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7. OLIGOCENE–EARLY MIOCENE DINOFLAGELLATE STRATIGRAPHY, SITE 1148, ODP LEG 184, SOUTH CHINA SEA[1]

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ABSTRACT

Dinoflagellate stratigraphy is described for the section from 364.75 to 843.85 meters below seafloor (mbsf) at Site 1148 (Sections 184-1148A-40X-1 through 76X-6 and 184-1148B-39X-CC through 56X-1) in the South China Sea. Two assemblage zones and two subzones are defined, based on characteristics of the assemblages and lowest/highest occurrences of some key species. These are the *Cleistosphaeridium diversispinosum* Assemblage Zone (Zone A; Oligocene), with the *Enneadocysta pectiniformis* Subzone (Subzone A-1) and the *Cordosphaeridium gracile* Subzone (Subzone A-2), and the *Polysphaeridium zoharyi* Assemblage Zone (Zone B; early Miocene). The highest concurrent occurrence of *Enneadocysta arcuata, Eneadocysta multicornuta, Homotryblium plectilum,* and *Homotryblium tenuispinosum* delineates the upper boundary of Zone A, which appears to mark a hiatus. Subzone A-1 is of early Oligocene age, as evidenced by the highest occurrences of *E. pectiniformis* and *Phthanoperidinium amoenum* at the upper boundary of the subzone. Subzone A-2 is of late Oligocene age based on the highest occurrences of *C. gracile* and *Wetzeliella gochtii* close to the upper boundary of the subzone and the occurrence of *Distatodinium ellipticum* and *Membranophoridium aspinatum* within the subzone. Zone B is dated as early Miocene based on the lowest occurrences of *Cerebrocysta satchelliae*, *Hystrichosphaeropsis obscura, Melitasphaeridium choanophorum, Membranilarnacia*? *picena,* and *Tuberculodinium vancampoae* within the zone. The present assemblage zones/subzones are correlative to various degrees with co-

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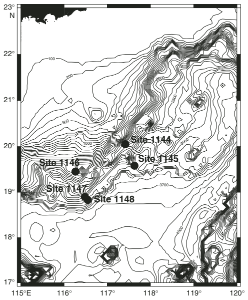
eval zones/assemblages from areas of high to low latitudes in terms of common key species. We have compared the species content of the assemblage Zones A and B, and the subzones A-1 and A-2, with coeval assemblage(s)/zone(s) described from many, often widely distant, high- and low-latitude regions of the world. These comparisons show that, to various degrees and aside from a number of key species, the coordinated presence of certain important species may also help to assign an age to a given assemblage.

INTRODUCTION

Site 1148 is the deepest site for Ocean Drilling Program (ODP) Leg 184, at a water depth of 3294 m. It is located on the lowermost continental slope off southern China at 18°50.17′N, 116°33.94′E (Fig. F1). Lying near the continental/oceanic crust boundary, Site 1148 recovered a rather thin, but continuous sequence of hemipelagic sediment, from which the early evolution and paleoclimate history (Oligocene–Miocene) of the South China Sea may be reconstructed (Wang, Prell, Blum, et al., 2000). To achieve this objective, it is necessary to precisely calibrate the seismic stratigraphic section using paleontological and other chronostratigraphic methods. The stratigraphic value of dinoflagellate fossils has been proven in Deep Sea Drilling Project (DSDP)/ODP history for 30 yr (Habib, 1972; Poulsen et al., 1996). Dinoflagellate stratigraphy represents one of the most important paleontological tools because of their planktonic habit and the good preservation potential of organic cycsts. Dinoflagellates are used in this paper, along with data from nannofossils and other microfossils, to achieve an integrated biostratigraphy for Site 1148.

F1. Location map of Site 1148, p. 22.



Dinoflagellate stratigraphy of the Oligocene and Miocene, mainly from the North Atlantic and Western Europe, has made great progress over the last 30 yr (Williams, 1975; Biffi and Manum, 1988; Köthe, 1990; Brinkhuis et al., 1992; de Verteuil and Norris, 1996). The accumulated data proved useful for stratigraphic correlation in the current study. In the last decade, Williams et al. (1993, unpubl. data [N1, N2]) compiled worldwide chronological ranges of Mesozoic–Cenozoic (Upper Cretaceous–Neogene) key species, which has helped considerably in studies of dinoflagellate stratigraphy. However, little published information on Oligocene and Miocene dinoflagellates exists from low-latitude areas of the Pacific region, such as the South China Sea (Mao and Lei, 1996). Fortunately, Site 1148 yielded a continuously cored section of Oligocene–Pleistocene strata (Wang, Prell, Blum, et al., 2000), which provided us with a rare opportunity to study Oligocene–Miocene dinoflagellates from the South China Sea.

Two holes were drilled at Site 1148, ~20 m apart from each other, in an attempt to recover coring gaps in Hole 1148A in the cores drilled in Hole 1148B (Wang, Prell, Blum, et al., 2000). Hole 1148A was drilled to a total depth of 704 meters below seafloor (mbsf), and Hole 1148B was drilled to 853 mbsf. The nominal depths of cores reported in mbsf have uncertainties of up to a few meters as a result of operational and environmental conditions, and the mbsf depth of stratigraphic horizons may therefore vary by a few meters across the two holes. These depth uncertainties are reflected in the different depths of lithologic unit boundaries in Holes 1148A and 1148B given below. A meters composite depth (mcd) scale was constructed for Site 1148 during Leg 184 that correlates stratigraphic features between cores from the two holes. Tables T1 and T2 list the mcd depths along with the mbsf depths for all samples analyzed, but the text and Figure F2 refer to hole-specific mbsf depths only.

The dominant lithology at Site 1148 is clay containing variable amounts of nannofossils. Seven lithologic units were identified on the basis of lithologic composition, depositional facies, and, especially, color variations. A detailed description of the upper three lithologic units, ranging from Pleistocene through middle Miocene (Cores 184-1148A-1H through 38X) can be found in Wang, Prell, Blum, et al. (2000). Samples for the present study are from the lower four Units IV, V, VI, and VII (Sections 184-1148A-40X-1 through 76X-6 and 184-1148B-39X-CC through 56X-1) (Fig. F2).

Unit IV (348–400 mbsf; Cores 184-1148A-38X through 43X) is composed of brownish nannofossil clay with minor intercalations of greenish gray nannofossil clay. Generally, the sediments appear reddish and oxidized. Bioturbation is intense throughout this unit.

Unit V (400–445 mbsf; Cores 184-1148A-43X through 48X and 439.9–449.5 mbsf; Core 184-1148B-17X) comprises greenish gray nannofossil clay interbedded with minor amounts of clay with nannofossils. This unit is distinguished from the overlying Unit IV by its greenish rather than reddish brown appearance. Trace fossils are often recognized throughout the unit, mostly those characteristic of deepwater (bathyal) forms. Evidence for redeposition is sparse in the unit.

Unit VI (445–482.7 mbsf; Cores 184-1148A-48X through 53X and 449.5–487.9 mbsf; Cores 184-1148B-17X through 21X) differs from the overlying Unit V in facies and color. The light greenish gray color at the top of Unit V rapidly changes to tan at the boundary between Units V and VI; greenish clay layers, common in Unit V, are almost absent throughout this unit. Though similar in composition to Unit V, this unit shows evidence of episodic gravitational redeposition, including mass flows and slumping, and therefore does not represent continuous hemipelagic sedimentation. In addition, Unit VI shows the first clear evidence in the cored stratigraphy, going downsection, of brittle faulting. All these features are indicative of tectonic activity associated with the formation of the South China Sea.

Unit VII (482.7–704.4 mbsf; Cores 184-1148A-54X through 77X and 487.9–853.2 mbsf; Cores 184-1148B-22X through 56X) is composed of an intensely bioturbated sequence of grayish olive-green nannofossil clay. The whole section is monotonous with only minor lithologic variation. The abundant bioturbation traces are strongly compacted and give the sediment a laminated appearance. Toward the base of the unit, the general picture of hemipelagic sedimentation is disrupted by occasional flaser sandstone laminae. The sandstones are predominantly composed of quartz and lithic fragments, with small quantities of mica, glauconite, and foraminifer fragments (Wang, Prell, Blum, et al., 2000).

MATERIALS AND METHODS

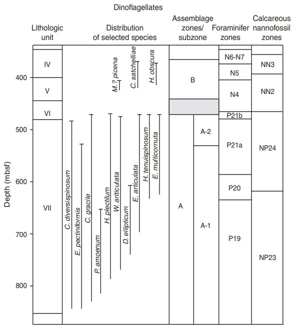
The samples studied are mainly clays from a ~479-m-thick section of cores recovered from Holes 1148A and 1148B (Sections 184-1148A-40X-1 through 76X-6 and 184-1148B-39X-CC through 56X-1).

Sampling intervals at Site 1148 are ~2–3 m, and 289 samples were processed. However, because of time constraints, only 105 samples were investigated microscopically. Each dried sample, weighing ~10 g, was processed at the Key Laboratory of the Ministry of National Education,

T1. Dinoflagellate cysts and other palynomorphs, p. 24.

T2. Range chart, p. 26.

F2. Dinoflagellate distribution, p. 23.



Tongji University, using standard palynological processing (Wood et al., 1996). Maceration was achieved using hydrochloric acid (10%) and dissolution in concentrated hydrofluoric acid (40%, cold). Oxidation with nitric acid or Schulze's solution was omitted to avoid damage to delicate cysts. No heavy liquid separation was applied because of the small amounts of residue remaining after acid maceration. Instead, a Nitex sieve of 7 µm mesh size, coupled with ultrasonic vibration technique, was used to remove tiny inorganic particles. Exotic *Lycopodium* spores were added to the samples before acid maceration to allow calculation of dinoflagellate concentration (abundance). Permanent slides, made with glycerin jelly with a wax seal, are stored in the Key Laboratory of the Ministry of National Education, Tongji University.

Microscopic investigation for each sample was commonly carried out on one to two permanent slides (each slide with two 20-mm × 20-mm coverslips). Abundance of dinoflagellate cysts was determined by the number of dinoflagellate cysts recorded in casual scanning when 200 exotic *Lycopodium* spores were encountered. The same method was used for other palynomorphs (Table T1). However, for samples in which dinoflagellate cysts are very rare, it was necessary to scan four to five slides in order to document more representative assemblages. In such cases, the number of cysts registered may be smaller than the total number of species observed in a given sample. Relative abundance of each taxon is designated by the following ranking:

R = rare (1%–5%),
C = common (>5%–25%),
A = abundant (>25%–50%), and
V = very abundant (>50%).

"P" indicates "present" when the total counts of dinoflagellate cysts/200 grains of exotic *Lycopodium* spores are <50 (Table T2). Unless specified otherwise, the dinoflagellate cyst taxonomy used in the present work follows the Lentin and Williams Index of Fossil Dinoflagellates (Williams et al., 1998), in which the full citations and authorships can be found.

RESULTS

General Aspects

Palynological assemblages from the majority of the samples of the section at Site 1148 contain abundant pollen and spores (mostly bisaccate pollen) as well as dinoflagellate cysts. These are accompanied by variable numbers of organic foraminiferal linings (microforams), and trace amounts of *Tasmanites* and the freshwater green algae *Pediastrum* (Table T1). The dinoflagellate assemblages generally show a mixture of neritic and oceanic taxa in the same sample. This indicates that horizontal transportation from a coastal/neritic environment played an important role during deposition of the assemblages. Vertical recycling at this site was generally not prevalent, as there is no evidence of assemblages containing uncharacteristic species. Virtually no pre-Paleogene taxa occur. Still, the fact that the early Miocene Sample 184-1148A-44X-CC contains late Oligocene nannofossil species indicates pronounced reworking. In addition, the evidence in lithologic Unit VI of episodic gravitational redeposition (Wang, Prell, Blum, et al., 2000) implies relatively short-period or local reworking. Thus, we assume that the palynological/dinoflagellate assemblages at Site 1148 may represent pericontemporaneous thanatocoenoses.

Among the 105 samples investigated, 27 contain no dinoflagellate cysts, 22 contain few, and the other 56 yielded moderate to abundant dinoflagellate cysts. Preservation of the dinoflagellate cysts is generally moderate to good. A total of 110 species/subspecies of 48 genera were recorded from the section studied. Dinoflagellate cyst assemblages from the whole section are dominated by chorate gonyaulacoid cysts. Two zones can be distinctly recognized in Table T1, the boundary between which lies at 448.05–473.1 mbsf. The lower part is sharply different from the upper part in cyst abundance, species diversity, and component taxa. On that basis, two assemblage zones and two subzones were recognized (Tables T1, T2). They will be discussed in ascending order.

Dinoflagellate Zonation and Age Assignment

Cleistosphaeridium diversispinosum Assemblage Zone (Zone A)

This zone covers Cores 184-1148B-56X through Section 39X-CC and Sections 184-1148A-76X-6 through 52X-CC (844–473 mbsf) (Table T2).

With 93 species/subspecies in 41 genera recorded (see the "Appendix," p. 17), Zone A is defined by the highest occurrences (last abundant datum; LAD) of *Enneadocysta arcuata, Enneadocysta multicornuta, Homotryblium plectilum,* and *Homotryblium tenuispinosum* at its top. It is characterized by the co-occurrence of *Cleistosphaeridium ancyreum, C. diversispinosum, Cleistosphaeridium placacanthum, Cordosphaeridium gracile, Cordosphaeridium inodes, H. plectilum, Hystrichokolpoma rigaudiae, Lingulodinium machaerophorum, Operculodinium centrocarpum,* and *Polysphaeridium zoharyi*, which are all common and present almost continuously throughout the zone. *Achomosphaera crassipellis, Apteodinium nanhaicum, Cordosphaeridium cantharellum, Cordosphaeridium exilimurum, Distatodinium ellipticum, E. arcuata, E. multicornuta, Hystrichokolpoma salacia, Lejeunecysta hyalina, Pentadinium laticinctum, Reticulatosphaera actinocoronata,* and *Selenopemphix nephroides* occur intermittently in the zone, usually in small numbers. Those like *Hystrichokolpoma cinctum, Thalassiphora patula, Thalassiphora pelagica, Wetzeliella articulata, Wetzeliella gochtii,* and *Wetzeliella symmetrica* occur in one to several samples of Zone A. No species of *Deflandrea* was recorded.

Eighteen Zone A species, including *C. inodes, Cribroperidinium tenuitabulatum, Enneadocysta pectiniformis, H. cinctum, Membranophoridium aspinatum, O. centrocarpum, P. laticinctum, T. pelagica,* and *W. symmetrica,* were recorded more than 40 yr ago by Gerlach (1961) in her Oligocene dinoflagellate assemblages from northwest Germany. Some of these 18 species and other Zone A species were also found in contemporaneous dinoflagellate assemblages from different parts of the world (Table T3). For example, *E. arcuata*, *E. pectiniformis, T. pelagica,* and *W. symmetrica* were recorded in the Oligocene assemblage of the Labrador Sea (calibrated by nannofossil Zones NP21 through NP24; Head and Norris, 1989).

T3. Zone A with Oligocene assemblage(s)/zone(s), p. 27.

In a recent study on dinoflagellates from northwest Germany, Köthe (1990) recognized two dinoflagellate zones, Zones D14 and D15. Sixteen species including *C. inodes*, *C. ancyreum*, *C. placacanthum*, *C. tenuitabulatum*, *E. arcuata*, *E. pectiniformis*, *H. tenuispinosum*, and *Phthanoperidinium amoenum* occur in her Zone D14, which was calibrated by nannofossil Zones NP23–NP24 and foraminifer Zones P19–P21 as having a Rupelian age. In addition, the following six species occurred in the Köthe (1990) Zones D14 and D15: *C. cantharellum, H. plectilum, M. aspinatum, P. laticinctum, T. pelagica,* and *W. symmetrica;* Zone D15 was calibrated as having a Chattian age by the nannofossil Zone NP25 and foraminifer Zone P22. All of the 22 species from Zones D14 and D15 occur in our Zone A, which therefore may be correlated not only with the Oligocene assemblage of the Labrador Sea but also with Zones D14 and D15 of northwest Germany.

Moreover, the presence of *W. gochtii* (ranging 32.8–26.6 Ma in the mid-latitudes of the Northern Hemisphere and 34–26? Ma in the low-latitude equatorial regions) (Williams et al., unpubl. data, [**N1**]) further supports an Oligocene age for Zone A. The co-occurrence of the following species gives further confidence for this age assignment: *E. pectiniformis* (36.5–29.3 Ma; Williams et al., unpubl. data [**N1, N2**]), *D. ellipticum* (41.4–26.3 Ma; Williams et al., unpubl. data [**N2**]), *M. aspinatum* (39.64–24.6 Ma; Williams et al., unpubl. data [**N2**]), *Impagidinium dispertitum* (41.3–24.6 Ma; Williams et al., unpubl. data [**N2**]), and *P. laticinctum* (50.15–8.55 Ma; Williams et al., unpubl. data [**N2**]).

Two subzones, the *E. pectiniformis* Subzone (Subzone A-1) and the *C. gracile* Subzone (Subzone A-2) were recognized based on general features and the occurrence of some key species (Fig. **F2**).

Subzone A-1

Cores 184-1148B-56X through Section 39X-CC and Sections 184-1148A-76X-6 through 60X-CC (844–531 mbsf) constitute Subzone A-1 (Fig. **F2;** Table **T2**). Its upper boundary with the overlying Subzone A-2 is defined by the LAD of *E. pectiniformis*. *Distatodinium ellipticum*, *P. amoenum,* and *Xenicodinium conispinum* have their ranges within the subzone. *Homotryblium* and *Impagidinium* are observed only rarely or sporadically in this subzone. The known range of *E. pectiniformis* (36.5–29.3 Ma; Williams et al., unpubl. data [**N1, N2**]) and *P. amoenum* (34–29 Ma; Williams et al., unpubl. data [**N1, N2**]) would constrain the age of Subzone A-1 to be early Oligocene (Rupelian). *Xenicodinium conispinum,* recorded in the lower Oligocene Boom Clay Formation of Belgium (Stover and Hardenbol, 1993) gives further support for this age assignment.

Subzone A-2

Sections 184-1148A-59X-4 through 52X-CC (526–473 mbsf) constitute Subzone A-2 (Fig. **F2;** Table **T2**). Directly overlying the LAD of *E. pectiniformis*, this subzone is marked by the simultaneous LADs of *E. arcuata, E. multicornuta, H. plectilum, H. tenuispinosum,* and *H. cinctum* as its top. *Membranophoridium aspinatum* occurs within this subzone. Many typical Paleogene species such as *C. diversispinosum, C. gracile, C. inodes, D. ellipticum, E. arcuata, Heteraulacacysta campanula, W. articulata, W. gochtii, W. symmetrica,* and *T. pelagica* have their LADs within Subzone A-2. *Wetzeliella articulata* and *W. symmetrica* are particularly abundant in one sample near the top of the subzone. *Homotryblium* and *Impagidinium* occur almost continuously throughout Subzone A-2; *Homotryblium,* in particular, may be abundant to very abundant (Table **T2**). As mentioned, *C. cantharellum, H. plectilum, M. aspinatum*, *P. laticinctum, T. pelagica,* and *W. symmetrica* were recorded in both the Chattian Zone D15 in northwest Germany (Köthe, 1990) and our Subzone A-2. *Membranophoridium aspinatum,* in particular, has a known range of 39.64–24.6 Ma (Williams et al., unpubl. data [**N2**]). Therefore, being part of the Oligocene Zone A and overlying the early Oligocene Subzone A-1, Subzone A-2 can be reasonably dated as late Oligocene.

Although *C. diversispinosum* has been reported to range from early Eocene (Ypresian) to early Oligocene (Rupelian), personal observation by Eaton et al. (2001) in material from the Grand Banks, offshore eastern Canada, showed that the species may be abundant in strata provisionally dated at least as young as late Oligocene. These authors expected a further upward extension of the range of this species. We find *C. diversispinosum* to be abundant throughout Subzone A-1 as well as Subzone A-2, with its LAD in Sample 184-1148A-54X-CC (i.e., close to the top of Subzone A-2). It often occurs together with *C. ancyreum* and *C. placacanthum*, and, although the occurrence of latter two species extends upward to above the lower Miocene interval, *C. diversispinosum* has its highest occurrence close to the top of Subzone A-2. These observations lend support for extending the range of *C. diversispinosum* to the late Oligocene.

Polysphaeridium zoharyi **Assemblage Zone (Zone B)**

This zone consists of Sections 184-1148A-48X-2 through 40X-1 (444–365 mbsf) (Tables **T1, T2;** Fig. **F2**).

A drastic change in component taxa, cyst abundance, and species diversity distinguishes Zone B from Zone A. The LADs of typical Paleogene species such as *E. arcuata* and *H. cinctum* in Sample 184-1148A-52X-CC marks the top of Zone A. Zone B is characterized by the first abundant datums (FADs) of typical Neogene or Miocene species such as *Hystrichosphaeropsis obscura* and *Melitasphaeridium choanophorum*. In addition, the following species also have their FADs in Zone B: *Achomosphaera callosa*, *Cerebrocysta satchelliae*, *Membranilarnacia? picena*, *Operculodinium israelianum, Operculodinium piaseckii, Schematophora speciosa,* and *Spiniferites ramosus* subsp. *angustus*. The ranges of *Cleistosphaeridium ancyreum, C. placacanthum, H. rigaudiae, P. laticinctum, Pentadinium taenigerum,* and *P. zoharyi* extend from Zone A into Zone B.

At the boundary between Zones A and B the number of cysts drops from 137 (Sample 184-1148A-52X-CC; 473 mbsf) at the top of Zone A to only 16 specimens (Section 48X-2; 444 mbsf) at the base of Zone B. Indeed, cyst abundance over the entire Zone A is generally much higher (54–7790 cysts, usually >100) than that for Zone B (0–81 cysts, usually <30). Species diversity drops from 93 species/subspecies of 41 genera in Zone A to 54 species/subspecies of 32 genera in Zone B (Table **T1;** also see **"Appendix"**). A striking feature of Zone B is the steady presence of *Impagidinium*, no matter how low the cyst abundance in the individual assemblage. The upper part of Zone B, corresponding to the interval of lithologic Unit IV, has particularly low cyst abundance and species diversity, with only 21 species of 14 genera recorded.

Williams et al. (unpubl. data [**N2**]) tabulated an age range of 18.93–7.34 Ma for *H. obscura*. Heilmann-Clausen and Costa (1990) thought this species, well known from the Miocene in various parts of the world, to be an index fossil defining the base of their standard European dinoflagellate Zone D17 (early Miocene). However, they recorded the FAD of this species in association with *Tuberculodinium vancampoae* (index fossil of Zone D16, latest Oligocene–earliest Miocene) from a transitional horizon in northwest Germany. Stover and Hardenbol (1993) reported *H. obscura* from the Rupelian (lower Oligocene) Boom Clay Formation of Belgium. Biffi and Manum (1988) defined the Oligocene/Miocene boundary in the Marche region of central Italy by the last occurrence of *Deflandrea phosphoritica* (and three other less common species) coupled with the earliest occurrence of *H. obscura*. De Verteuil and Norris (1996) recorded from the United States Mid-Atlantic coastal margin the FAD of *H. obscura* within their DN1 *Chiropteridium galea* Interval Zone (late Oligocene–early Miocene; calibrated with the top of nannofossil Zone NP25–NN1 to the lower NN2 and with the top of foraminifer Zone P22 to the lower N4). Based on these records, *H. obscura* is a typical Miocene species, but its earliest occurrence may extend into the (latest) Oligocene.

Melitasphaeridium choanophorum, a typical Miocene indicator that ranges from 23.9 to 3.75 Ma (Williams et al., unpubl. data [N2]), has been recorded from Miocene strata of northwest Germany (Gerlach, 1961) and from early Miocene offshore eastern Canada (Williams and Bujak, 1977).

Tuberculodinium vancampoae was originally reported only from the Miocene (Benedek, 1986), and the FAD of this species was thought to be early Miocene (Williams and Bujak, 1977; Williams et al., 1993). However, its range was extended to latest Oligocene by de Verteuil and Norris (1996). This is compatible with its occurrence in Zone D16 of northwest Germany and the top sample of our Subzone A-2. Yet, this species is generally recognized as a Neogene indicator.

The earliest occurrence of *M.*? *picena* is taken as defining the base of the early Miocene Zone DM1, calibrated by nannofossil Zone NN1 and foraminifer Zone N4, in the Marche Region of central Italy (Biffi and Manum, 1988).

Cerebrocysta satchelliae was first described in the DN2 *Sumatradinium soucouyantiae* Interval Zone of the United States Mid-Atlantic coastal margin (de Verteuil and Norris, 1996), which is middle lower Miocene–upper lower Miocene, its LAD coinciding with the upper boundary of nannofossil Zone NN2 and located within foraminifer Zone N5. *Schematophora speciosa*, although described originally from the ?lower Eocene of Australia (Deflandre and Cookson, 1955), has a range of Eocene–Miocene (Williams et al., 1998).

Operculodinium longispinigerum and *O. piaseckii* were recorded mostly in the lower lower Miocene sediments from different parts of the world (de Verteuil and Norris, 1996). The *P. zoharyi* Assemblage Zone (Zone B in short) thus can be confidently dated as early Miocene on the basis of the records discussed above.

An interval of ~25–30 m (473–449 or 473–444 mbsf) between Zones A and B is barren of dinoflagellates and other palynomorphs. Nannofossil and foraminifer records indicate a hiatus at 473 mbsf, the period between the lowermost Zone NP25/P22 and Zone NN2/N4 (27–24 Ma) missing (Wang, Prell, Blum, et al., 2000). This is evidence for significant environmental shift during the transition from latest Paleogene to earliest Neogene.

COMPARISON

For the last two and one-half decades, many Oligocene to early Miocene dinoflagellate cyst zonations have been proposed. These include

Atlantic: Stover (1977), Costa and Downie (1979), Edwards (1984), and Brown and Downie (1985);

North America: Duffield and Stein (1986), Edwards (1986), and de Verteuil and Norris (1996);

Europe: Benedek and Müller (1974), Powell (1986a, 1986b), Biffi and Manum (1988), Köthe (1990), and Brinkhuis and Biffi (1993);

Norwegian–Greenland and Barents Seas: Manum (1976), Manum et al. (1989), Poulsen et al. (1996), and Edvin et al. (1998); and

Pacific: Bujak (1984), Bujak and Matsuoka (1986), and Mao and Lei (1996).

Detailed correlation of a given individual zone with coeval zone(s) elsewhere is often difficult to accomplish because the zonal concepts may be different or provincialism or environmental setting may limit the occurrence of some key species. This may be caused by more differentiated oceanic regimes and complicated environments in the Oligocene and Miocene compared to pre-Oligocene time. For example, the Oligocene *Deflandrea heterophlycta* Assemblage Zone and *Chiropteridium dispersum* Assemblage Zone proposed by Williams (1975) for offshore eastern Canada cannot be correlated satisfactorily with the Oligocene *Chiropteridium lobospinosum* Zone, *Areosphaeridium? actinocoronatum* Zone, and *Impagidinium* spp. Zone proposed by Manum et al. (1989) for the Norwegian Sea. Brinkhuis et al. (1992) efficiently used the youngest acmes of *Chiropteridium* and *Deflandrea* when working on a high-resolution dinoflagellate stratigraphy of the Oligocene–Miocene transition interval in the Piedmont Basin of northwest Italy and the Marche Basin of central Italy, but *Chiropteridium* is very rare and *Deflandrea* is lacking in the South China Sea section we studied. Regardless of these difficulties, comparison of similarities or differences between our zones and other coeval zones is possible and may reveal some interesting results on the distribution patterns of some taxa relating to provincialism or environmental settings.

Cleistosphaeridium diversispinosum Assemblage Zone (Zone A)

The *C. diversispinosum* Assemblage Zone (Zone A) can be generally correlated with the Oligocene dinoflagellate assemblage(s) or zone(s) from areas where upwelling is not well developed (e.g., from offshore eastern Canada) (Williams and Bujak, 1977), with which it has 21 species in common (Table T3). However, our Zone A has less similarity in species composition when compared with the coeval dinoflagellate cyst assemblages from the Niger Delta (Biffi and Grignani, 1983), which are dominated by peridinioid cysts like *Lejeunecysta,* with only few gonyaulacoid chorate taxa being present; this is typical for environments with well-developed upwelling of the water mass.

Enneadocysta pectiniformis Subzone (Subzone A-1)

The *E. pectiniformis* Subzone (Subzone A-1) has 12 species in common with the early Oligocene *C. lobospinosum* Zone from the Norwegian Sea (Manum et al., 1989). They are *C. cantharellum, C. inodes, C. placacanthum, D. ellipticum, E. arcuata, E. pectiniformis, H. campanula, L. machaerophorum, P. laticinctum, Spiniferites pseudofurcatus, T. pelagica,* and *W. articulata*. Subzone A-1 shares 24 species with the early Oligocene four interval zones from central Italy (Brinkhuis and Biffi, 1993), which constitutes more than 40% of all species (subspecies) recorded from Subzone A-1. Except for *C. placacanthum, E. arcuata, L. machaerophorum,* and *W. articulata,* the other 8 are common to both the early Oligocene *C. lobospinosum* Zone of the Norwegian Sea and four interval zones from central Italy. In addition, *C. ancyreum, H. plectilum, H. cinctum, R. actinocoronata,* and *W. gochtii* are also among the 24 species.

Twelve dinoflagellate assemblages from the early Oligocene Boom Clay Formation of northwest Belgium (Stover and Hardenbol, 1993) have seven species in common with our Subzone A-1 including *C. diversispinosum* and *E. pectiniformis*. The coeval dinoflagellate Zone D14 from northwest Germany (Köthe, 1990) shares 18 species with Subzone A-1. Among these 18 species, 8 are also found in the early Oligocene *C. lobospinosum* Zone from the Norwegian Sea, 11 are also found in central Italy, and 2 are also found in the Boom Clay Formation in northwest Belgium (Table T3).

Subzone A-1 has less similarity to the early Oligocene *D. heterophlycta* Assemblage Zone from offshore eastern Canada (Williams, 1975) and Zone VI of the Rockall Plateau, North Atlantic (Costa and Downie, 1979) because they have few species, such as *E. multicornuta,* in common. *Deflandrea* spp. are common in the latter two zones but are absent from our Subzone A-1.

***Cordosphaeridium gracile* Subzone (Subzone A-2)**

The *C. gracile* Subzone (Subzone A-2) can be correlated with the *H. plectilum–C. gracile* Assemblage from the Pearl River Mouth Basin of the South China Sea (Mao and Lei, 1996) with 28 species in common, which represents 50% of the species (or subspecies) recorded from Subzone A-2. *Cleistosphaeridium ancyreum, C. diversispinosum, C. placacanthum, C. gracile, P. zoharyi,* and *H. plectilum* occur throughout both Subzone A-2 and the assemblage; *H. plectilum* is particularly abundant in both. Subzone A-2 contains 15 species (including *H. campanula, H. plectilum,* and *R. actinocoronata*) in common with the *Areosphaeridium*? (now *Reticulatosphaera*) *actinocoronata* Zone and *Impagidinium* sp. 1 Zone from the lower upper Oligocene–upper Oligocene in the Norwegian Sea (Manum et al., 1989) (Table T3).

Subzone A-2 has 13 species (including *C. inodes*, *Dapsilidinium pseudocolligerum,* and *E. arcuata*) in common with the late Oligocene assemblage from Blake Plateau, North Atlantic (Stover, 1977). A number of species, such as *C. cantharellum, H. cinctum, H. rigaudiae, P. laticinctum* and *S. pseudofurcatus,* are common to all four areas: the Norwegian Sea, the Blake Plateau, the Pearl River Mouth Basin, and Subzone A-2. The latest Oligocene dinoflagellate assemblage from the Lemme section of northwest Italy (Powell, 1986a) may be correlated with our Subzone A-2, as it shares 22 species, including *C. gracile, C. cantharellum, H. plectilum, H. tenuispinosum,* and *T. pelagica*. However, the coeval *T. vancampoae* Assemblage Biozone from the same region but near the Langhe Region (Powell, 1986b) has only 3 species (*C. cantharellum, T. pelagica,* and *T. vancampoae*) in common with Subzone A-2. The Zone D15 from northwest Germany (Heilmann-Clausen and Costa, 1990; Köthe, 1990) may be correlated as well with our Subzone A-2, having 8 species in common.

The late Oligocene *Operculodinium xanthium* Zone and *Homotryblium floripes* Zone from the Lower Rhine Basin of western Germany (Benedek and Müller, 1974) have less similarity with Subzone A-2 because both have only few species, such as *O. xanthium*, in common.

***Polysphaeridium zoharyi* Assemblage Zone (Zone B)**

The *P. zoharyi* Assemblage Zone (Zone B) has many similarities to the early Miocene *P. zoharyi–L. machaerophorum* Assemblage from the Pearl

River Mouth Basin of the South China Sea (Mao and Lei, 1996). Fossil abundance and species diversity are distinctly low in both Zone B and the assemblage, but they still have 12 species (including *H. obscura* and *P. zoharyi*) in common. The early Miocene BB I to lower part of BB II Assemblage Zones from Baffin Bay (Head et al., 1989) have 10 species in common with Zone B, including *C. ancyreum, C. tenuitabulatum, H. obscura, M. choanophorum, R. actinocoronata,* and *T. vancampoae*.

Zone B may correlate to some extent with the early Miocene dinoflagellate assemblages from the Rockall Plateau of the eastern North Atlantic (Costa and Downie, 1979) and the Goban Spur of the Atlantic (Brown and Downie, 1985), in sharing 7 species, which include *C. placacanthum, H. obscura, Impagidinium aculeatum,* and *M. choanophorum*. Likewise, Zone B may also correlate to some extent with the early Miocene dinoflagellate assemblages from the Gulf of Mexico, offshore Louisiana (LeNoir and Hart, 1986), with which it shares 8 species, including *C. tenuitabulatum, H. obscura, P. zoharyi, Tectatodinium pellitum, T. vancampoae,* and others (Table **T4**). However, it has less similarity with the coeval assemblages from near–delta shelf environments of the same area (Duffield and Stein, 1986), which are characterized by the dominance of peridiniacean cysts and scarcity of *Impagidinium*.

T4. Zone B with early Miocene assemblage(s)/zone(s), p. 28.

Zone B has little similarity with the early Miocene dinoflagellate assemblages from the western and northern Pacific (Bujak, 1984; Bujak and Matsuoka, 1986) because it lacks the cold-water indicator *Spiniferites ellipsoideus* and the abundance of protoperidiniacean cysts seen in the north Pacific. Although both have eight species in common, most of these, except for *H. obscura,* are long-ranging species such as *L. machaerophorum* and *O. centrocarpum*.

De Verteuil and Norris (1996) studied Miocene dinoflagellate stratigraphy of the Maryland and Virginia Mid-Atlantic coastal margins and established 10 interval zones with detailed information. Unfortunately, it is difficult to compare their four early Miocene zones with our Zone B in detail, except for the ubiquitous occurrence of *C. placacanthum* and *C. satchelliae* in both, which may correlate them in a general way. However, most of their key species, such as *D. phosphoritica, S. soucouyantiae,* and *Cousteaudinium aubryae,* were not recognized in Zone B. The earliest Miocene dinoflagellate assemblage from the Lemme section of northwest Italy (Powell, 1986a) may be correlated with our Zone B in that they share 11 species, which include *C. placacanthum, H. obscura, M. choanophorum*, and *P. laticinctum*. But the three early Miocene Oppel zones DM1–DM3 from the Marche Region of central Italy (Biffi and Manum, 1988) may be linked with our Zone B by virtue of sharing *M.? picena*.

It is difficult to compare the four early Miocene interval zones of *Ascostomocystis granosa, Evittosphaerula paratabulata, Impagidinium patulum*, and *Apteodinium spiridoides* from the Norwegian Sea (Manum et al., 1989) with our Zone B in any detail because the four eponymic species and other key species are not present in Zone B. However, the interval zones do have eight species in common with our Zone B, including *H. obscura, P. laticinctum*, *T. vancampoae, C. tenuitabulatum,* and *I. aculeatum*.

In summary, certain important species are always present in any of these coeval assemblage(s) and zone(s) and make it possible to correlate them (Tables **T3, T4**). The following 18 species (or most of them), when present together in an assemblage, provide clues to an Oligocene aspect: *C. ancyreum, C. placacanthum, C. cantharellum, C. gracile, C. inodes, C. tenuitabulata, D. pseudocolligerum, E. arcuata, H. campanula, H. plecti-*

lum, *H. tenuispinosum*, *H. cinctum*, *H. rigaudiae*, *L. machaerophorum*, *P. laticinctum*, *S. pseudofurcatus*, *R. actinocoronata,* and *T. pelagica*. When any of *E. pectiniformis*, *P. amoenum*, *D. ellipticum,* or *M. aspinatum* occurs in association with any of the previous 18 species, it may be evidence for further differentiation into early or late Oligocene age.

The ranges of *C. cantharellum, C. tenuitabulata, H. plectilum, H. rigaudiae, L. machaerophorum, P. laticinctum,* and *P. zoharyi* may extend upward into younger strata. However, when present together with key species such as *C. satchelliae*, *H. obscura*, *M. choanophorum*, *M.? picena*, *O. longispinigerum*, *O. piaseckii,* and *T. vancampoae,* their co-occurrence indicates a Miocene age.

Presence of species of *Deflandrea* (mainly *D. phosphoritica*), *Wetzeliella* (mainly *W. articulata*, *W. gochtii,* and *W. symmetrica*), and *P. zoharyi* may have some environmental significance. *Deflandrea* prefers the medium to cold waters of mid- to high latitudes. Abundant *P. zoharyi* has often been recovered in assemblages from low-latitude warm waters such as the Pearl River Mouth Basin of the South China Sea (Mao and Lei, 1996), the offshore South China Sea, and Taiwan (Mao et al., 2002). *Cleistosphaeridium ancyreum*, *C. diversispinosum*, and *C. placacanthum* appear to favor offshore settings, whereas *Wetzeliella* prefers a shallow brackish water environment.

CONCLUSIONS

1. The dinoflagellate biostratigraphic results of the present study are in agreement with the ship-based biostratigraphy, based on foraminifers and calcareous nannofossils, assigning an Oligocene age to Sections 184-1148B-56X-1 through 39X-CC and 184-1148A-76X-6 through 52X-CC and an early Miocene age to Sections 184-1148A-48X-2 through 40X-1. A barren interval above 473.1 mbsf indicates a great environmental shift during the transition from the latest Paleogene to earliest Neogene (Fig. F2). Some discrepancy exists among the data from dinoflagellate cysts, nannofossils, and foraminifers regarding the position of the boundary between early and late Oligocene.
2. In spite of the many factors that can influence the detailed character of dinoflagellate zones, our two assemblage zones and two subzones can be correlated, with various degrees of confidence, with coeval assemblage(s) or zone(s) from other regions on the basis of shared species. The most significant species include *E. pectiniformis, D. ellipticum, M. aspinatum,* and *P. amoenum* as key indicator species for an Oligocene age, and *C. satchelliae*, *H. obscura, M. choanophorum,* and *M.? picena* as key species indicating a Miocene age. These key species often are accompanied by other important species such as *C. ancyreum*, *C. cantharellum*, *E. arcuata, H. plectilum, H. cinctum, P. laticinctum*, and *T. pelagica.*

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APPENDIX

Species/Subspecies Lists for the Assemblage Zones

Cleistosphaeridium diversispinosum Assemblage Zone (Zone A)

Achomosphaera alcicornu (Eisenack, 1954) Davey and Williams, 1966

Achomosphaera crassipellis (Deflandre and Cookson, 1955) Stover and Evitt, 1978

Achomosphaera grallaeformis (Brosius, 1963) Davey and Williams, 1969

Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963

Achmosphaera sp.

Apteodinium granulatum Eisenack, 1958

Apteodinium maculatum Eisenack and Cookson, 1960

Apteodinium nanhaicum He Chengquan and Li Peng, 1981

Apteodinium sp.

Areoligera sp.

Batiacasphaera baculata Drugg, 1970

Batiacasphaera biornata (Jiabo, 1978) Jan du Chêne et al., 1985

Batiacasphaera minuta (Matsuoka, 1983) Matsuoka and Head, 1992

Batiacasphaera sp.

Cleistosphaeridium ancyreum (Cookson and Eisenack, 1965) Eaton et al., 2001

Cleistosphaeridium diversispinosum Davey et al., 1966, emend. Eaton et al., 2001

Cleistosphaeridium placacanthum (Deflandre and Cookson, 1955) Eaton et al., 2001

Cleistosphaeridium sp.

Cordosphaeridium cantharellum (Brosius, 1963) Gocht, 1969

Cordosphaeridium exilimurum Davey and Williams, 1966

Cordosphaeridium gracile (Eisenack, 1954) Davey and Williams, 1966

Cordosphaeridium inodes (Klumpp, 1953) Eisenack, 1963, emend. Sarjeant, 1981

Cordosphaeridium minimum (Morgenroth, 1966) Benedek, 1972

Cordosphaeridium sp.

Cribroperidinium tenuitabulatum (Gerlach, 1961) Helenes, 1984

Cribroperidinium sp.

Dapsilidinium pseudocolligerum (Stover, 1977) Bujak et al., 1980

Dapsilidinium sp.

Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965, emend. Goodman and Witmer, 1985

Distatodinium ellipticum (Cookson, 1965) Eaton, 1976

Enneadocysta arcuata (Eaton, 1971) Stover and Williams, 1995

Enneadocysta multicornuta (Eaton, 1971) Stover and Williams, 1995

Enneadocysta pectiniformis (Gerlach, 1961) Stover and Williams, 1995

Glaphyrocysta intricata (Eaton, 1971) Stover and Evitt, 1978

Glaphyrocysta sp.

Heteraulacacysta campanula Drugg and Loeblich Jr., 1967

Heteraulacacysta fehmarnensis Lentin and Williams, 1973

Heteraulacacysta sp.

Homotryblium abbreviatum Eaton, 1976

Homotryblium plectilum Drugg and Loeblich Jr., 1967

Homotryblium tenuispinosum Davey and Williams, 1966
Homotryblium vallum Stover, 1977
Hystrichokolpoma cinctum Klumpp, 1953
Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955
Hystrichokolpoma salacia Eaton, 1976
Hystrichokolpoma wilsonii Lentin and Williams, 1993
Hystrichokolpoma sp.
Hystrichosphaeridium? *latirictum* Davey and Williams, 1966
Hystrichosphaeridium sp.
Impagidinium dispertitum (Cookson and Eisenack, 1965) Stover and Evitt, 1978
Impagidinium minus Biffi and Manum, 1988
Impagidinium multiplice (Wall and Dale, 1968) Lentin and Williams, 1981
Impagidinium torsium Stover and Hardenbol, 1994
Impagidinium velorum Bujak, 1984
Impagidinium spp.
Impletosphaeridium sp.
Kallosphaeridium sp.
Lejeunecysta communis Biffi and Grignani, 1983
Lejeunecysta fallax (Morgenroth, 1966) Artzner and Dörhöfer, 1978, emend. Biffi and Grignani, 1983
Lejeunecysta globosa Biffi and Grignani, 1983
Lejeunecysta hyalina (Gerlach, 1961) Artzner and Dörhöfer, 1978, emend. Kjellström, 1972
Lejeunecysta lata Biffi and Grignani, 1983
Lejeunecysta sp.
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967
Lingulodinium sp.
Melitasphaeridium asterium (Eaton, 1976) Bujak et al., 1980
Melitasphaeridium sp.
Membranophoridium aspinatum Gerlach, 1961
Multispinula sp.
Nematosphaeropsis lemniscata Bujak, 1984, emend. Wrenn, 1988
Nematosphaeropsis sp.
Oligosphaeridium sp.
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
Operculodinium divergens (Eisenack, 1954) Stover and Evitt, 1978
Operculodinium microtriainum (Klumpp, 1953) Islam, 1983
Operculodinium tiara (Klumpp, 1953) Stover and Evitt, 1978
Operculodinium xanthium (Benedek, 1972) Stover and Evitt, 1978
Operculodinium spp.
Pentadinium? *circumsutum* (Morgenroth, 1966) Stover and Evitt, 1978
Pentadinium imaginatum (Benedek, 1972) Stover and Hardenbol, 1994
Pentadinium laticinctum Gerlach, 1961, emend. Benedek et al., 1982
Pentadinium taenigerum Gerlach, 1961
Pentadiniun sp.
Phthanoperidinium amoenum Drugg and Loeblich Jr., 1967
Polysphaeridium subtile Davey and Williams, 1966, emend. Bujak et al., 1980
Polysphaeridium zoharyi (Rossignol, 1962) Bujak et al., 1980

Polysphaeridium zoharyi subsp. *ktana* (Rossignol, 1962) Lentin and Williams, 1981

Pyxidiella sp.

Pyxidinopsis sp.

Reticulatosphaera actinocoronata (Benedek, 1972) Bujak and Matsuoka, 1986

Selenopemphix armata Bujak et al., 1980

Selenopemphix nephroides Benedek, 1972, emend. Bujak et al., 1980

Selenopemphix sp.

Sentusidinium sp.

Spiniferites bulloideus (Deflandre and Cookson, 1955) Sarjeant, 1970

Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970

Spiniferites mirabilis (Rossignol, 1964) Sarjeant, 1970

Spiniferites monilis (Davey and Williams, 1966) Sarjeant, 1970, emend. Eaton, 1976

Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970, emend. Sarjeant, 1981

Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854

Spiniferites ramosus subsp. *granosus* (Davey and Williams, 1966) Lentin and Williams, 1973

Spiniferites ramosus subsp. *multibrevis* (Davey and Williams, 1966) Lentin and Williams, 1973

Spiniferites spp.

Tanyosphaeridium regulare Davey and Williams, 1966

Tectatodinium grande Williams et al., 1993

Tectatodinium sp.

Thalassiphora patula (Williams and Downie, 1966) Stover and Evitt, 1978

Thalassiphora pelagica (Eisenack, 1954) Eisenack and Gocht, 1960, emend. Benedek and Gocht, 1981

Thalassiphora velata (Deflandre and Cookson, 1955) Eisenack and Gocht, 1960

Wetzeliella articulata Eisenack, 1938

Wetzeliella gochtii Costa and Downie, 1976

Wetzeliella symmetrica Weiler, 1956

Xenicodinium conispinum Stover and Hardenbol, 1994

Xenicodinium echiniferum Stover and Hardenbol, 1994

Polysphaeridium zoharyi Assemblage Zone (Zone B)

Achomosphaera callosa Matsuoka, 1983

Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963

Achomosphaera sp.

Apteodinium nanhaicum He Chengquan and Li Peng, 1981

Apteodinium sp.

Batiacasphaera biornata (Jiabo, 1978) Jan du Chêne et al., 1985

Batiacasphaera micropapillata Stover, 1977

Batiacasphaere minuta (Matsuoka, 1983) Matsuoka and Head, 1992

Batiacasphaera sp.

Canningia sp.

Cerebrocysta satchelliae de Verteuil and Norris, 1996

Cerebrocysta spp.

Chiropteridium galea (Maier, 1959) Sarjeant, 1983

Chiropteridium sp.

Cleistosphaeridium ancyreum (Cookson and Eisenack, 1965) Eaton et al., 2001

Cleistophaeridium placacanthum (Deflandre and Cookson, 1955) Eaton et al., 2001

Cleistosphaeridium sp.

Cribroperidinium tenuitabulatum (Gerlach, 1961) Helenes, 1984

Cribroperidinium sp.

Dapsilidinium pseudocolligerum (Stover, 1977) Bujak et al., 1980

Dapsilidinium sp.

Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955

Hystrichokolpoma sp.

Hystrichosphaeridium? *latirictum* Davey and Williams, 1966

Hystrichosphaeropsis obscura Habib, 1972

Impagidinium aculeatum (Wall, 1967) Lentin and Williams, 1981

Impagidinium minus Biffi and Manum, 1988

Impagidinium multiplice (Wall and Dale, 1968) Lentin and Williams, 1981

Impagidinium spp.

Impletosphaeridium sp.

Lejeunecysta hyalina (Gerlach, 1961) Artzner and Dörhöfer, 1978, emend. Kjellström, 1972

Lejeunecysta sp.

Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967

Lingulodinium sp.

Melitasphaeridium choanophorum (Deflandre and Cookson, 1955) Harland and Hill, 1979

Melitasphaeridium sp.

Membranilarnacia? *picena* Biffi and Manum, 1988, emend. Zevenboom and Santarelli, 1995

Nematosphaeropsis labyrinthus (Ostenfeld, 1903) Reid, 1974

Nematosphaeropsis lemniscata Bujak, 1984, emend. Wrenn, 1988

Nematosphaeropsis sp.

Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967

Operculodinium israelianum (Rossignol, 1962) Wall, 1967

Operculodinium longispinigerum Matsuoka, 1983

Operculodinium piaseckii Strauss and Lund, 1992, emend. de Verteuil and Norris, 1996

Operculodinium spp.

Pentadinium laticinctum Gerlach, 1961, emend. Benedek et al., 1982

Pentadinium taenigerum Gerlach, 1961

Pentadinium sp.

Polysphaeridium zoharyi (Rossignol, 1962) Bujak et al., 1980

Polysphaeridium zoharyi subsp. *ktana* (Rossignol, 1962) Lentin and Williams, 1981

Pyxidiella sp.

Pyxidinopsis spp.

Reticulatosphaera actinocoronata (Benedek, 1972) Bujak and Matsuoka, 1986, emend. Bujak and Matsuoka, 1986

Schematophora speciosa Deflandre and Cookson, 1955

Selenopemphix sp.

Sentusidinium sp.

Spiniferites bulloideus (Deflandre and Cookson, 1955) Sarjeant, 1970

Spiniferites hyperacanthus (Deflandre and Cookson, 1955) Cookson and Eisenack, 1974

Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970

Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970, emend. Sarjeant, 1981

Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854

Spiniferites ramosus subsp. *angustus* (Wetzel, 1952) Lentin and Williams, 1973, emend. Sarjeant, 1984

Spiniferites ramosus subsp. *multibrevis* (Davey and Williams, 1966) Lentin and Williams, 1973

Spiniferites spp.

Tectatodinium pellitum Wall, 1967, emend. Head, 1994

Tectatodinium sp.

Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967

Figure F1. Location map of Site 1148, Leg 184.

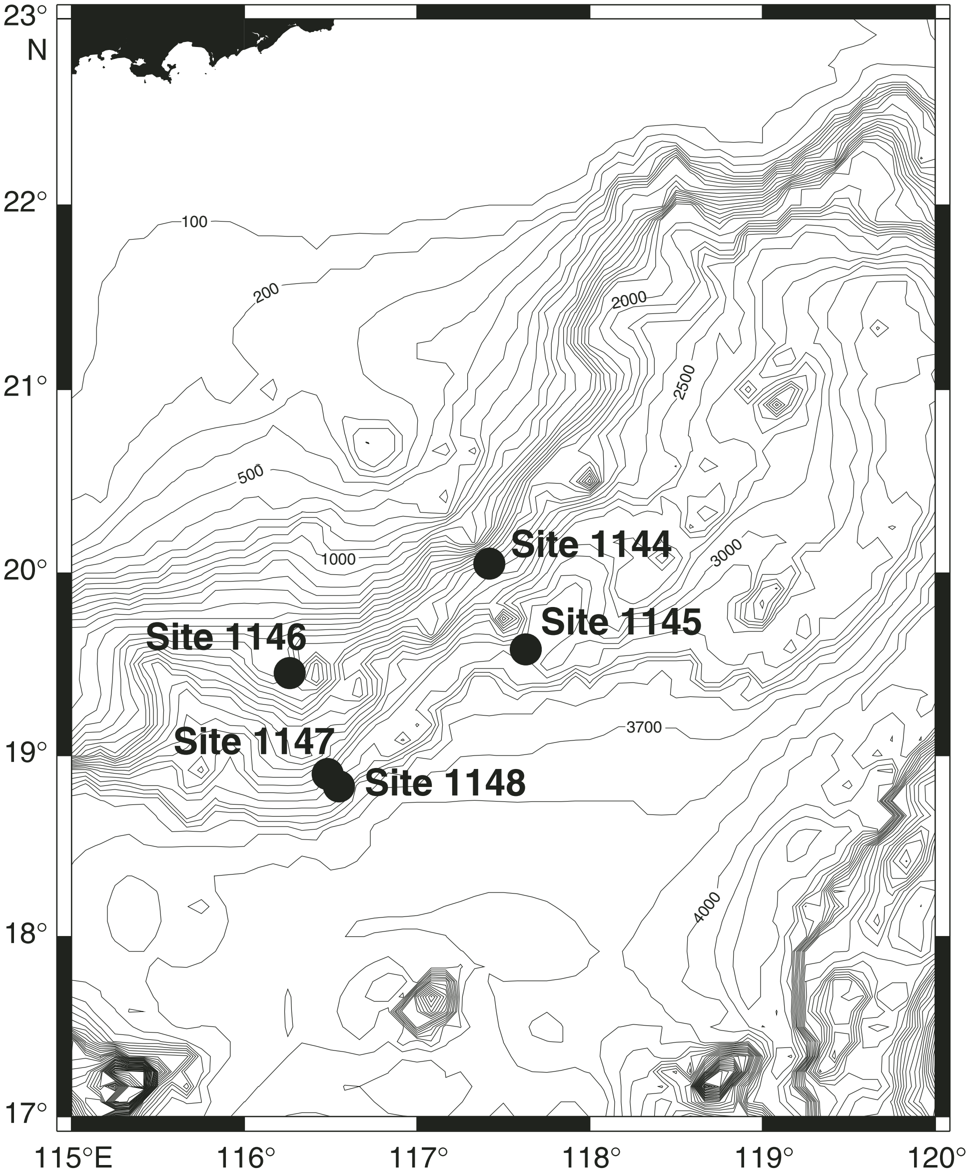

Figure F2. Dinoflagellate assemblage zones and subzones and distribution of selected species.

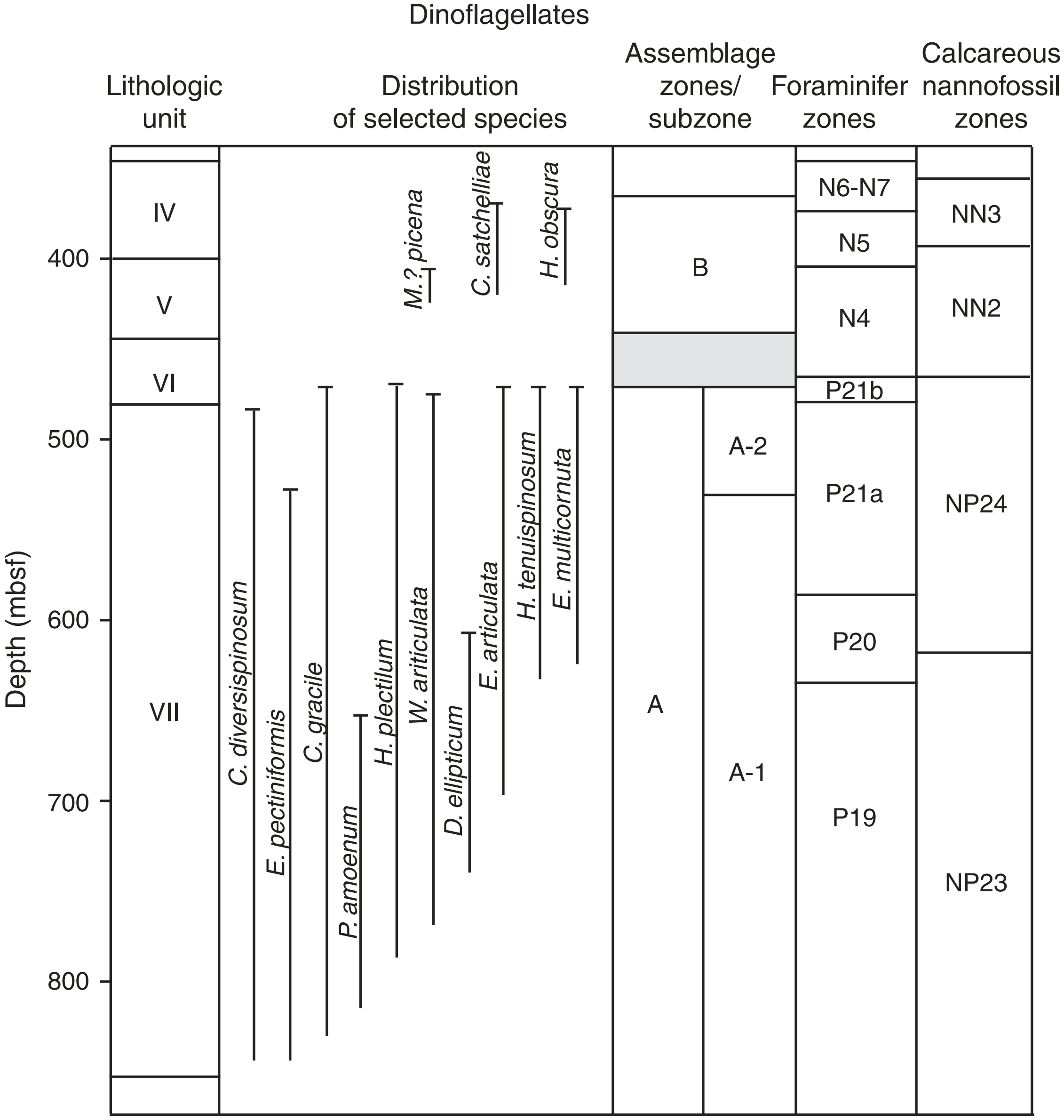

Table T1. Abundance of dinoflagellate cysts and other palynomorphs, cyst species diversity, and bisaccate pollen. (See table note. Continued on next page.)

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Dinocysts (*N*)	Pollen/ spores (*N*)	Foraminifer linings (*N*)	Terrigenous algae (*N*)	Bisaccate pollen (%)	Dinocyst species (*N*)
184-1148A-								
40X-1, 25–27	364.75	376.97	2	0	0	0		4
40X-3, 25–27	367.75	379.97	3	2	0	0		3
40X-6, 25–27	372.25	384.47	5	2	0	0		13
41X-3, 25–27	377.45	389.67	2	1	0	0		2
41X-4, 25–27	378.95	391.17	3	2	0	0		3
41X-7, 25–27	383.45	395.67	4	2	0	0		6
42X-1, 25–27	384.15	396.37	45	1	0	0		6
43X-2, 25–27	395.25	407.47	14	3	0	0		13
43X-6, 25–27	401.25	413.47	2	0	0	0		2
44X-1, 25–27	403.45	415.67	11	14	0	0		15
44X-2, 25–27	404.95	417.17	6	3	0	0		5
44X-4, 25–27	407.95	420.17	22	19	0	0		17
44X-6, 25–27	410.95	423.17	9	3	0	0		15
44X-CC, 25–27	412.9	425.12	9	5	0	0		14
45X-2, 25–27	414.65	426.87	22	16	0	0		20
45X-4, 25–27	417.65	429.87	6	3	0	0		9
45X-5, 25–27	419.15	431.37	13	6	0	0		20
45X-7, 25–27	422.15	434.37	50	24	0	0		17
46X-1, 25–27	422.75	434.97	19	9	0	0		18
46X-3, 25–27	425.75	437.97	16	7	0	0		17
46X-5, 25–27	428.75	440.97	25	9	0	0		21
46X-CC, 25–27	431.67	443.89	3	9	0	0		18
47X-1, 25–27	432.45	444.67	13	16	0	0		16
47X-3, 25–27	435.45	447.67	81	40	0	0		16
47X-4, 25–27	436.95	449.17	60	81	0	0		16
47X-CC, 25–27	441.93	454.15	3	1	0	0		3
48X-2, 25–27	443.55	455.77	16	42	0	0		13
48X-5, 25–27	448.05	460.27	3	1	0	0		12
49X-4, 25–27	456.15	468.37	5	1	0	0		10
52X-CC, 0–2	473.1	485.32	137	116	23	0	84	23
53X-CC, 0–2	478.38	490.6	164	294	16	1	77	23
54X-1, 0–2	482.7	494.92	115	424	26	0	70	23
54X-CC, 0–2	483.5	495.72	54	360	37	0	70.5	12
55X-1, 25–27	487.55	499.77	95	377	20	1	75	26
56X-1, 25–27	492.55	504.77	88	368	30	0	70	24
56X-CC, 25–27	494.02	506.24	62	355	9	1	81	13
57X-1, 25–27	501.95	514.17	134	262	29	0	76	23
57X-2, 25–27	503.45	515.67	114	282	30	0	69	29
57X-3, 25–27	504.95	517.17	153	338	21	1	79	26
57X-4, 25–27	506.45	518.67	100	242	12	0	73	21
57X-5, 25–27	507.95	520.17	97	315	30	1	77	25
57X-6, 25–27	509.45	521.67	80	434	15	0	75	18
57X-CC, 25–27	509.73	521.95	219	240	29	0	79	20
58X-1, 25–27	511.55	523.77	102	327	9	1	64	26
58X-2, 25–27	512.65	524.87	77	348	37	0	78.5	26
58X-3, 25–27	514.15	526.37	181	310	35	0	74.5	27
58X-CC, 25–27	516.34	528.56	295	288	6	0	71	20
59X-2, 25–27	522.75	534.97	72	486	20	1	73	21
59X-4, 25–27	525.75	537.97	81	201	41	0	79	17
60X-CC, 25–27	531.36	543.58	82	410	14	0	73	20
62X-1, 25–27	550.15	562.37	172	562	16	0	78	26
62X-4, 25–27	554.65	566.87	370	150	5	0	74.5	26
63X-1, 25–27	559.75	571.97	83	94	3	1	64	23
63X-5, 25–27	565.45	577.67	235	425	28	0	68.5	24
64X-1, 25–27	569.35	581.57	180	179	10	0	83	24
64X-3, 25–27	572.35	584.57	215	212	10	0	81.5	29
65X-1, 25–27	579.05	591.27	150	168	15	0	62	28
65X-CC, 25–27	581.35	593.57	100	216	9	0	76	29
66X-1, 25–27	588.65	600.87	238	238	48	2	71.5	22
66X-3, 25–27	591.65	603.87	109	227	36	0	69	19
67X-3, 25–27	601.25	613.47	96	185	25	0	73.5	18
68X-5, 25–27	612.39	624.61	86	208	38	1	71.5	24
68X-CC, 25–27	617.4	629.62	63	189	46	0	62	26
69X-5, 25–27	623.45	635.67	311	227	49	0	79	28
70X-5, 25–27	633.05	645.27	106	427	44	0	84	26

Table T1 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Dinocysts (*N*)	Pollen/ spores (*N*)	Foraminifer linings (*N*)	Terrigenous algae (*N*)	Bisaccate pollen (%)	Dinocyst species (*N*)
72X-5, 25–27	652.45	664.67	140	212	36	0	63	25
74X-6, 25–27	673.25	685.47	80	411	18	0	70	29
76X-6, 25–27	692.34	704.56	177	330	10	1	72.5	22
39X-CC, 25–27	709.47	715.72	157	181	43	7	59	26
42X-1, 25–27	728.95	735.2	126	141	18	1	50	29
43X-2, 25–27	740.05	746.3	78	214	22	1	62	22
45X-3, 25–27	760.55	766.8	172	171	7	0	57	32
46X-3, 25–27	770.15	776.4	339	200	12	0	62	29
48X-2, 25–27	786.55	792.8	511	154	17	0	67	23
50X-1, 25–27	804.35	810.6	7790	279	38	0	61	16
52X-1, 25–27	814.95	821.2	588	131	39	1	48	26
55X-1, 25–27	834.25	840.5	105	58	22	0	57	29
56X-1, 25–27	843.85	850.1	129	77	13	1	57	18

Note: *N* = number.

Table T2. Range chart for Zones A and B. (This table is available in an **oversized format.**)

Table T3. Zone A species shared with Oligocene assemblage(s)/zones(s) from different areas.

	Reference										
Species	1	2	3	4	5	6	7	8	9	10	11
Cordosphaeridium inodes	A	+	D14			+	+		+	+	+
Cribroperidinium tenuistabulatum	A, B	+	D14		+				+	+	
Enneadocysta pectiniformis	A-1	+	D14		+	+	+		+		
Hystrichokolpoma cinctum	A	+	D14		+	+	+	+	+	+	
Membranophoridium aspinatum	A-2	+	D14, D15						+	+	
Operculodinium centrocarpum	A, B	+		+	+			+		+	
Pentadinium laticinctum	A, B	+	D14, D15	+	+	+	+	+	+	+	+
Thalassiphora pelagica	A	+	D14, D15	+	+	+	+	+		+	+
Wetzeliella gochtii	A-2		D14				+		+		
Wetzeliella symmetrica	A-2	+	D14, D15						+		
Enneadocysta arcuata	A		D14	+	+	+					+
Distatodinium ellipticum	A			+		+					
Lingulodinium machaerophorum	A, B			+	+	+		+	+	+	+
Cleistosphaeridium ancyreum	A, B		D14	+	+		+			+	
Cleistosphaeridium placacanthum	A, B		D14	+		+		+	+	+	
Cordosphaeridium cantharellum	A		D14, D15	+	+	+	+	+	+	+	+
Homotryblium tenuispinosum	A-2		D14					+	+	+	
Phthanoperidinium amoenum	A-1		D14	+							
Homotryblium plectilum	A		D14, D15		+	+	+	+	+	+	+
Selenopemphix nephroides	A, B		D14					+		+	
Melitasphaeridium asterium	A		D14						+		
Hystrichokolpoma rigaudiae	A, B		D14	+		+	+	+	+	+	+
Dapsilidinium pseudocolligerum	A, B		D15		+		+		+	+	+
Reticulatosphaera actinocoronata	A, B		D15		+	+	+		+		
Spiniferites pseudofurcatus	A		D14	+	+	+	+	+			+
Wetzeliella articulata	A				+	+			+		
Heteraulaca campanula	A			+		+	+				
Xenicodinium conispinum	A								+		
Cleistosphaeridium diversispinosum	A								+	+	
Operculodinium xanthium	A								+		
Cordosphaeridium gracile	A				+			+	+	+	+
Impagidinium dispertitum	A-2				+		+		+	+	+
Polysphaeridium zoharyi	A, B			+						+	+
Deflandea		+	+	+	+	+	+	+			

Notes: 1 = Site 1148, present paper. 2 = northwest Germany (Gerlach, 1961). 3 = northwest Germany (Heilmann-Clausen and Costa, 1990; Köthe, 1990). 4 = offshore eastern Canada (Williams and Bujak, 1977). 5 = Labrabor Sea (Head and Norris, 1989). 6 = Norwegian Sea (Manum et al., 1989). 7 = Central Italy (Brinkhuis and Biffi, 1993). 8 = northwest Italy (Powell, 1986a). 9 = Belgium (Stover and Hardenbol, 1993). 10 = South China Sea (Mao and Lei, 1996). 11 = Blake Plateau (Stover, 1977).

Table T4. Zone B species shared with early Miocene assemblage(s)/zone(s) from different areas.

Species	Reference									
	1	2	3	4	5	6	7	8	9	10
Cleistosphaeridium ancyreum	A, B	+	+							
Cribroperidinium tenuitabulatum	A, B	+	+		+	+				
Hystrichosphaeropsis obscura	B	+	+	+	+	+	+		+	
Melitasphaeridium choanophorum	B	+	+	+					+	
Polysphaeridium zoharyi	A, B	+								
Reticulatosphaera actinocoronata	A, B		+							
Tuberculodinium vancampoae	B	+	+		+	+				
Cleistosphaeridium placacanthum	A, B			+				+	+	
Cerebrocysta satchelliae	B							+		
Impagidinium aculeatum	B			+	+				+	
Lingulodinium machaerophorum	A, B					+	+			
Membranilarnacia ?picena	B									+
Operculodinium centrocarpum	A, B						+			
Pentadinium laticinctum	A, B				+				+	
Tectatodinium pellitum	B					+			+	

Notes: 1 = Site 1148, the present paper. 2 = South China Sea (Mao and Lei, 1996). 3 = Baffin Bay (Head et al., 1989). 4 = Rockall Plateau (Costa and Downie, 1979) and Goban Spur (Brown and Downie, 1985). 5 = Norwegian Sea (Manum et al., 1989). 6 = Gulf of Mexico (Lenoir and Hart, 1986). 7 = western and northern Pacific (Bujak, 1984; Bujak and Matsuoka, 1986). 8 = Mid-Atlantic (de Verteuil and Norris, 1996). 9 = northwest Italy (Powell, 1986b). 10 = Central Italy (Biffi and Manum, 1988).

CHAPTER NOTES*

N1. Williams, G.L., Boessenkool, K.P., and Brinkhuis, H., unpubl. data. Upper Cretaceous–Neogene dinoflagellate cyst course, morphology, stratigraphy and (paleo)ecology. Urbino, Italy. June 4–8, 2001.

N2. Williams, G.L., Bujak, J.P., and Brinkhuis, H., unpubl. data. Mesozoic–Cenozoic dinoflagellate cyst course. Urbino, Italy. May 17–22, 1999.

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*Dates reflect file corrections or revisions.