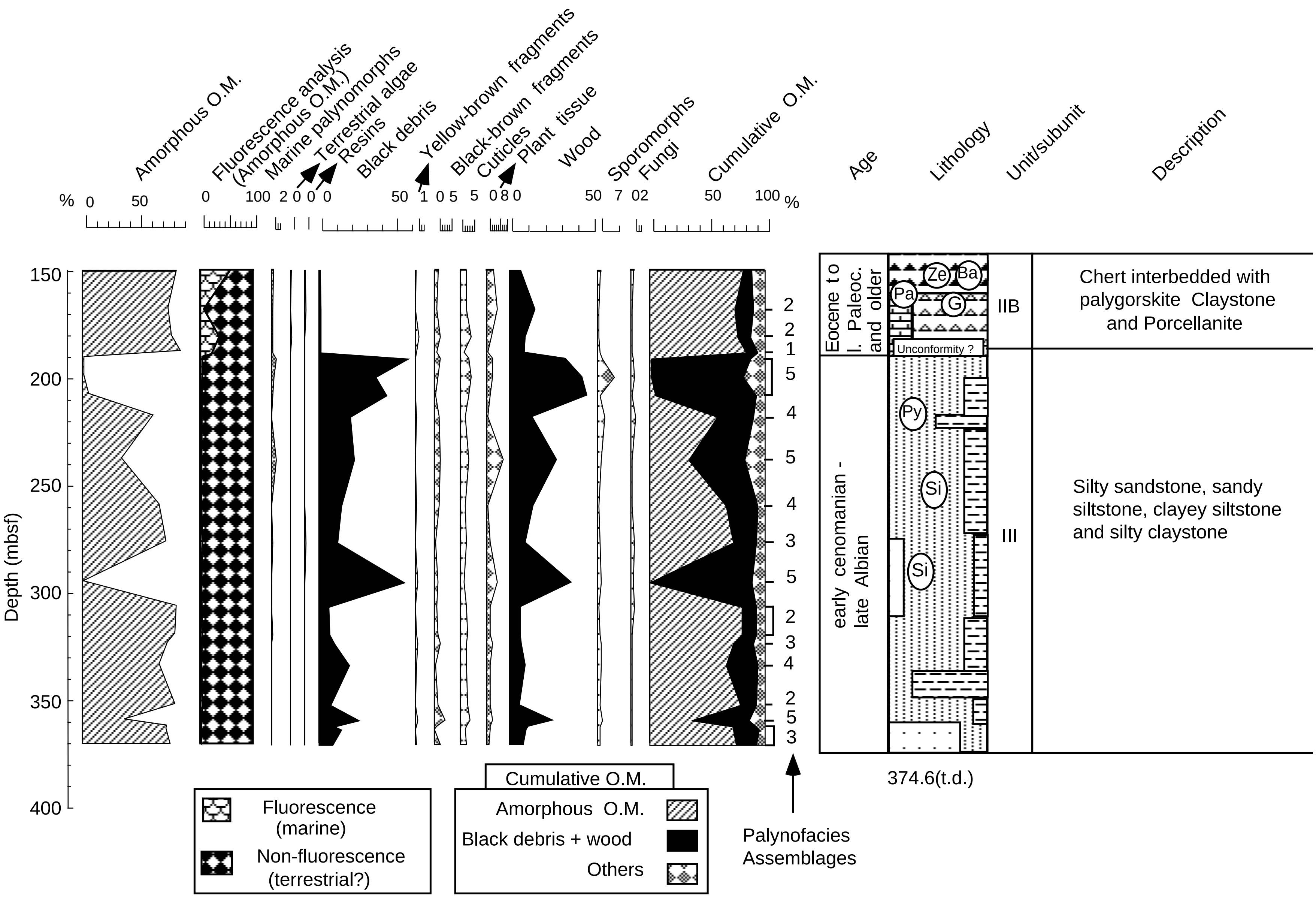


Figure 6. Percent distribution of dispersed organic matter at Site 961, including the fluorescence analysis of AOM, cumulative organic matter types derived from R-mode cluster analysis, sample positions of palynofacies assemblages, and lithofacies. In the lithofacies column, Py = pyrite; Pa = palygorskite claystone; Ba = barite nodule; Ze = zeolite; Si = silica. The current water depth at this site is 3303 m (modified from Oboh-Ikuenobe et al., 1997). Age assignments and lithology for Subunit IIB and Unit III are based on Shipboard Scientific Party (1996d) and J. Mascle (pers. comm., 1996).

**Table 3. List of samples, sample depths, and palynomorphs identified in Holes 961A and 961B.**

| Core, section, interval (cm) | Depth (mbsf) | Dinoflagellate cysts and acritarchs | Pollen and spores | Remarks |
|---|---|---|---|---|
| 159-961A- | | | | |
| 19R-1, 35-38 | 167.75 | Barren | Barren | |
| 20R-2, 100-105 | 179.50 | Barren | Barren | |
| 21R-1, 63-68 | 187.33 | Barren | Barren | |
| 21R-2, 130-135 | 189.50 | Barren | *Ephedripites* spp.<br>*Cyathidites minor* | |
| 22R-2, 20-23 | 198.10 | Barren | *Cyathidites minor* | *Pediastrum* sp. |
| 23R-1, 44-47 | 206.54 | Barren | Barren | |
| 24R-1, 147-150 | 217.17 | Barren | *Cyathidites minor*<br>*Ephedripites* spp. | *Pediastrum* sp. |
| 28R-3, 20-22 | 258.50 | Barren | *Ephedripites* spp. | |
| 30R-1, 66-68 | 275.16 | Barren | *Cyathidites minor* | |
| 32R-1, 26-29 | 294.06 | Barren | *Ephedripites* sp. 1 | |
| 34R-2, 32-37 | 305.32 | Barren | *Ephedripites* sp. 2<br>*Cyathidites minor* | *Pediastrum* sp. |
| 159-961B- | | | | |
| 11R-1, 72-75 | 318.12 | Barren | *Cyathidites minor*<br>*Ephedripites* spp.<br>*Monosulcites* sp. | |
| 12R-1, 68-71 | 323.08 | Barren | *Cyathidites minor*<br>*Ephedripites* spp. | |
| 13R-1, 35-38 | 332.45 | Barren | *Retitriporites* sp. | |
| 15R-1, 20-22 | 351.60 | Barren | Barren | *Pediastrum* sp. |
| 16R-3, 30-33 | 359.00 | Barren | *Cyathidites minor*<br>*Ephedripites* spp. | |
| 17R-1, 24-28 | 360.90 | Barren | *Ephedripites* spp. | |
| 18R-1, 48-51 | 363.39 | Barren | *Cyathidites minor*<br>*Ephedripites* spp. | |
| 19R-CC, 1-3 | 369.91 | Barren | | |

Note: A single specimen was found for the listed taxa with the exception of *Ephedripites* spp. and *Cyathidites minor.*

AOM is often accompanied by an increase in terrestrially derived components such as wood and black debris. Q-mode cluster analysis of samples was used to identify palynofacies assemblages in the entire suite of sediments. The results, which are discussed in detail in Oboh-Ikuenobe et al. (1997), are summarized in Table 5. Figures 4 to 7 illustrate the distribution of palynodebris and cumulative patterns based on R-mode cluster analysis of Cretaceous to Paleocene sediments at the four sites. Five of the seven assemblages identified at Site 959 and one assemblage at Site 960 are illustrated and described in Plate 11, Figures 13 through 18. The amount of AOM in the sediments is the single most important factor that defines these assemblages. A paleobathymetric curve is also shown for Site 959 in Figure 4. This curve was reconstructed by integrating lithofacies, paleodepths of the CCD, trace fossils, benthic foraminifer, and tectonic setting with palynofacies data (see Oboh-Ikuenobe et al., 1997, for details and references).

Geochemical analysis using organic carbon vs. total nitrogen ratios (C/N) indicate that the organic components in the sediments were derived from both marine and terrestrial (dominant African) sources (Shipboard Scientific Party 1996b). This observation is confirmed by palynofacies analysis which shows that AOM is the dominant component in many samples. Fluctuations in TOC values and organic matter components show some correlation with lithology, although variations within lithologic units demonstrate changes in paleoenvironmental conditions and/or different stages of diagenetic overprint. Data obtained by Rock-Eval pyrolysis (Hydrogen Index and $T_{max}$) provide further information on the origin and stage of thermal maturity of organic matter in marine sediments (Espitalié et al., 1977; Tissot and Welte, 1984). Palynofacies data indicate that a high level of degradation has occurred at some intervals at all the sites. High values of nonfluorescing, more likely terrestrially derived AOM, are recorded, and the presence of poorly preserved spores, pollen, wood, and other fragments are documented for these intervals, such as lithologic Units III (black claystones) and Unit V (tectonized siliciclastic sediments) at Site 959 (Fig. 4). Hydrogen index values below 50 for Unit V suggest oxidation and biodegradation. Since this unit has the highest TAI value at this site, poor preservation may also be related to thermal maturation (see discussion below).

Terrestrially derived organic matter or AOM of terrestrial origin dominate the organic matter components of the siliciclastic sediments of the basal tectonized Unit V at Sites 959 and 960, and Unit III at Site 961 (Figs. 4–6). The absence of dinoflagellate cysts and microforaminiferal linings in these sediments is probably due to high degradation and/or dilution by high influx of sediment and land-derived organic components (from Africa and possibly Brazil) into the basin. Based on the presence of varves in the siliciclastic sediments of Subunit VB at Site 960, these sediments have been interpreted as lacustrine (Shipboard Scientific Party, 1996c). The recovery of the highest percentages of cuticles and plant tissues in this subunit supports the above interpretation. Most of the organic matter components in these sediments have been degraded to nonfluorescing AOM. At Site 962, the basal Unit III contains interbedded hemipelagic siliciclastics and carbonate sediments (Fig. 7), and is rich in fluorescing AOM. Site 962 was deeper during the syntransform Albian stage with respect to the other three sites.

The general assumptions of palynofacies studies of passive margins (e.g., Oboh, 1992; Habib et al., 1994) indicate that a high concentration of terrestrially derived organic matter suggests proximity to the paleoshoreline, while a high concentration of marine-derived AOM is indicative of a distal location. In a transform margin setting, this assumption may not hold true in all cases because of tectonic processes. For example, the paleobathymetric curve for Site 959 (Fig. 4) shows that Unit IV, which is richer in marine AOM, is shallower than Unit V which is AOM poor (Palynofacies Assemblage 7 vs. Assemblages 1 and 2; Pl. 11, Figs. 13, 17). Lithologic evidence indicates that turbiditic processes have transported terrestrial organic matter into deep marine environments at some intervals, but in the absence of such lithologic evidence, we have related a high amount of such components to proximity to source.

The drastic increase in AOM and decrease in black debris and wood above lithologic Unit V at Sites 959 and 960 coincides with an unconformity between lithologic Units IV and V at these sites (Shipboard Scientific Party, 1996b; 1996c). The Upper Cretaceous to Paleocene black claystones of Unit III at Site 959 are absent at the other three sites. These sediments contain a high proportion of nonfluorescing, terrestrial AOM, and some input of wood, black debris, and

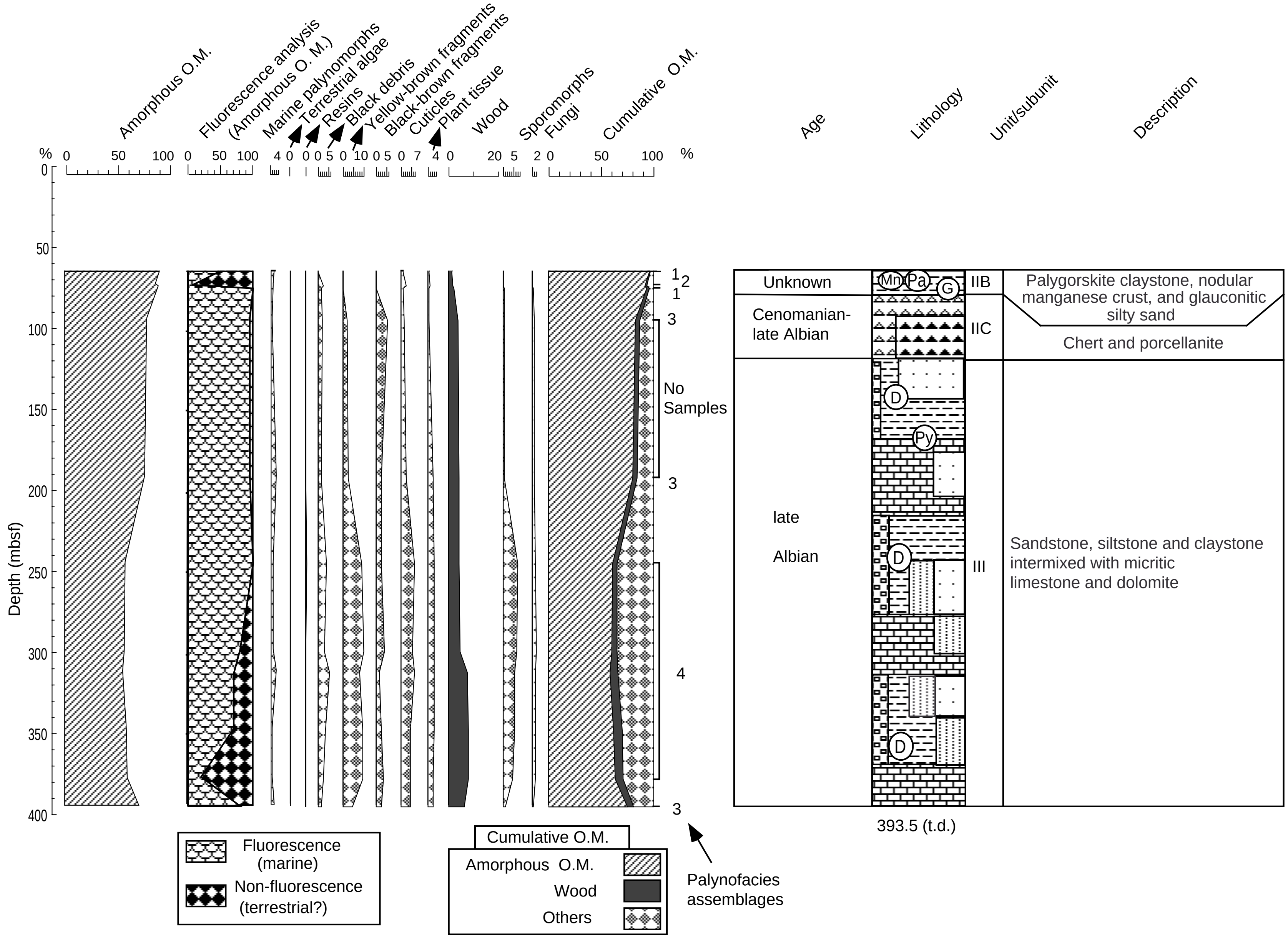


Figure 7. Percent distribution of dispersed organic matter at Site 962, including the fluorescence analysis of AOM, cumulative organic matter types derived from R-mode cluster analysis, sample positions of palynofacies assemblages, and lithofacies. In the lithofacies column, Py = pyrite; G = glauconite; Pa = palygorskite claystone; Mn = manganese nodule; D = dolomite. The current water depth at this site is 4662 m (modified from Oboh-Ikuenobe et al., 1997). Age assignments and lithology for Subunits IIB and IIC, and Unit III are based on Shipboard Scientific Party (1996e).

**Table 4. List of samples, sample depths, and palynomorphs identified in Holes 962B and 962D.**

| Core, section, interval (cm) | Depth (mbsf) | Dinoflagellate cysts and acritarchs | Pollen and spores | Remarks |
|---|---|---|---|---|
| 159-962B- | | | | |
| 8H-1, 40-45 | 64.90 | *Spiniferites* spp.<br><br>*Leiosphaeridia “minor”* | *Tricolpites* sp. 3<br>*Tricolpopollenites* spp. | *Pediastrum* sp. |
| 8H-6, 61-66 | 72.61 | *Cerodinium* cf. *C. leptoderma* | *Multiporopollenites* sp. 1 | *Pediastrum* sp.<br>Not older than late Campanian |
| 9H-1, 69-73 | 74.69 | *Cerodinium* sp.<br>*Palaeohystrichophora infusorioides*<br>*Circulodinium distinctum*<br>*Trichodinium castaneum*<br>*Coronifera*? cf. C. oceanica<br>*Oligosphaeridium* sp.<br>*Exocosphaeridium* sp.<br>Spiniferites spp.<br>*Areoligera* sp.<br>*Cleistosphaeridium* sp.<br>*Spinidinium* sp.<br>*Leiosphaeridia* sp.<br>*Pterospermella* cf. *P. ginginensis* | *Tricolpites* sp. 3<br>*Tricolpopollenites* spp.<br>*Tricolporopollenites* spp.<br>*Classopollis torosus* | Santonian-Campanian |
| 13X-CC, 3-5 | 94.33 | *Palaeohystrichophora infusorioides*<br><br>Spiniferites sp.<br>*Spiniferites ramosus* subsp. *ramosus*<br>*Spiniferites* cf. *S. dentatus*<br>*Leiosphaeridia* sp. | *Tricolpites* sp. 3 | Not older than late Albian-early Cenomanian? |
| 159-962D- | | | | |
| 13R-1, 23-25 | 191.23 | Barren | *Tricolporopollenites* spp. | late Albian |
| 18R-4, 90-93 | 244.50 | Barren | | |
| 24R-2, 41-45 | 298.91 | *Circulodinium distinctum*<br>*Exocosphaeridium*? sp.<br>*Spiniferites* sp. | *Corollina torosus*<br>*Ephedripites* sp. 2<br>*Circulina parva*<br>*Elaterosporites castelaini*<br>*Leiotriletes* spp.<br>*Triorites* cf. *T. africaensis* | late Albian |
| 27R-1, 80-83 | 312.10 | *Exocosphaeridium bifidum*<br>*Cribroperidinium* cf. *C. auctificum*<br>*Pterospermopsis* sp.<br>Acritarch forma B | *Corollina jardinei*<br>*Striatopollis* sp. | late Albian |
| 31R-2, 89-92 | 347.69 | *Spiniferites ramosus* | *Corollina jardinei*<br>*Buttinia*? *andreevi* | late Albian |
| 35R-2, 140-144 | 377.20 | Barren | *Cyathidites minor* | late Albian |
| 37R-4, 81-84 | 393.81 | Barren | *Corollina torosus*<br>*Triorites africaensis* | late Albian |

black-brown fragments. This probably suggests an influx of terrestrial organic matter from Africa into the deep Ivorian Basin, and possibly from erosion of the marginal ridge to the south. However, there is no evidence to suggest that turbiditic processes transported these organic components into the deep basin. An increase in terrestrially derived organic matter, which is accompanied by relative abundances of *Spiniferites* spp. and *Manumiella seelandica*, in our uppermost Maastrichtian sample (159-959D-49R-4, 99–102 cm; 875.69 mbsf) at Site 959, is probably a reflection of the relative sea-level drop proposed just below the Cretaceous/Paleocene boundary (Haq et al., 1987).

## THERMAL MATURATION ANALYSIS

Three major stages of thermal evolution have been documented for transform margins, namely intracontinental active transform with shear heating effect, continent-ocean active transform with friction and heat conduction, and passive transform margin with heat conduction (Todd and Keen, 1989; Mascle, Lohmann, Clift, et al., 1996). These thermal events are recorded by some of the sediments recovered at the Côte d’Ivoire-Ghana Transform Margin. By integrating TAI values for Cretaceous to Pleistocene sediments from Sites 959 to 962 with $T_{max}$ data from Site 959 (Shipboard Scientific Party, 1996b) and clay mineral data (Shipboard Scientific Party, 1996a; Pletsch et al., 1996), Oboh-Ikuenobe et al. (1997) reconstructed the paleothermal history of the study area. Generally, TAI values lower than 2 correspond to vitrinite reflectance values <0.4% VRo, and are indicative of an immature thermal stage (Robert, 1988). TAI values between 2 and 3 represent moderate maturity and correspond to the oil-window maturation, whereas values greater than 3 are considered mature to overmature. Some correlation exists between TAI and $T_{max}$ data at Site 959 (see Oboh-Ikuenobe et al., 1997). $T_{max}$ data indicate a persistent immature level for most samples (mainly those younger than the Campanian) close to the lower limit of the oil window ($T_{max}$ scattering about 375°–420°C), although two samples from Unit III occur in the oil window, while Unit V samples are overmature (465°–485°C). A description of the thermal maturation analysis of the tectonic stages represented by Cretaceous to Paleocene sediments is given below.

### Intracontinental Transform Stage

Clay mineral data for Sites 960 to 962 indicate that the basal tectonized siliciclastic units (i.e., Unit V at 959 and 960, and Unit III at 961 and 962) have been affected by high temperatures. The sediments are characterized by large amounts of chlorite and/or highly illitic mixed-layer clay minerals, but lack smectitic mixed-layer and other thermally unstable clay minerals. Moreover, mixed-layer clays are more ordered in the sediments of lithologic Unit III at Site 961 (R = 3 vs. R = 0; Moore and Reynolds, 1989), and this is confirmed by higher TAI values recorded for the unit at this site. The values for the basal units at all the sites are typically greater than 2.5, but Site 961 records are the highest values. These observations indicate that either these sediments reached a higher temperature during burial at Site 961 than at Site 960, or that they were subjected to a high temperature for a longer period of time. The organic matter components in the three lowermost samples from Unit V at Site 959 were so dark that we could not identify any spore or pollen for measurement. These

**Table 5. Characteristics of palynofacies assemblages at Sites 959 through 962.**

| Palynofacies | Units/subunits | Characteristics |
|---|---|---|
| Site 959 | | |
| 1 | V siliciclastics | AOM <15%; black debris 35%-39%; wood 37%-46%; moderately high TAI values (2.6-3). |
| 2 | V siliciclastics | AOM 2%; black debris 65%; wood 25.3%; TAI values >2.5. |
| 3 | IB nannofossil clay | AOM 30%-35%; marine palynomorphs 7%-15%; cuticles 6%-7%; wood and black brown fragments 12%-17% each. |
| 4 | IB, IIA, IV nannofossil chalk/clay, diatomite/clay, and sandy limestone, respectively | AOM 43%-54%; wood 9%-13.5%. |
| 5 | IB, IIA, III nannofossil chalk/clay, diatomite/clay, and black claystone, respectively | AOM 55%-65%; black-brown fragments 8%-12%; fairly high TAI values (2-2.5) in some Unit III claystones. |
| 6 | IIA, IIC, III diatomite/nannofossil clay, porcellanite, and black claystone respectively | AOM 65%-78%; black debris very rare; fairly high TAI values (2-2.5) in some Unit III claystones. |
| 7 | IIB, IIC, III chert/claystone porcellanite/clay, and black claystone, respectively | AOM >78%; black debris very rare; fairly high TAI values (2-2.5) in some Unit III claystones. |
| Site 960 | | |
| 1 | VA siliciclastics | AOM 7.5%; dominated by wood fragments and black debris; TAI 2.5-2.9. |
| 2 | VA, VB siliciclastics | AOM 62%-72%; cuticle and wood >7%; TAI 2.5-2.9. |
| 3 | III palygorskite claystone | AOM 67%-75%. |
| 4 | III, IV, VB palygorskite claystone, limestone, and siliciclastics | AOM 73%-80%; wood 7%-15%; much of the AOM in Subunit VB appears to be terrestrially |
| 5 | VA, VB Siliciclastics | AOM 81%-88% mainly terrestrially derived; wood and black debris <6% each; no marine palynomorphs were found; TAI >2.5. |
| Site 961 | | |
| 1 | IIA, IIB claystones with diatoms and porcellanite with clay | AOM 84%-85.3%; wood 2%-9%; cuticles 1.3%-2.7%. |
| 2 | IIB and III siliciclastics and nannofossil porcelanite | AOM 73%-80%; probably terrestrially derived in Unit III samples; wood 6%-15.3%; cuticles 2.3%-4.7%; black debris 1.3%-7%. |
| 3 | III siliciclastics | AOM 72%-75%; wood and black debris 7%-13% each; TAI generally >3. |
| 4 | III siliciclastics | AOM 61%-66%; wood and black debris 10%-19% each; TAI 2.8-3. |
| 5 | III siliciclastics | AOM 0%-36%; wood and black debris 21%-53% each; TAI generally >3. |
| Site 962 | | |
| 1 | IIB, IIC palygorskite claystone and porcellanite | AOM 94%-96%. |
| 2 | IA, IIA, IIC clay, claystone, and porcellanite, respectively | AOM 86%-92%. |
| 3 | IA, IIC and III interbedded carbonates and siliciclastics | AOM 74%-83%; wood and black debris <11%. |
| 4 | III clayey dolomitic siltstone | AOM 58%-63%; wood 4.3%-8%; black debris 2.7%-5.7%; cuticle 4.3%-6.7%; yellow-brown 8%-10%; pollen/spores 4.3%-6.7%; TAI >2.5. |

Notes: AOM = amorphous organic matter, TAI = thermal alteration index (modified from Oboh-Ikuenobe et al., 1997).

samples represent an overmature thermal stage. Apatite fission track data of Clift et al. (1995, 1996) suggest peak thermal temperatures (>120°C) during the Albian. Therefore, the tectonized basal siliciclastic sediments record a thermal anomaly associated with the intracontinental to syntransform basin phase in the region.

## Continent-Ocean Transform Stage

The uplift of the marginal ridge began during the continent-ocean transform stage (latest Albian?/Cenomanian to Turonian) because of the proximity of the hot oceanic lithosphere to the nearby continental margin, and the passage of the oceanic spreading center south of the transform margin (Shipboard Scientific Party, 1996a). Reef deposits at Sites 959 and 960 (Unit IV) mark the maximum uplift of the ridge during the Turonian to early Coniacian. There is no TAI record of any thermal anomaly associated with the spreading center because this event is marked by an unconformity below the reef sediments at the four sites. With the exception of one carbonate sample at Site 959, and one porcellanite sample at Site 962, the reef and other deposits representing this stage of evolution are thermally immature (with TAI values lower than 2).

## Passive Transform Stage

The passive transform margin phase began during the late Coniacian and has continued until the present time. At Site 959, TAI values indicate moderate maturity for black claystones (basal Unit III) of late Coniacian to Campanian age. The presence of phosphatic hardgrounds at this site (Core 159-959D-66R) and at Site 960 (Core 159-960C-23X) is indicative of very low sedimentation rates and hiatuses during the late Coniacian to late Santonian, which probably affected the organic matter in the sediments. Clay minerals also indicate a change from illite-bearing assemblages (Coniacian to Santonian) to assemblages that are almost exclusively composed of smectite and minor kaolinite (Campanian to Maastrichtian; Pletsch et al., 1996).

A thermal anomaly of Santonian to Campanian age, which accompanied heavy subsidence, has been reported in the northwestern section of the neighboring Benue Trough and in the Anambra Basin in Nigeria (Allix et al., 1984; Robert, 1988). Although the Benue Trough and the Côte d'Ivoire-Ghana Transform Margin are both linked to the fossil Romanche Fracture Zone, their structural settings are different. We do not have any evidence to link the moderate maturity of the organic matter in our samples to the same thermal anomaly in the Benue Trough and Anambra Basin.

# CONCLUSIONS

Biostratigraphic interpretations of the Upper Cretaceous to Paleocene sediments at Sites 959 to 962 were based largely on the occurrences of dinoflagellate cysts, and to a lesser extent on spores and pollen. Ages were assigned to samples whenever possible, and a summary is given below.

159-959D-67R-1, 10−14 cm, and 68R-1, 16−19 cm, Turonian to early Coniacian.

159-959D-62R-1, 21−24 cm, through 65R-6, 10−13 cm, Santonian.

159-959D-60R-4, 94−96 cm, and 60R-2, 100−104 cm, early Campanian.

- 159-959D-58R-1, 2–5 cm, and 59R-2, 45–50 cm, late Campanian.
- 159-959D-55R-3, 85–88 cm, through 56R-2, 80–82 cm, early Maastrichtian.
- 159-959D-54R-1, 37–39 cm, latest early Maastrichtian to earliest late Maastrichtian.
- 159-959D-49R-4, 99–102 cm, through 53R-4, 67–70 cm, late Maastrichtian.
- 159-959D-48R-5, 37–41 cm, Danian.
- 159-959D-47R-1, 66–69 cm, and 46R-1, 7–12 cm, not older than latest Danian.

The presence of the dinoflagellate cysts *Kenleyia* spp. in sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), may indicate a condensed Maastrichtian/Danian boundary in this sample. This hypothesis can be proved by analyzing additional samples and specimens of *Kenleyia* spp.

- 159-960A-21R-1, 43–48 cm, not younger than early Maastrichtian but not older than Santonian.
- 159-962B-8H-6, 61–66 cm, not older than late Campanian
- 159-962B-9H-1, 69–73 cm, Santonian to Campanian.
- 159-962B-13X-CC, 3–5 cm, not older than late Albian to early Cenomanian?
- 159-962D-13R-1, 23–23 cm, through 37R-4, 81–84 cm, late Albian

Palynofacies analysis has been used in the reconstruction of the sedimentary environments represented and the clarification of the origin of dispersed organic matter in the sediments. The organic matter is predominantly of marine origin (composed primarily of AOM), and a decrease in AOM is often accompanied by an increase in terrestrially derived organic matter (mostly wood and black debris). At Sites 959 and 960, carbonate and clastic rocks of lithologic Unit IV above the post-Albian unconformity are much richer in AOM and poorer in terrestrial organic matter with respect to the underlying tectonized rocks of lithologic Unit V. The high concentration of black debris and wood just below the unconformity surface may be due to degradation of organic matter during long exposure, oxygenation, and probably erosion of the depositional surface. The higher amounts of terrestrially derived organic matter in the Unit V are related to high input from Africa and possibly Brazil during the syntransform phase. An increase in terrestrial organic matter in the Cretaceous/Paleocene boundary at Site 959 may be related to a drop in sea level.

The organic matter in several of the samples analyzed is thermally immature. TAI values greater than 2.0, which indicate moderate thermal maturity, occur in some black claystones and limestone at Site 959 (Units III and IV), and in the tectonized basal siliciclastic sediments at all the sites (Unit V at Sites 959 and 960, and Unit III at Sites 961 and 962). They correlate well with Rock-Eval pyrolysis and clay mineral data. The tectonized basal siliciclastic sediments typically have values greater than 2.5, with the highest values (up to 3.13) occurring at Site 961. These sediments at Site 961 either reached a higher temperature during burial, or they were subjected to a high temperature for a longer period of time. The thermal event in the basal sediments is related to the syntransform phase of the basin.

## SYSTEMATICS

Division *DINOFLAGELLATA* (Bütschli 1885) Fensome et al., 1993
Subdivision *DINOKARYOTA* Fensome et al., 1993
Class *DINOPHYCEAE* Pascher, 1914
Subclass *PERIDINIPHYCIDAE* Fensome et al., 1993
Order *GONYAULACALES* Taylor, 1980

*Kenleyia* sp. A
(Pl. 7, Figs. 4–7)

**Description:** Cyst proximochorate, body spherical to subspherical with a microreticulate autophragm. One apical and one or two antapical hornlike projections up to 10 µm long, with blunt tips. An external and discontinuous layer is discernible forming variable projections of short fibrous processes, and discontinuous lace-like lamellar structures. In two of the four specimens analyzed, the processes are slightly more prominent at each side of the paracingulum. Specimen illustrated in Plate 7, Figure 4, shows a microreticulate autophragm, bearing few nontabular spines and thin, longer fibrous processes (9 µm) that have an apparent alignment parallel to the expected location of the paracingulum, which is not clearly expressed. Spine length varies from 2–3 µm. Antapical horn has a hair-like projection on its tip and three more on one of its margins. Paracingulum faintly evident. Archeopyle precingular, prominent, isomegaform (Pl. 7, Fig. 5) or eurymegaform (Pl. 7, Fig. 7).

**Dimensions:** Total length 76.8–83.2 µm, breadth 60.8–75.2 µm, length of apical and antapical horns 8–12.8 µm. Number of specimens measured: 4.

**Comparison:** These specimens differ from *Kenleyia pachycerata* in the absence of two smaller projections on each side of the apical and antapical horns, and in having short and discontinuous ornamentation. *Kenleyia leptocerata* has accessory apical outgrowths, which are absent in these specimens. The specimens differ from *Fibrocysta* in having low, poorly delimited fibrous projections or lamellar lace-like structures, rather than more or less distinct and generally long processes.

**Occurrence:** Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf).

*Kenleyia* cf. *K. lophophora*, Cookson and Eisenack, 1965
(Pl. 7, Figs. 8 and 9)

**Description:** Cyst proximochorate, body subspherical to ellipsoidal with one apical and one antapical horn-like projections. Autophragm microreticulate, bearing low tuft-like processes or fibrous lamellar structures of variable width. Some of the processes end with short spines or hair-like projections. The tuft-like processes are slightly better developed on either side of the apical and antapical horns and on the lateral limits of the paracingulum. The apical horn has a blunt tip and has spines along its margins. Paracingulum indicated by two closely spaced, low, transverse ridges. Archeopyle precingular and large.

**Dimensions:** Length 99.2 µm, breadth 75.2 µm, length of apical and antapical horn 19.2 µm, height of processes 3–7 µm, width of processes 5–20 µm. Number of specimens measured: 1.

**Comparison:** This specimen differs from *Kenleyia lophophora* in having an apical horn with spines in its margin and in having less-developed tuft-like projections.

**Occurrence:** Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf).

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## APPENDIX A

Alphabetical list of phytoplankton species identified in this study. All the references cited can be found in Lentin and Williams (1993).

*Achomosphaera* cf. *A. danica* (W. Wetzel, 1952) Sarjeant, 1984
*Achomosphaera mariannae* (Philipott, 1949) Stover and Evitt, 1978
*Achomosphaera ramulifera* (Deflandre, 1937) Evitt, 1963
*Achomosphaera*? *ramulifera* subsp. *gabonensis* (Boltenhagen, 1977) Lentin and Williams, 1981
*Achomosphaera ramulifera* subsp. *ramulifera* (Deflandre, 1937b) Evitt, 1963
*Achomosphaera sagena* Davey and Williams, 1966a
*Achomosphaera* sp. A
Acritarch Forma A
Acritarch Forma B
*Alterbidinium*? sp.
*Alterbidinium varium* Kirsch, 1991
*Alysogymnium euclaense* (Cookson and Eisenak, 1970a) Lentin and Vozzhennikova, 1990
*Andalusiella gabonense* Stover and Evitt, 1978
*Andalusiella* sp.
*Apteodinium* sp.
*Areoligera* cf. *A. senonensis* Lejeune-Carpentier, 1938
*Areoligera coronata* (O. Wetzel, 1933b) Lejeune-Carpentier, 1938
*Areoligera lemniscata* Stover and Evitt, 1978
Areoligera senonensis Lejeune-Carpentier, 1938
*Areoligera* sp. A
*Areoligera* spp.
*Batiacasphaera* sp.
*Canningia senonica* Clarke and Verdier, 1967
*Canningia* sp.
*Cerodinium boloniense* (Riegel, 1974b) Lentin and Williams, 1989
*Cerodinium* cf. *C. leptodermum* (Vozzhennikova, 1963) Lentin and Williams, 1987
*Cerodinium diebelii* (Alberti, 1959b) Lentin and Williams, 1987
*Cerodinium granulostriatum* (Jain and Millepied, 1973) Lentin and Williams, 1987
*Cerodinium leptodermum* (Vozzhennikova, 1963) Lentin and Williams, 1987
*Cerodinium* spp.
*Cerodinium* sp. A
*Cerodinium speciosum* (Alberti, 1959b) Lentin and Williams, 1987
*Cerodinium striatum* (Drugg, 1967) Lentin and Williams, 1987
"*Chytroeisphaeridia everricula*" of Wilson, 1974
*Chytroeisphaeridia* spp.
*Circulodinium distinctum* (Deflandre and Cookson, 1955) Jansonius, 1986
*Circulodinium* sp.
*Circulodinium* sp. A
*Cleistosphaeridium* cf. *C. clavulum* (Davey 1969) Below, 1982c
*Cleistosphaeridium* spp.
*Cleistosphaeridium flexuosum* Davey et al., 1966b
*Cometodinium* sp. cf. *C.*? *whitei* (Deflandre and Courteville, 1939) Stover and Evitt, 1978
*Cordosphaeridium fibrospinosum* Davey and Williams, 1966b
*Cordosphaeridium exilimurum* Davey and Williams, 1966b
*Cordosphaeridium inodes* (Klumpp, 1953) Eisenack, 1963b emend. Morgenroth, 1968
*Cordosphaeridium* spp.
*Cordosphaeridium* sp.
*Coronifera oceanica* Cookson and Eisenack, 1958 emend. May, 1980
*Cribroperidinium* cf. *C. auctificum* (Brideaux, 1971) Stover and Evitt, 1978
*Cribroperidinium wetzelii* (Lejeune-Carpentier, 1939) Helenes, 1984b
Cyclapophysis monmouthensis
Cyclonephelium? castelcasiense Corradini, 1973
*Cyclonephelium* cf. *C. crassimarginatum* Cookson and Eisenack, 1974
*Cyclonephelium compactum* Deflandre and Cookson, 1955
*Cyclonephelium crassimarginatum* Cookson and Eisenack, 1974
*Cyclonephelium* sp. A
*Cyclonephelium paucispinum* Davey 1969a
*Cyclonephelium vannophorum* Davey, 1969a
*Dinogymnium acuminatum* Evitt et. al., 1967
*Dinogymnium cretaceum* (Deflandre, 1935) Evitt et al., 1967
*Dinogymnium longicorne* (Vozzhennikova, 1967) Harland, 1973a
*Dinogymnium* sp.
*Dinogymnium undulosum* Cookson and Eisenack, 1970a
*Dinogymnium westralium* (Cookson and Eisenack, 1958) Evitt, Clarke and Verdier, 1967 emend. May, 1977
*Diphyes* cf. *D. colligerum* (Deflandre and Cookson, 1955) Cookson, 1965a emend. Goodman and Witmer, 1985
*Diphyes colligerum* (Deflandre and Cookson, 1955) Cookson, 1965a emend. Goodman and Witmer, 1985
*Exochosphaeridium bifidum* (Clarke and Verdier, 1967) Clarke et al., 1968
*Exochosphaeridium phragmites* Davey et al., 1966b
*Exocosphaeridium* sp. A
*Exocosphaeridium* sp. B
*Exophosphaeridium* spp.
*Fibrocysta bipolaris* (Cookson and Eisenack, 1965b) Stover and Evitt, 1978
*Fibrocysta* cf. *F. klumppiae* (Corradini, 1973) Stover and Evitt, 1978
*Fibrocysta* sp. A
*Fibrocysta* spp.
*Fibrocysta* cf. *F. bipolaris* (Cookson and Eisenack, 1965b) Stover and Evitt, 1978
*Fibrocysta vectensis* (Eaton, 1976) Stover and Evitt, 1978
*Florentinia cooksoniae* (C. Singh, 1971) Duxbury, 1980
*Florentinia ferox* (Deflandre, 1937b) Duxbury, 1980
*Geiselodinium psilatum* Jain and Millepied, 1973
*Glaphyrocysta* cf. *G.divaricata* (Williams and Downie, 1966c) Stover and Evitt, 1978
*Glaphyrocysta divaricata* (Williams and Downie, 1966c) Stover and Evitt, 1978
*Glaphyrocysta exuberans* (Deflandre and Cookson, 1955) Stover and Evitt, 1978
*Glaphyrocysta ordinata* (Williams and Downie, 1966c) Stover and Evitt, 1978
*Glaphyrocysta perforata* Hultberg and Malmgren, 1985.
*Glaphyrocysta* sp. B
Granodiscus granulatus
*Hystrichodinium pulchrum* Deflandre, 1935
*Hystrichosphaeridium* cf. *H. tubiferum* (Ehrenberg, 1838) Deflandre, 1937b emend. Davey and Williams, 1966b
*Hystrichosphaeridium* sp.
*Hystrichosphaeridium tubiferum* (Ehrenberg, 1838) Deflandre, 1937b emend. Davey and Williams, 1966b
*Isabelidinium cooksoniae* (Alberti, 1959b) Lentin and Williams, 1977a
*Kallosphaeridium*? sp.
*Kallosphaeridium*? *ringnesiorum* (Manum and Cookson, 1964) Helby, 1987b
*Kenleyia leptocerata* Cookson and Eisenack, 1965b.

*Kenleyia* cf. *K. lophophora* Cookson and Eisenack, 1965b.
*Kenleyia* sp. A.
*Lejeunecysta* sp.
*Leiosphoeridia* sp. A
*Leiosphaeridia* sp. B
*Manumiella raijae* (Kjellström, 1973) Bujak and Davies, 1983
*Manumiella seelandica* (Lange, 1969) Bujak and Davies, 1983 emend. Firth, 1987
*Membranilarnacia*? sp.
*Micrhystridium* sp.
*Micrhystridium* sp. cf. *M. castaneoideum* Stockmans and Willière, 1969
*Odontochitina operculata* (O. Wetzel, 1933a) Deflandre and Cookson, 1955
*Odontochitina porifera* Cookson, 1956
*Odontochitina* spp.
*Oligosphaeridium complex* (White, 1842) Davey and Williams, 1966b
*Palaeocystodinium australinum* (Cookson, 1965b) Lentin and Williams, 1976
*Palaeocystodinium benjaminii* Drugg, 1967
*Palaeocystodinium lidiae* (Gorka, 1963) Davey, 1969b
*Palaeocystodinium* sp.A of Bujak and Davies, 1983
*Palaeocystodinium* sp. B
*Palaeocystodinium* sp. C
*Palaeocystodinium* cf. *P. golzowense* Alberti, 1961
*Palaeocystodinium* spp.
*Palaeohystrichophora infusorioides* Deflandre, 1935
*Palaeoperidinium* cf. *P. pyrophorum* (Ehrenberg, 1838) Sarjeant, 1967b
*Palaeoperidinium cretaceum* Pocock, 1962a
*Palambages* spp.
*Palambages morulosa* Wetzel, 1991
*Phelodinium gaditanum* (Riegel, 1974b) Lentin and Williams, 1981 emend. Riegel and Sarjeant, 1982
*Phelodinium* sp.
*Pierceites pentagona* (May, 1980) Habib and Drugg, 1987
*Pterospermopsis australiensis* Deflandre and Cookson, 1954
*Pterospermopsis ginginensis* Deflandre and Cookson, 1955
*Pterospermopsis* spp.
*Senegalinium laevigatum* (Malloy, 1972) Bujak and Davies, 1983
*Senegalinium* spp.
*Spinidinium*? sp.
*Spinidinium* cf. *S.densispinatum* Stanley, 1965
*Spinidinium*? sp. A
*Spinidinium* sp. B
*Spinidinium* sp. C
*Spiniferites* cf. *S. lenzii* Below, 1982c
*Spiniferites cornutus* subsp. *laevimurus* (Davey and Williams, 1966a) Lentin and Williams, 1973.
*Spiniferites cornutus* subsp. A
*Spiniferites fluens* (Hansen, 1977) Stover and Williams, 1987
*Spiniferites ramosus* subsp. *ramosus* Ehrenberg, 1838
*Spiniferites septatus* (Cookson and Eisenack, 1967b) McLean, 1971
*Spiniferites* cf. *S.*? *dentatus* (Gocht, 1959) Lentin and Williams, 1973
*Spiniferites* spp.
*Spiniferites supparus* (Drugg, 1967) Sarjeant, 1970
*Spiniferites twistringiensis* Maier, 1959. Fensome et al., 1990a
*Spiniferites wetzelii* (Deflandre, 1937b) Sarjeant, 1970a
*Subtilisphaera*?*pirnaensis* (Alberti, 1959b) Jain and Millepied, 1973
*Subtilisphaera* sp.
*Subtilisphaera zawia* Below, 1981a
*Systematophora placacantha* (Deflandre and Cookson, 1955) Davey et al., 1969 emend. May, 1980
*Tanyosphaeridium regulare* Davey and Williams, 1966b
*Tanyosphaeridium salpinx* Norvick, in Norvick and Burger, 1976
*Tanyosphaeridium* sp.
*Tanyosphaeridium variecalamus* Davey and Williams, 1966b
*Tanyosphaeridium xanthiopyxides* (O. Wetzel, 1933b) Stover and Evitt, 1978
*Tasmanites* sp
*Thalassiphora pelagica* (Eisenack, 1954b) Eisenack and Gocht, 1960 emend. Benedek and Gocht, 1981a
*Trichodinium castanea* (Deflandre, 1935) Clarke and Verdier, 1967
*Trichodinium* cf. *T. hirsutum* Cookson, 1965b

## APPENDIX B

Alphabetical list of spore and pollen taxa recorded in this study.

*Arecipites* sp. *Brevicolporites* sp.
*Buttinia andreevi* Boltenhagen, 1967
*Chenopodipollis* sp.*Circulina parva* Brenner, 1963
*Corollina jardinei* Herngreen, 1972
*Corollina torosus* (Reissinger) Klaus 1955 emend. Cornet and Traverse, 1975
*Corollina*? sp.
*Corrugatisporites ivoriensis* Jardiné and Magloire, 1965
*Cyathidites minor* Couper, 1963
*Deltoidospora* sp.
*Dicolpites* sp.
*Elaterosporites castelaini* Jardiné and Magloire, 1965
*Ephedripites multicostatus* Brenner, 1963
*Ephedripites* sp. 1
*Ephedripites* sp. 2
*Ephedripites* sp. 3
*Ephedripites* spp.
*Foveotricolpites* sp.
*Foveotriletes margaritae* Germeraad, Hopping and Muller, 1968
*Granulatisporites* sp.
*Laevigatosporites gracilis* Wilson and Webster, 1946
*Leiotriletes* spp.
*Longapertites vaneendenburgi* Germeraad, Hopping and Muller, 1968
*Monocolpopollenites* sp.
*Monosulcites* spp.
*Multiporopollenites* sp. 1
*Multiporopollenites* sp. 2
*Parvisaccites* cf. *P. radiatus* Couper, 1963
*Proxapertites*? sp.
*Retitriporites* sp.
*Rugulatisporites caperatus* van Hoeken-Klinkenberg, 1964
*Striamonocolpites* sp.
*Striatopollis* sp.
*Toroisporis* sp.
*Tricolpites reticulominutus* Jardiné and Magloire, 1965
*Tricolpites* sp. 1
*Tricolpites* sp. 2
*Tricolpites* sp. 3
*Tricolpites* sp. 4
*Tricolpopollenites* spp.
*Tricolporopollenites* spp.
Trilete spore
*Triorites africaensis* Jardiné and Magloire, 1965
*Triorites* cf. *T africaensis* Jardiné and Magloire, 1965
*Triporopollenites* sp.
*Verrutriletes* sp.

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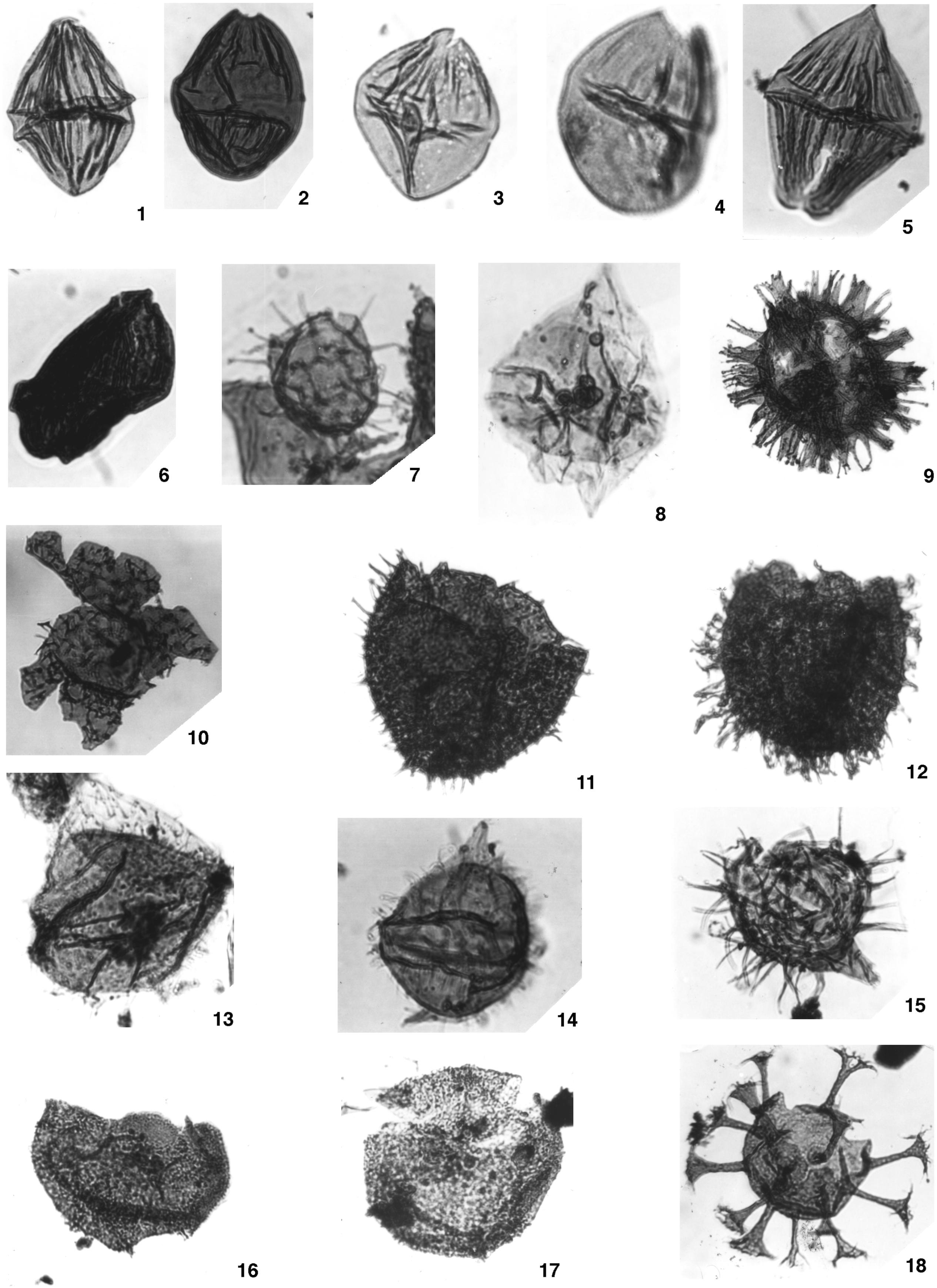
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Plate 1. All dinoflagellate cysts and acritarchs illustrated in Plates 1 to 9 are from Hole 959D, unless otherwise stated. All coordinates quoted in Plates 1 to 10 can be located on the Lovins Micro-Slide Field Finder (Catalog No. 7100). **1.** *Dinogymnium acuminatum* Evitt et al., 1967, Sample 159-959D-65R-6, 10−13 cm (1031.7 mbsf), P21 (4, –2.5), length: 56 µm. **2.** *Dinogymnium cretaceum* (Deflandre, 1935) Evitt et al., 1967, Sample 159-959D-67R-1, 10−14 cm (1043.4 mbsf), J10 (–4, –2.5), length: 56 µm. **3, 4.** *Alysogymnium euclaense* (Cookson and Eisenak, 1970) Lentin and Vozzhennikova, 1990, Sample 159-959D-56R-2, 80−82 cm (939.70 mbsf), (3) G28 (–3, –4), length: 48 µm, (4) T10 (5, –3), length: 43.2 µm. **5.** *Dinogymnium undulosum* Cookson and Eisenack, 1970, Sample 159-959D-49R-4, 99−102 cm (875.69 mbsf), Q20 (–4, –3), length: 78.4 µm. **6.** *Dinogymnium westralium* (Cookson and Eisenack, 1958) Evitt, et al., 1967, emend. May, 1977, Sample 159-959D-64R-5, 89−93 cm (1021.59 mbsf), T3 (0, 0), length: 56 µm. **7.** *Tanyosphaeridium salpinx* Norvick, in Norvick and Burger, 1976, Sample 159-959D-67R-1, 10−14 cm (1043.4 mbsf), P33 (1, 2), central body: 28.8 × 24 µm, processes length: 11.2 µm. **8.** *Subtilisphaera zawia* Below, 1981, Sample 159-959D-65R-6, 10−13 cm (1031.70 mbsf), J29 (–3, 2), length: 67.2 µm. **9.** *Florentinia ferox* (Deflandre, 1937) Duxbury, 1980, Sample 159-959D-64R-5, 89−93 cm (1021.59 mbsf), M9 (–4, –4), total length: 115 µm. **10.** *Cyclonephelium vannophorum* Davey 1969, antapical view. Note the precingular paraplates and part of the archeopyle suture. Sample 159-959D-67R-1, 10−14 cm (1043.4 mbsf), Q36/Q37, maximum length of the fragment: 60.8 µm. **11.** *Circulodinium distinctum* (Deflandre and Cookson, 1955) Jansonius, 1986, Sample 159-959D-64R-5, 89−93 cm (1021.59 mbsf), K33 (–4, –3), archeopyle length: 70.4 µm. **12.** *Circulodinium* sp. A., Sample 159-959D-64R-5, 89−93 cm (1021.59 mbsf), F4 (–4, –4), archeopyle length: 51.2 µm. **13, 14.** *Palaeohystrichophora infusorioides* Deflandre, 1935, (13) Sample 159-960A-21R-1, 43−48 cm (184.53 mbsf), D9 (4, –3), length: 52.8 µm, (14) 962B-9H-1, 69−73 cm (74.69 mbsf), P12 (–3, –3.5), length: 60.8 µm. **15.** *Coronifera oceanica* Cookson and Eisenack, 1958 emend. May, 1980, Sample 159-959D-67R-1, 10−14 cm (1043.4 mbsf), G31 (–3, –3), central body breadth: 48 µm, antapical horn: 16 µm. **16, 17.** *Canningia senonica* Clarke and Verdier, 1967, Sample 159-959D-65R-6, 10−13 cm (1031.70 mbsf), (16) F29 (–4, –4), breadth: 56 µm, (17) H22 (2.5, 4), breath: 56 µm. **18.** *Oligosphaeridium complex* (White, 1842) Davey and Williams, 1966, Sample 159-959D-64R-5, 89−93 cm (1021.59 mbsf), H19 (3, –1), central body breadth: 54 µm, length of processes: 24 to 27.2 µm.

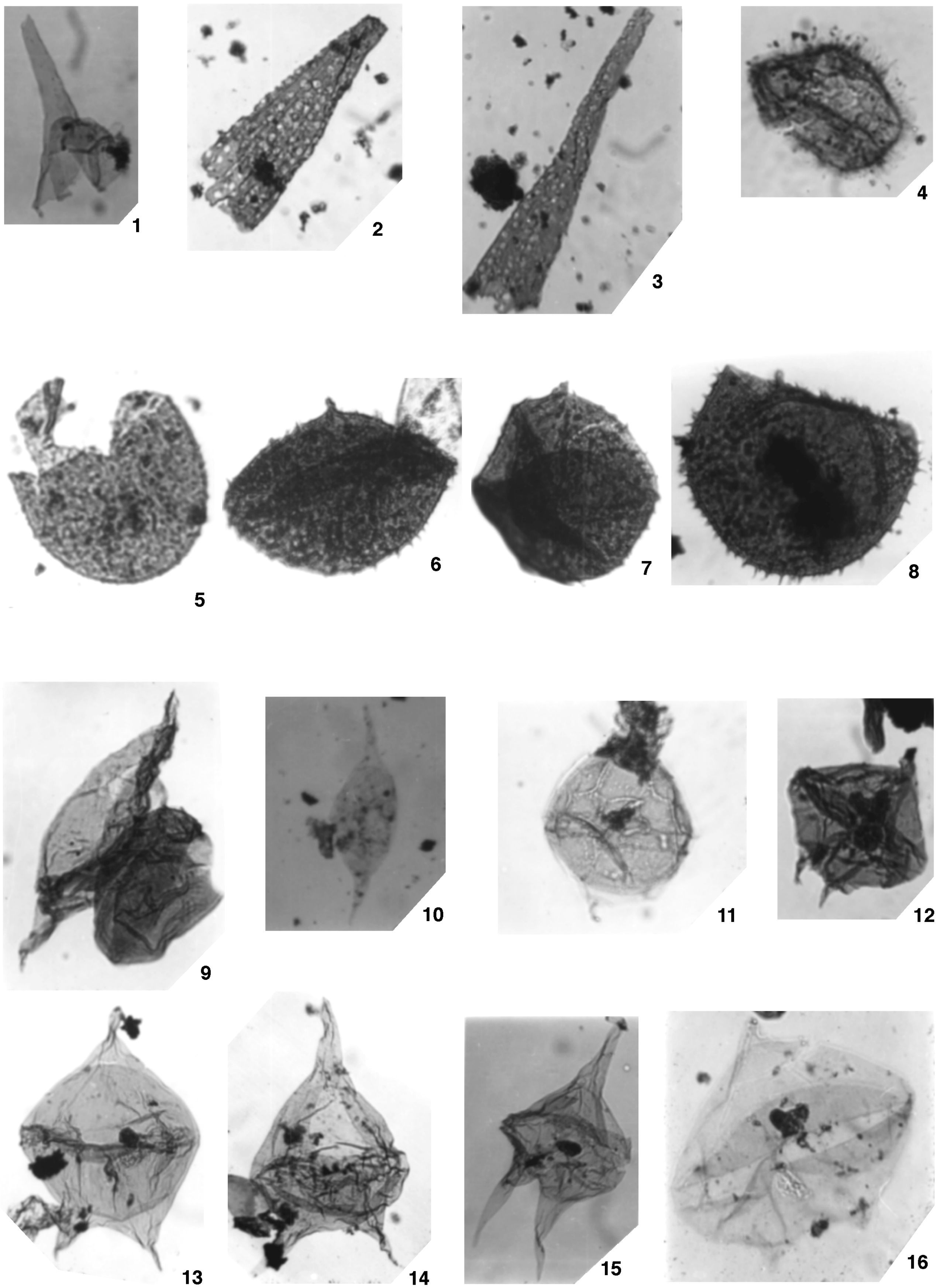
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Plate 2. **1.** *Odontochitina operculata* (O. Wetzel, 1933) Deflandre and Cookson, 1955, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), A10/A11, length: 65.6 µm. **2, 3.** *Odontochitina porifera* Cookson, 1956, Sample 159-959D-62R-1, 21–24 cm (995.61 mbsf), (2) M31 (–2.5, 0), length: 84.8 µm, (3) C7 (–2, –1), length 113.6 µm. **4.** *Cometodinium* sp. cf. *C.?whitei* (Deflandre and Courteville, 1939) Stover and Evitt, 1978, Sample 159-959D-67R-1, 10–14 cm (1043.4 mbsf), E6 (–2.5, 0), breadth: 45 µm. **5.** *Kallosphaeridium ?ringnesiorum* (Manum and Cookson, 1964) Helby, 1987, Sample 159-959D-62R-1, 21–24 cm (995.61 mbsf), H6 (–1, 3), breadth: 41.6 µm. **6–8.** *Trichodinium castanea* (Deflandre, 1935) Clarke and Verdier, 1967, Sample 159-959D-60R-2, 100–104 cm (978.6 mbsf), (6) K22 (–4, 5), breadth: 80 µm, (7) B8 (0, 4), breadth; 64 µm, (8) S8 (3.5, 4), breadth: 54.4 µm.**9.** *Palaeocystodinium lidiae* (Gorka, 1963) Davey, 1969, Sample 159-959D-60R-2, 100–104 cm (978.6 mbsf), H15 (0, 0), length: 115.2 µm. **10.** *Palaeocystodinium* sp. A of Bujak and Williams, 1983, Sample 159-959D-53R-4, 67–70 cm (912.46 mbsf), P26 (4.5, 4.5), length: 192 µm. **11.** *Spinidinium* ?cf. *S. densispinatum* Stanley, 1965, Sample 159-959D-60R-2, 100–104 cm (978.6 mbsf), B21 (0, 4), length: 65 µm. **12.** *Geiselodinium psilatum* Jain and Millepied, 1973, Sample 159-959D-60R-2, 100–104 cm (978.6 mbsf), M7 (–1, –3), breadth: 56 µm. **13.** *Cerodinium boloniense* (Riegel, 1974) Lentin and Williams, 1989, Sample 159-959D-59R-2, 45–50 cm (968.45 mbsf), R9/R8, length: 131.2 µm. **14.** *Cerodinium obliquipes* (Deflandre and Cookson, 1955) Lentin and Williams, 1987, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), L23 (–2.5, 4), length: 160 µm. **15.** *Cerodinium diebelii* (Alberti, 1959) Lentin and Williams, 1987, Sample 159-959D-51R-2, 55–57 cm (891.25 mbsf), H6 (1.5, 1.5), length: 141.6 µm. **16.** *Phelodinium gaditanum* (Riegel, 1974) Lentin and Williams, 1981 emend. Riegel and Sarjeant, 1982, Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), H18 (1, 2.5), breadth: 86.4 µm.

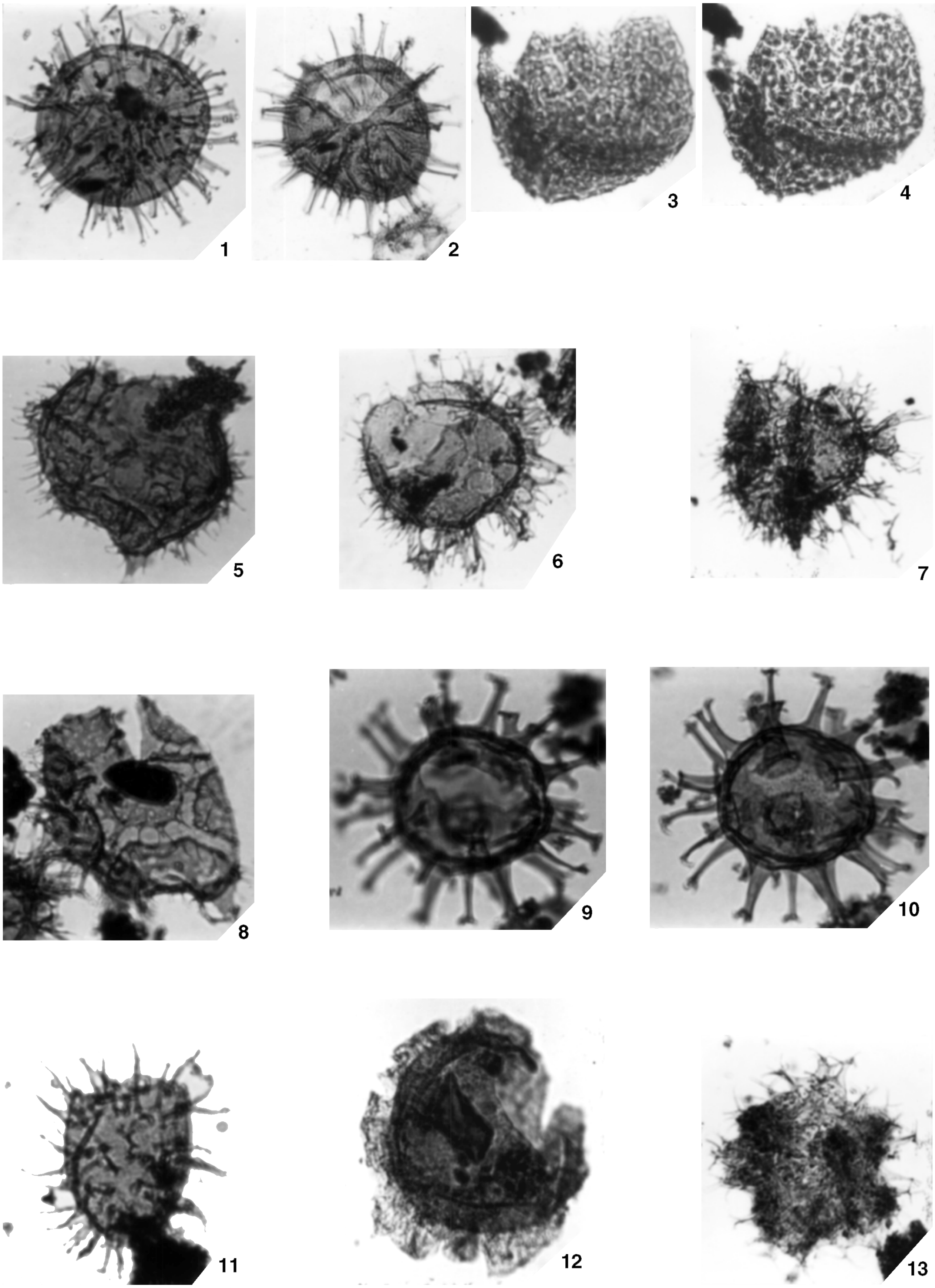
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Plate 3. **1, 2.** *Exochosphaeridium bifidum* (Clarke and Verdier, 1967) Clarke et al., 1968, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), L6 (–3, 3), central body diameter: 56 µm. **3, 4.** *"Chytroeisphaeridia everricula"* of Wilson (1974), Sample 159-959D-59R-2, 45–50 cm (968.45 mbsf), R8 (–2, –1), breadth 75.2 µm, (3) high focus, (4) low focus. **5.** *Areoligera senonensis* Lejeune-Carpentier, 1938, Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), R10 (0, 1), breadth: 59.2 µm. **6, 7.** *Areoligera coronata* (O. Wetzel, 1933b) Lejeune-Carpentier, 1938, (6) Sample 159-959D-52R-1, 18–20 cm (898.98 mbsf), D5/D4, central body breadth: 51.2 µm, (7) Sample 159-959D-57R-1, 31–34 cm (947.41 mbsf), A4 (–1, –1), central body breadth: 62.4 µm. **8.** *Systematophora placacantha* (Deflandre and Cookson, 1955) Davey et al., 1969 emend. 1980, Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), R11 (0, –3), length: 56 µm. **9, 10.** *Hystrichosphaeridium tubiferum* (Ehrenberg, 1838), Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), (9) high focus, G30 (–3, 3), central body diameter: 40 µm, length of processes up to 16 µm, (10) same specimen, low focus. **11.** *Tanyosphaeridium regulare* Davey and Williams, 1966, Sample 159-959D-58R-1, 2–5 cm (956.82 mbsf), G19 (4, 4), central body: 35.2 µm × 27 µm. **12.** *Cordosphaeridium fibrospinosu* Davey and Williams, 1966, Sample 159-959D-56R-2, 80–82 cm (939.70 mbsf), K23 (4, 3), central body diameter: 75.2 µm. **13.** *Spiniferites supparus* (Drugg, 1967) Sarjeant, 1970, Sample 159-959D-56R-2, 80–82 cm (939.70 mbsf), G23 (3, 5), length: 80 µm.

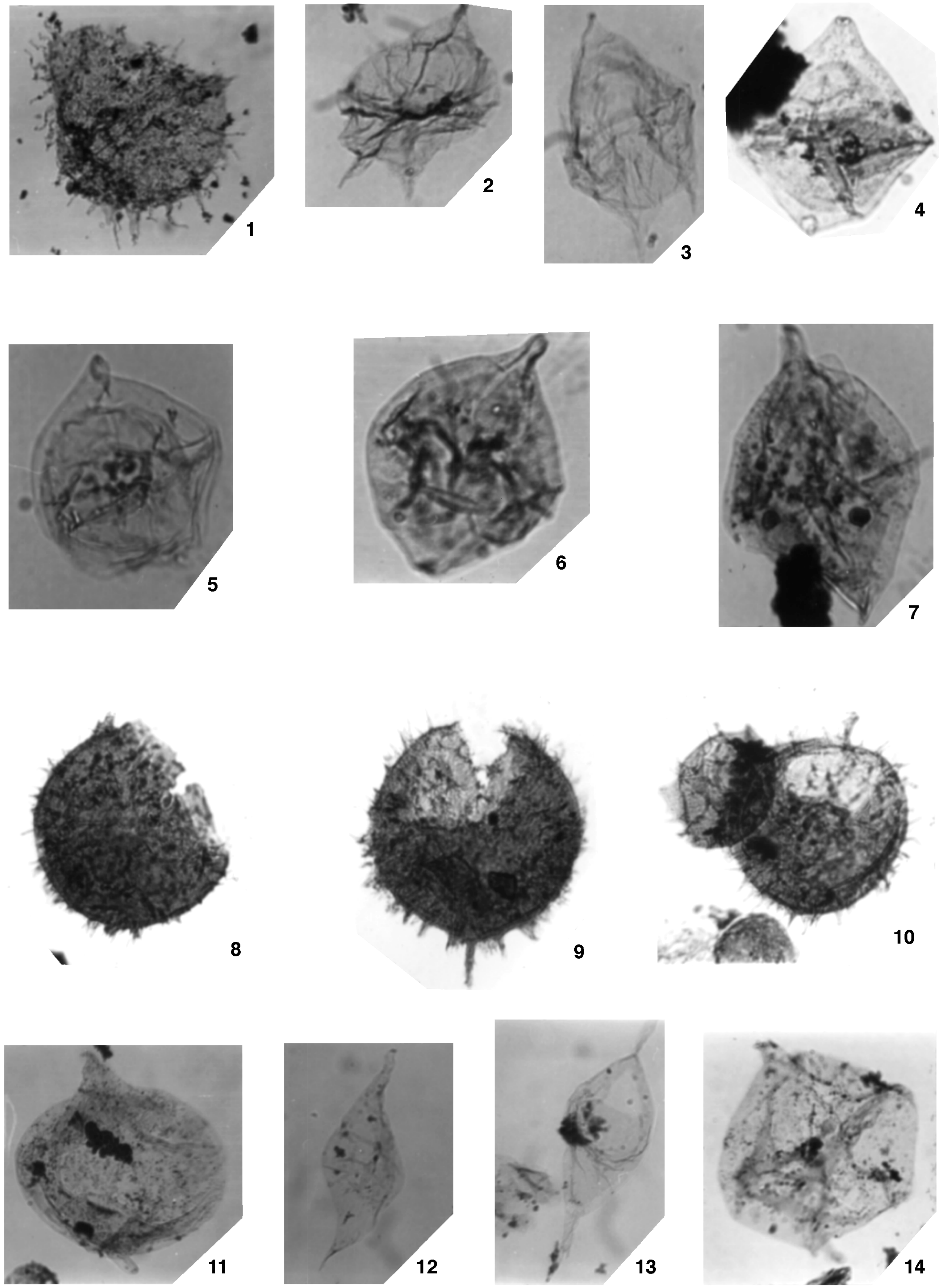
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Plate 4. **1.** *Hystrichodinium pulchrum* Deflandre 1935, Sample 159-959D-62R-1, 21–24 cm (995.61 mbsf), B16 (0, 2), length: 70 µm. **2, 3.** *Cerodinium* sp. A. Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), T20 (3, –3), (2) length: 57.6 µm, (3) length: 72 µm. **4.** *Alterbidinium varium* Kirsch, 1991, Sample 159-959D-54R-1, 37–39 cm (918.47 mbsf), K7 (–5, –4), length: 49.6 µm. **5–7.** *Manumiella raijae* (Kjellström, 1973) Bujak and Davies, 1983, Sample 159-959D-54R-1, 37–39 cm (918.47 mbsf), (5) M30 (1, 0), length: 49.6 µm, (6) N4 (–2, –1), length: 57.6 µm, (7) U34 (4, 3), length: 67.2 µm. **8–10.** *Trichodinium* cf. *T. hirsutum* Cookson, 1965, Sample 159-959D-52R-1, 18–20 cm (898.98 mbsf), (8) S10 (3, 2.5), length: 96 µm, (9) D25 (1, –3), central body diameter: 73.6 µm × 78.4 µm, (10) M31 (1, 1), central body diameter: 72 µm, processes: 6.4 µm–11.2 µm, apical process: 16 µm. **11.** *Andalusiella gabonensis* Stover and Evitt, 1978, Sample 159-959D-52R-1, 18–20 cm (898.98 mbsf), A31 (–2, –2.5), length: 115.2 µm. **12.** *Palaeocystodinium* sp. B, Sample 159-959D-52R-1, 18–20 cm (898.98 mbsf), G24 (–2, –3), length: 121.6 µm. **13.** *Palaeocystodinium australinum* (Cookson, 1965) Lentin and Williams, 1976, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), C5 (5, 4), length: 168 µm. **14.** *Senegalinium laevigatum* (Malloy, 1972) Bujak and Davies, 1983, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), M31 (2, –4), breadth: 75.2 µm.

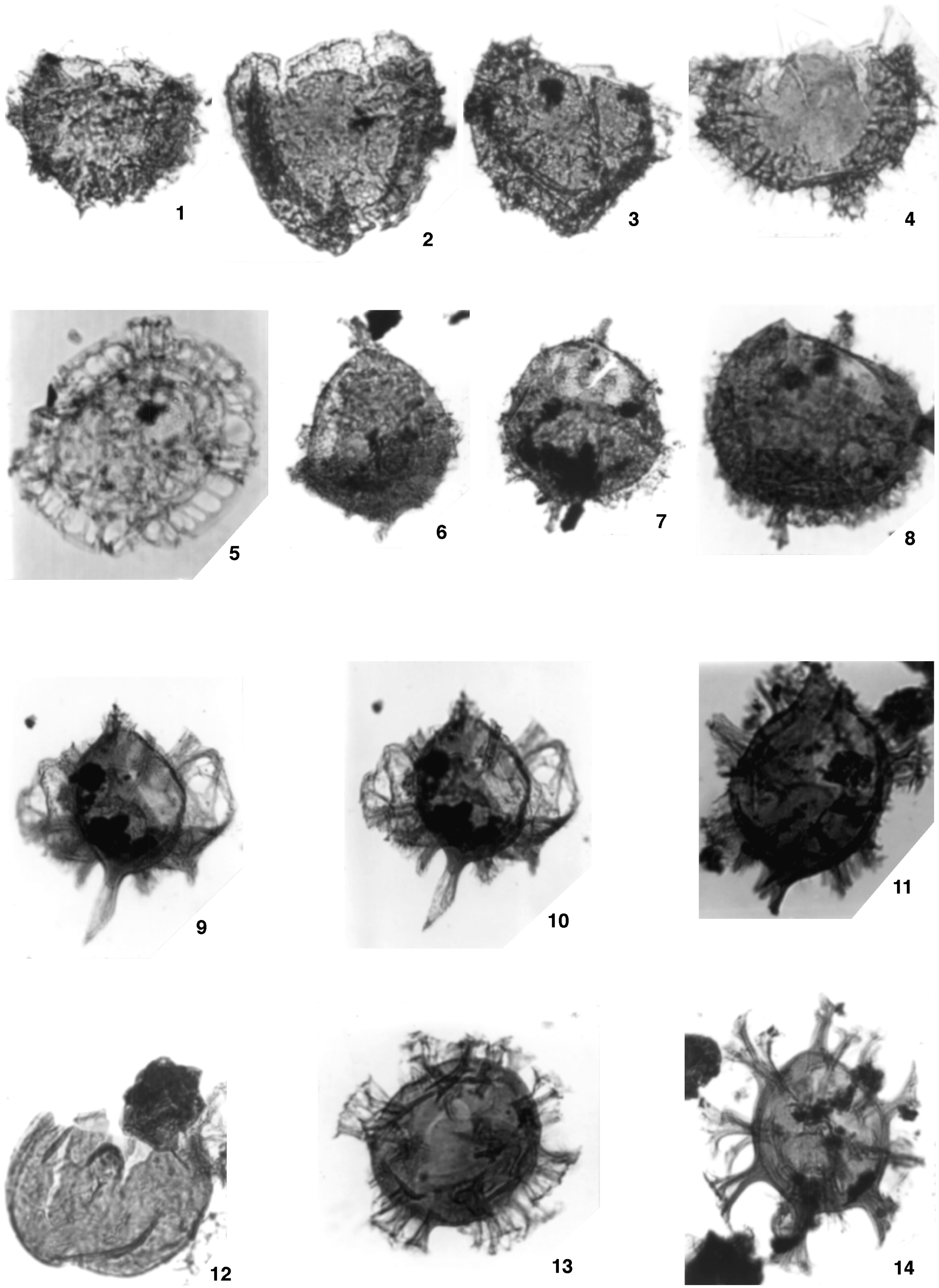
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Plate 5. **1.** *Cyclonephelium crassimarginatum* Cookson and Eisenack, 1974, Sample 159-959D-57R-1, 31–34 cm (947.41 mbsf), 57/58, overall breadth: 75 µm. **2.** *Cyclonephelium compactum* Deflandre and Cookson, 1955, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), B17 (–4, –4), breadth: 60.8 µm. **3.** *Cyclonephelium* cf. *C. paucispinum* Davey, 1969, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), K3 (2, 5), breadth: 67.2 µm. **4.** *Cyclonephelium* sp. A., Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), A2 (5, 5), archeopyle breadth: 64 µm. **5.** *Membranilarnacia*?sp. Morgenroth, 1968, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), F14 (–1.5, –1.5), central body: 43.2 µm × 49.6 µm. **6–8.** *Kenleyia leptocerata* Cookson and Eisenack, 1965, Sample 159-959D-51R-5, 53–56 cm (895.73 mbsf), (6) M17 (2, –1), length: 99.2 µm, (7) T10 (3, 1), length: 96 µm, (8) N25 (1, 4), breadth: 80 µm. **9, 10.** *Cyclapophysis monmouthensis* O. Wetzel, 1933 emend. Sarjeant, 1985, Sample 159-959D-51R-2, 55–57 cm (891.25 mbsf), (9) high focus, F22 (2, 3), length: 120 µm, (10) same specimen, low focus. **11.** *Cordosphaeridium* sp**.** A., Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), E31 (–2, 2) length: 105.6 µm. **12.** *Chytroeisphaeridia* sp**.** A**,** Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), C33 (3, 4), breadth: 88 µm. **13.** *Cordosphaeridium exilimurum* Davey and Williams, 1966, Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), J30 (–4, 2), central body: 64 µm × 56 µm, processes up to 19.2 µm. **14.** *Cordosphaeridium* cf. *C. inodes* (Klumpp, 1953) Eisenack, 1963 emend. Morgenroth, 1968, Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), C6 (2, –4), central body 72 µm × 57.6 µm.

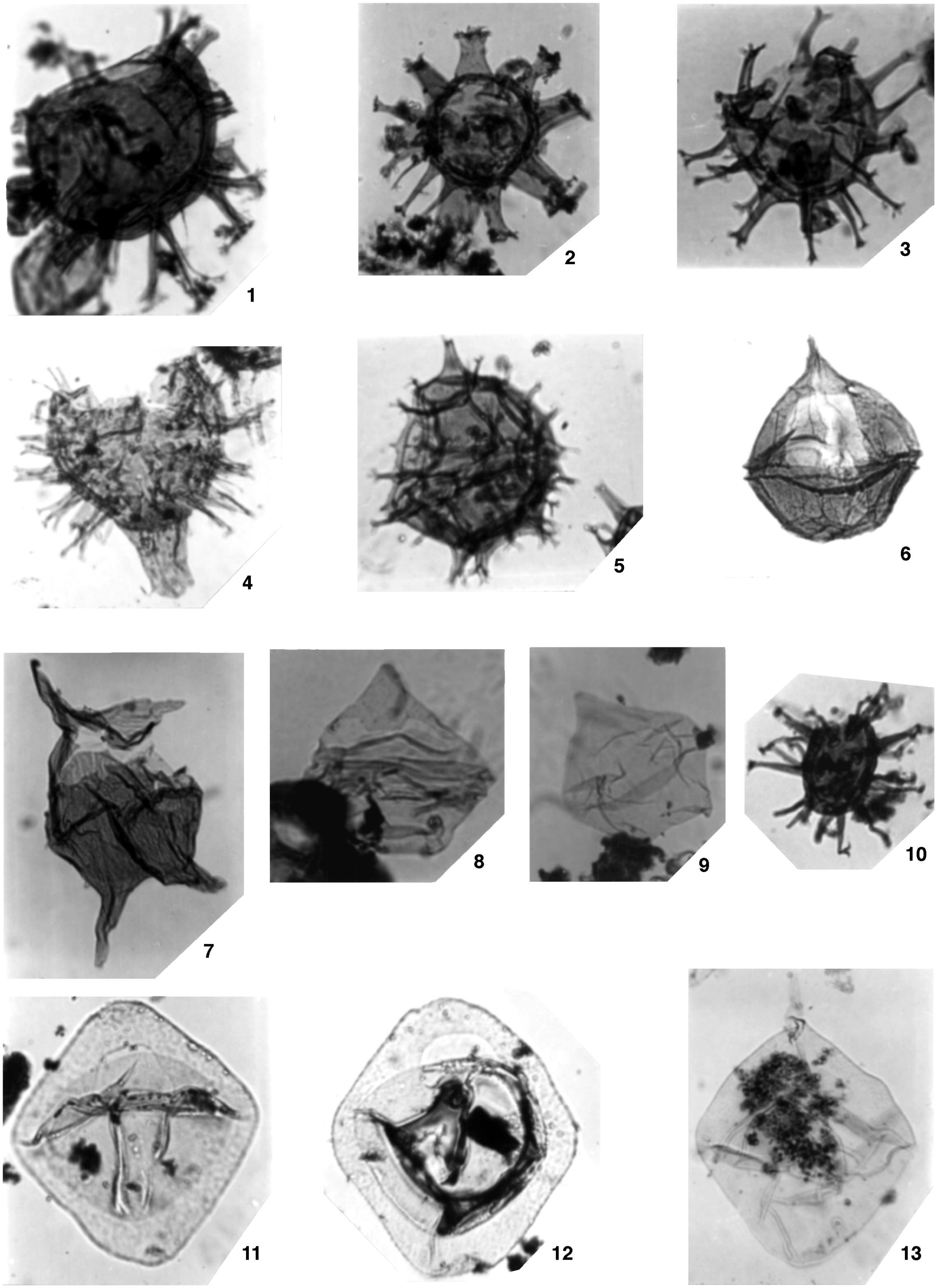
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Plate 6. **1.** *Cordosphaeridium inodes* (Klumpp, 1953) Eisenack, 1963 emend. Morgenroth, 1968, Sample 159-959D-50R-4, 105–108 cm (885.45 mbsf), C19 (–3, –4), central body: 73.6 µm × 64 µm. **2.** *Florentinia cooksoniae* (C. Singh, 1971) Duxbury, 1980, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), L8 (–3, –4), central body diameter: 40 µm. **3.** *Diphyes colligerum* (Deflandre and Cookson, 1955) Cookson, 1965a emend. Goodman and Witmer, 1985, Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), U30 (1,-1.5), overall breadth: 72 µm. **4.** *Diphyes* cf. *D. colligerum* (Deflandre and Cookson, 1955) Cookson, 1965 emend. Goodman and Witmer, 1985, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), E18 (0, –3), archeopyle breadth: 48 µm. **5.** *Spiniferites cornutus* subsp. *laevimurus* (Davey and Williams, 1966) Lentin and Williams, 1973, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), Q20 (–4, 3), length: 67.2 µm. **6.** *Cribroperidinium wetzelii* (Lejeune-Carpentier, 1939) Helenes, 1984, Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), D-5/E-5, length: 104 µm. **7.** *Cerodinium striatum* (Drugg, 1967) Lentin and Williams, 1987, Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), B29 (2, –3), length: 84.8 µm. **8.** *Pierceites pentagona* (May, 1980) Habib and Drugg, 1987, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), C30/C29, length: 23 µm. **9.** *Lejeunecysta sp*., Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), A18 (–5, –5), breadth: 51.2 µm. **10.** *Hystrichosphaeridium* cf. *H. tubiferum* (Ehrenberg, 1838), Sample 159-959D-49R-2, 99–102 cm (872.69 mbsf), K26 (2.5, 1), central body breadth: 24 µm. **11–13.** *Manumiella seelandica* (Lange, 1969) Bujak and Davies, 1983 emend. Firth, 1987, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), (11) J8 (2, 2.5), length: 91.2 µm, (12) K32 (–2, –2), length: 96 µm, (13) C21 (1.5, 1), length: 120 µm.

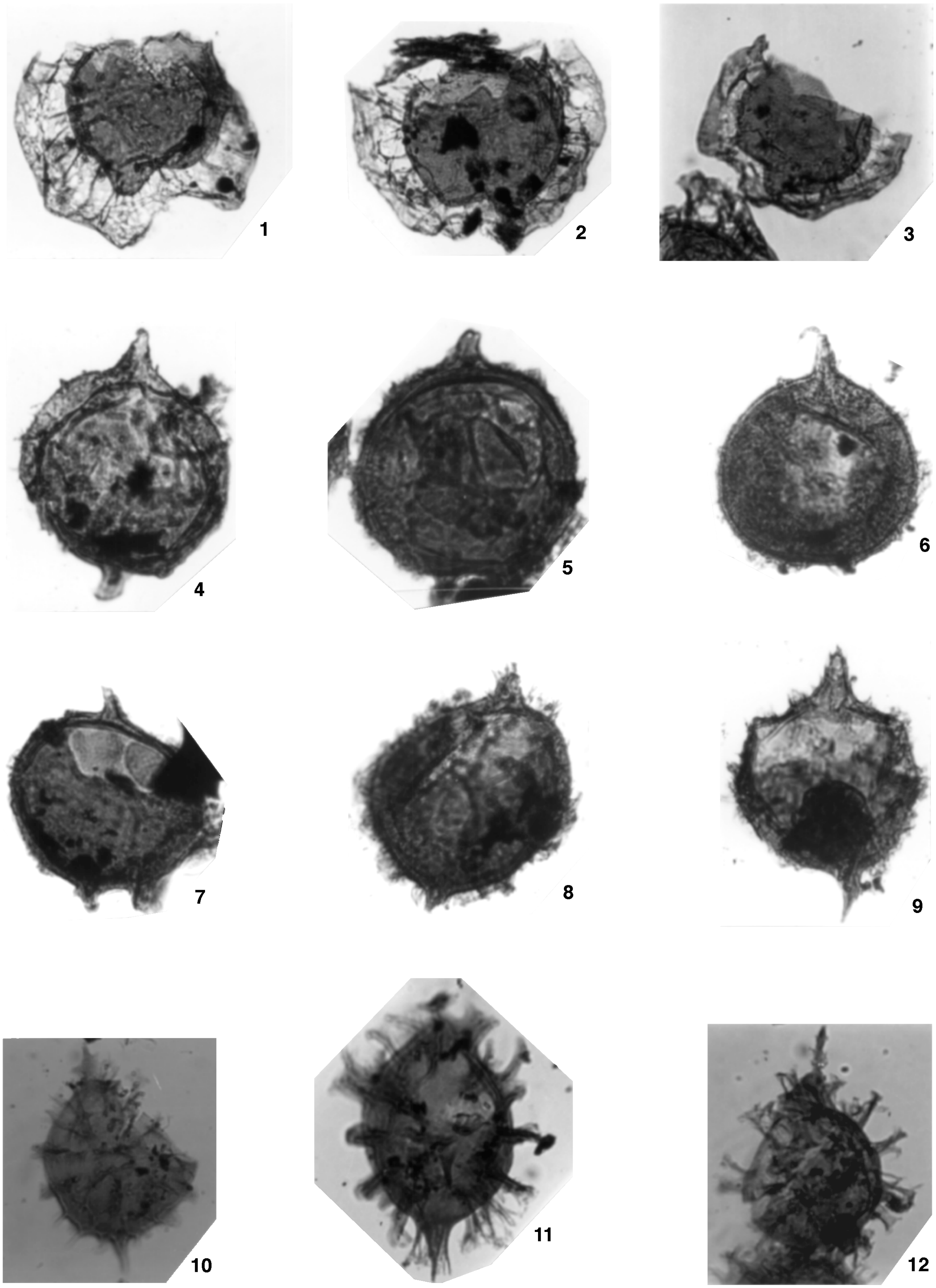
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Plate 7. **1–3.** *Glaphyrocysta perforata* Hultberg and Malmgren (1985), Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), (1) P27 (0, 0), central body breadth: 56 µm, (2) A25 (–3, –3), central body breadth: 67.2 µm, (3) F29 (1, 0), central body breadth: 59.2 µm. **4–7.** *Kenleyia* sp. A, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), (4) L3 (2, 3), length: 78.4 µm, (5) G12 (5, 5), length: 76.8 µm, (6) S4 (4, –2), length: 83.2 µm, (7) U2 (4, –2), length: 80 µm. **8, 9.** *Kenleyia* cf. *K. lophophora* Cookson and Eisenack, 1965, Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), (8) K33 (–1, –1), length: 92.8 µm. (9) A24 (0, 4), length: 99.2 µm. **10, 11.** *Fibrocysta bipolaris* (Cookson and Eisenack, 1965) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), (10) F13 (0, –4), length: 96 µm, (11) A32 (–3, 5), length: 92.8 µm. **12.** *Fibrocysta* cf. *F. bipolaris* (Cookson and Eisenack, 1965) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), F33 (–3, –2), central body breadth: 48 µm.

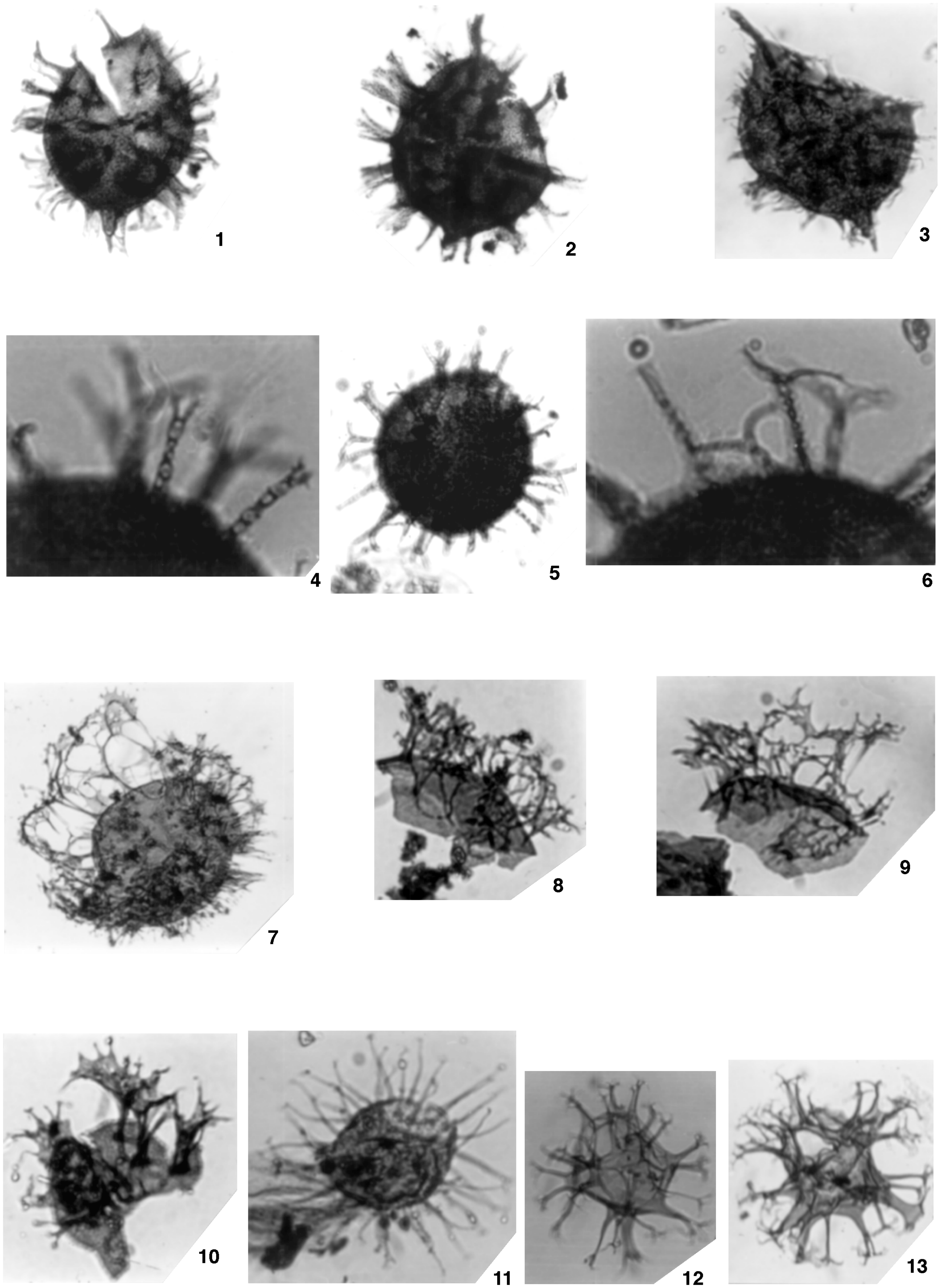
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Plate 8. **1, 2.** *Fibrocysta vectensis* (Eaton, 1976) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), (1) D26 (2, 4), length: 64 µm, (2) A29 (4, 3), length: 83.2 µm. **3.** *Fibrocysta bipolaris* (Cookson and Eisenack, 1965) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), C15 (3, 1), length: 100.8 µm. **4–6.** *Spiniferites septatus*, (Cookson and Eisenack, 1967) McLean, 1971, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), (4) F31 (4, 1), processes length: 10–14 µm, (5) same specimen, overall breadth: 73 µm, (6) same specimen, processes length: 10–14 µm. **7.** *Glaphyrocysta exuberans* (Deflandre and Cookson, 1955) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), central body diameter: 45 µm, length of processes up to 25.6 µm. **8, 9.** *Glaphyrocysta divaricata* (Williams and Downie, 1966) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), (8) D26 (–4, –2), operculum breadth: 43.2 µm. (9) S31 (–1, 1), operculum breadth: 38.4 µm. **10.** *Glaphyrocysta ordinata* (Williams and Downie, 1966) Stover and Evitt, 1978, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), B25 (0, –2), operculum breadth: 36.8 µm. **11.** *Cleistosphaeridium flexuosum* Davey et al., 1966, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), C18 (–2, –1), central body breadth: 24 µm. **12, 13.** *Spiniferites ramosus* subsp*. ramosus* Ehrenberg, 1838, (12) Sample 159-959D-50R-1, 105–108 cm (880.95 mbsf), C29 (1, –1), overall length: 67.2 µm, (13) Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), P1 (1, –2), total length: 72 µm.

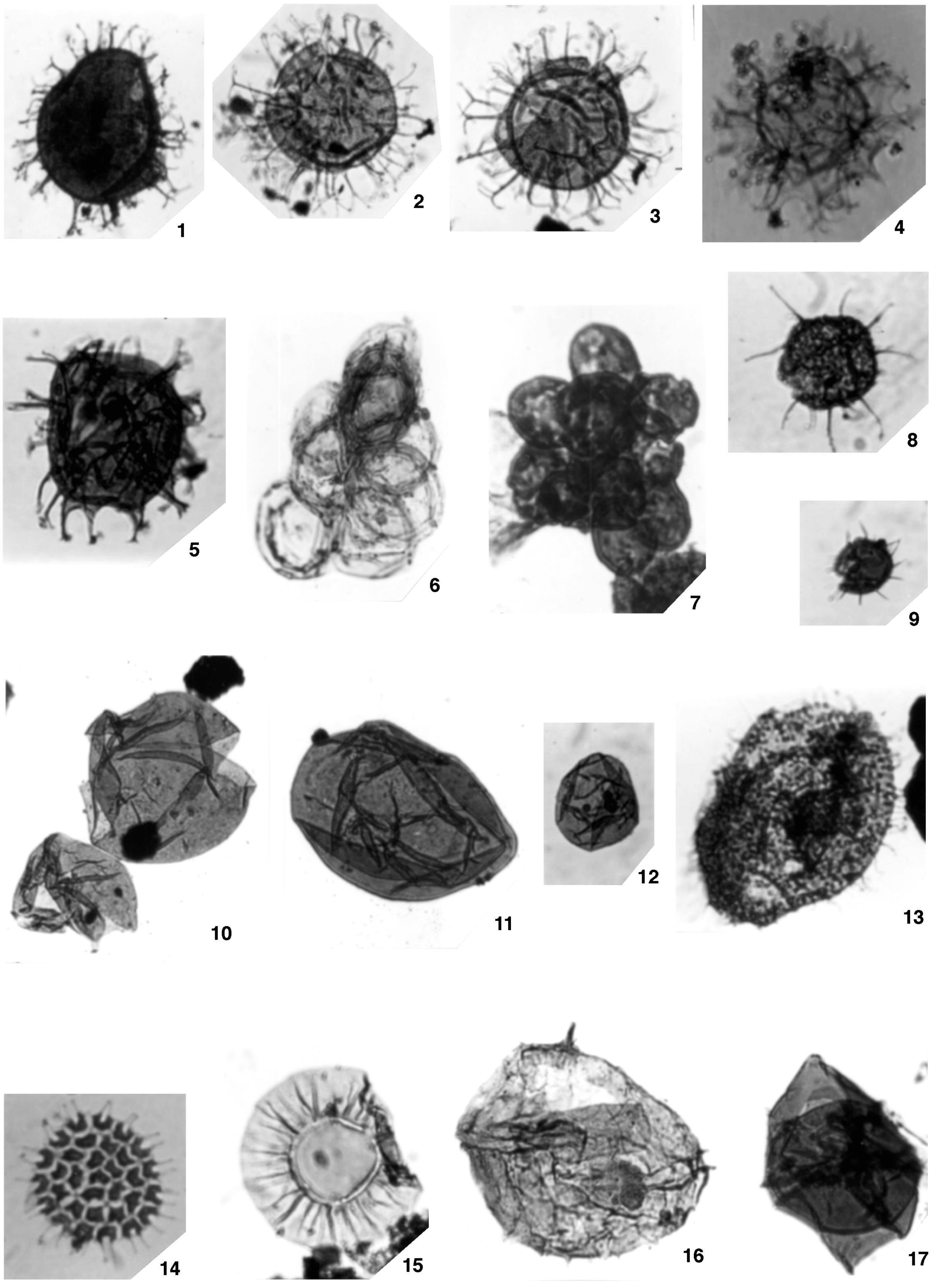
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Plate 9. All specimens are from Hole 959D except Figures 16 (Hole 962D) and 17 (Hole 960A). **1.** *Spiniferites fluens* (Hansen, 1977) Stover and Williams, 1987, Sample 159-959D-54R-1, 37–39 cm (918.47 mbsf), N20 (0, 3), central body length: 52.8 µm. **2, 3.** *Spiniferites* cf. *S. lenzii* Below, 1982c, Sample 159-959D-51R-2, 55–57 cm (891.25 mbsf), (2) M7 (0, 0), overall length: 70.4 µm, (3) M6 (1, 1), overall length: 75 µm. **4.** *Spiniferites wetzelii* (Deflandre, 1937b) Sarjeant, 1970a, Sample 159-959D-48R-5, 37–41 cm (866.97 mbsf), E33 (3.5, 3), central body breadth: 30.4 µm. **5.** *Spiniferites twistringiensis* Maier, 1959 emend. Fensome et al., 1990, Sample 159-959D-67R-1, 10–14 cm (1043.4 mbsf), C12 (–4, 5), central body length: 44.8 µm. **6.** *Palambages morulosa* Wetzel, 1961. Sample 159-959D-49R-4, 99–102 cm (875.69 mbsf), F2 (–4, –2.5), average diameter of one cell in the colony: 33.6 µm**. 7.** *Palambages* sp., Sample 159-959D-52R-01, 18–20 cm (898.98 mbsf), B34 (–2.5, 0), average diameter of one cell in the colony: 16 µm. **8, 9.** *Micrhystridium* sp. (8) Sample 159-959D-64R-5, 89–93 cm (1021.59 mbsf), M28 (–4, 1), central body diameter: 20.8 µm, (9) Sample 159-959D-67R-1, 10–14 cm (1043.4 mbsf), M24 (–1, –3.5), central body diameter: 15 µm. **10, 11.** *Leiosphoeridia* sp. A, Sample 159-959D-64R-5, 89–93 cm (1021.59 mbsf), (10) K6 (–3, –4), diameter 44.8 × 51.2 µm, (11) J21 (1, 4), diameter: 81.6 × 56 µm. **12.** *Leiosphaeridia* sp. *B.*, Sample 159-959D-64R-5, 89–93 cm (1021.59 mbsf), L30 (5,-5), diameter: 35.2 µm × 28.8 µm. **13.** Acritarch forma A., Sample 159-959D-64R-5, 89–93 cm (1021.59 mbsf), H14/J14, length: 87.5 µm. **14.** *Pediastrum*? sp., Sample 159-960A-41R-2, 18–21 cm (352.68 mbsf), H30 (3, 5), diameter: 30.4 µm. length of processes: 4.8 µm. **15.** *Pterospermopsis australiensis* Deflandre and Cookson, 1954, Sample 159-959D-65R-6, 10–13 cm (1031.70 mbsf), K34 (–3, –3), diameter: 50 µm. **16.** *Cribroperidinium* cf. *C. auctificum* (Brideaux, 1971) Stover and Evitt, 1978, Sample 159-962D-27R-1, 80–83 cm (312.10 mbsf), J15 (–2, 4), length: 84.8 µm. **17.** *Isabelidinium cooksoniae* (Alberti, 1959) Lentin and Williams, 1977, Sample 159-960A-21R-1, 43–48 cm (184.53 mbsf), C13 (5, –5), length: 81.6 µm.

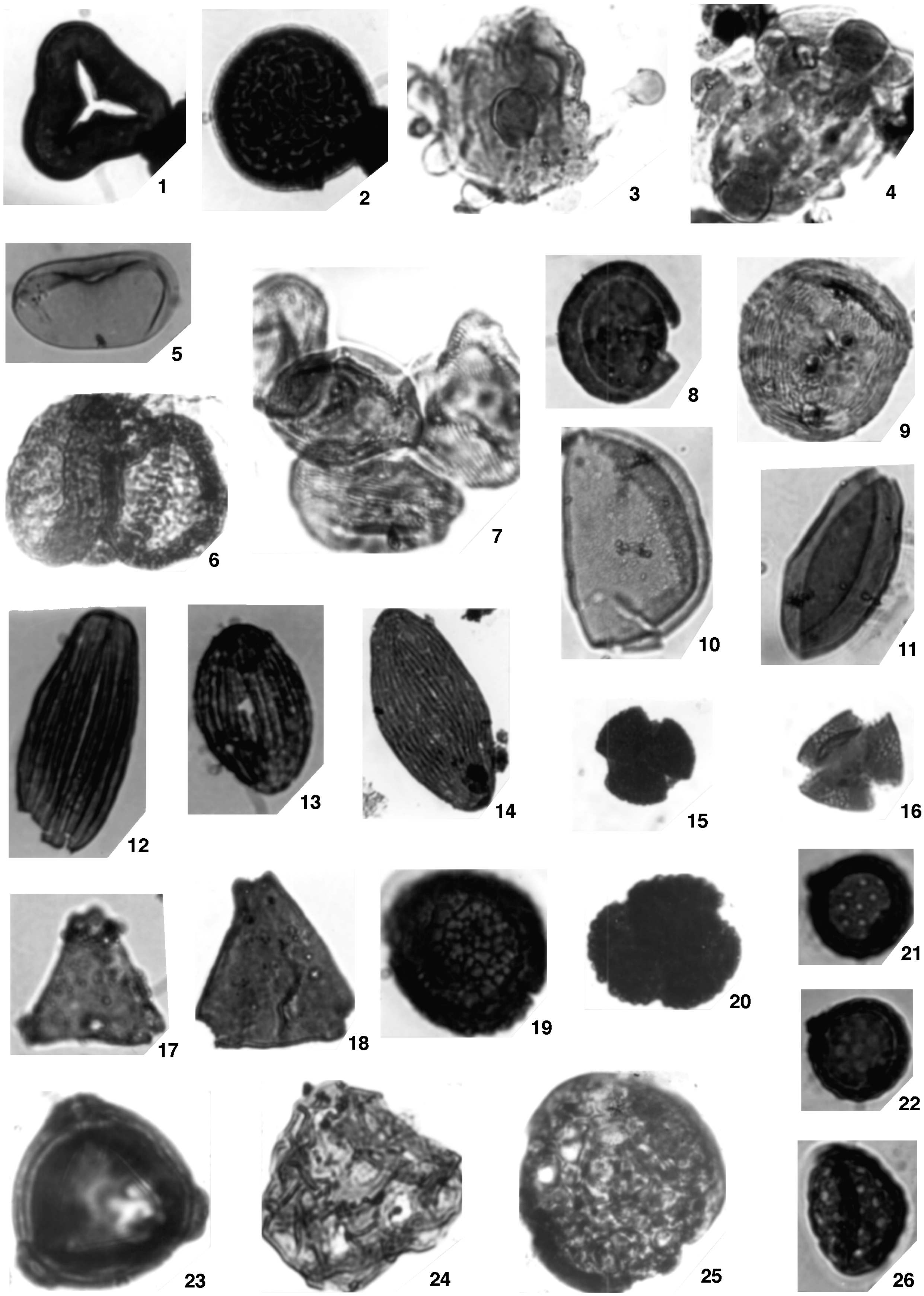
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Plate 10. Selected sporomorphs from Sites 959 to 962. Sizes quoted represent the maximum diameter or length of each specimen, unless otherwise stated. **1.** *Cyathidites minor* Couper, 1963, Sample 159-961B-12R-1, 68–71 cm, M32/N32, size 32 µm. **2.** *Rugulatisporites caperatus* van Hoeken-Klinkenberg, 1964, Sample 159-959D-60R-4, 94–96 cm, C23/C24, size 36.8 µm. **3, 4.** *Elaterosporites castelaini* Jardiné and Magloire, 1965, (3) Sample 159-962D-24R-2, 41–45 cm, L13 (0.0), size 44.8 µm (central body), (4) Sample 159-962D-31R-2, 89–92 cm, J20 (–1, 3), 54 µm. **5.** *Laevigatosporites gracilis* Wilson and Webster, 1946, Sample 159-959D-48R-5, 37–41 cm, N24/N25, 64 µm. **6.** *Parvisaccites* cf. *P. radiatus* Brenner, 1963, Sample 159-959D-49R-4, 99–102 cm, A25 (3, 2), 51.2 µm. **7.** *Corollina torosus* (Reissinger) Klaus 1955 emend. Cornet and Traverse, 1975, one tetrad, Sample 159-962D-37R-4, 81–84 cm, G6 (0, 3), 25.6 µm (lowermost grain). **8.** *Circulina parva* Brenner, 1963, Sample 159-962D-24R-2, 41–45 cm, G29 (–4, 4), 32 µm. **9.** *Corollina jardinei* Herngreen, 1972, Sample 159-962D-31R-2, 89–92 cm, E16 (–2, 2), 40 µm. **10.** *Longapertites vaneendenburgi* Germeraad, Hopping and Muller, 1968, Sample 159-959D-48R-5, 37–41 cm, P31 (–3, 5), 60.8 µm. **11.** *Monosulcites* sp. Sample 159-959D-49R-4, 99–102 cm, R4 (3, 2), 44.8 µm. **12.** *Ephedripites multicostatus* Brenner, 1963, Sample 159-961A-34R-2, 32–37 cm, S16 (0, 0), 57.6 µm. **13.** *Ephedripites* sp. 1, Sample 159-960A-60R-2, 73–76 cm, J23 (3, 2), 40 µm. **14.** *Ephedripites* sp. 2, Sample 159-962D-24R-2, 41–45 cm, E34 (4, –2), 128 µm. **15.** *Tricolpites reticulominutus* Jardiné and Magloire, 1965, Sample 159-959D-67R-1, 10–14 cm, E6 (2, 4), 16 µm. **16.** *Tricolpites* sp. 1. Sample 159-959D-67R-1, 10–14 cm, A3 (2, –4), 28.8 µm. **17.** *Triorites africaensis* Jardiné and Magloire, 1965, Sample 159-962D-37R-4, 81–84 cm, Q23 (2, 1), 28.8 µm. **18.** *Triorites* cf. *T. africaensis* Jardiné and Magloire, 1965, Sample 159-962D-24R-2, 41–45 cm, N10 (4, –4), 44 µm. **19.** *Proxapertites* sp. Sample 159-959D-64R-5, 89–93 cm, T10 (1, 3), 38.4 µm. **20.** *Tricolpites* sp. 2. Sample 159-959D-67R-1, 10–14 cm, C25 (4, –4), 36.8 µm. **21, 22.** *Chenopodipollis* sp. Sample 159-960A-21R-1, 43–48 cm, H26/H27, 24 µm; (21) low focus, (22) high focus. **23.** *Brevicolporites* sp. Sample 159-960A-59R-3, 26–29 cm, R34 (–1, –2), 16 µm. **24, 25.** *Buttinia andreevi* Boltenhagen, 1967, (24) Sample 159-959D-48R-5, 37–41 cm, E12 (–2, 4), 30.4 µm, (25) Sample 159-960A-53R-2, 29–32 cm, poorly preserved specimen, U17 (3, –4), 56 µm. **26.** *Multiporopollenites* sp. Sample 159-962B-8H-6, 61–66 cm, A22, 28.8 µm.

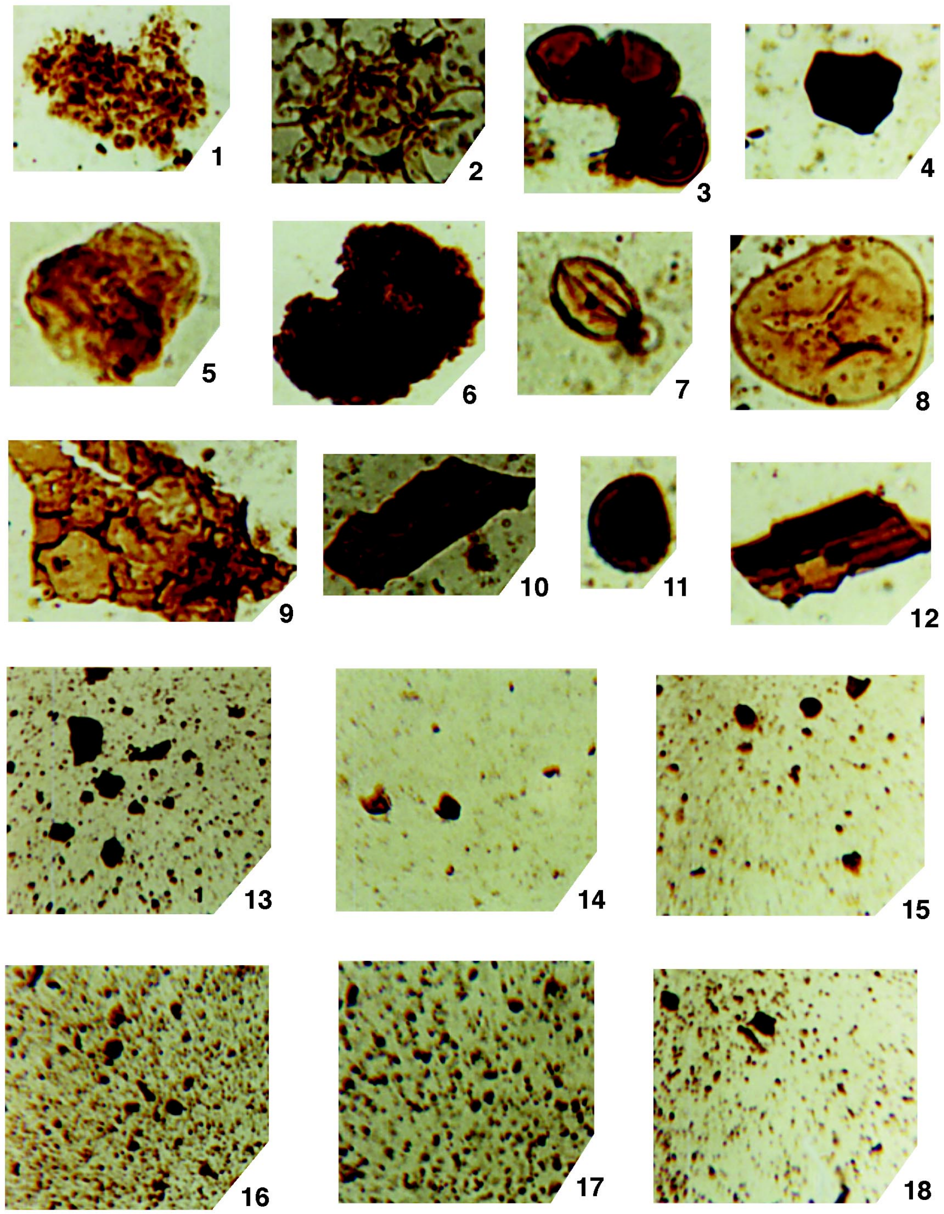


Plate 11. Some dispersed organic components used in the classification scheme (1–12), and selected palynofacies assemblages from Site 959 (13–17) and 960 (18). **1.** Amorphous organic matter, Sample 159-959A-33X-2, 143–146 cm. **2.** Dinoflagellate cyst, Sample 159-959D-44R-2, 4–6 cm. **3.** Microforaminiferal test lining, Sample 159-959A-22X-2, 40–43 cm. **4.** Black debris, Sample 159-959A-8H-2, 30–35 cm. **5.** Yellow-brown fragment, Sample 159-959A-22X-2, 40–43 cm. **6.** Black-brown fragment, Sample 159-959A-8H-2, 30–35 cm. **7.** Tricolpate pollen, Sample 159-959A-22X-2, 40–43 cm. **8.** Trilete spore, Sample 159-959A-21X-3, 115–117 cm. **9.** Cuticle, Sample 159-959A-19H-3, 119–124 cm. **10.** Plant tissue, Sample 959A-8H-2, 30–35 cm. **11.** Fungal spore, Sample 159-959A-22X-2, 40–43 cm. **12.** Wood, Sample 159-959A-8H-2, 30–35 cm. **13.** Palynofacies Assemblage 1, Site 959 (note predominance of black debris and wood, AOM <15% in tectonized Unit V siliciclastics), TAI values 2.6–3.0, Sample 159-959D-76R-2, 49–53 cm. **14.** Palynofacies Assemblage 3, Site 959, AOM 30%–35% marine palynomorphs 7%–15%, wood and black-brown fragments 12%–17% each, TAI values <2.0, Sample 159-959A-22X-2, 40–43 cm. **15.** Palynofacies Assemblage 4, Site 959, AOM 43%–54%, wood 9%–13%, TAI values <2.0, Sample 159-959A-18H-1, 137–142 cm. **16.** Palynofacies Assemblage 6, Site 959, AOM 65%–78%, very rare black debris, TAI values 2.0–2.5 in some Unit III claystones, Sample 159-959D-28R-1, 121–124 cm. **17.** Palynofacies Assemblage 7, Site 959, Similar to assemblage 6 except that AOM >78%, Sample 159-959D-60R-4, 94–96 cm. **18.** Palynofacies Assemblage 5, Site 960, wood and black debris 21%–53%, AOM 0%–36% most of which is terrestrially derived in tectonized Unit V siliciclastics, TAI values 2.5–2.9, Sample 159-960A-59R-3, 26–29 cm.